



Performance of the 2013 Operational HWRF for the North Western Pacific and North Indian Ocean Basins

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*W/Inputs from Chanh Kieu, Sam Trahan and the
entire HWRF Team*

*Special Acknowledgements to Brian Strahl,
JTWC & Jet Admins, Boulder*

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Outline

- **Introduction**
- **HWRF real-time setup for WPAC and NIO basins**
- **FY2012 HWRF real-time performance**
- **FY2013 HWRF retrospective evaluation**
- **FY2013 HWRF real-time performance**
- **Research findings**
- **Summary**
- **Up-to-date statistics for other basins (Appendix)**

Introduction

- Starting in 2012, EMC HWRF team has been experimenting real-time forecasts for the WPAC basin, using NCEP Operational HWRF system, thanks to the support from NOAA's Hurricane Forecast Improvement Project (HFIP).
- Forecasts of all storms in WPAC basin including Invests and Depressions using the same configuration as for North Atlantic /Eastern Pacific basins except for ocean coupling.
- ~ 85% reliability in delivering forecast products to JTWC was accomplished using dedicated resources (three sets of infinite reservations) on HFIP machines in Boulder.
- FY13 HWRF retrospective testing included evaluation of performance in the Western Pacific basin with modifications specific for that basin
- **JTWC decided to include HWRF as one of their track and intensity consensus guidance tools starting with the 2013 typhoon season.**
- **Continued delivering real-time forecast guidance for all tropical systems in the Western Pacific basin in 2013, along with support for North Indian Ocean for Tropical Cyclone Phailin**

2012 WPAC real-time configuration

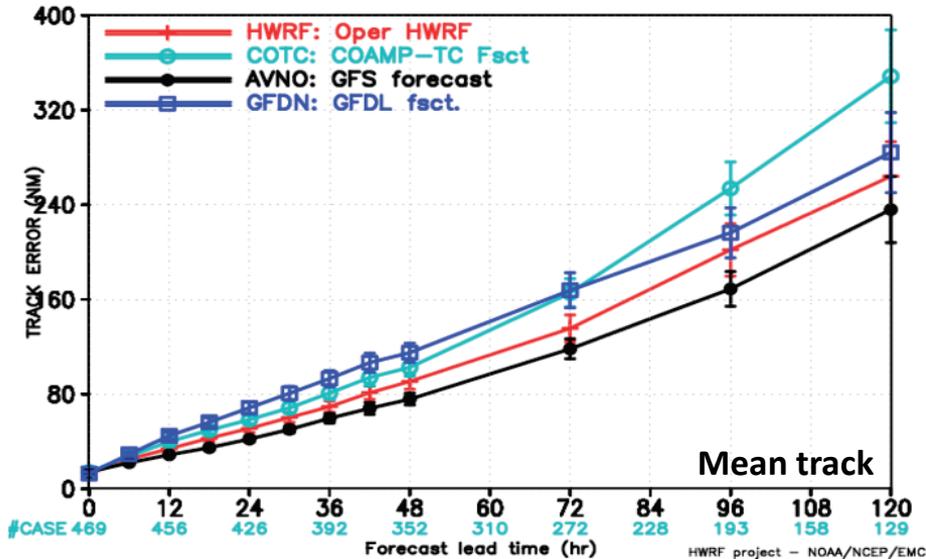
- FY2012 operational HWRF based on the latest community version WRF-NMM (V3.4a)
- *First ever high-resolution operational hurricane model operating at cloud-permitting 3km resolution*: triple nested domains 27/9/3 km; 43 vertical levels, the outermost domain is fixed, 9-km and 3-km domains follow the storm center.
- Model physics includes the GFS PBL scheme; improved GFDL surface physics; Ferrier Microphysics parameterization schemes; new GFS shallow convection parameterization.
- Lateral boundary conditions updated every 6 h. The model physics called every 3 minutes with explicit convection in the 3km domain.
- Vortex initialization capability for high resolution configuration. No ocean coupling.

2012 WPAC customization

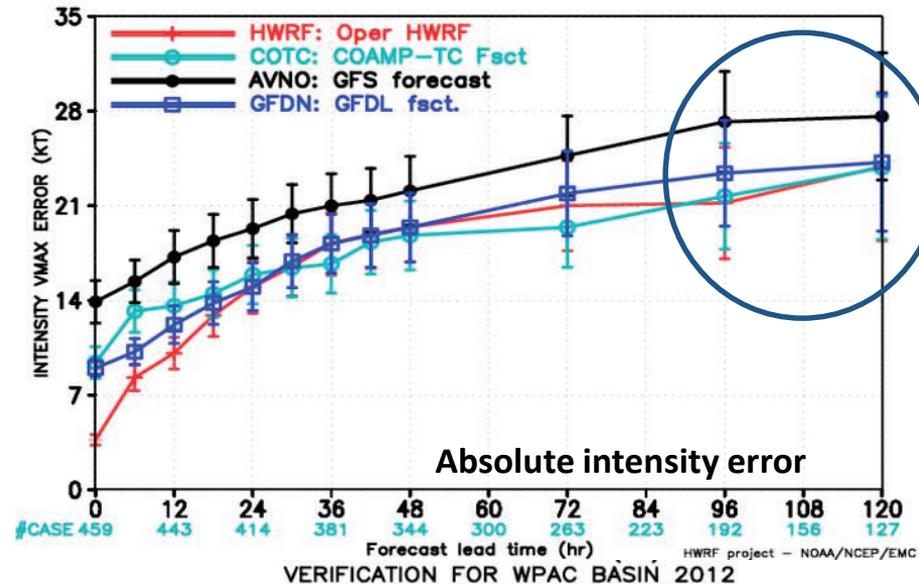
- Modified the operational HWRF to remove some limitations in terms of domain placement that prevents it to be configured beyond 60W
- Revised the vortex initialization procedure to work in WPAC and North Indian Ocean
- Increased the top of model sigma levels to 300 hPa. This reduced the steepness of the lower level sigma surface and prevented the model failures.
- Stopped nest movement if crossing over high terrain

2012 HWRF real-time performance in WPAC

HWRF FORECAST – TRACK ERROR (NM) STATISTICS
VERIFICATION FOR WPAC BASIN 2012

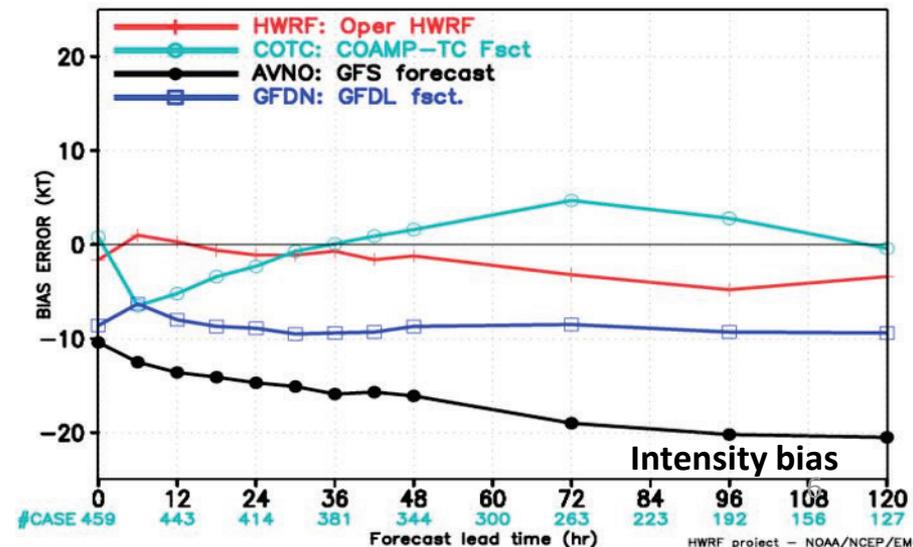


HWRF FORECAST – INTENSITY VMAX ERROR (KT) STATISTICS
VERIFICATION FOR WPAC BASIN 2012

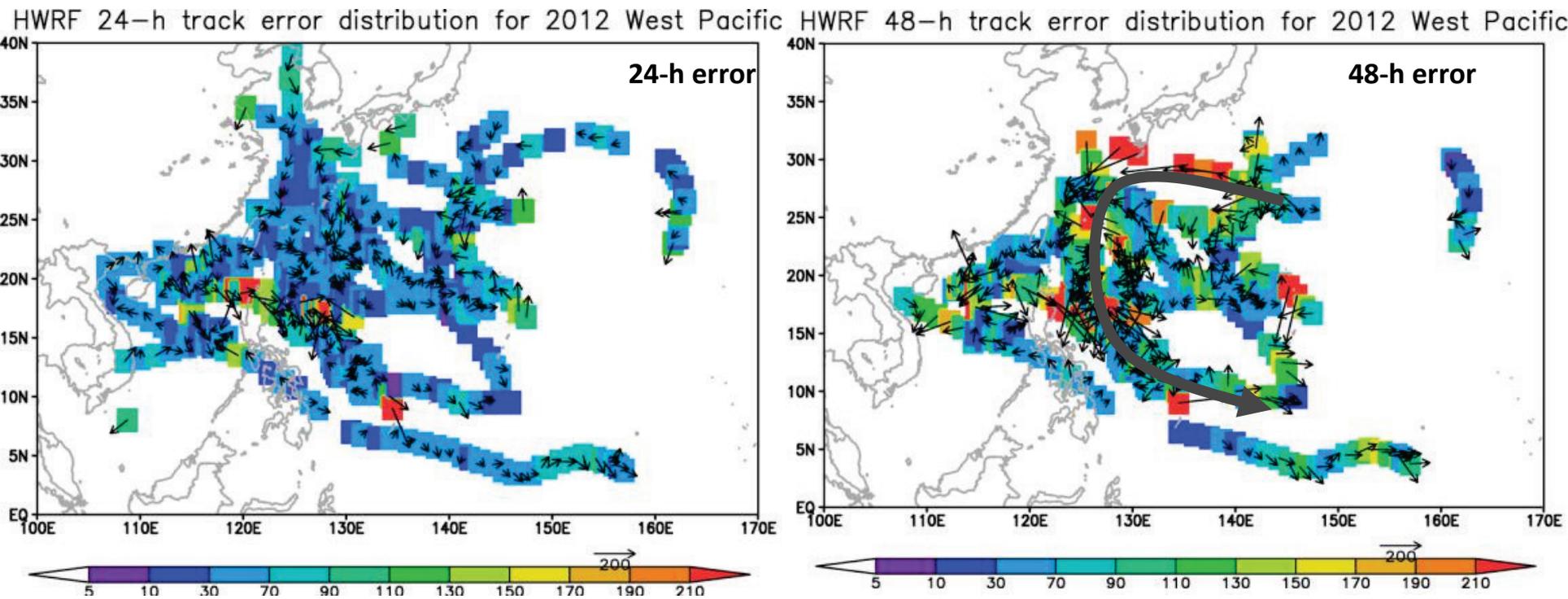


FY2012 HWRF real-time experiments for 2012 WPAC season showed

- HWRF outperforming all other operational regional models in track forecast skill;
- better intensity forecast skill out to lead time 24 hours owing to better vortex initialization;
- minimum intensity bias as compared to other models

