Review of HWRF-base Ensemble Prediction System 2014-2018 Atlantic Storms

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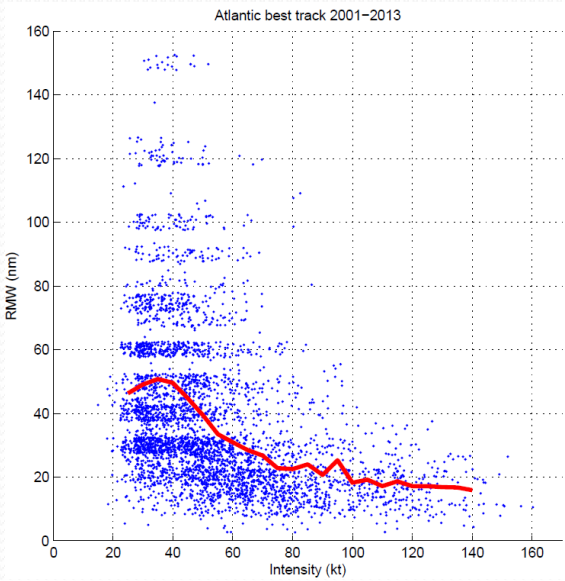
Outline

- Configuration of HWRF-base Ensemble Prediction System (HWRF-EPS)
- Methodology
- Statistical Features of HWRF-EPS
- Mean Vmax probability produced by HWRF-EPS
- Verification and Evaluation of HWRF-EPS
- Concluding Remarks

HWRF ensemble Configuration

- Use then operational deterministic HWRF model except for
  - Less horizontal resolution: 14.5/4.5/1.5km vs. 18/6/2km (27/9/3km, before 2018)
  - Less vertical resolution: L75 vs. L61 (L43 before 2018)
  - No GSI due to lack of GDAS data;
- IC/BC Perturbations (large scale): 20 member GEFS, 0.5x0.5 degree GRIB2 (1x1deg. Before 2018)
- 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;
- Situation-appropriate perturbations to the initial time position and intensity in TCVital.
- Initial ocean SST perturbations (Xiao Hui & Ryan Torn, added in 2017)
  - Climatological (2012-2016), GFS surface analysis
  - Remove climatological mean, scale to 0.5K standard deviation.
  - Mix the initial SST perturbation downward into upper ocean (150 m).
- Use values of coac and codamp for 2km resolution (2018)



Methodology

Posterior Analysis on Track/Intensity Forecasts

- The best track information is available at all forecast hours
- Select one ensemble member that is closest to the observed position to represent ensemble track forecasts, MPTE: Minimum Potential Track Error
- Select one ensemble member that is closest to the observed Vmax to represent ensemble intensity forecasts, MPIE: Minimum Potential Intensity Error
- Mean Probability Density Function (PDF) from HWRF-based Ensemble System
- Vmax distributions from each individual ensemble member (unsorted), and re-group member (sorted)
- Analysis Vmax distributions for unsorted and sorted ensembles

Post-processing on HWRF-EPS

- The best track information is available at forecast 12h
- Select a subset of ensemble members that both track and intensity forecasts at 12h are close to the best track, average over the subset
- Weight between track and intensity sets 0.5
- Subset of 12 members (out of 20) is found to provide best results, I129: HWRF ensemble track and intensity forecasts provided 12h later

Track/Intensity Verification

- All ensemble member average vs. un-perturbed control member and MPTE/MPIE
- Forecast skill improvement of sub-setting method over all ensemble member mean

Potential applications of MPTE/MPIE:

1. Verify/validate ensemble system by checking equal chance of being best forecast for each individual ensemble member
2. Investigate best forecast member to understand model physics;
3. Study the predictability of current dynamic model, intrinsic predictability limit.

Dataset

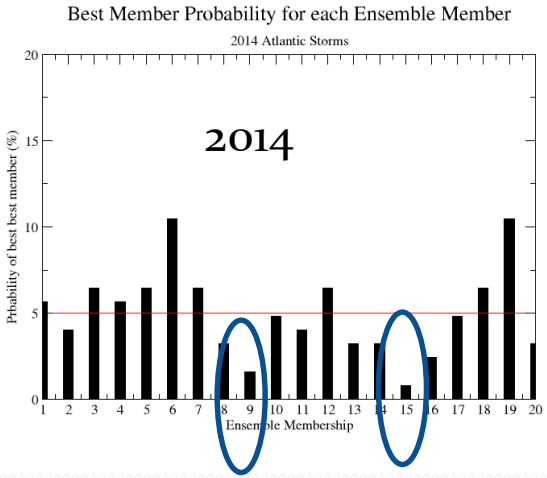
2014-2018 Atlantic storms:

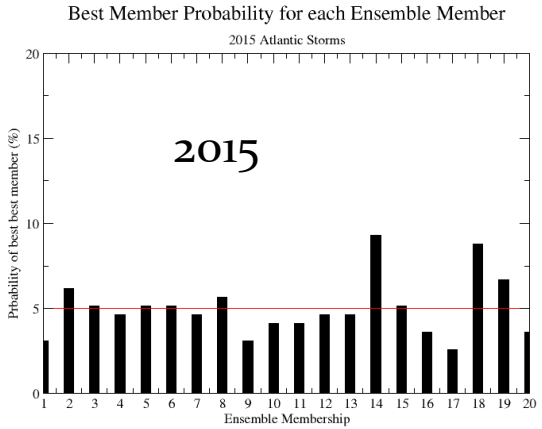
Fcst hrs	000	024	048	072	096	120
No. of Cycles	897	816	721	634	542	452

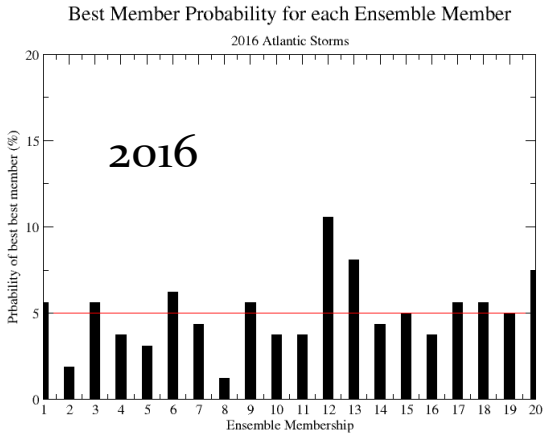
HW01-HW20: Perturbed Ensemble Members
HW00: Un-perturbed Control run
MPTE: Minimum Potential Track Error
MPIE: Minimum Potential Intensity Error
HWRF: Operational HWRF
I129: Sub-setting track/intensity forecasts

Statistical Features of HWRF-EPS

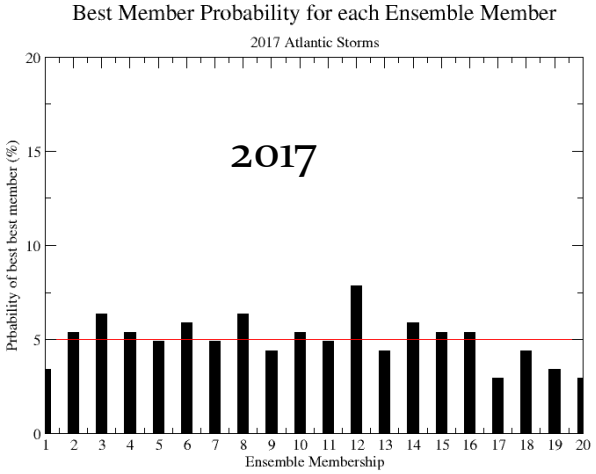
Statistic Features of HWRF-based Ensemble

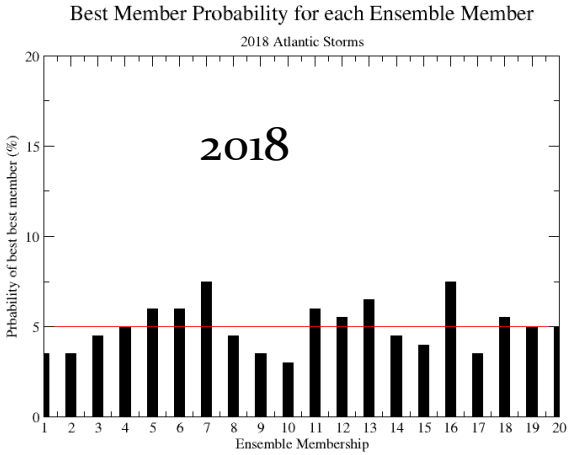


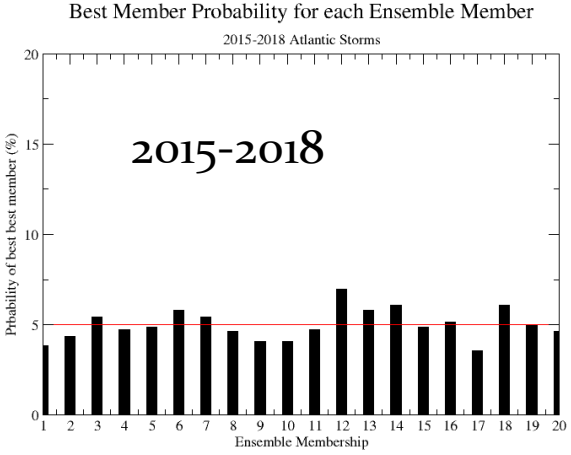




1/20 or 5% line

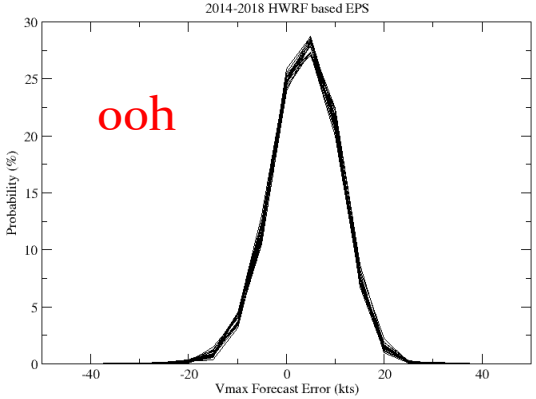




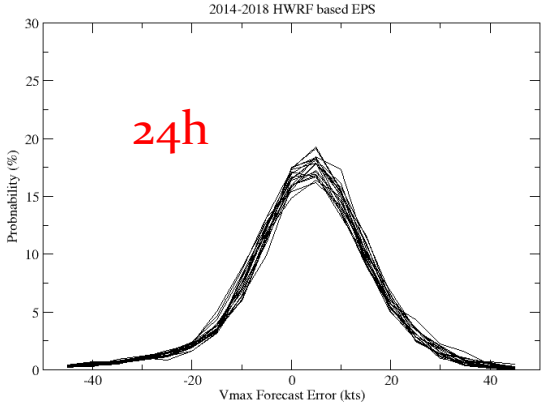


Vmax Distributions from Each individual Ensemble Members Averaged over Atlantic Storms from 2014-2018

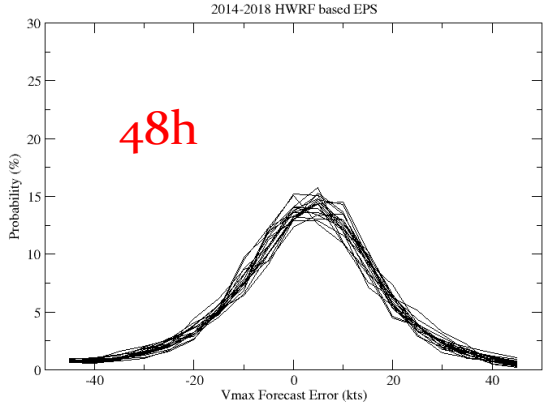
Vamx Error Probability at 000hr for Unsorted Ensemble



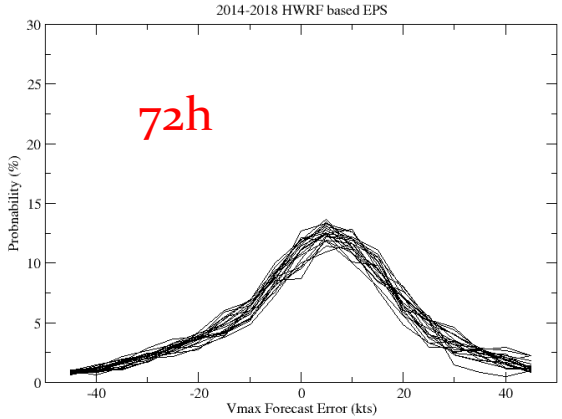
Vmax Error Probability at 024hr for Unsorted Ensemble



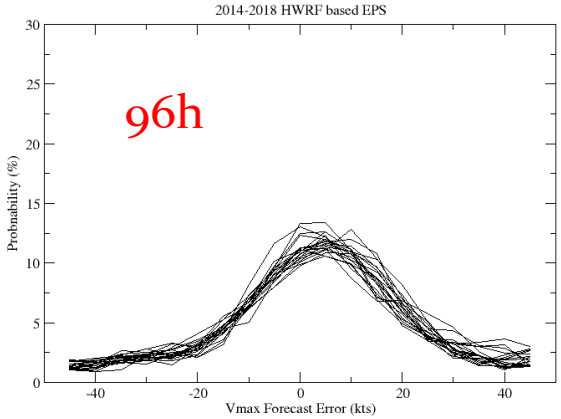
Vamx Error Probability at 048hr for Unsorted Ensemble



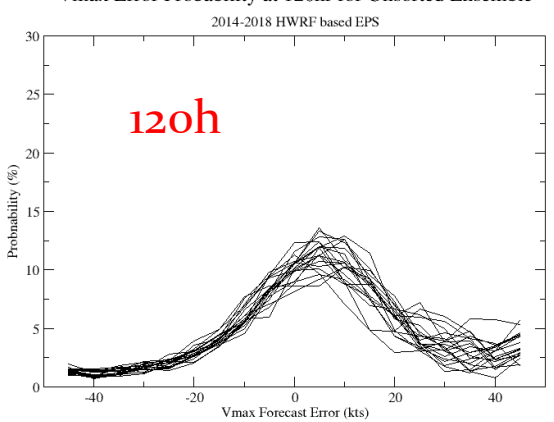
Vmax Error Probability at 072hr for Unsorted Ensemble



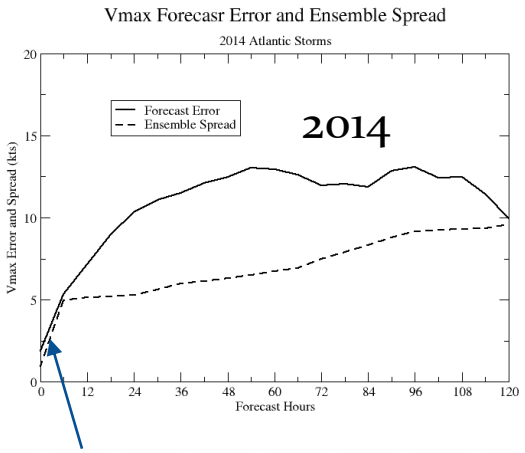
Vmax Error Probability at 096hr for Unsorted Ensemble