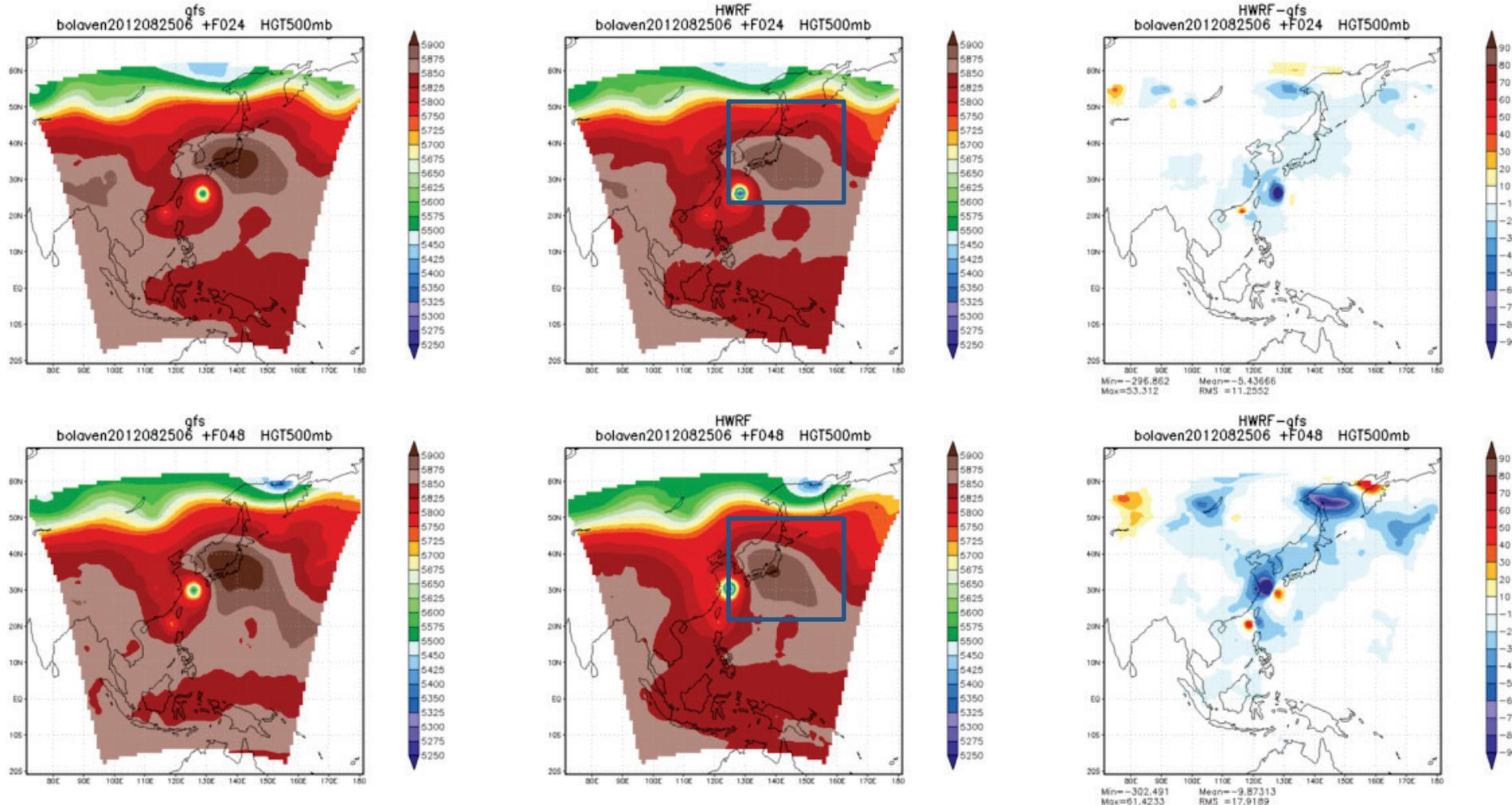


HWRF 2012: track error distribution



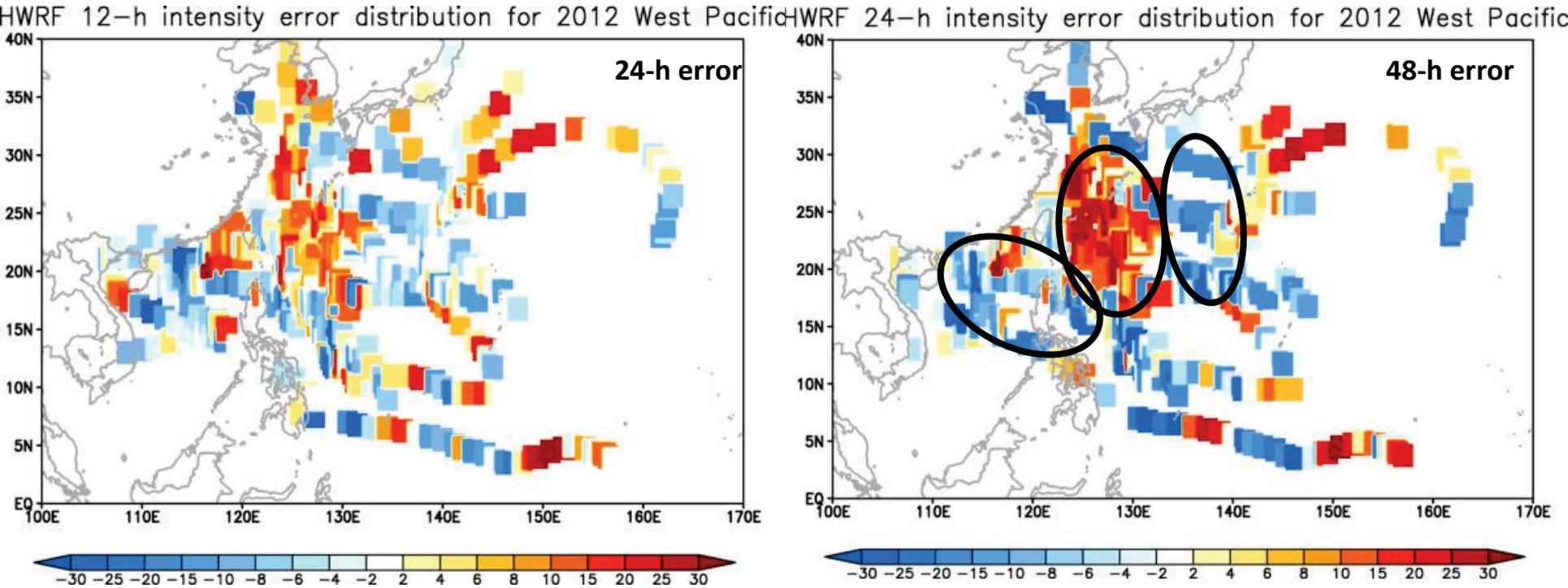
- Larger track errors near Philippine archipelago and higher latitudes.
- HWRF tends to have right bias at low latitude, slower storm translational speed between 15 and 25^oN, and left bias at higher latitude
- Appears to possess erroneous prediction of the environmental flow dominated by the Western Subtropical High
- Small overall cross track errors are not representative

HWRF 2012 track error distribution: a large-scale example (Bolaven 16W)



Weaker sub-tropical high compared to GFS forecasts

HWRF 2012: intensity error distribution



- For intensity error distribution, HWRF showed overestimation of storm intensity in the East China Sea
- Underestimation of storm intensity in the far ocean and South China Sea;
- There is a connection between storm bias intensity and translational speed

Issues with FY12 HWRF system

- Model innermost domain sometimes lost storm center, especially for weak systems;
- Innermost domain size was too small in some cases (e.g., Sandy had its 34-kt radii > 800 km at some stage of development).
- Over/underestimated storm intensity for strong/weak storms
- HWRF large-scale environment (e.g., STH) seems to be weaker than GFS analysis
- Several nest movement related issues

2013 HWRF new implementation

Infrastructure upgrades:

- Upgrade the nest tracking algorithm
- Re-design of nest-parent interpolations
- Increased frequency of physics calls and increased size of the third domain

Physics upgrades:

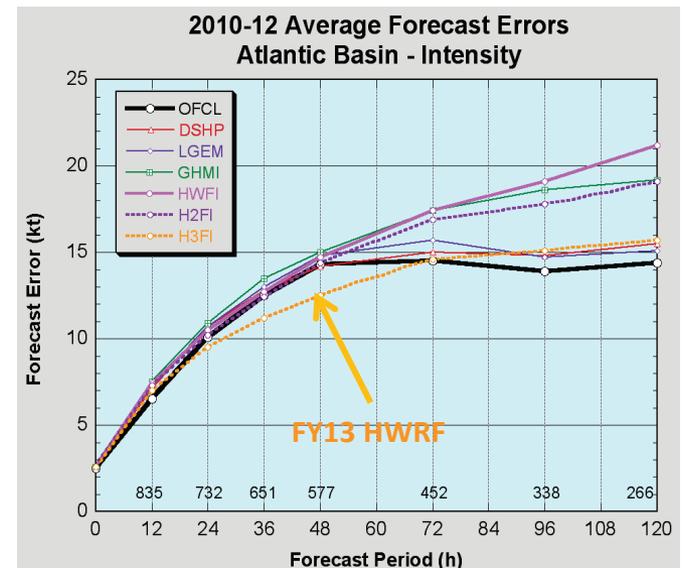
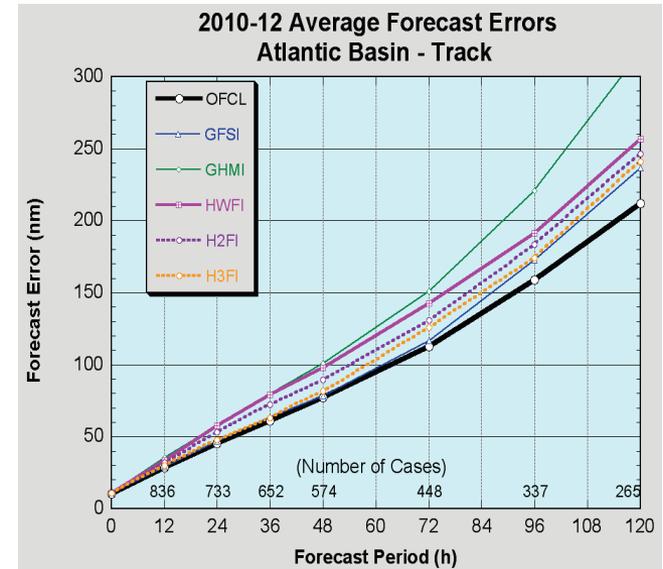
- Modifications to GFS PBL and bug fix for GFDL radiation