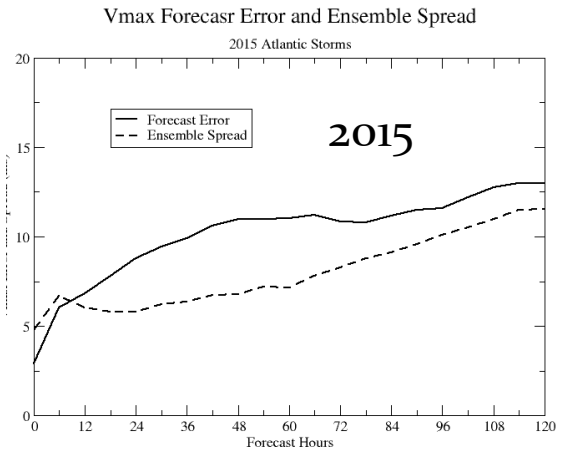


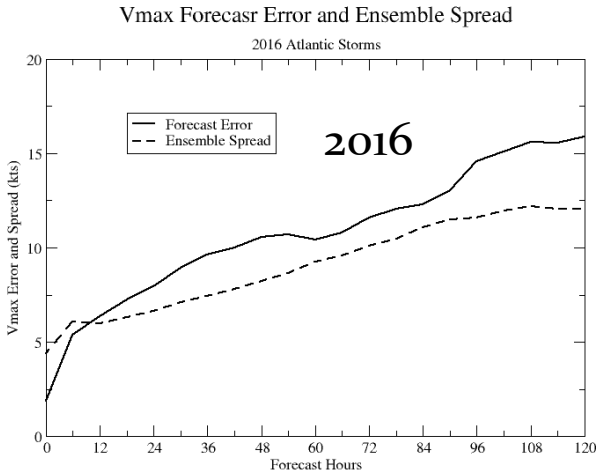
Vmax Error Probability at 120hr for Unsorted Ensemble



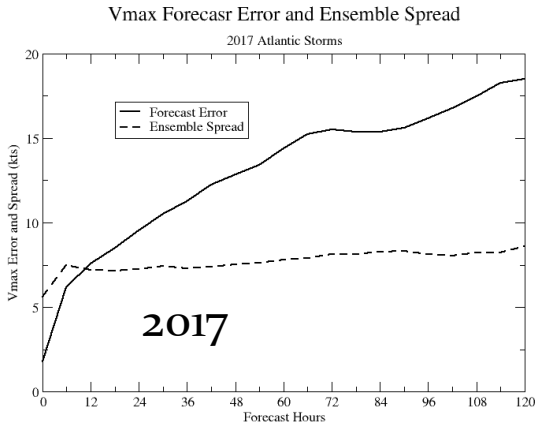
Vmax Forecast Error vs Ensemble Spread

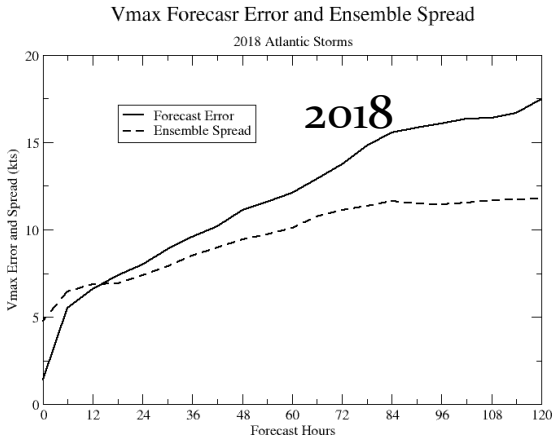


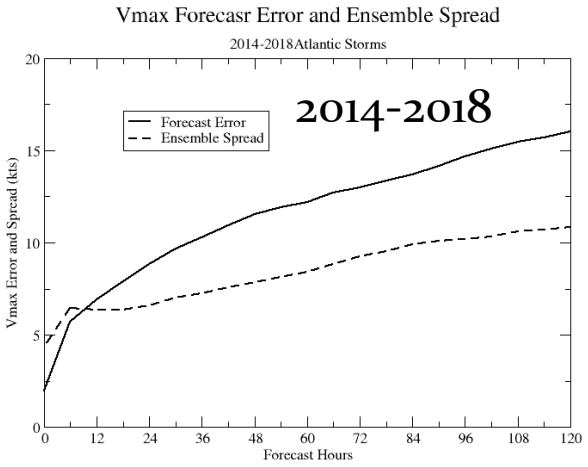




Small initial perturbation

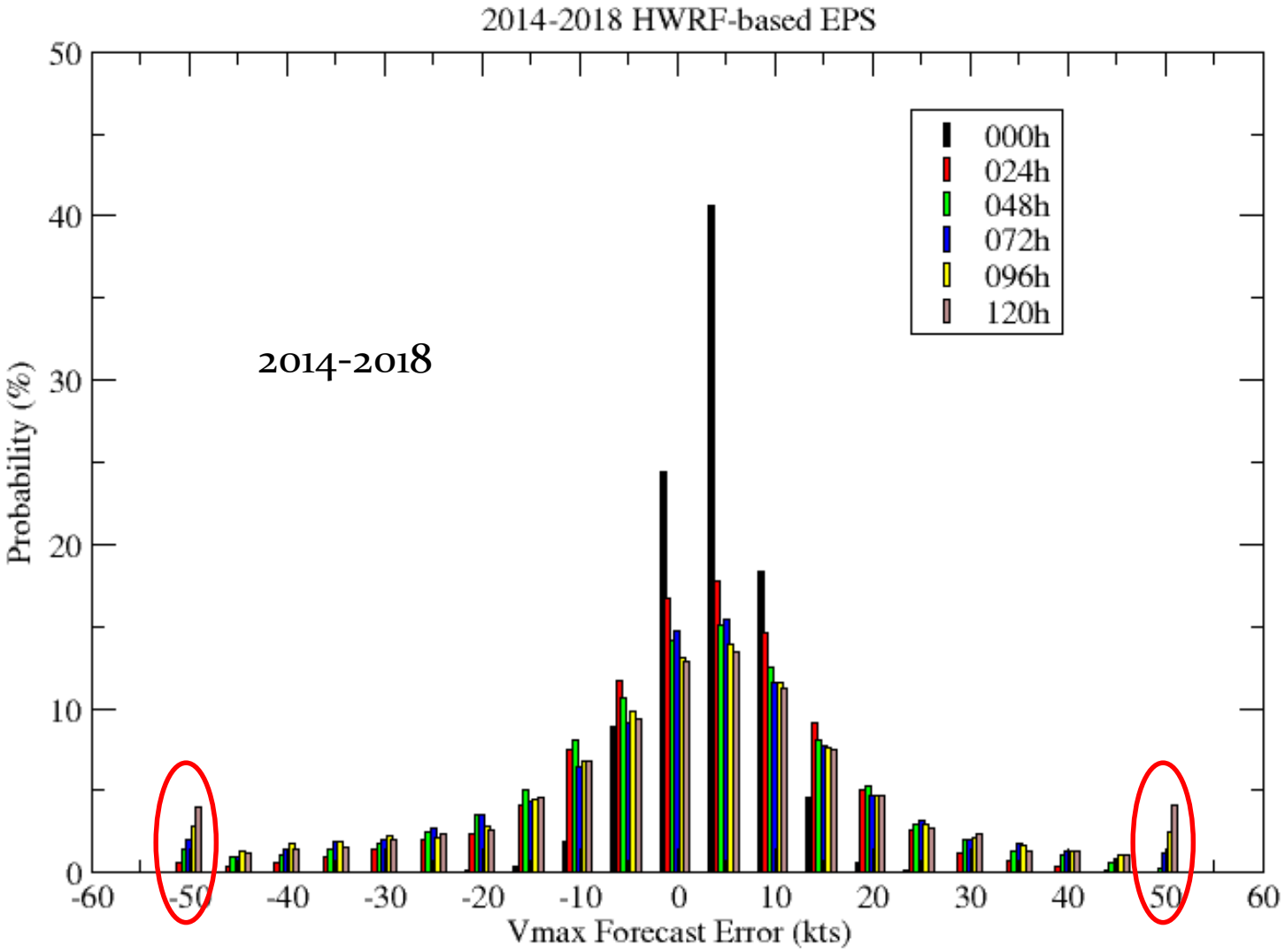






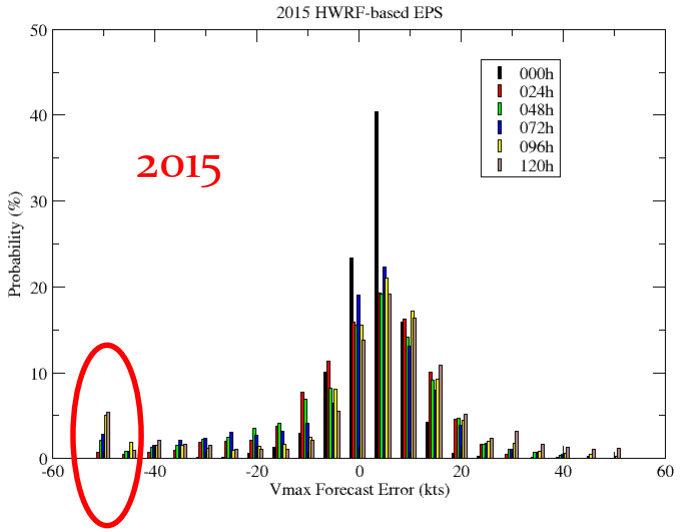
Under-disperse at all years

Ensemble Vmax Error Probability Averaged over All Storms/Cycles

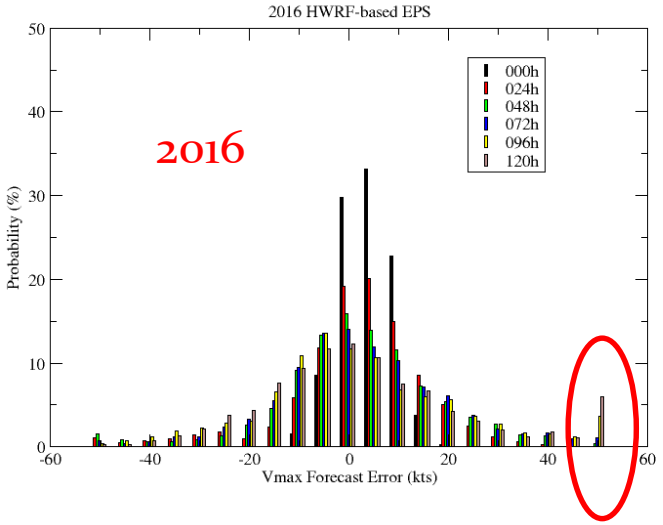


Ensemble Vmax Error Probability Averaged over All Storms/Cycles 2015-2018 Atlantic Basin

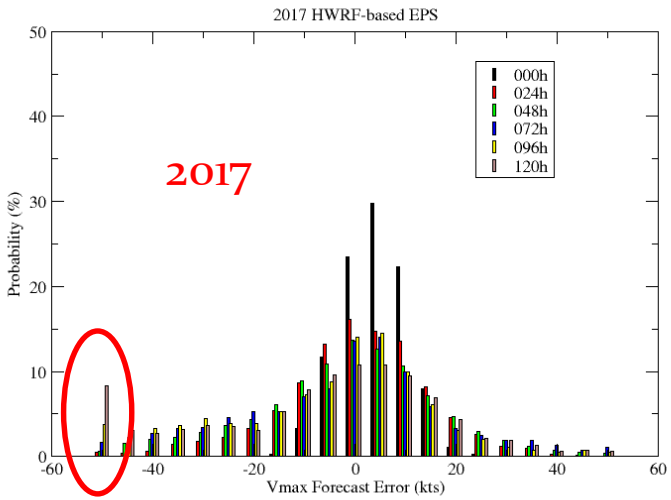
Ensemble Vmax Error Probability Averaged over All Storms/Cycles



Ensemble Vmax Error Probability Averaged over All Storms/Cycles



Ensemble Vmax Error Probability Averaged over All Storms/Cycles



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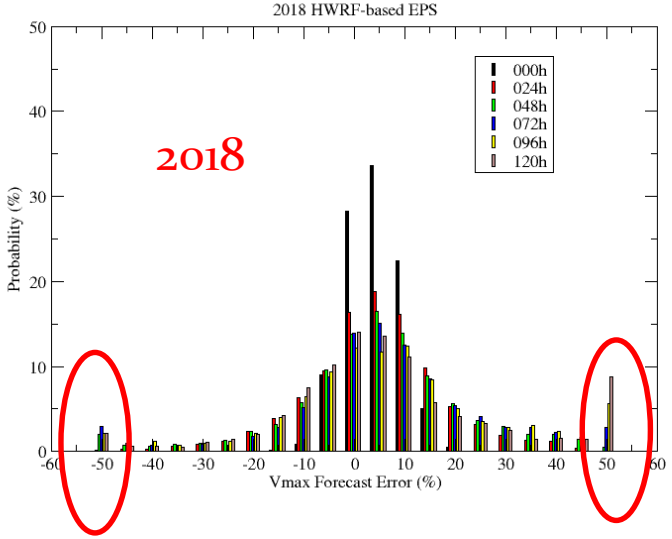


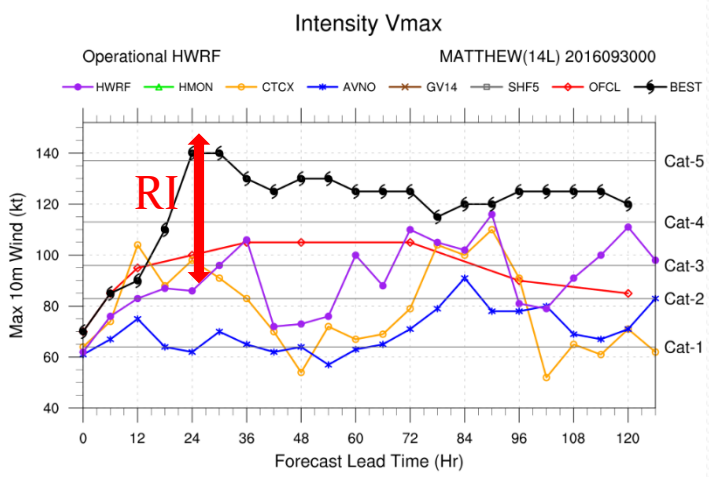
List of Hurricanes with Large Intensity Forecast Error

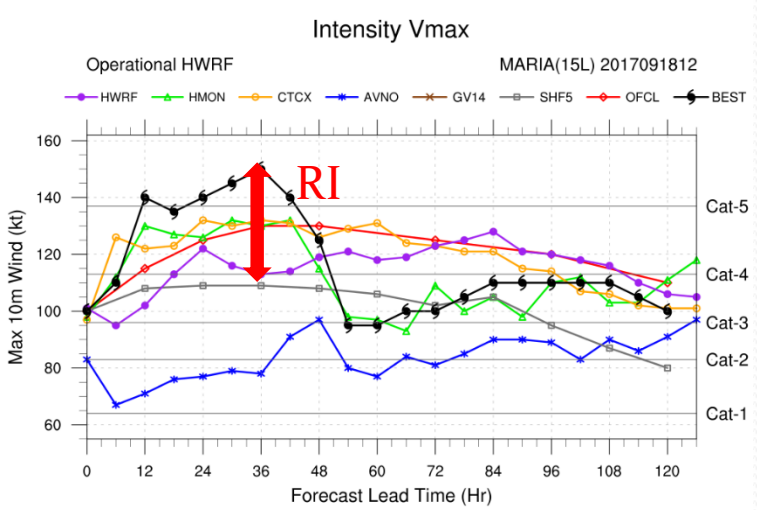
- Vmax error larger than absolute values of 50kts
- 50% of HWRF ensemble members failed: over/under predicted Vmax

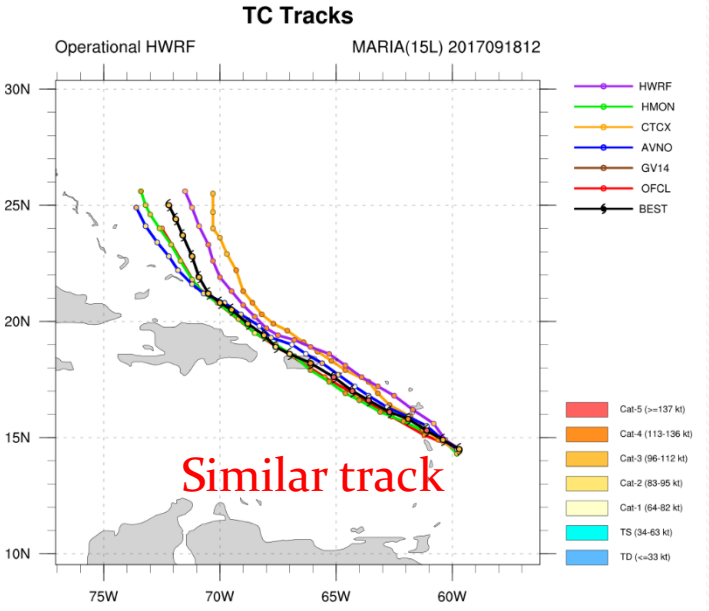
2014, Edouard/06L
2015: Danny/04L, Joaquin/11L
2016: Karl/12L, Matthew/14L
2017: Harvey/09L, Irma/11L, Maria/15L
2018: Florence/06L, Isaac/09L, Michael/14L

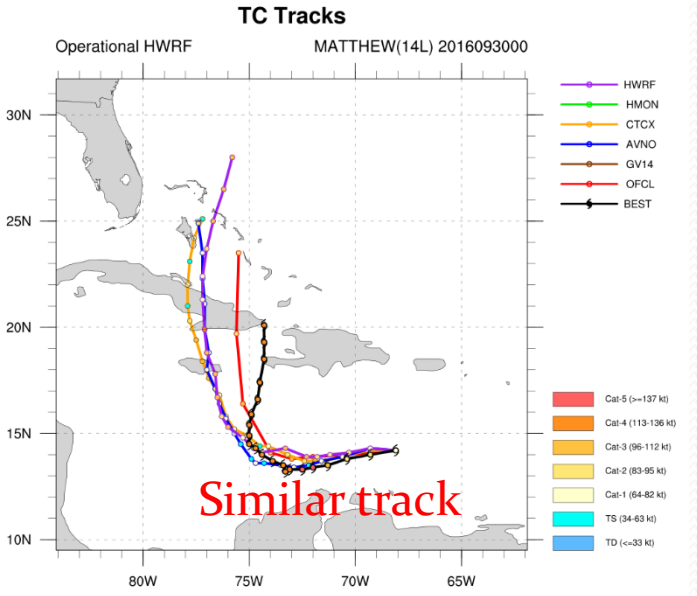
Large Intensity Forecast Error due to Rapid Intensification (RI)

Hurricanes Matthew 14L, 2016093000 and Maria 15L, 2017091812



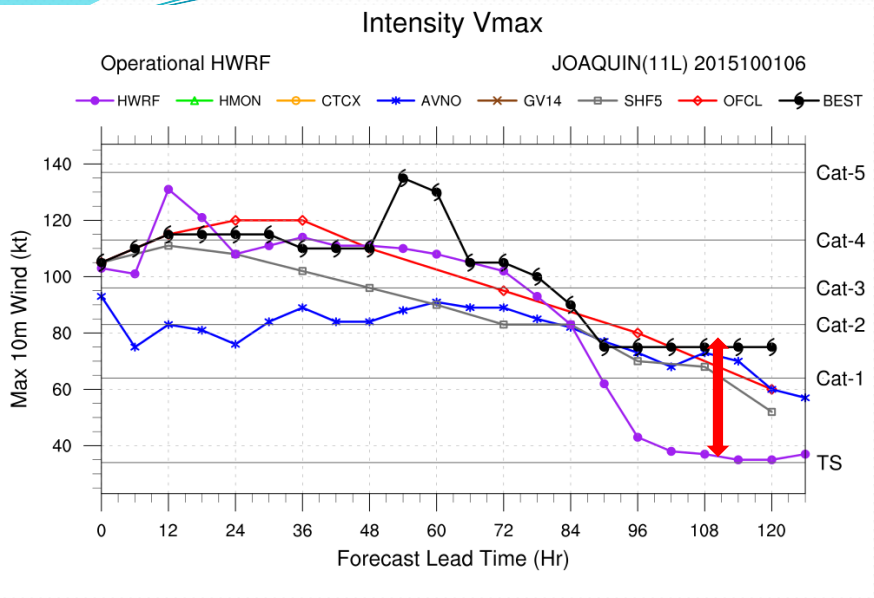


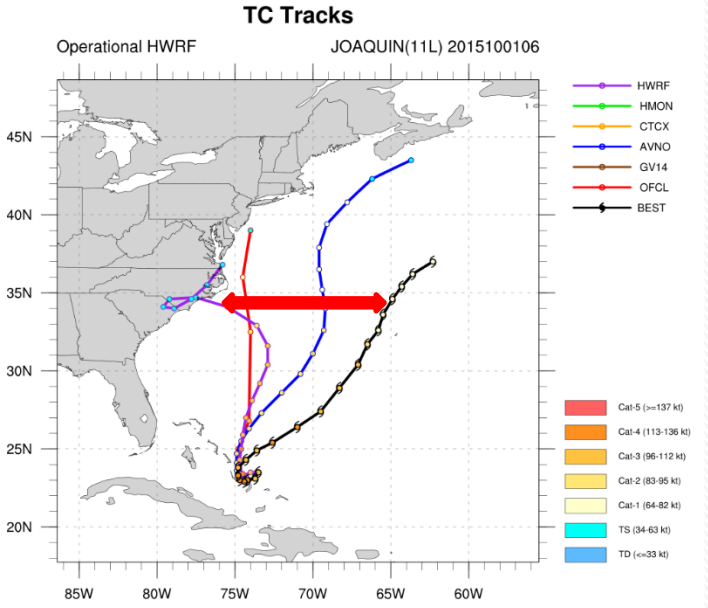


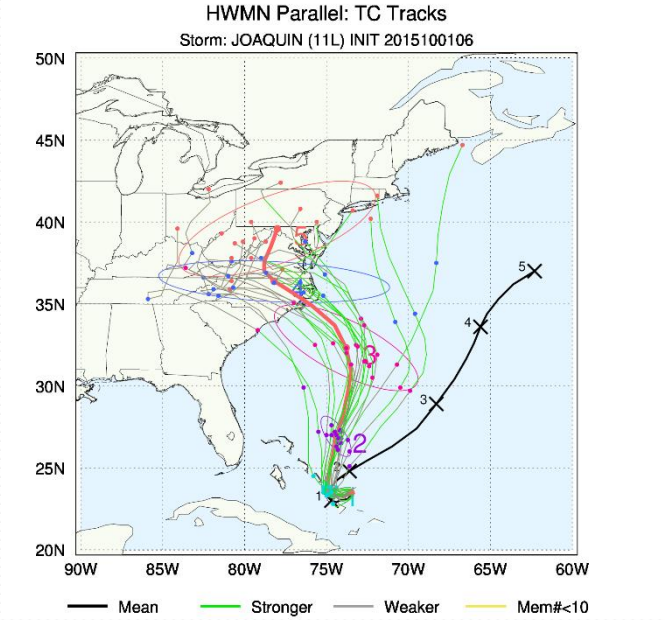


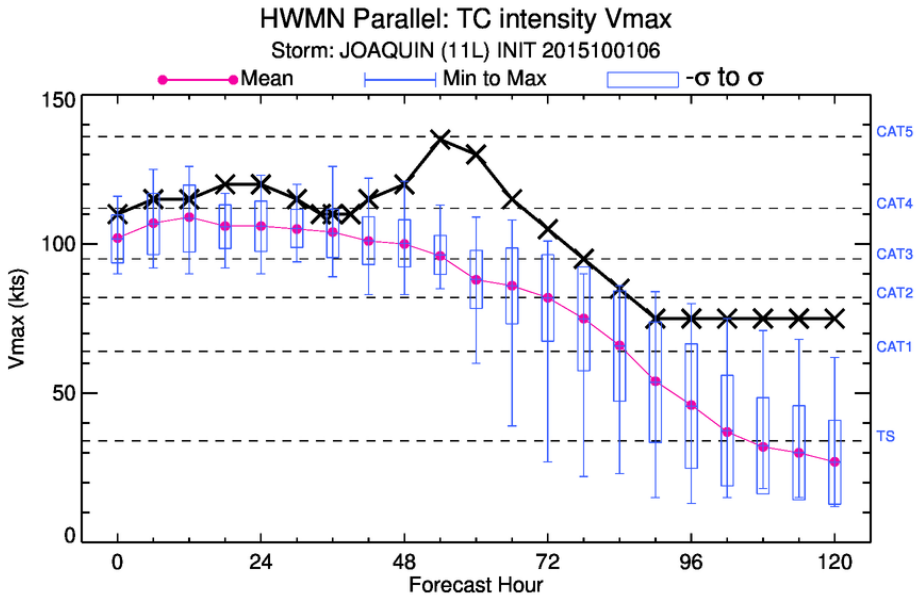
Large Vmax Forecast Error due to Large Track Error

Joaquin 11L, 2015100106



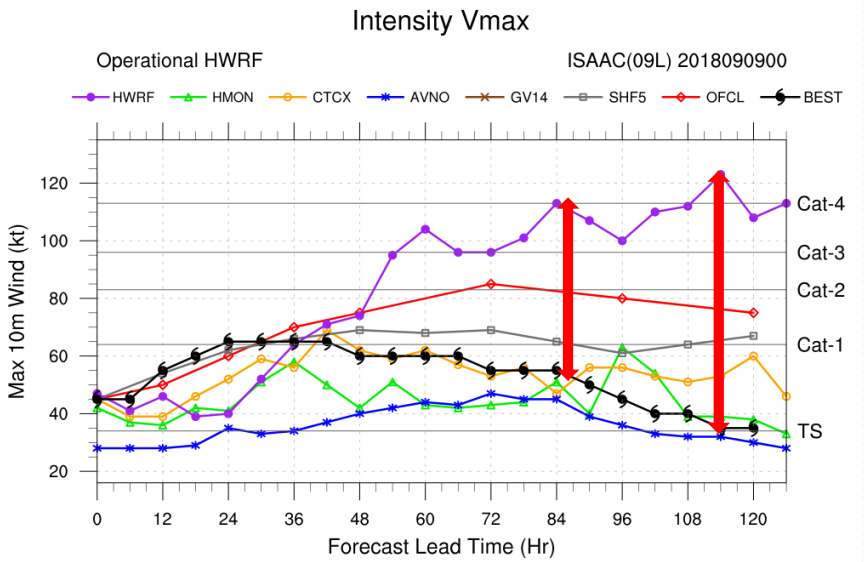


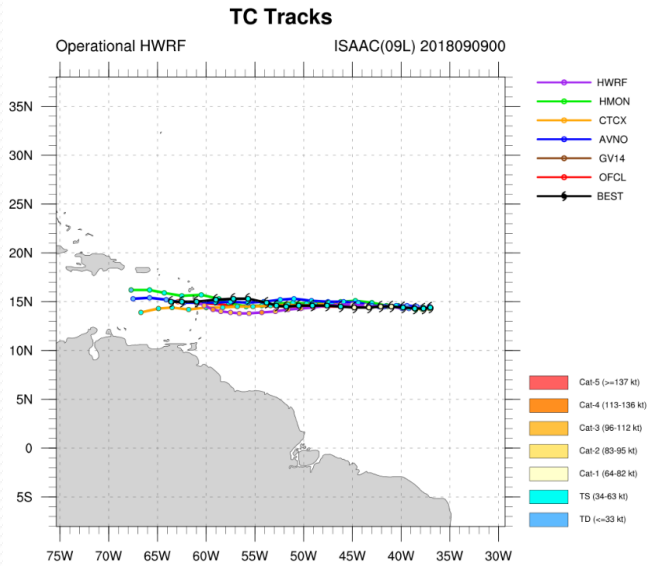


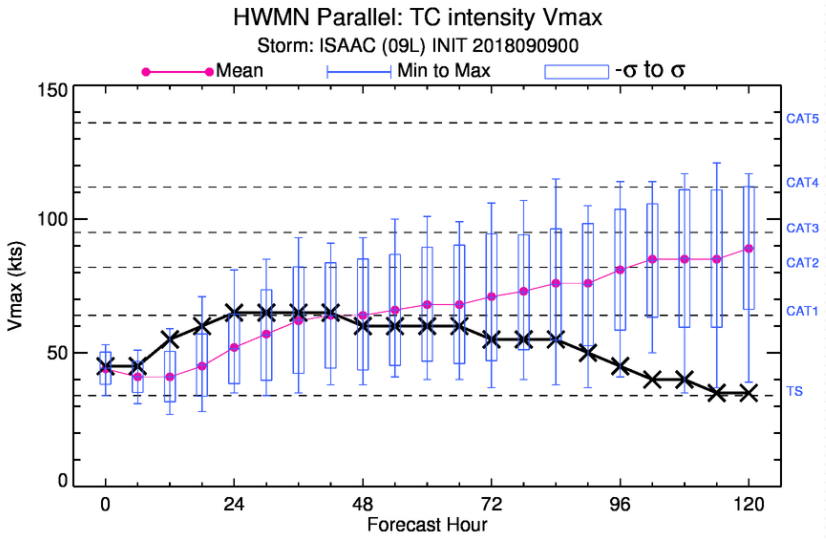


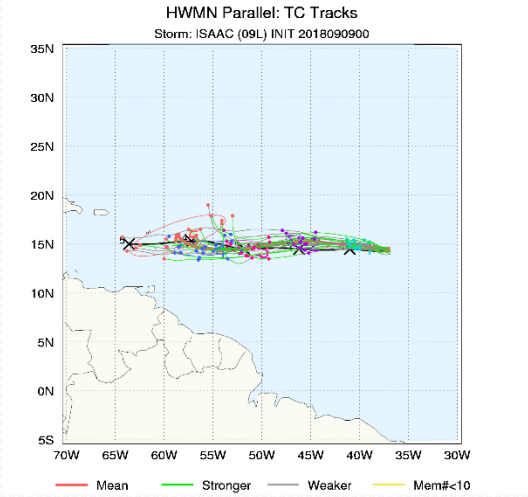
Large Vmax Forecast Error due to Model Physics

Issac 09L, 2018090900



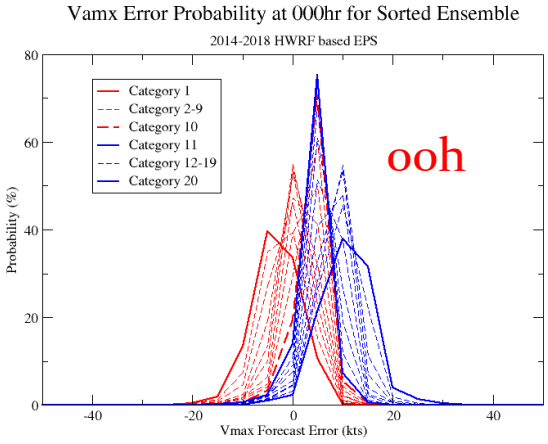


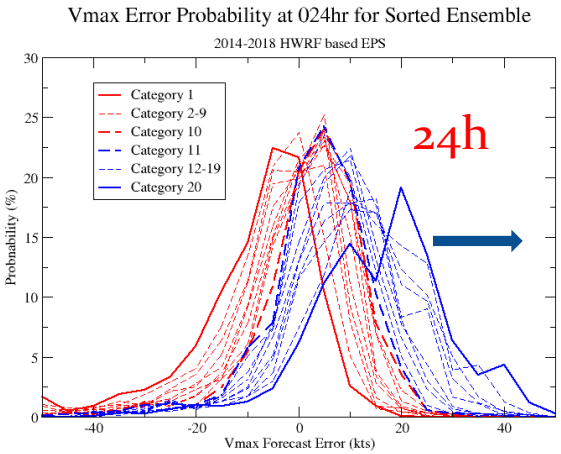


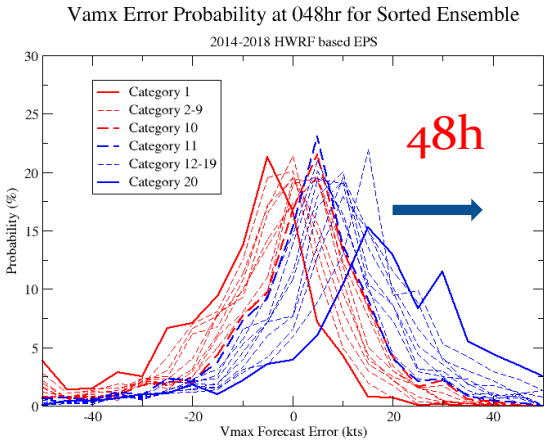


Large/small uncertainty in intensity/track forecast

Vmax Distributions from sorted Ensemble member (re-group) Averaged over Atlantic Storms from 2014-2018