Data Assimilation and Vortex Initialization upgrades:

- One-way hybrid EnKF-3DVAR data assimilation and assimilate real-time inner-core TDR datasets
- Improved storm size correction, modified filter domain and use of GFS vortex when the storm is weaker than 16 m/s

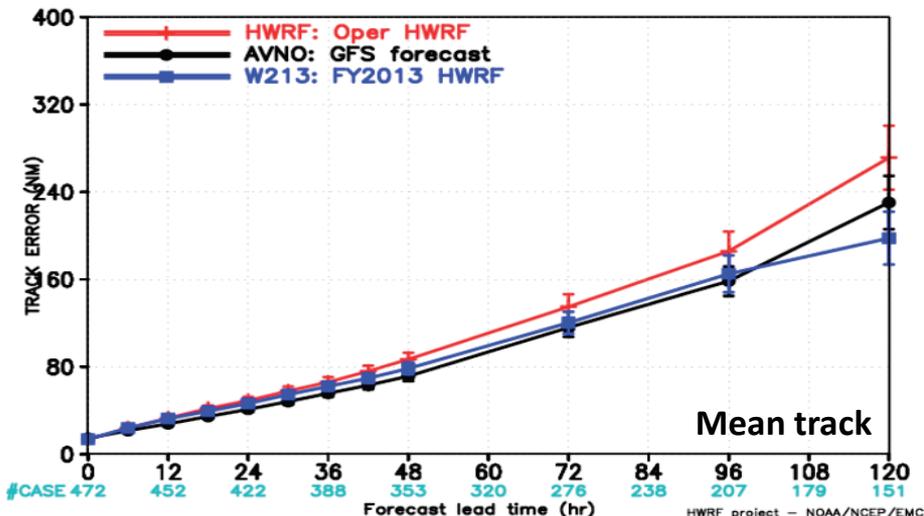
Extensive evaluation:

- Three-season (2010-12) comprehensive evaluation for NATL/EPAC
- 2012 typhoon season for WPAC

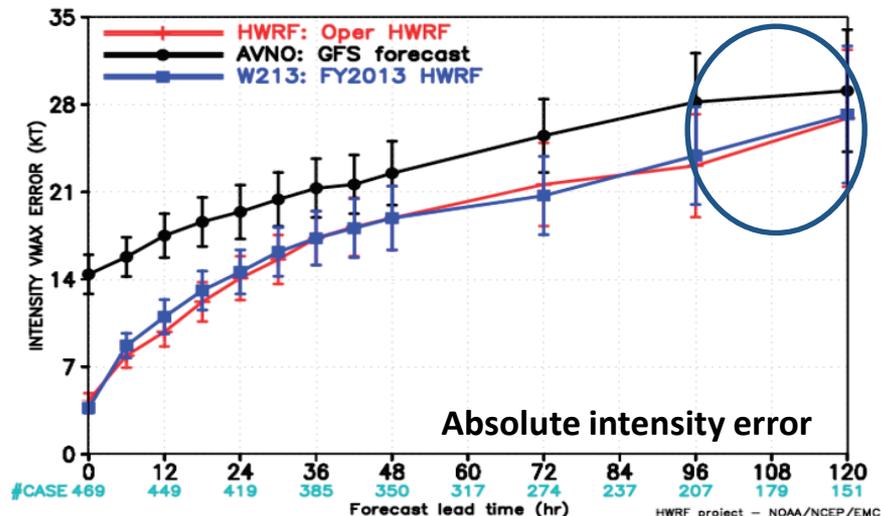


2013 HWRF : retrospective expts for WPAC

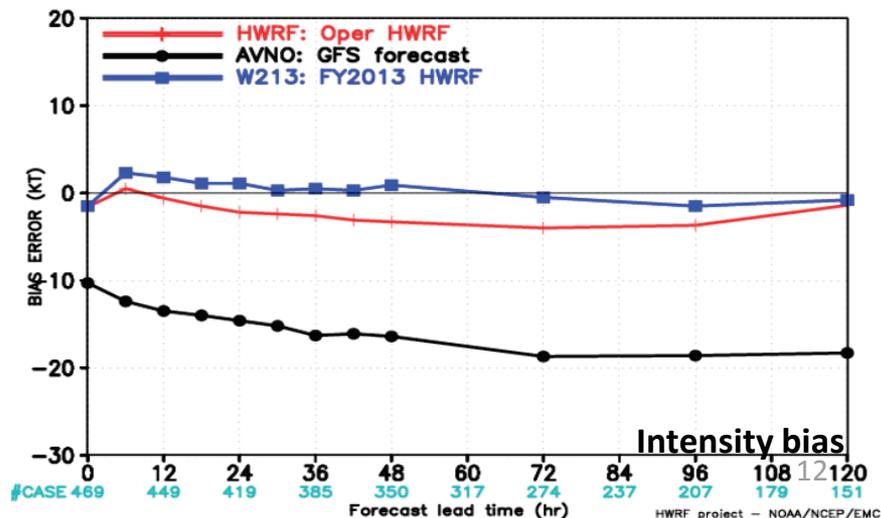
HWRF FORECAST – TRACK ERROR (NM) STATISTICS
VERIFICATION FOR WPAC BASIN 2012



HWRF FORECAST – INTENSITY VMAX ERROR (KT) STATISTICS
VERIFICATION FOR WPAC BASIN 2012



HWRF FORECAST – BIAS ERROR (KT) STATISTICS
VERIFICATION FOR WPAC BASIN 2012

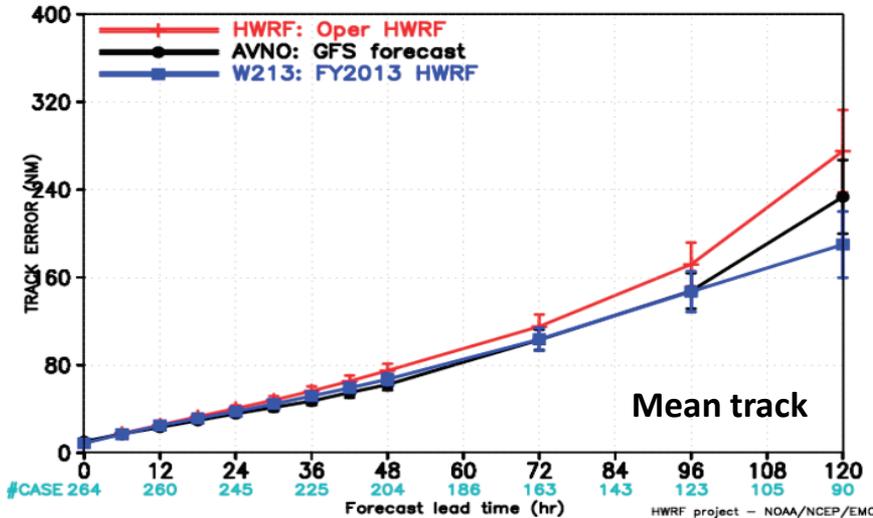


- FY2013 HWRF retrospective experiments for 2012 season shows dramatic track improvement (comparable now to GFS forecast, less than 200 nm at day 5);

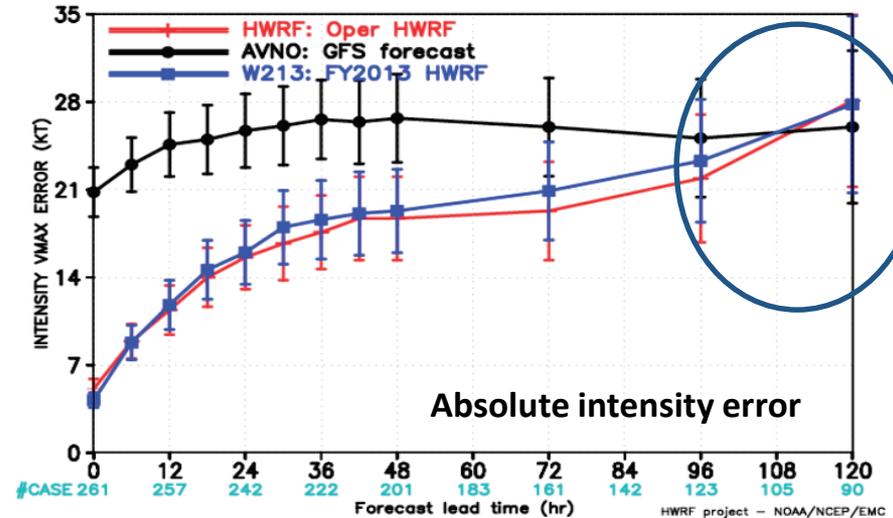
- Intensity errors show no significant improvement, however, negative bias reduced;