Larger negative error

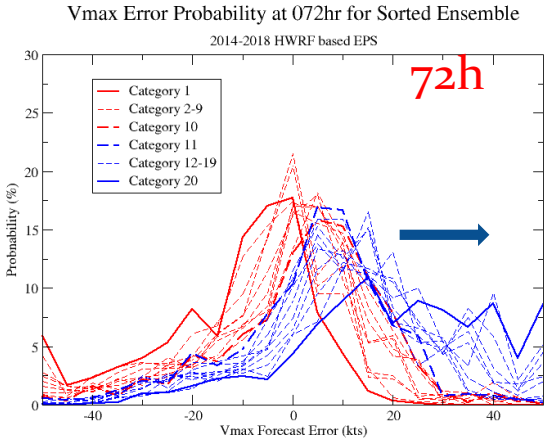
Larger positive error

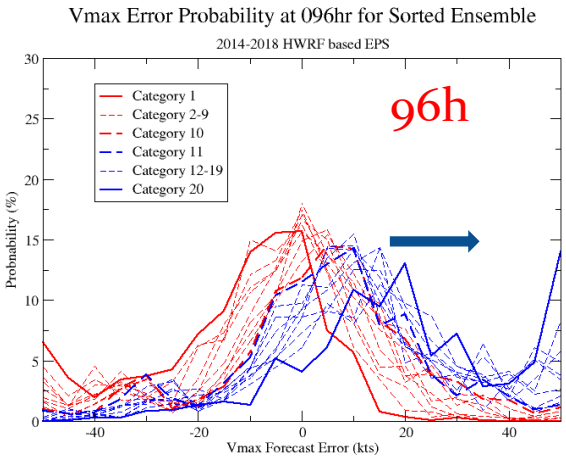
Cat-1

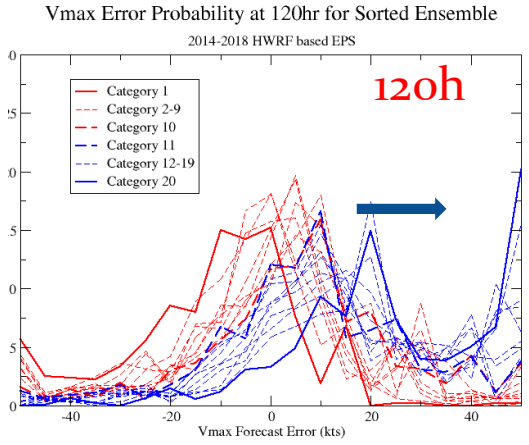
Cat-10

Cat-11

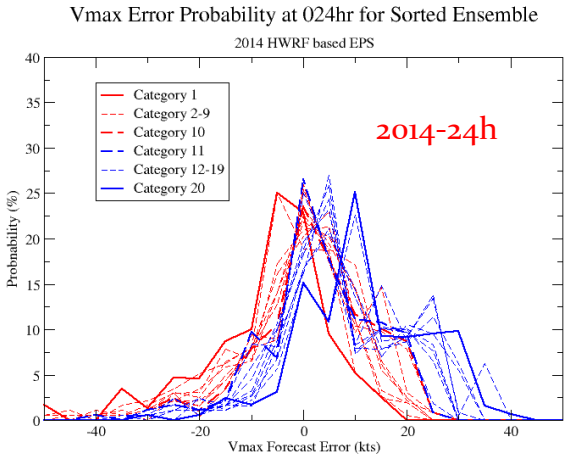
Cat-20

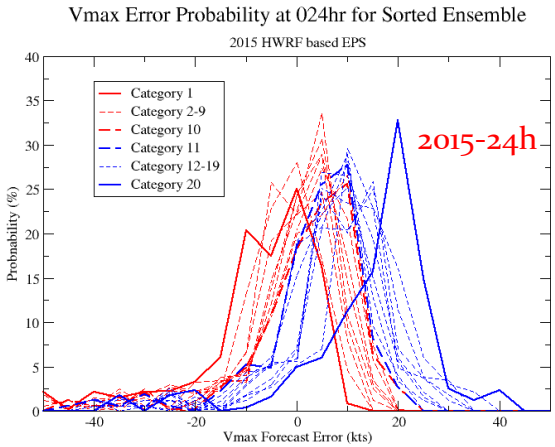


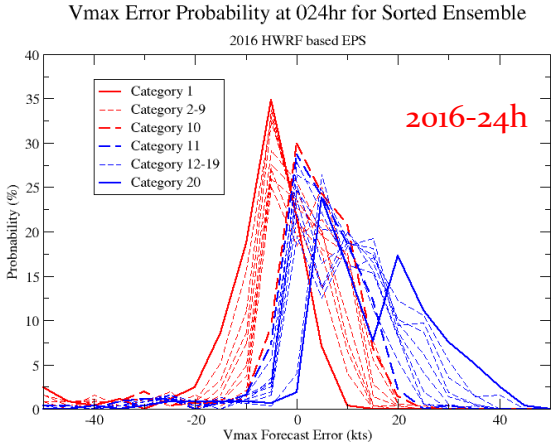




Yearly variation of Vmax Distributions from sorted Ensemble member at 24h







Larger negative error

Larger positive error

Cat-1

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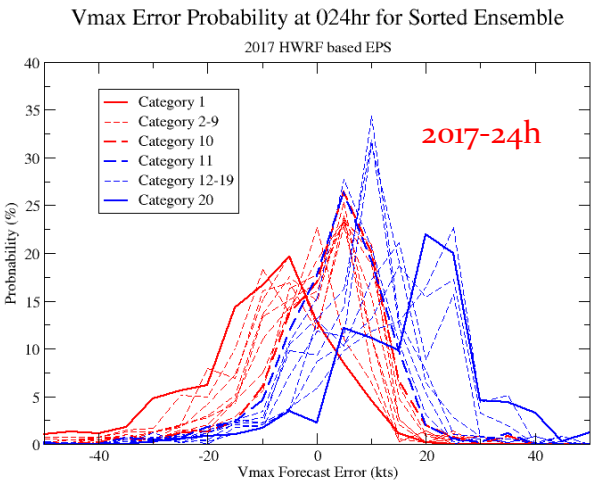
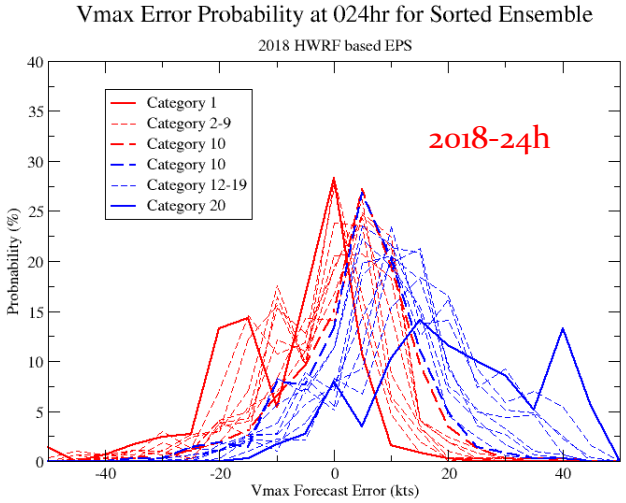
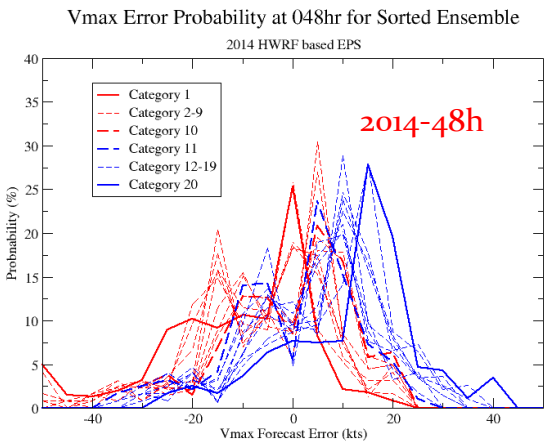
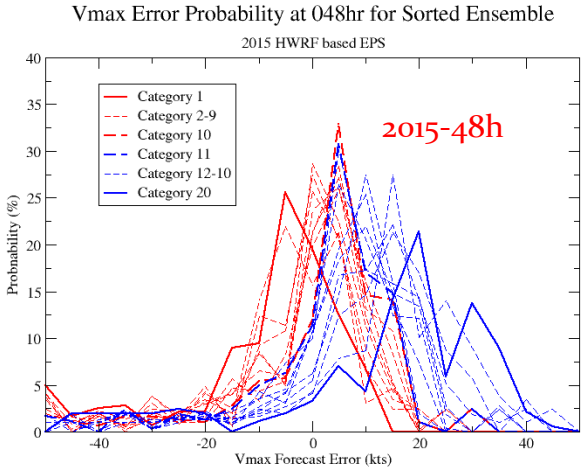
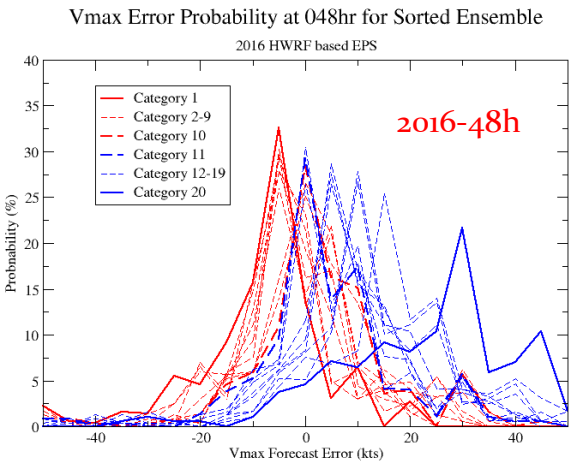




Yearly variation of Vmax Distributions from sorted Ensemble member at 48h







Larger negative error

Larger positive error

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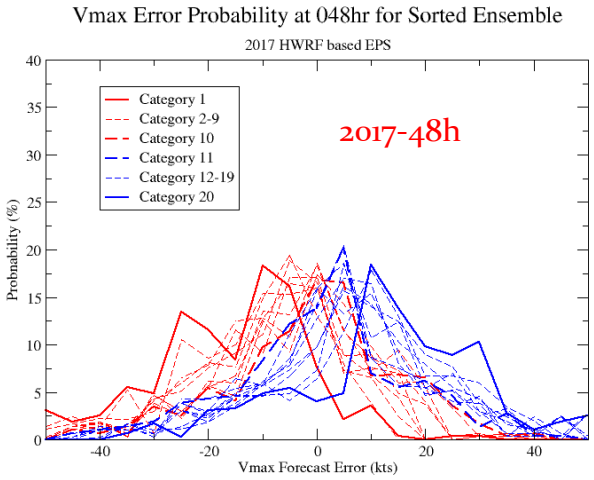
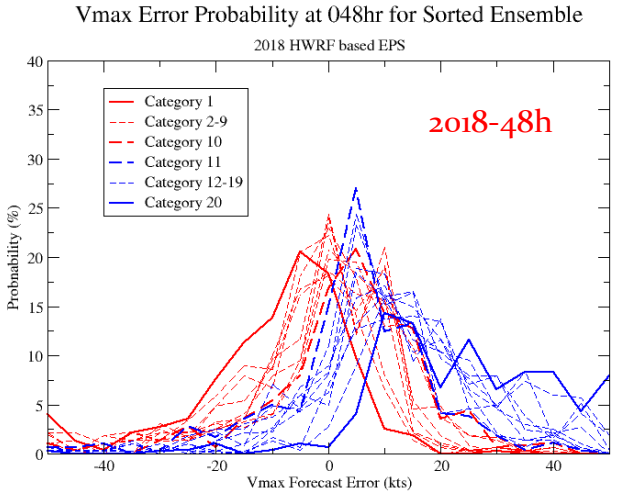
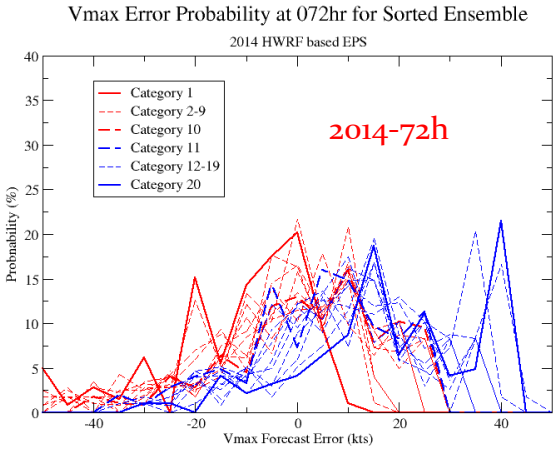
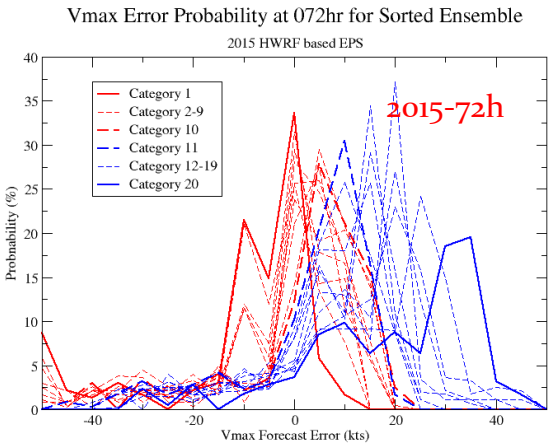
Cat-20

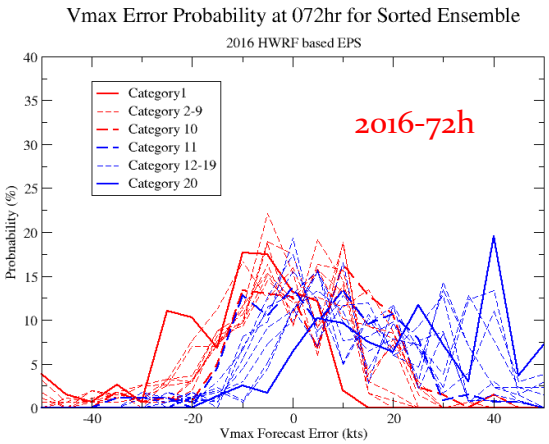




Yearly variation of Vmax Distributions from sorted Ensemble member at 72h







Larger negative error

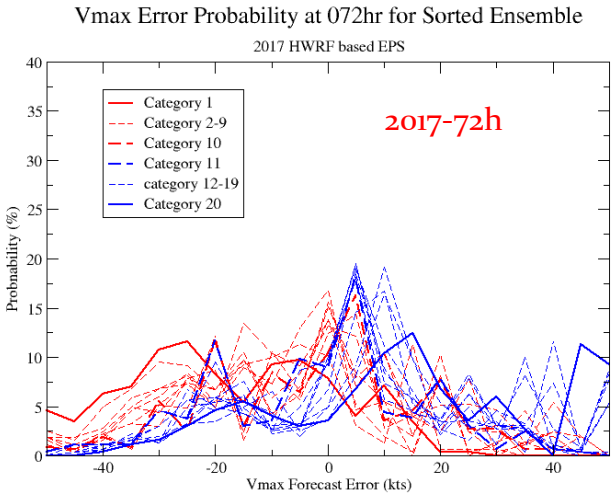
Larger positive error

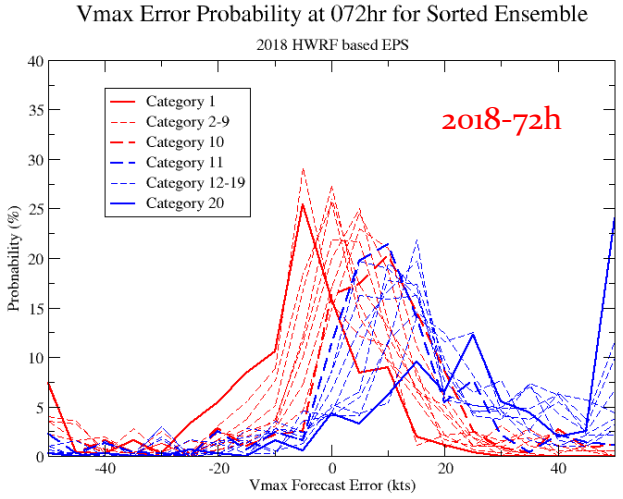
Cat-1

Cat-10

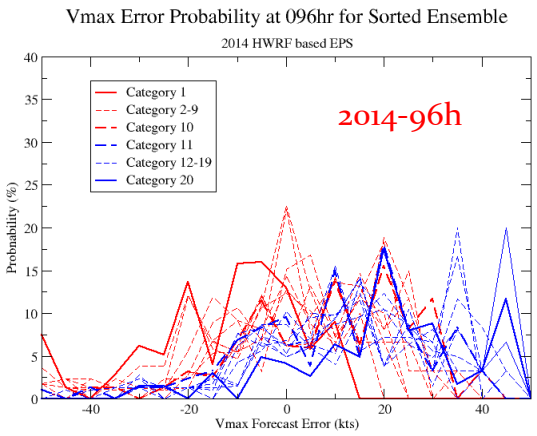
Cat-11

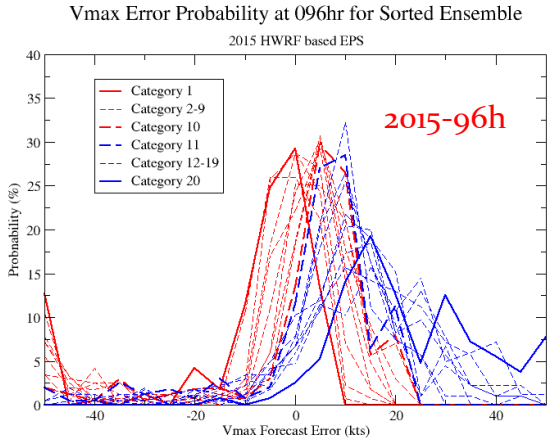
Cat-20

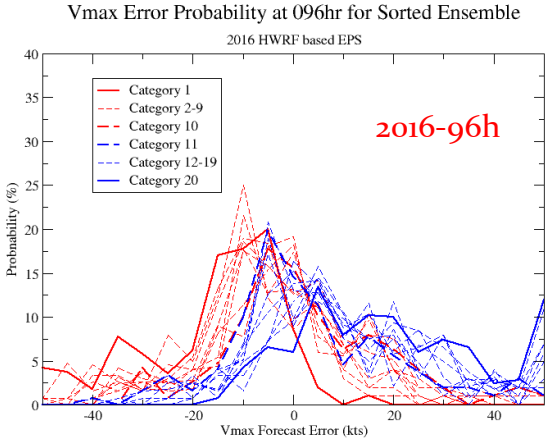




Yearly variation of Vmax Distributions from sorted Ensemble member at 96h







Larger negative error

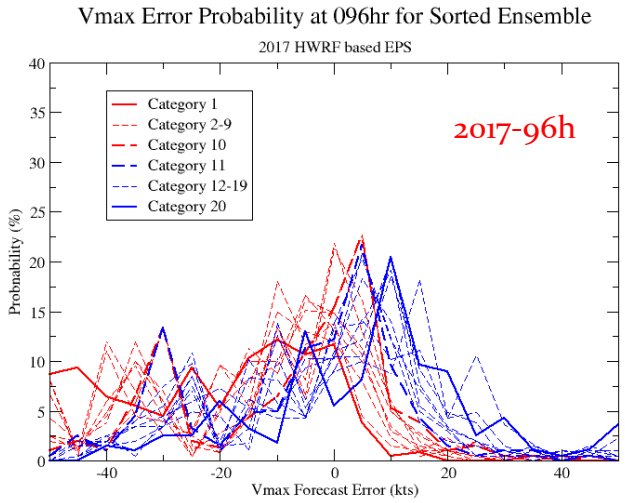
Larger positive error

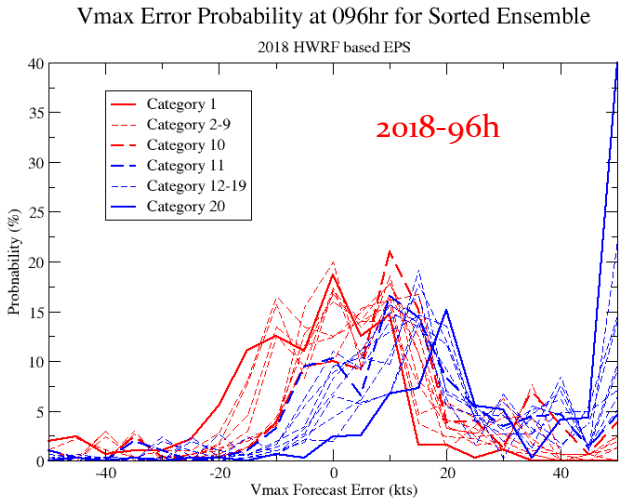
Cat-1

Cat-10

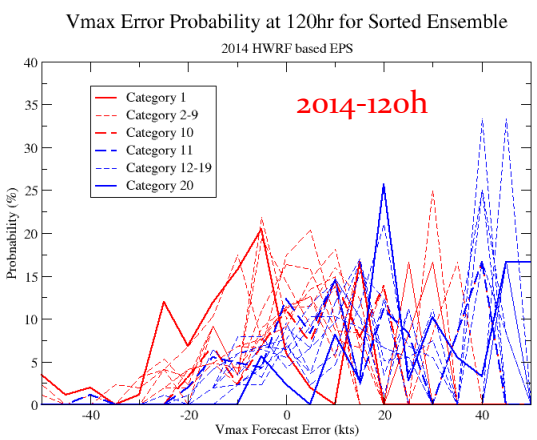
Cat-11

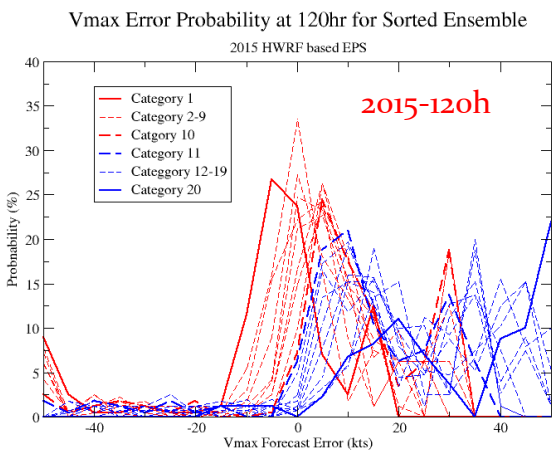
Cat-20

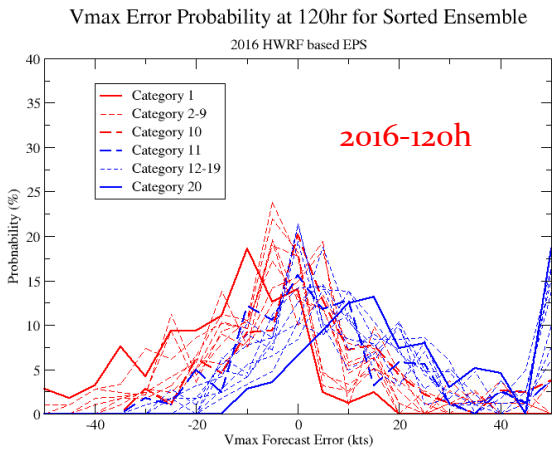




Yearly variation of Vmax Distributions from sorted Ensemble member at 120h







Larger negative error

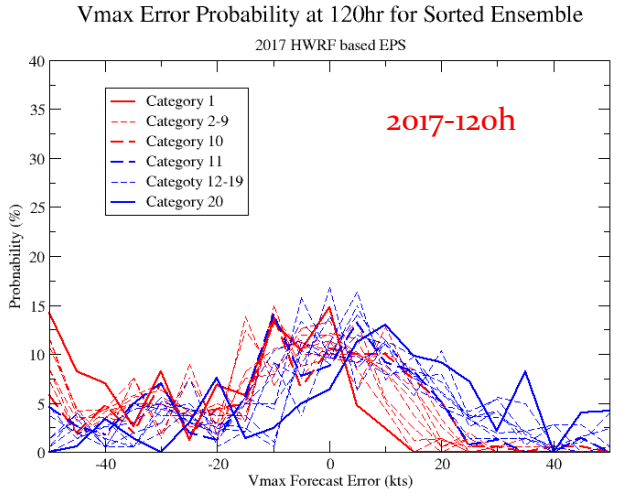
Larger positive error

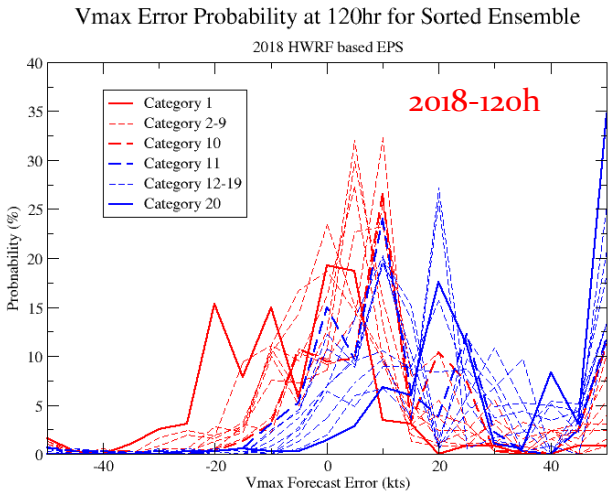
Cat-1

Cat-10

Cat-11

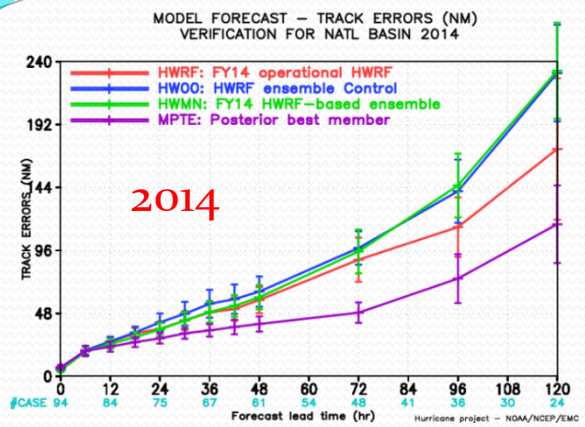
Cat-20

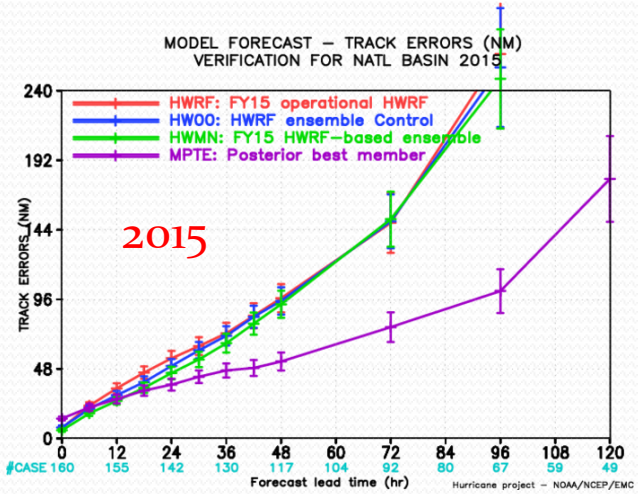


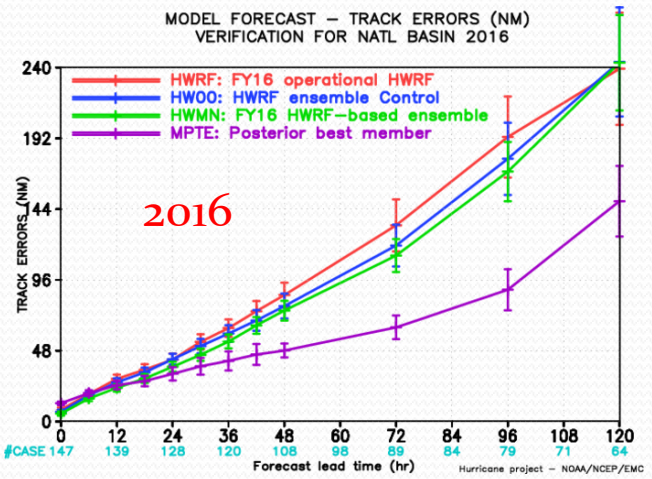


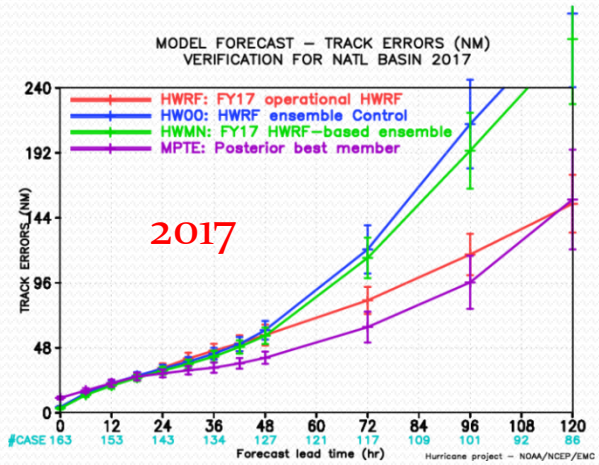
Track and Intensity Verification

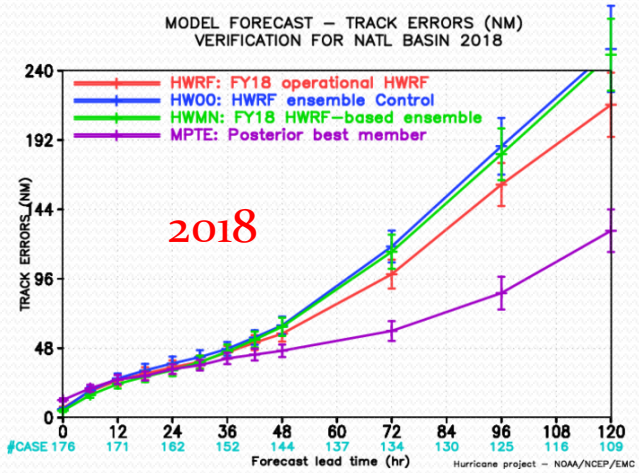
Track Verification for HWRF based Ensemble Prediction System 2014-2018