2013 HWRF retrospective: strong storms

HWRF FORECAST – TRACK ERROR (NM) STATISTICS
VERIFICATION FOR WPAC BASIN 2012 – STRONG STORMS

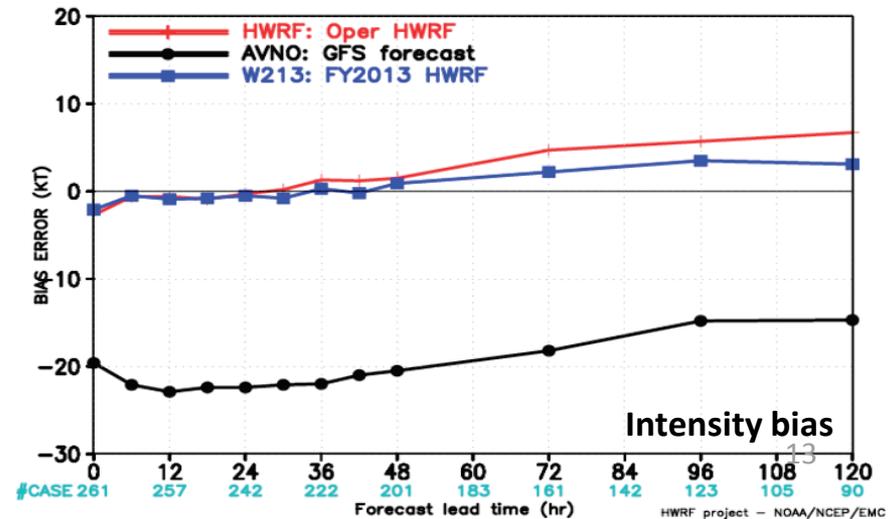


HWRF FORECAST – INTENSITY VMAX ERROR (KT) STATISTICS
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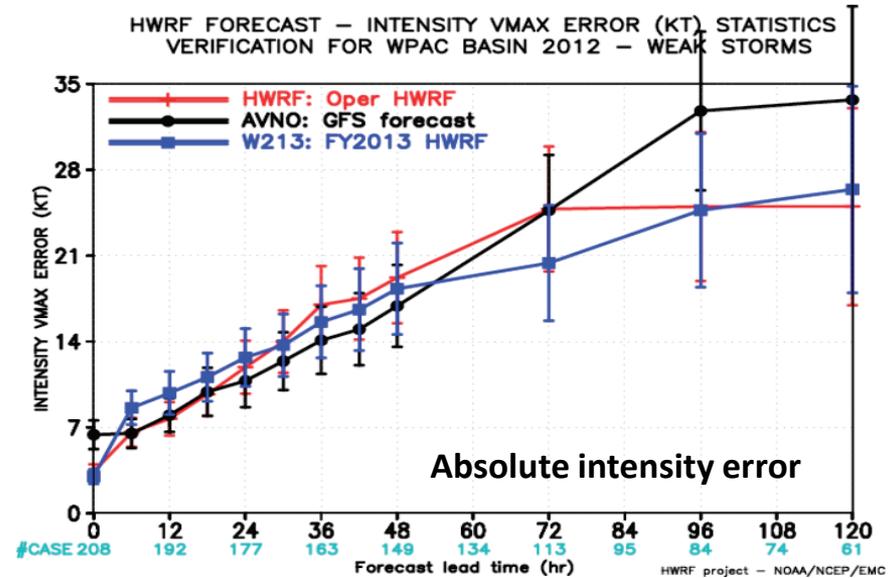
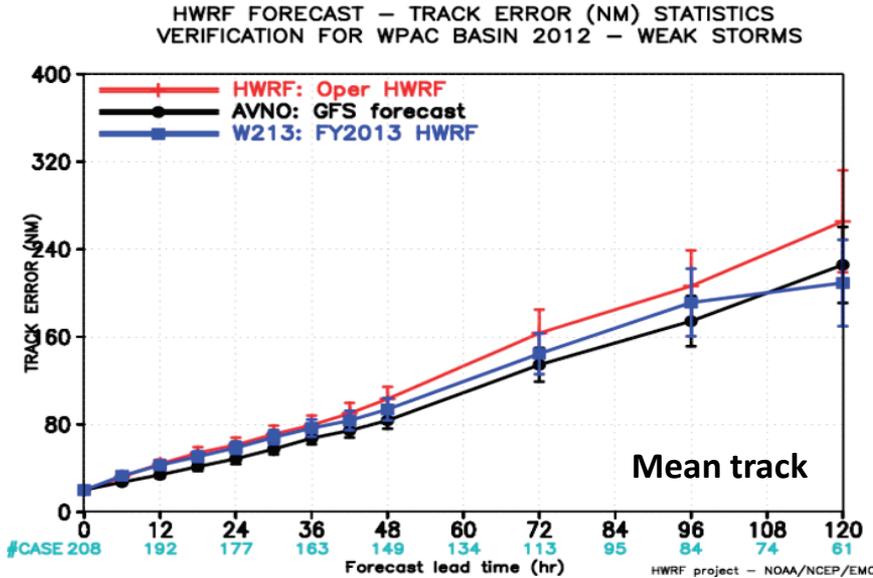


- Stratification with strong storms show track improvement is persistent
- Intensity errors still did not show any improvement; day-4/day-5 errors exceed 25 kts
- Intensity bias a little bit better than 2012 HWRF

HWRF FORECAST – BIAS ERROR (KT) STATISTICS
VERIFICATION FOR WPAC BASIN 2012 – STRONG STORMS



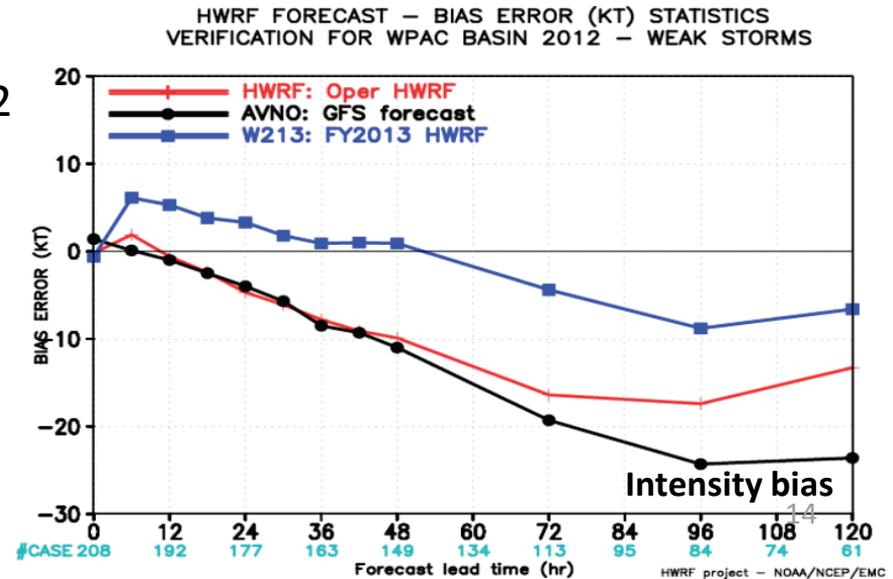
HWRF 2013 retrospective: weak storms



- Stratification with initial weak storms also shows that track forecast skill is better than 2012 HWRF and closer to GFS

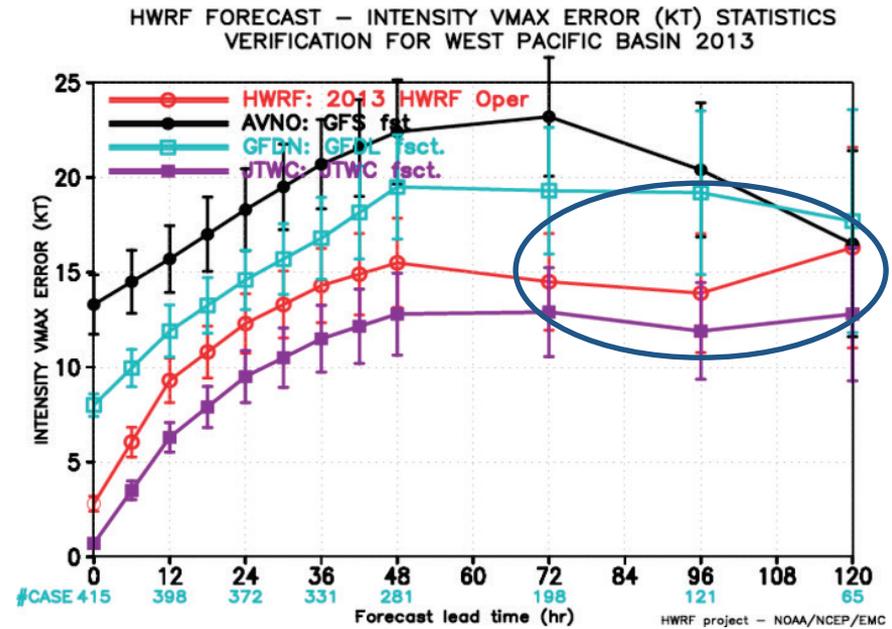
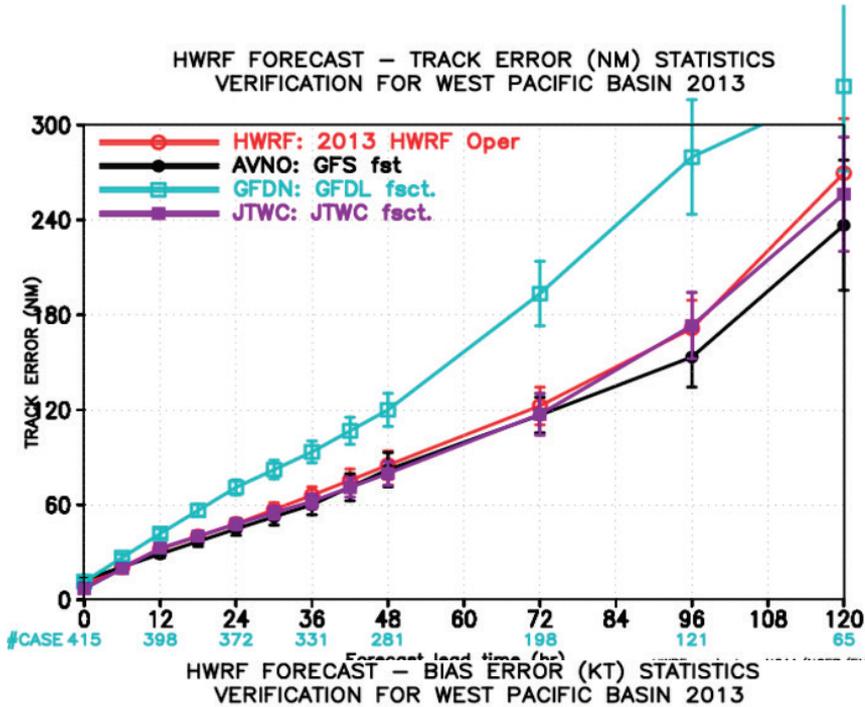
- Intensity errors for initial weak storms are smaller than overall statistics and better than H212