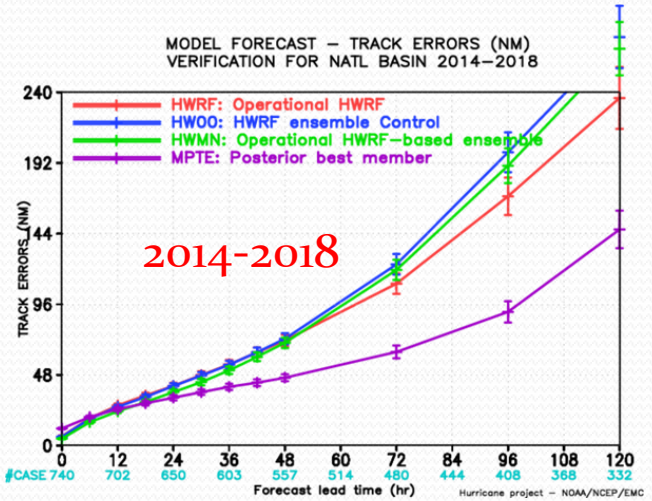






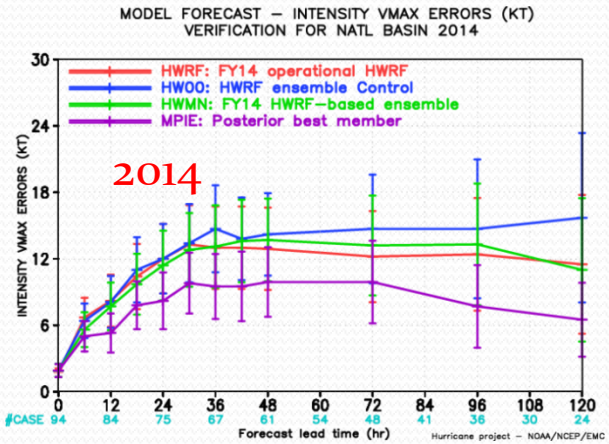


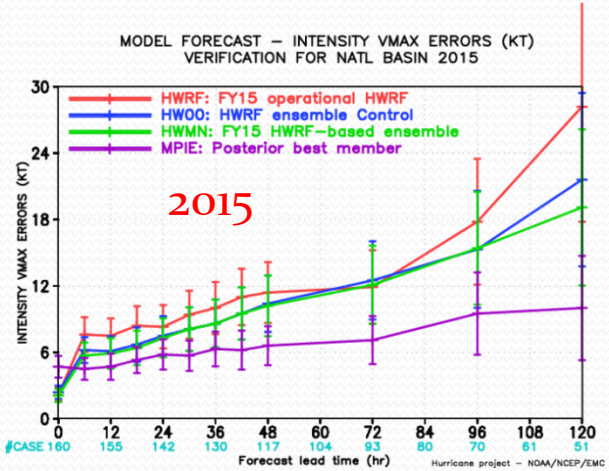


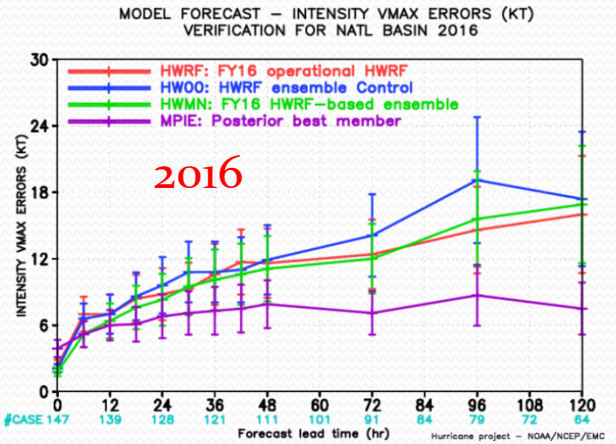


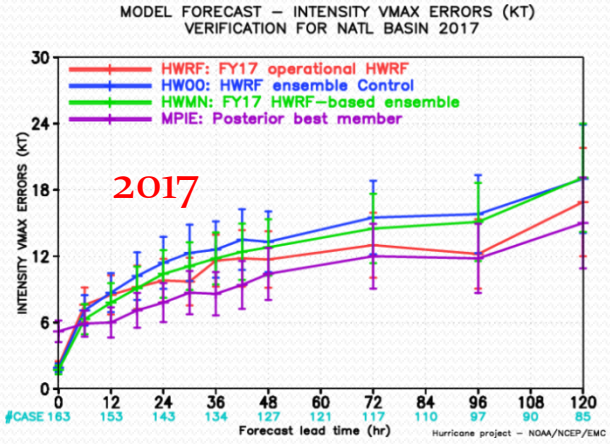
- Ensemble mean of HWRF-EPS (HWMN) always has lower track forecast than operational HWRF (HWRF)
- Posterior track forecasts (MPTE) have much lower track forecast error
- HWRF-EPS track forecast skills are comparable with operational HWRF at earlier forecast hours, and slightly degraded at later lead times due to lower resolution

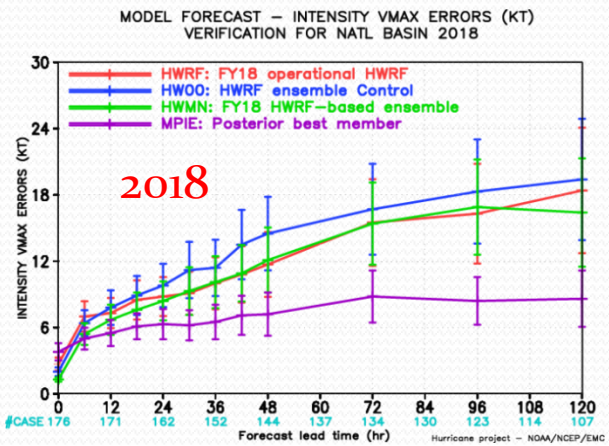
Intensity Verification for HWRF based Ensemble Prediction System 2014-2018

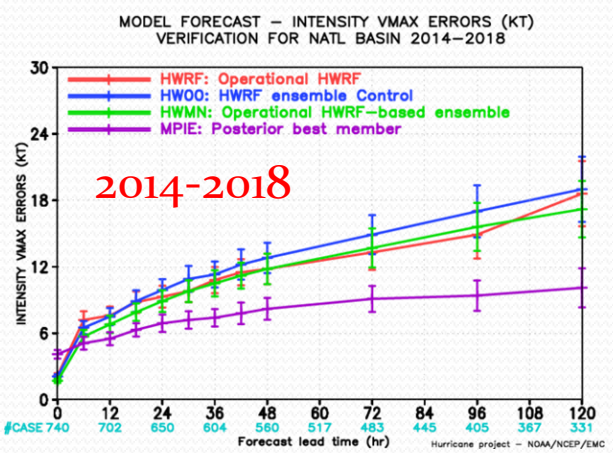






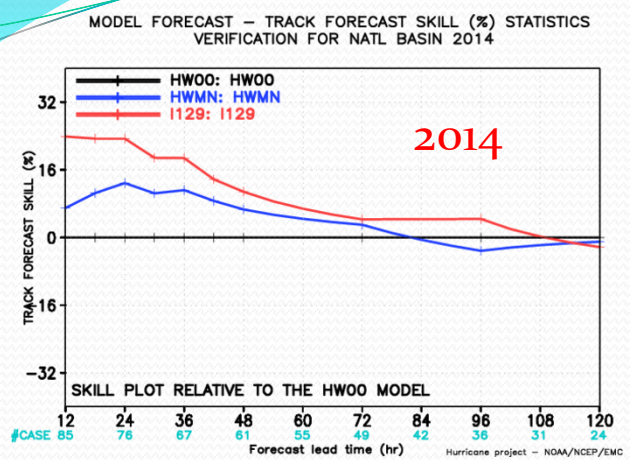


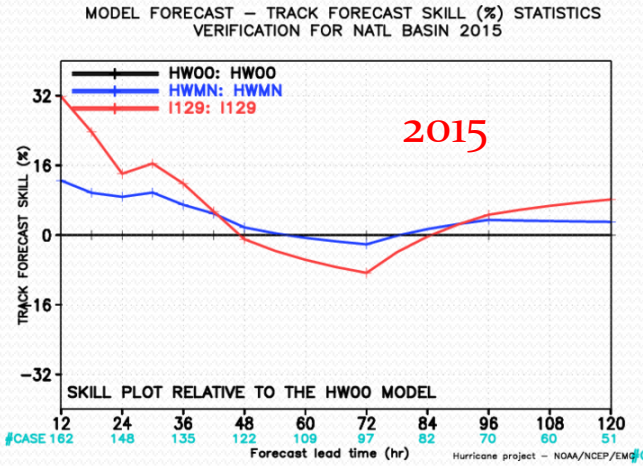


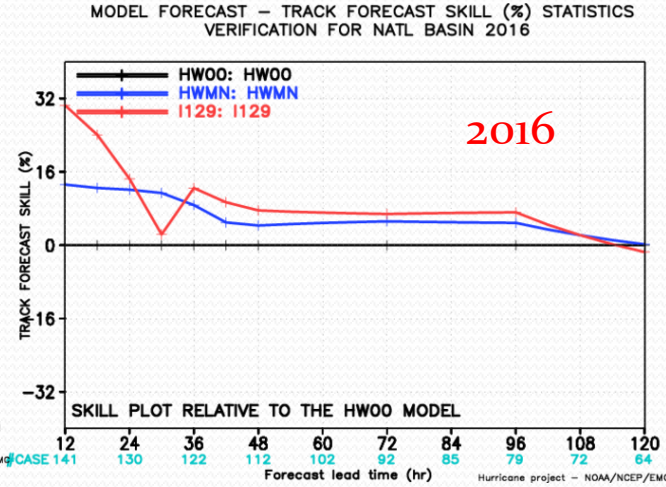


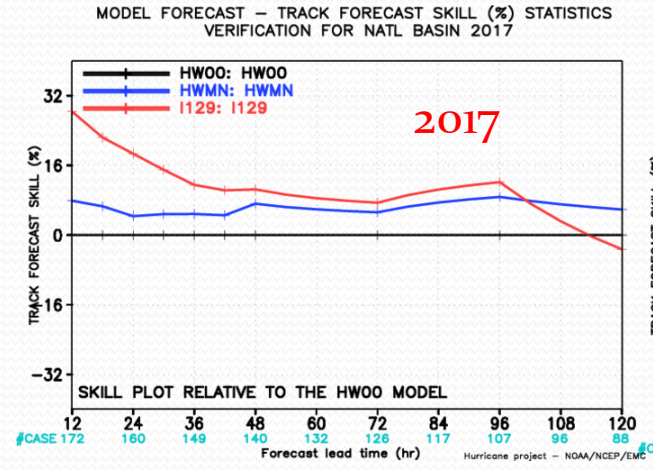
- Ensemble mean of HWRF-EPS (HWMN) generally has lower intensity forecast than operational HWRF (HWRF)
- Posterior intensity forecast (MPTE) have much lower intensity forecast error
- HWRF-EPS intensity forecast skills are comparable with operational HWRF at all lead forecast hours

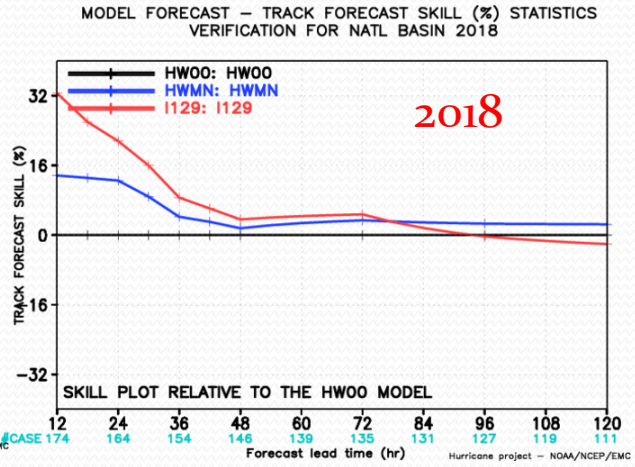
Track Forecast Skill Improvement of HWRF-EPS
(Average over Sub-setting at 12h vs All ensemble members)

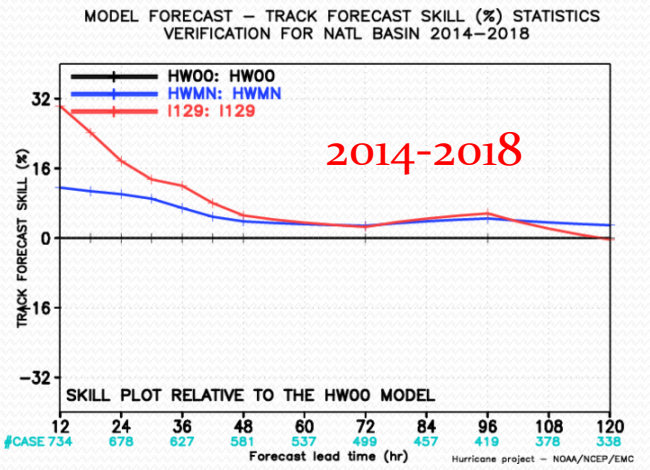






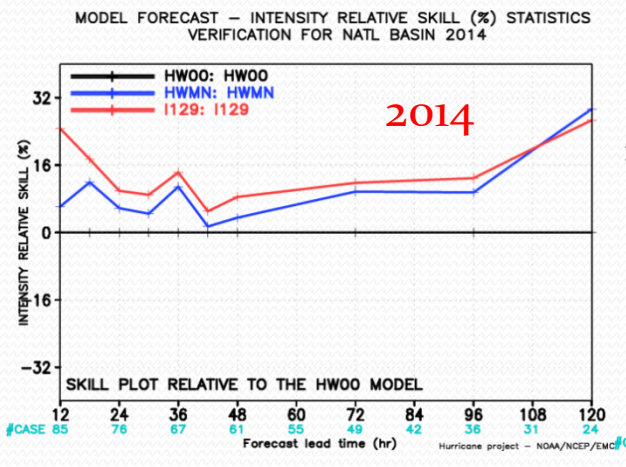


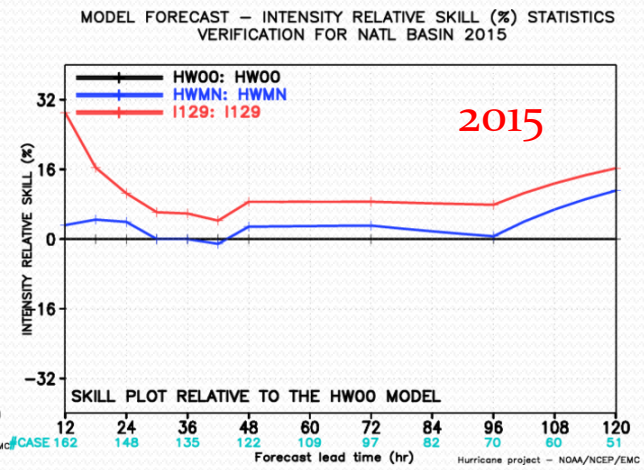


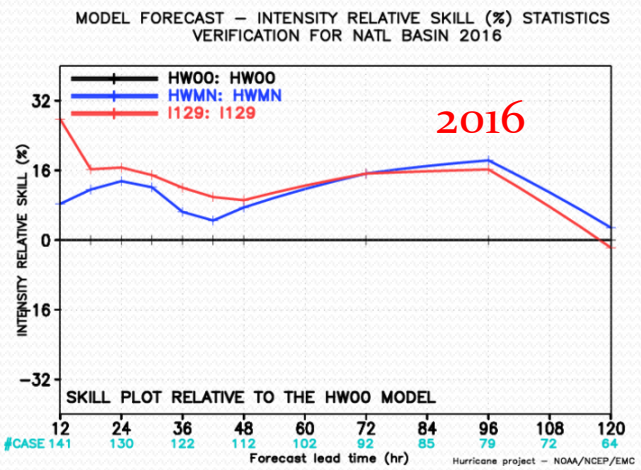


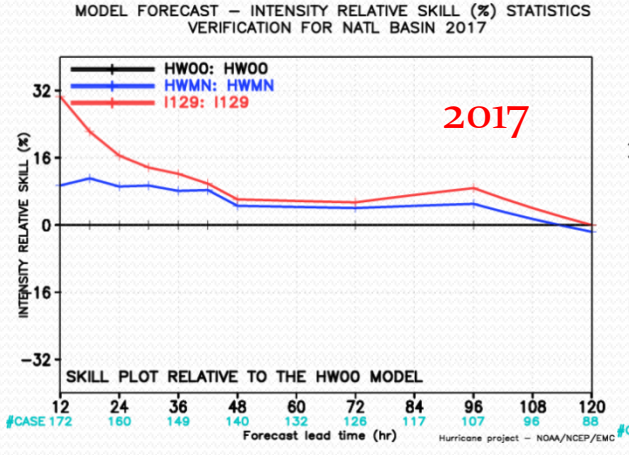
~5% intensity improvement, HWMN vs HWoo
Additional ~5% before 36h