- Intensity bias is better than H212 but turns out to be slightly underestimate storm intensity



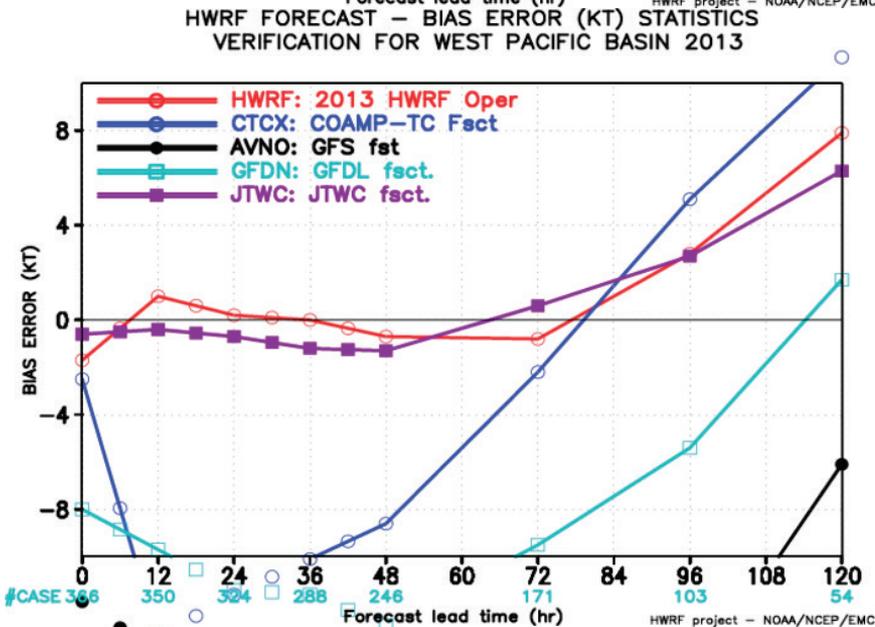
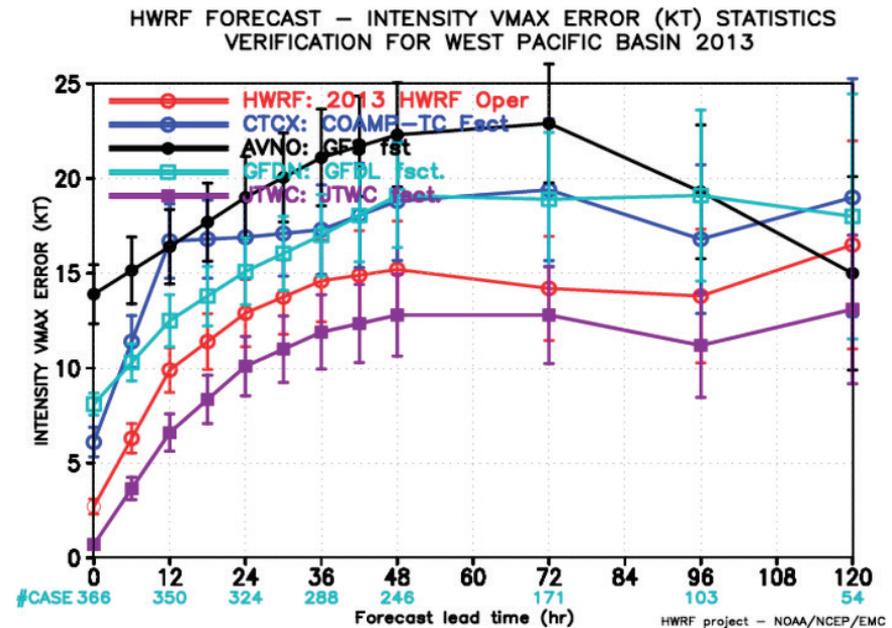
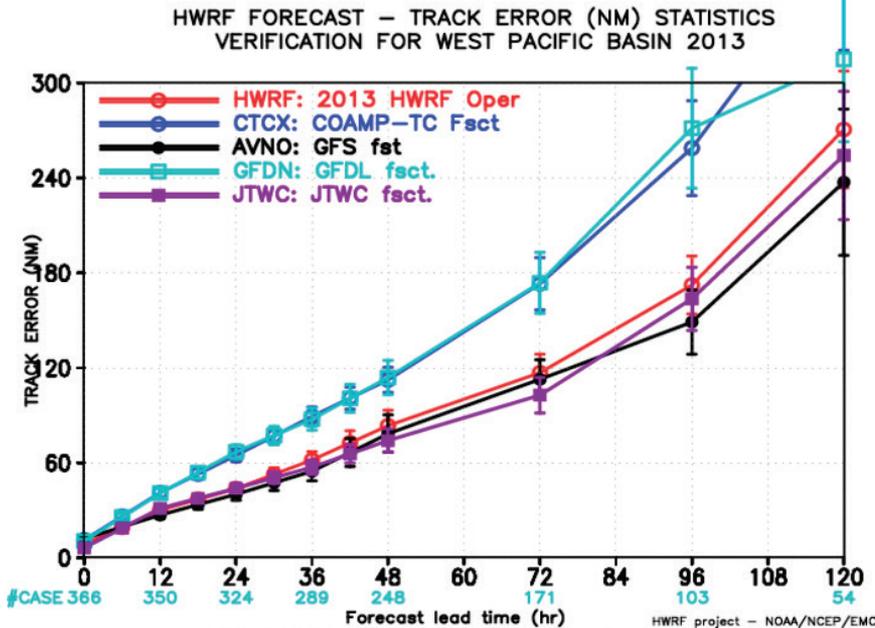
Real-time performance of HWRF for 2013 WPAC Typhoons

2013 HWRF real-time verification for WPAC



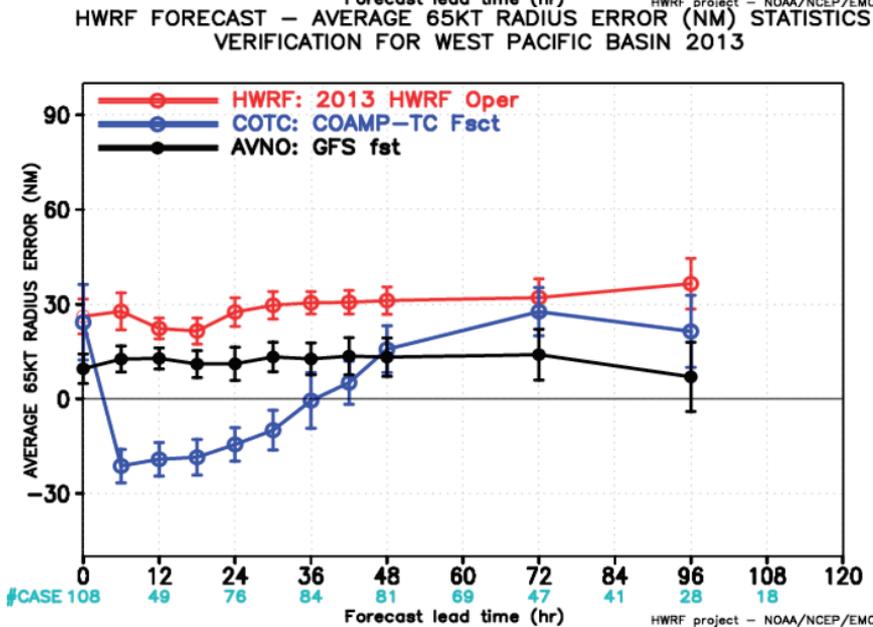
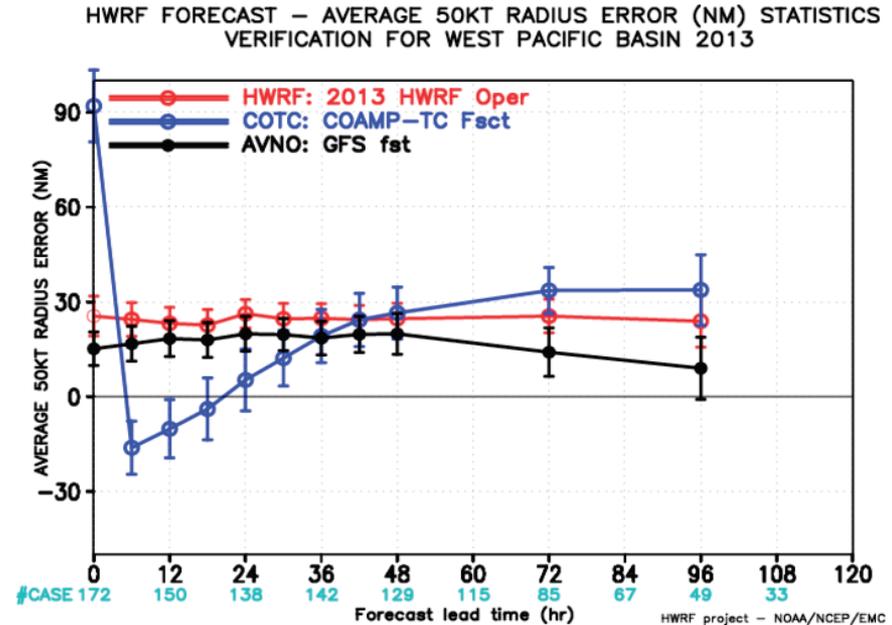
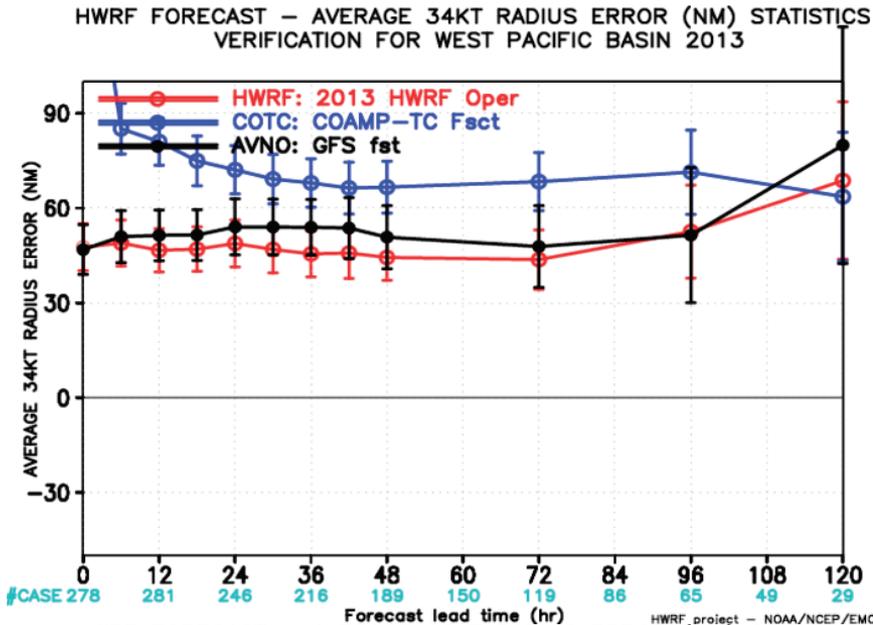
- HWRF track forecasts are so far better than all regional models up to day 4; very close to GFS forecasts;
- Intensity errors far superior to all other models
- Tendency of overestimation of strong intensity is still persisting (at later forecast hours)

2013 HWRF real-time verification for WPAC



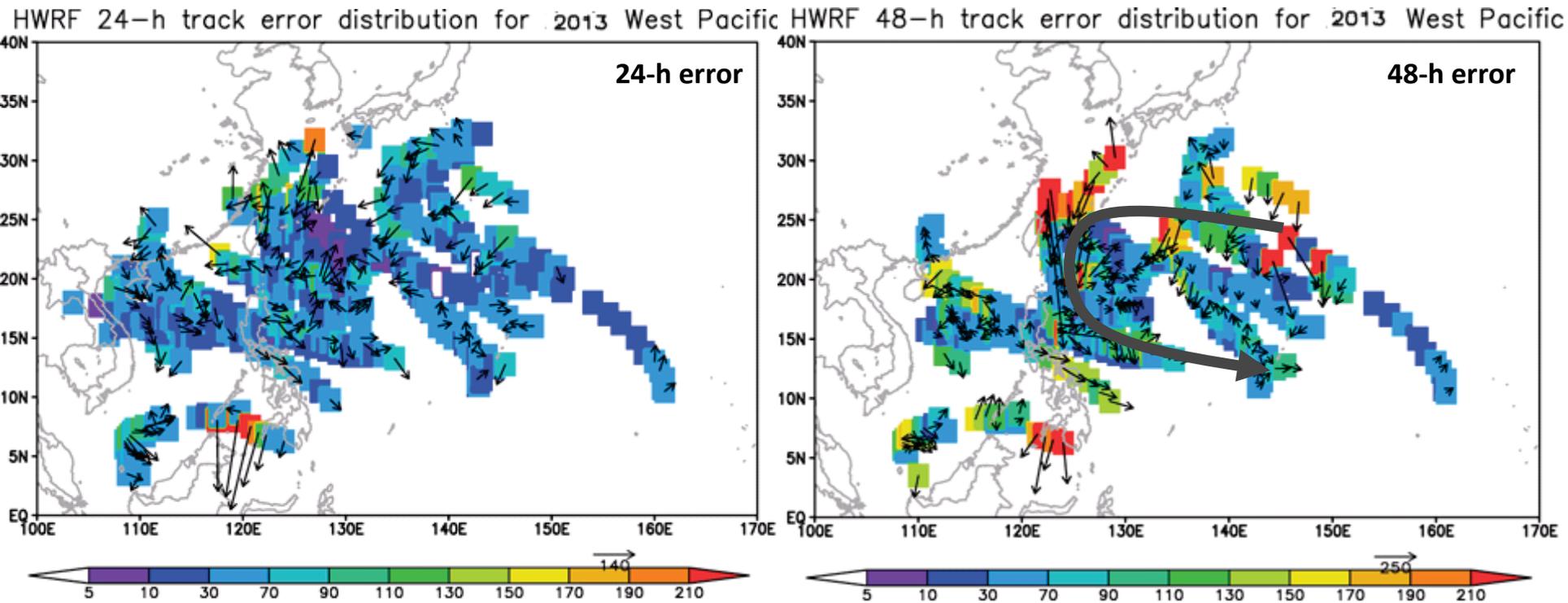
- HWRF track forecasts are so far better than all regional models up to day 4; very close to GFS forecasts;
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Structure verification



- HWRF could maintain well the radii error structure initially;
- Several cycles have missing R-34 in tcvitals, initialization can't adjust the size at $t = 0$.

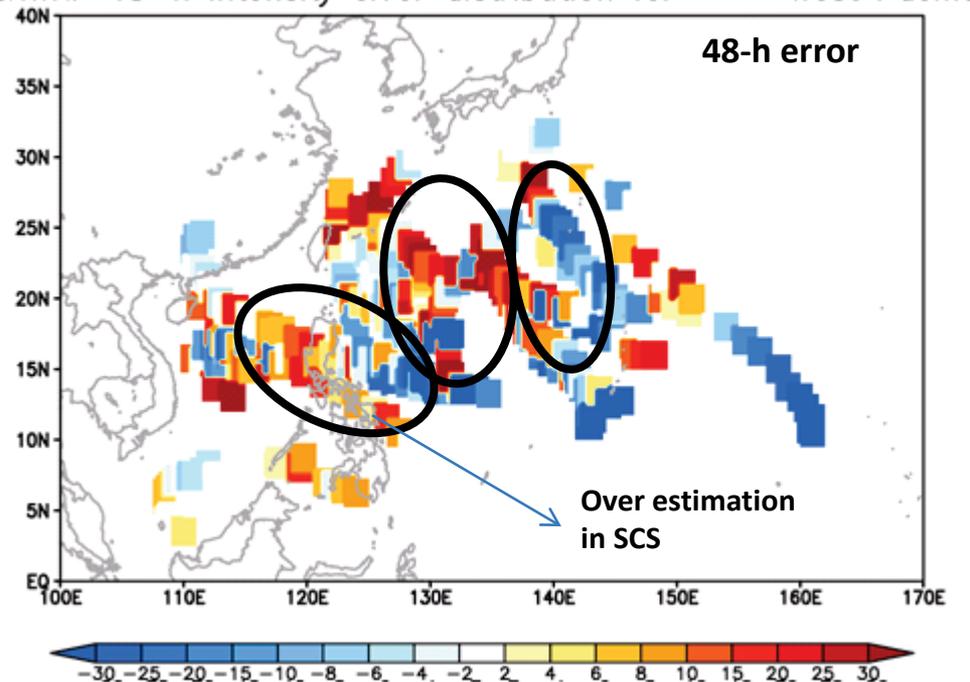
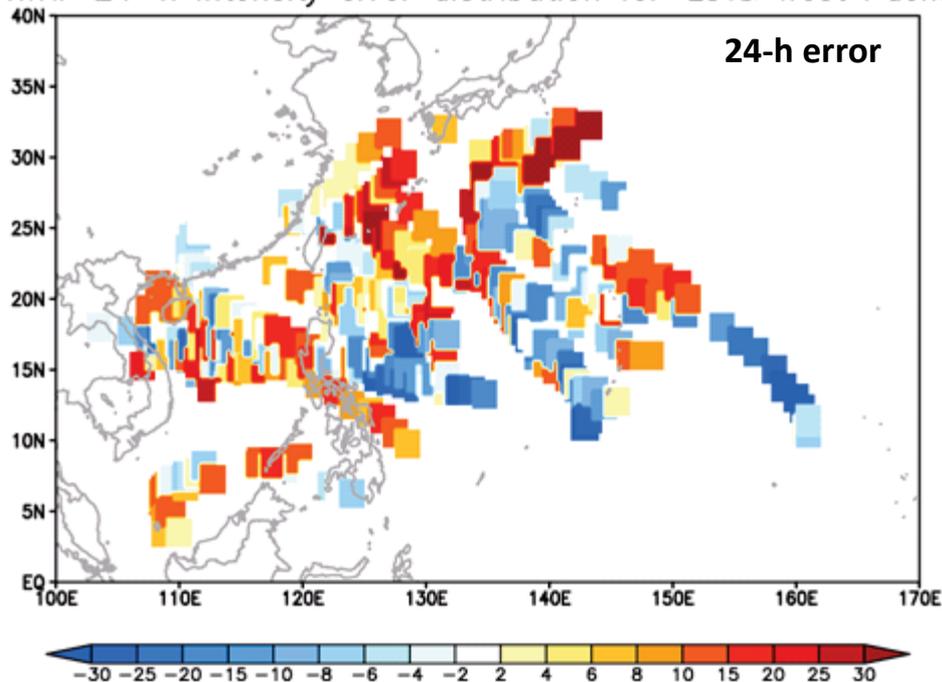
HWRF 2013 track error distribution



- Issues with right bias at low latitude, slower storm translational speed between 15 and 25°N and left bias at higher latitude still existing (albeit of less magnitude)
- The pattern of erroneous environmental flow dominated by the Western Subtropical High appears again in the 2013 season.