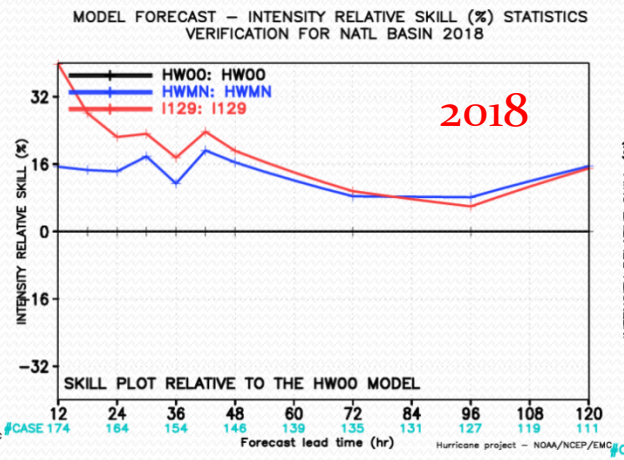
Intensity Skill Improvement of HWRF-EPS
(Average over Sub-setting at 12h vs All ensemble members)

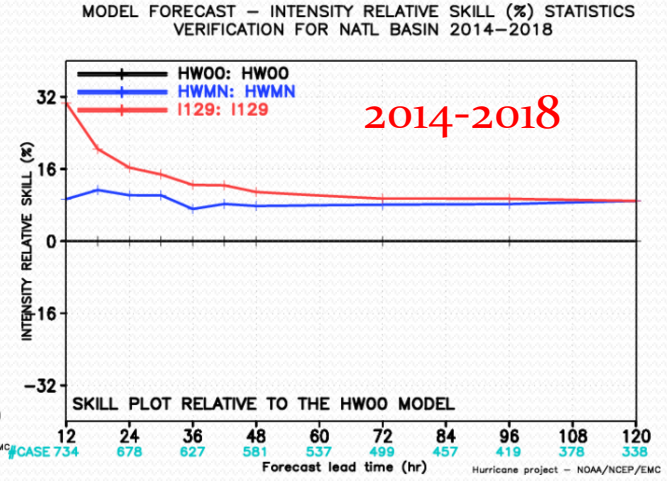






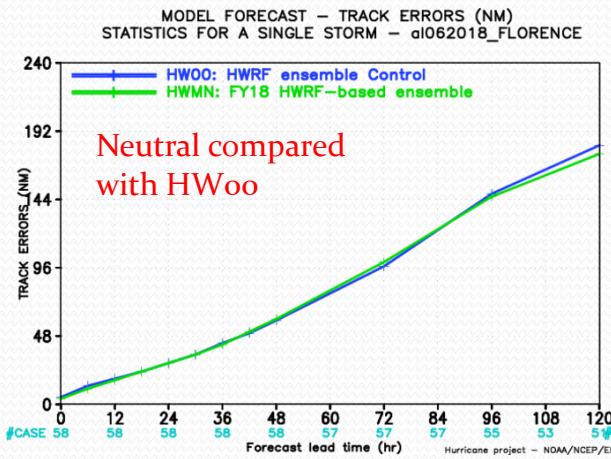


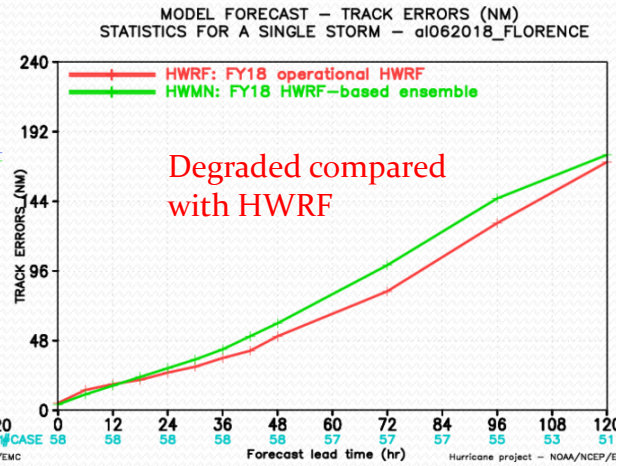


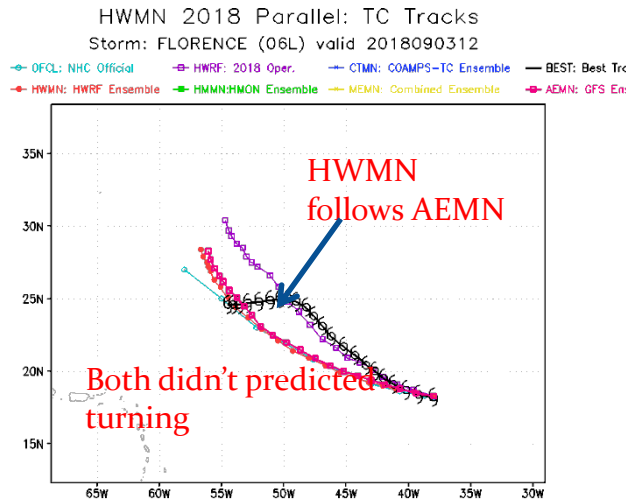


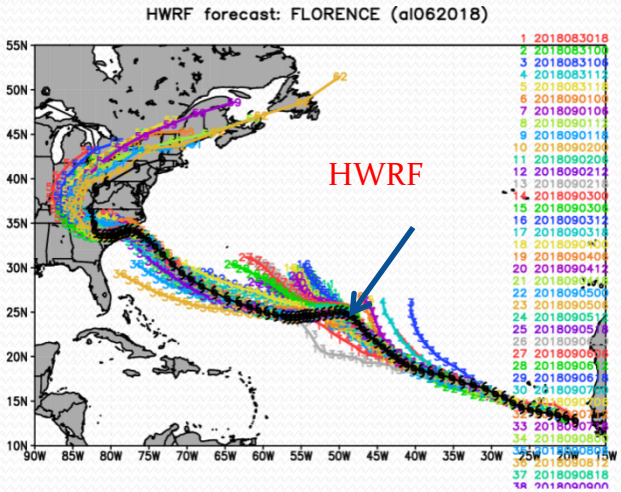
~10% intensity improvement, HWMN vs HWoo
Additional ~5-10% before 36h

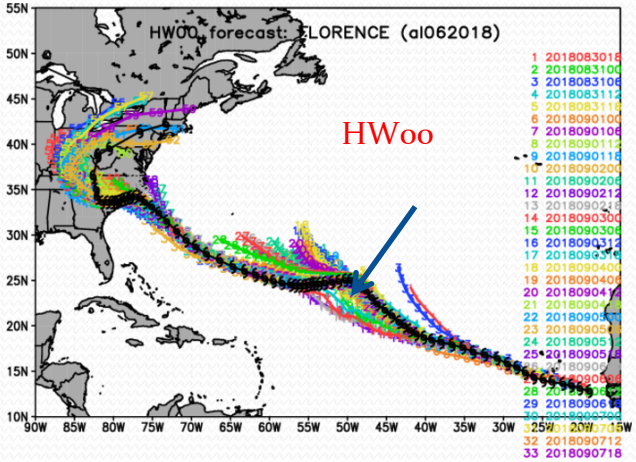
Composite Tracks for Florence, o6L

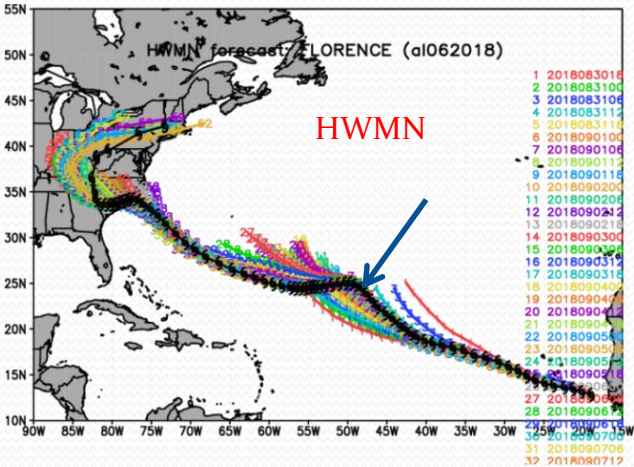






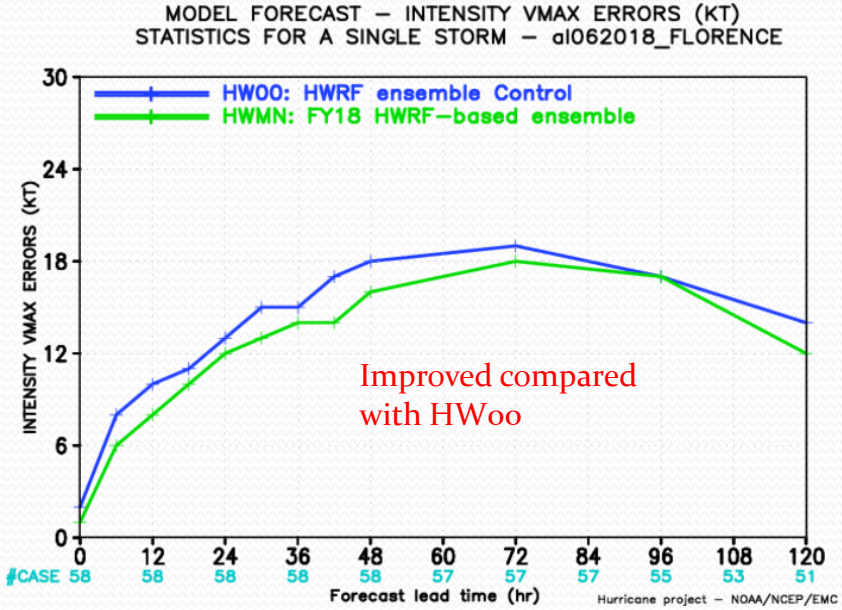


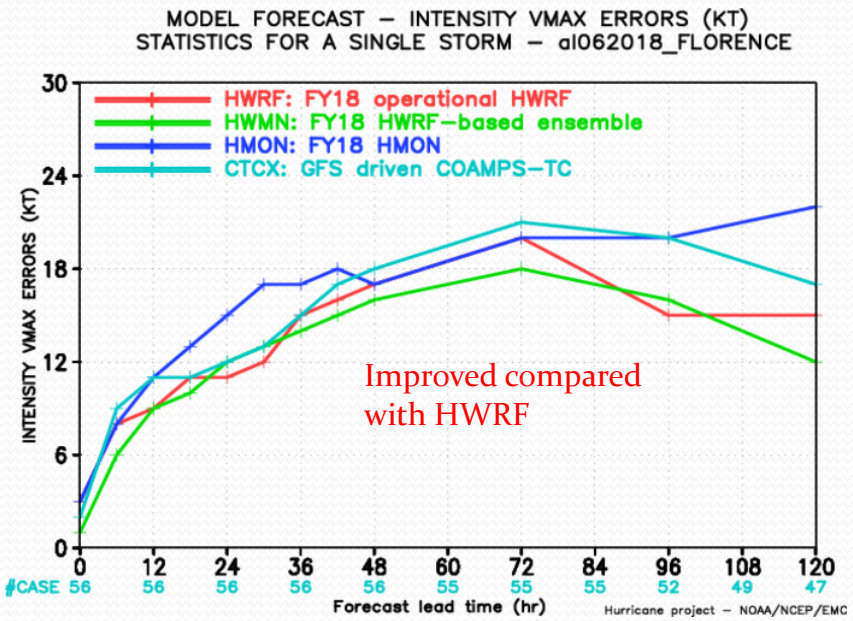


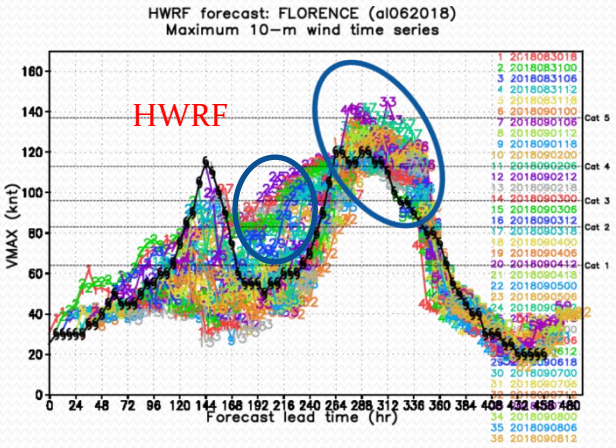


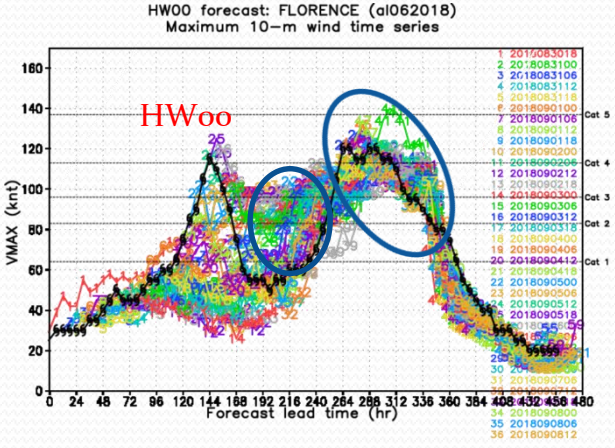
1. All three systems missed westward turning point;
2. HWoo/HWMN have southward track bias following GEFS.