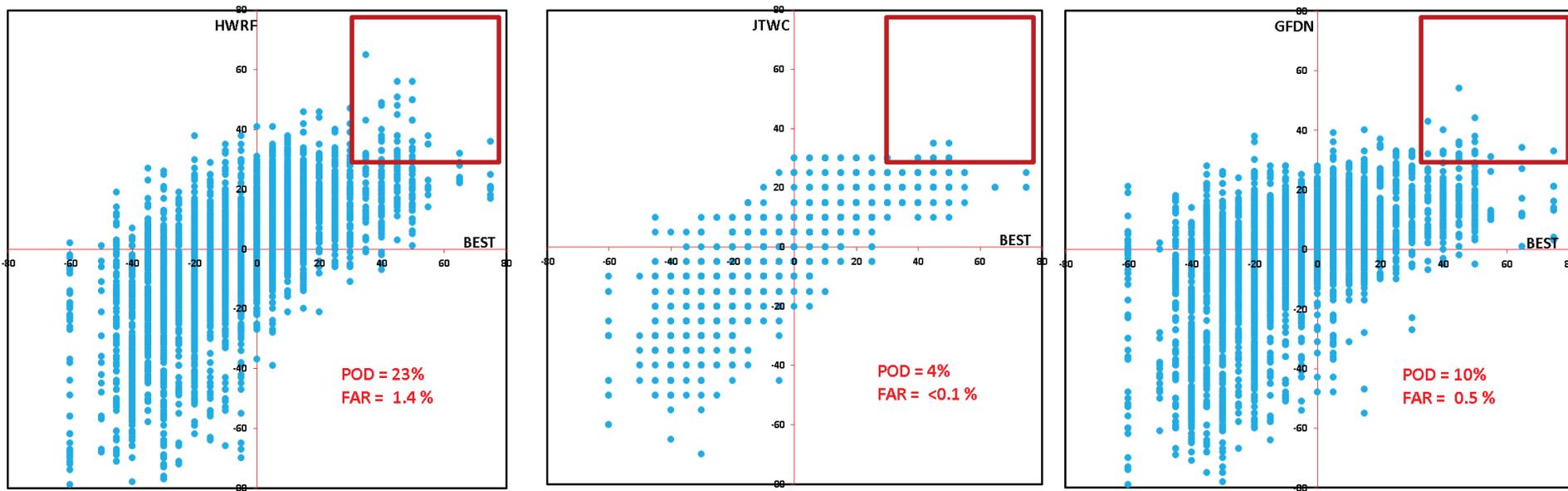
HWRF 2013 intensity error distribution

HWRF 24-h intensity error distribution for 2013 West Pacific HWRF 48-h intensity error distribution for 2013 West Pacific



- HWRF 2013 intensity error distribution continued showing overestimation of storm intensity in the East China Sea (importance of ocean coupling???)
- Unlike 2012, TC intensity in the far ocean and South China Sea now tends to be overestimated as well;
- There is a connection between storm intensity bias and translational speed

RI verification in WPAC

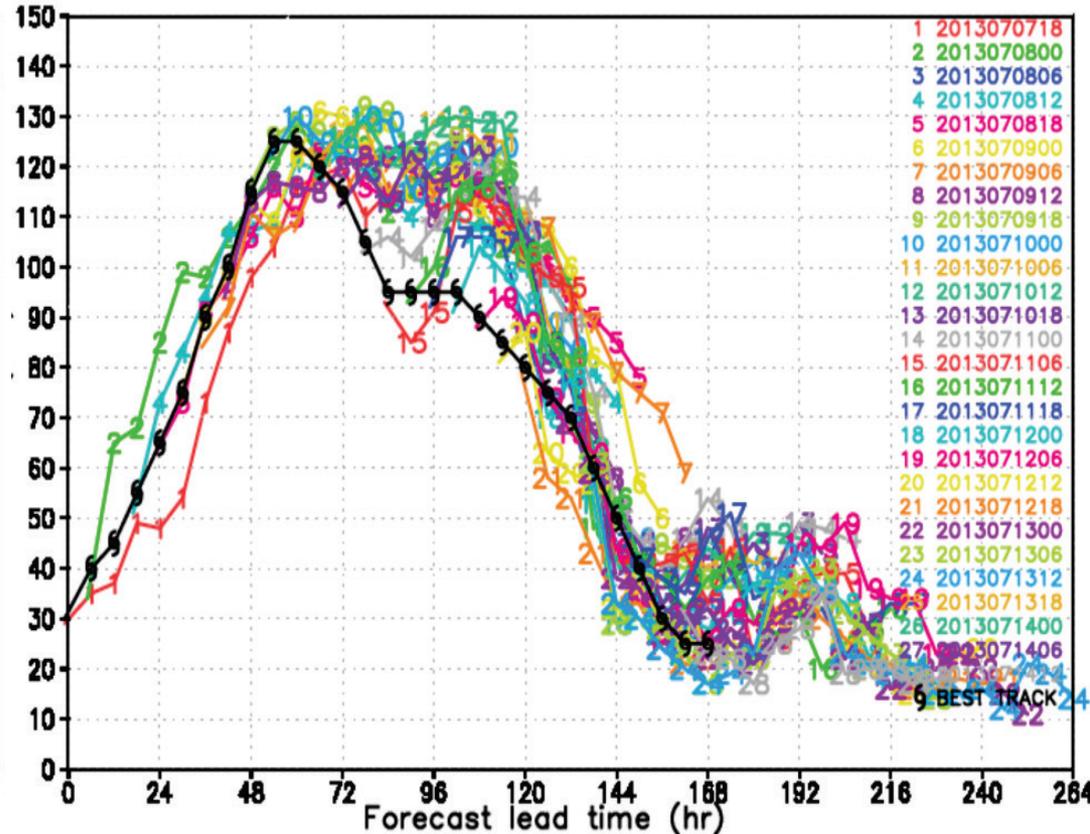
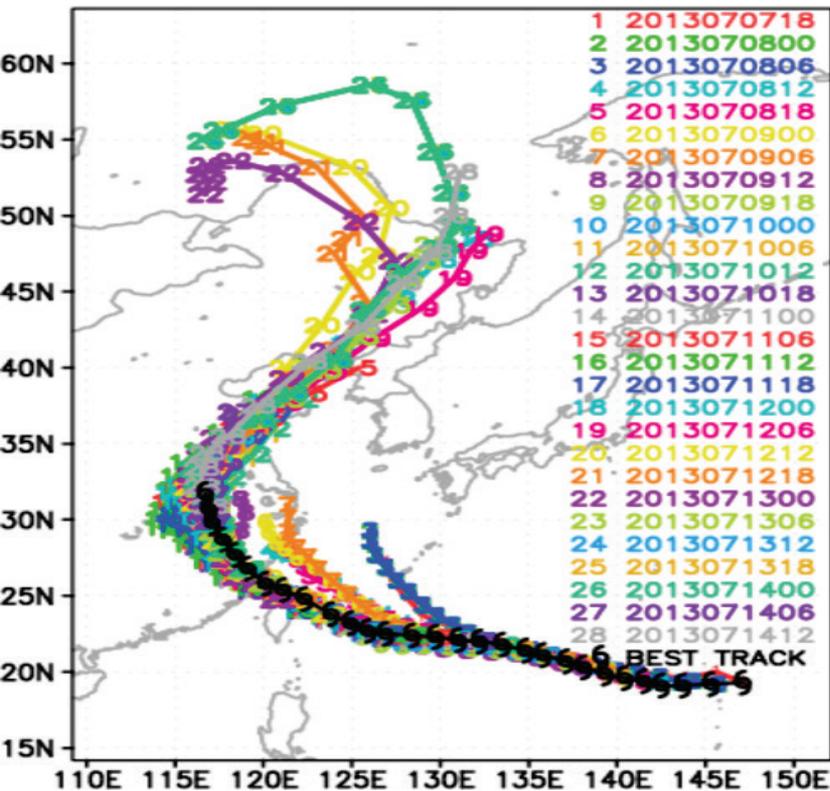


- If one define an RI event as >30 kt / 24 h, then HWRf RI POD skill is $\sim 23\%$ and by far has higher POD index as compared to other models and in other basins (*previous analysis of RI for WPAC from 2012 HWRf showed $<10\%$ skill*).
- The POD index is much higher (43%) if one simply considers the intensity change tendency, say 6-h change of VMAX > 5 kt.

Example of good RI for Soulik 07W (2013)

HWRf forecast: SOULIK07W (wp072013)

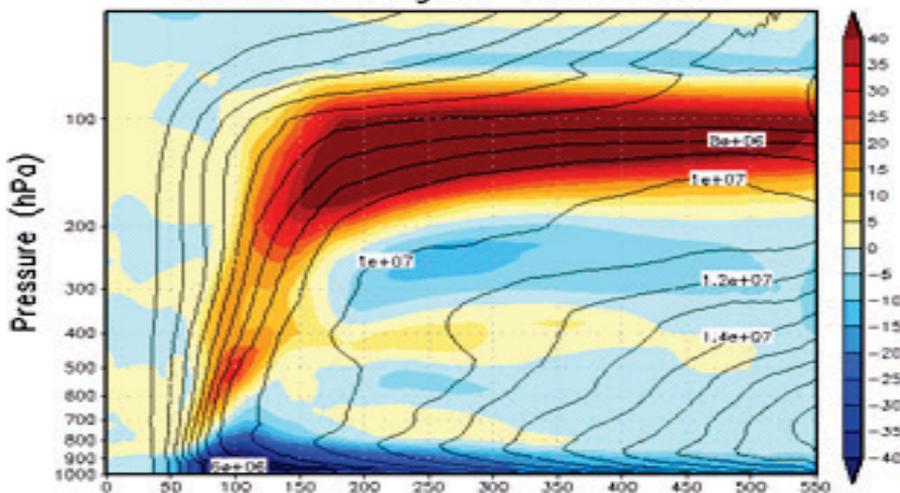
HWRf forecast: SOULIK07W (wp072013)
Maximum 10-m wind time series



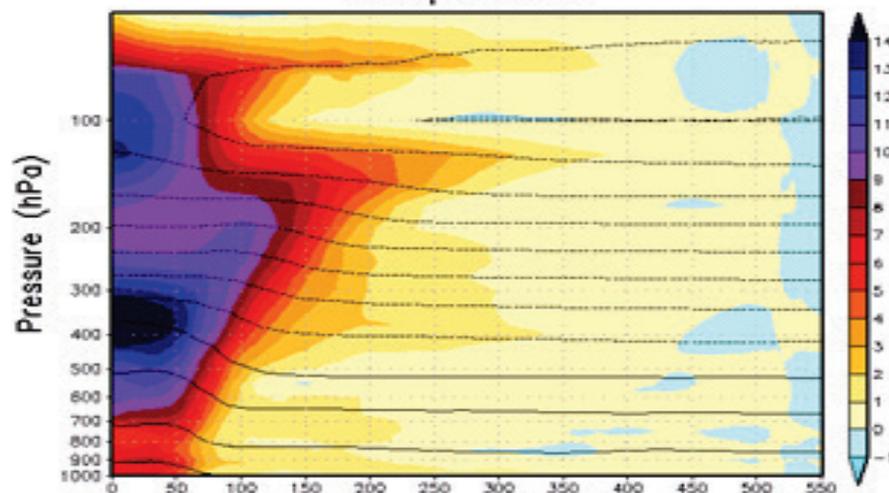
- HWRf captured well the RI event but prolonged strong wind resulted in a substantial positive bias at lead time > 4 days;
- Bias to the right at day 5 also dominates the overall statistics;