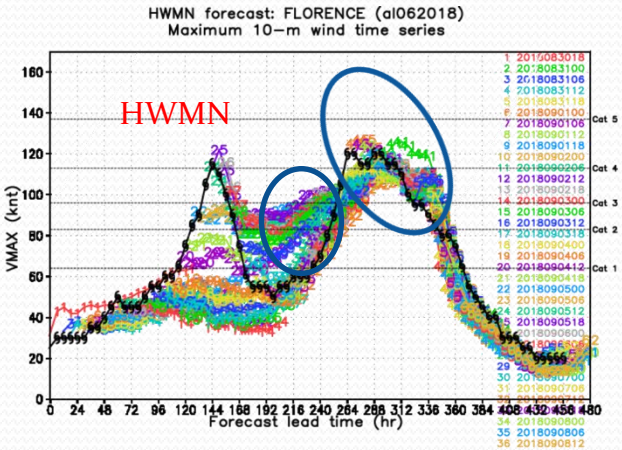
Composite Intensities for Florence 06L



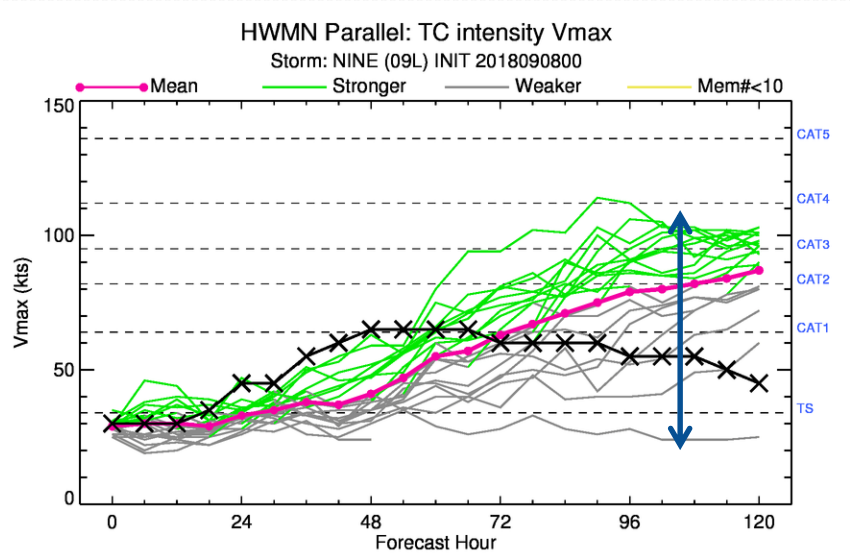


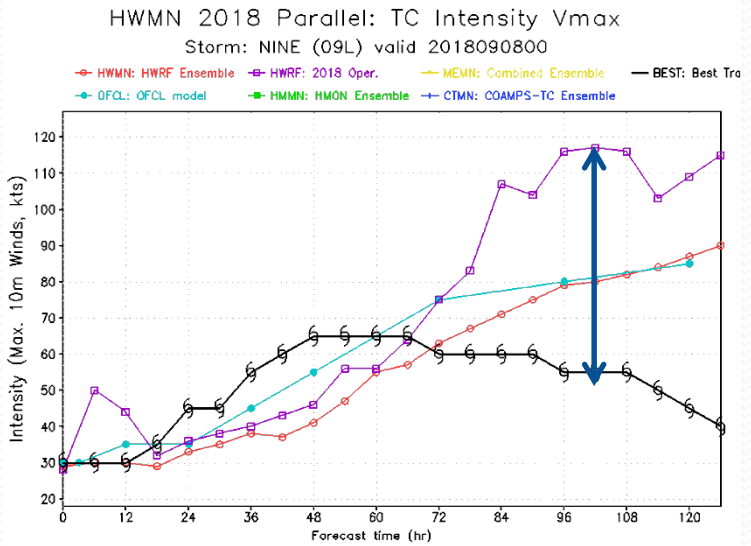


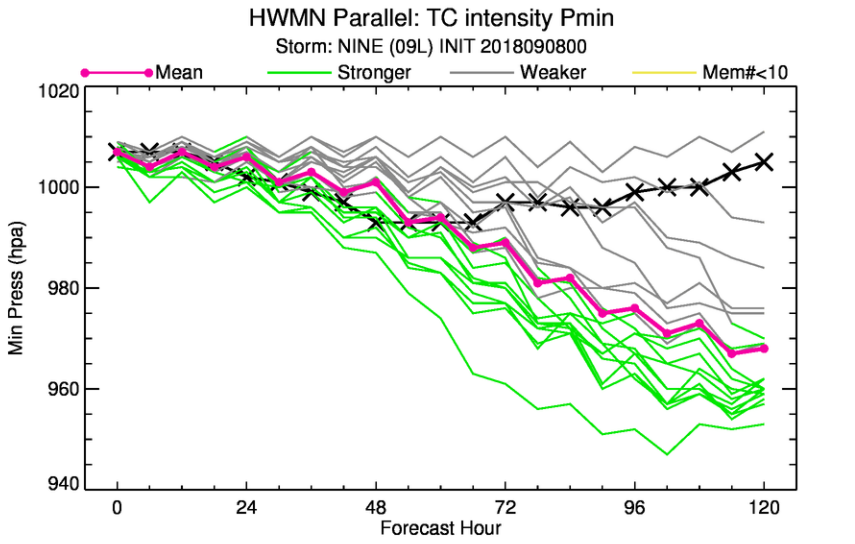


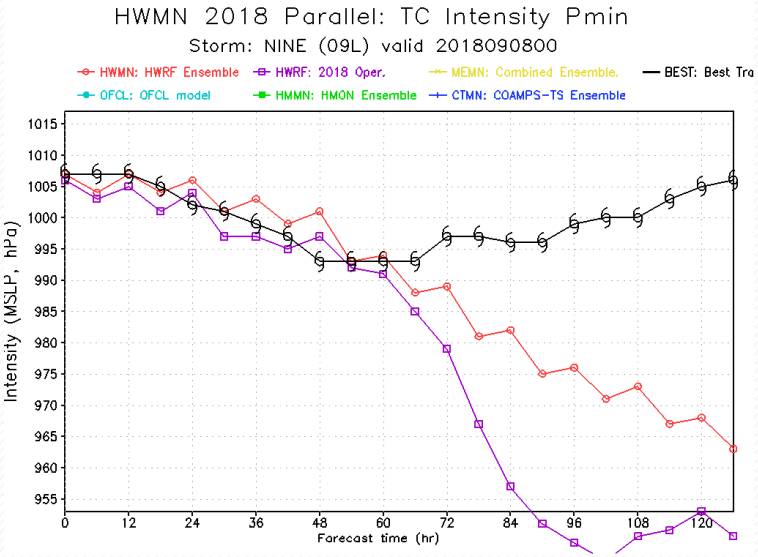


Larger Ensemble Spread indicates larger Forecast Errors

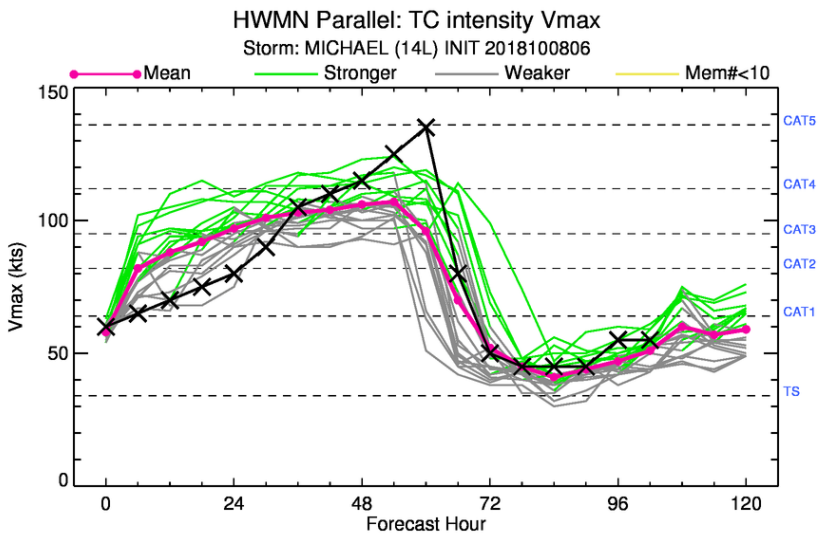


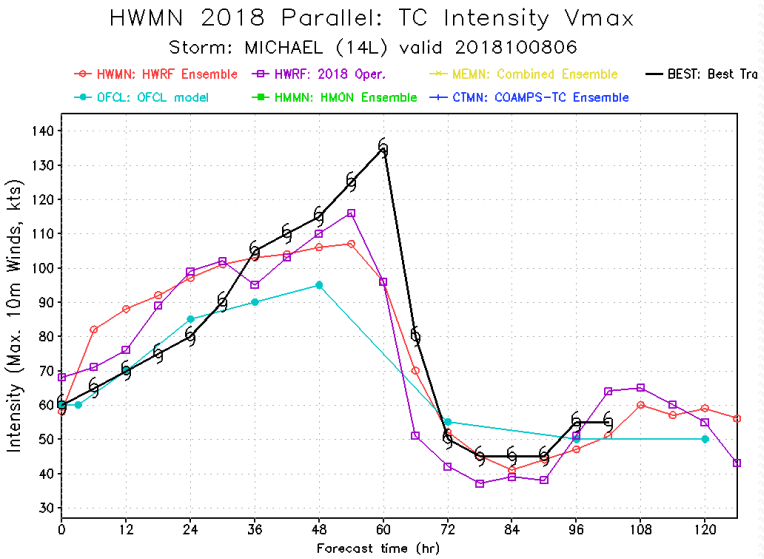


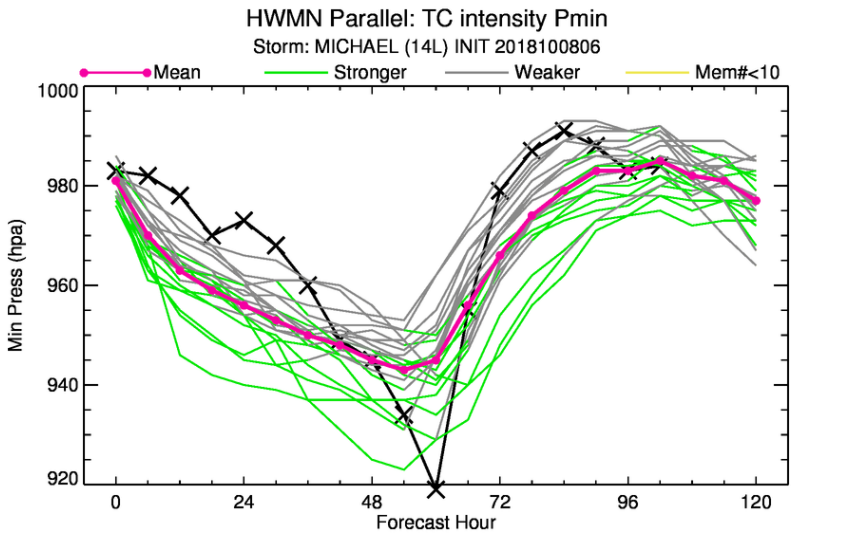


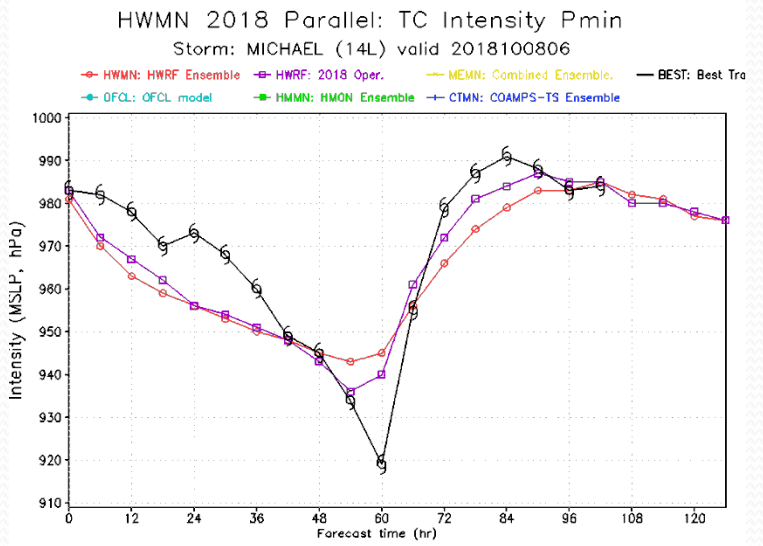


Smaller Ensemble Spread indicates Smaller Forecast Errors

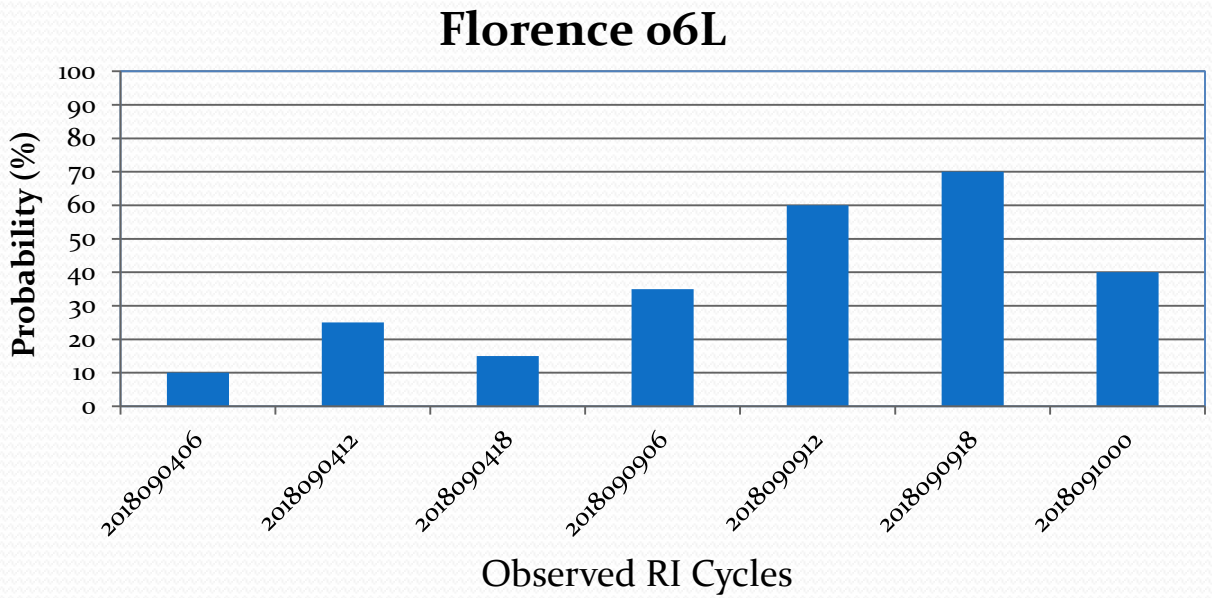


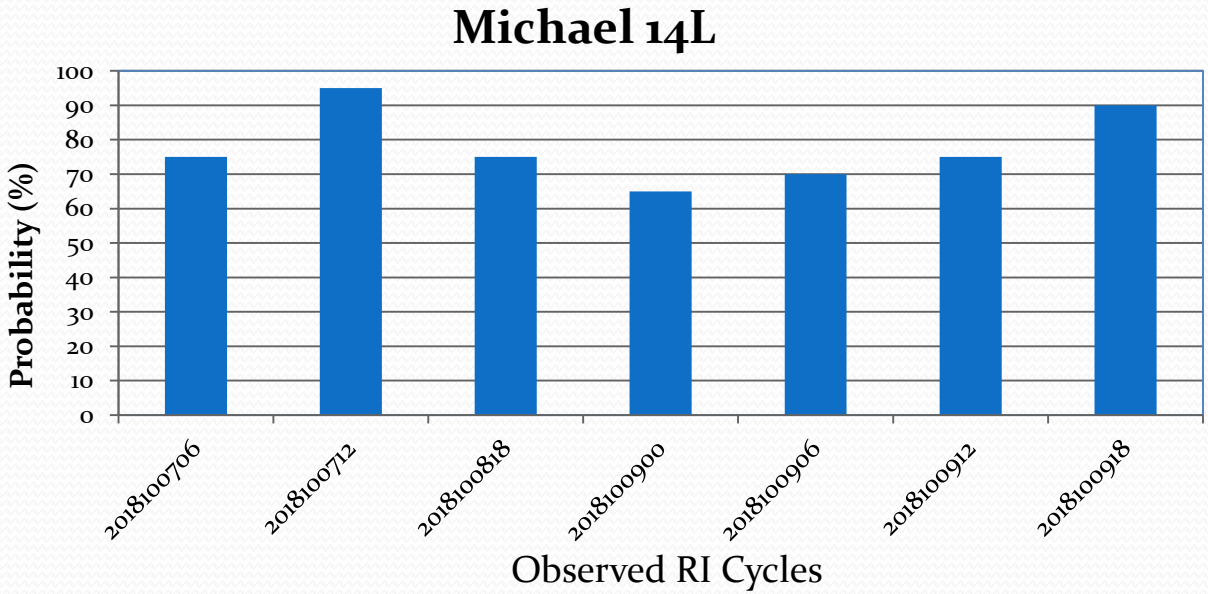






RI Probability Forecast from HWRF-EPS





$P_{RI} = N_{RI} / N_{total}$

N_{RI} is the max No of ensemble members that predicted RI event in 96h;

N_{total} equals 20, the total No. of ensemble numbers.

Concluding Remarks

- The statistical features of HWRF-EPS is evaluated
  - configured that each ensemble member has equal probability to be closest to the observed intensity and storm position
  - Ensemble spread is under-dispersed
  - Predicted Vmax is generally Gaussian distributed, except for relatively larger PDF at both ends
  - Cases of large Vmax forecast errors are investigated, and found 3 possible reasons: a). Rapid intensity, b). large track forecast errors; c). and model physics
- HWRF-EPS produces lower track/intensity forecast errors, compared to its deterministic control run at NATL basin for 2014-2018 hurricane seasons
- HWRF-EPS intensity forecasts have smaller errors compared to the operational HWRF even with lower resolutions and no data assimilation
- HWRF-EPS track forecast is still behind the operational HWRF (partially followed its parent model, GEFS)
- Assuming obs. At 12h is known, Sub-set of ensemble mean method provides further improvements on top of ensemble mean of all members
- HWRF-EPS demonstrated its capable of statistically predicting hurricane RI event.

Thank You!

HWRF-EPS:
http://www.emc.ncep.noaa.gov/HWRF/HWRFEPS/index.php