Double warm core of intense TCs: (Usagi 17W)

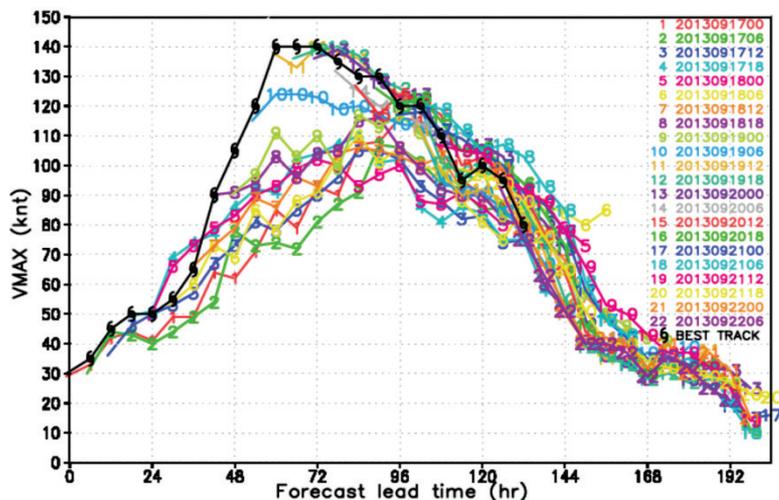
Absolute Angular momentum



Temperature



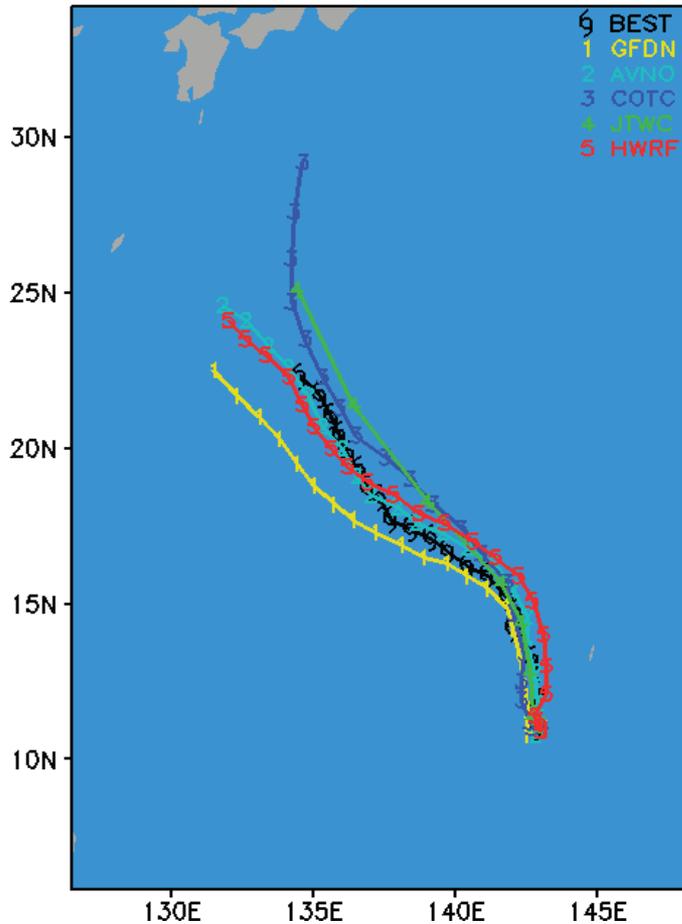
HWRF forecast: USAGI17W (wp172013)
Maximum 10-m wind time series



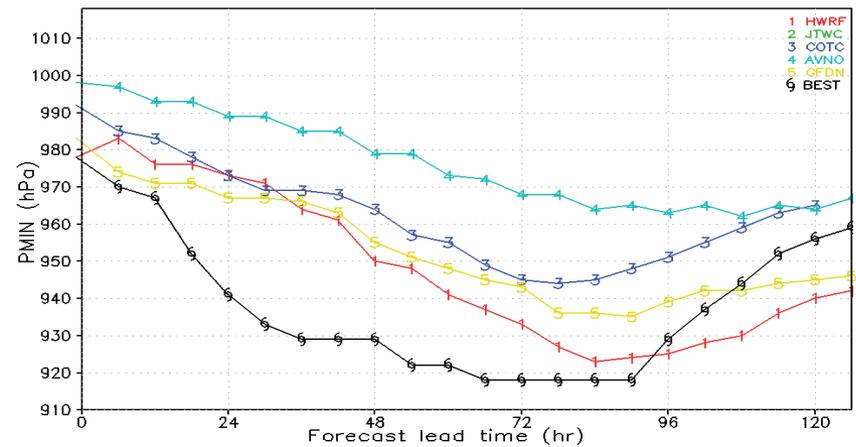
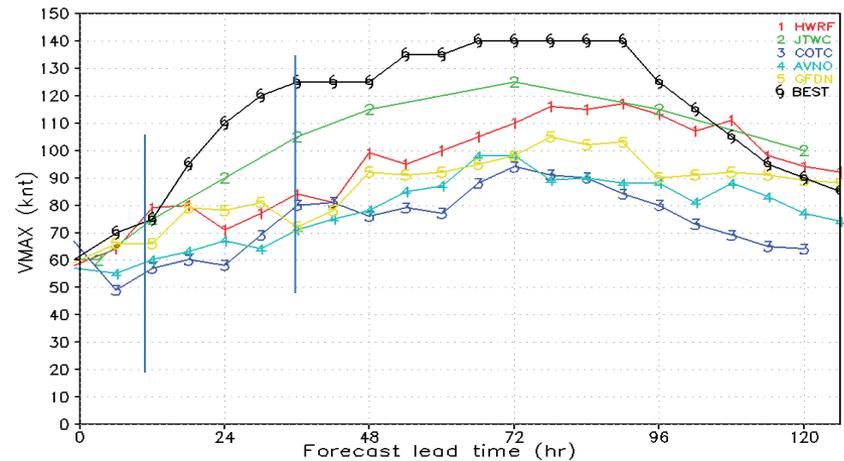
- Even though the magnitude of RI is not comparable with observation, HWRF captured well the RI for first 5 cycles; Note that Usagi RI was as large as 70 kt in 24 hours, posing real challenge for any forecast model;
- Peak intensity of 140-kt is a very special regime that could put any model in vigorous test of model physics and stability.
- HWRF captured consistently double warm core during the peak intensity (110 kt +);
- The upper warm core appears to be related to the inflow at the upper levels. Higher resolution at the upper levels seems to have large impact for this situation

Example of extreme RI (Francisco 26W)

HWRF Forecast of FRANCISCO26W at 2013101



HWRf Forecast of FRANCISCO26W at 2013101618
Maximum 10-m wind time series

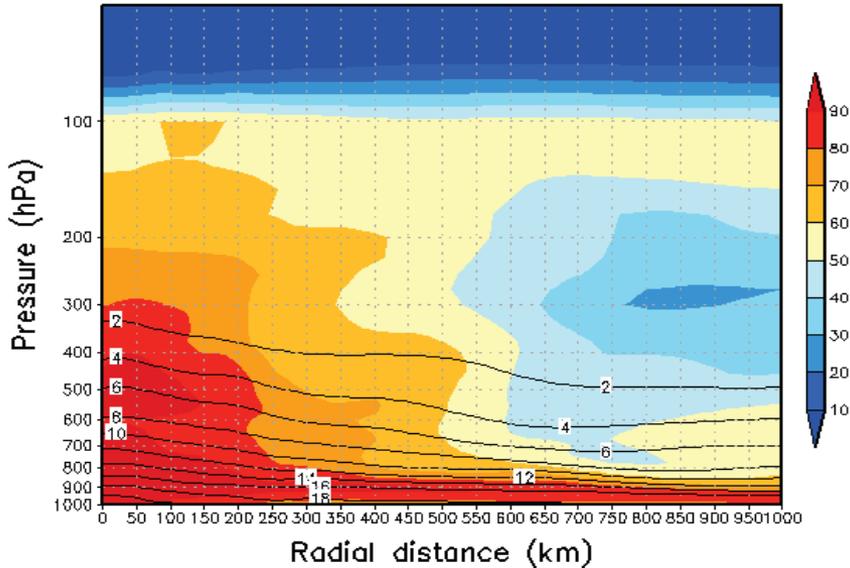


- HWRF intensity forecasts still suffer from these extreme RI events. This is seen repeatedly for few cycles. So what is the reason?

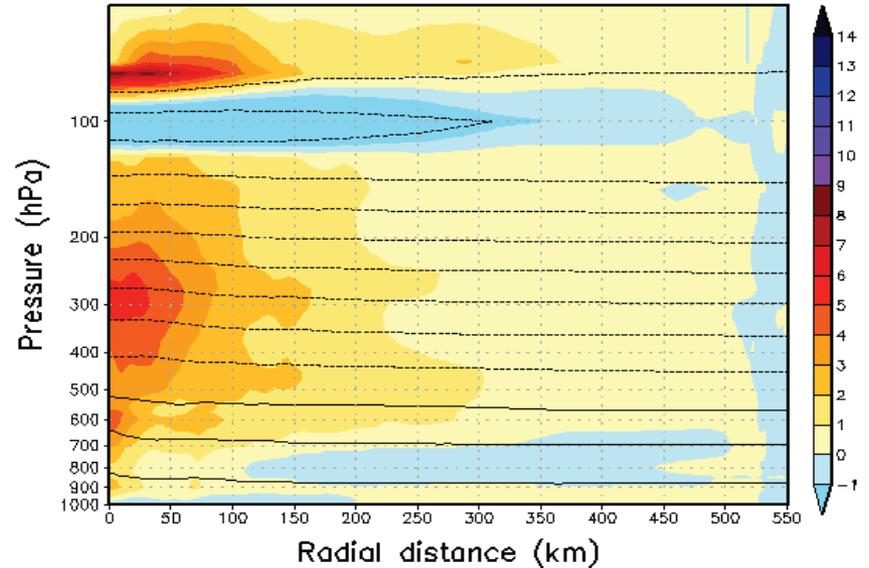
Consistent initial vortex structure at the RI onset

Phase-Lock Mechanism

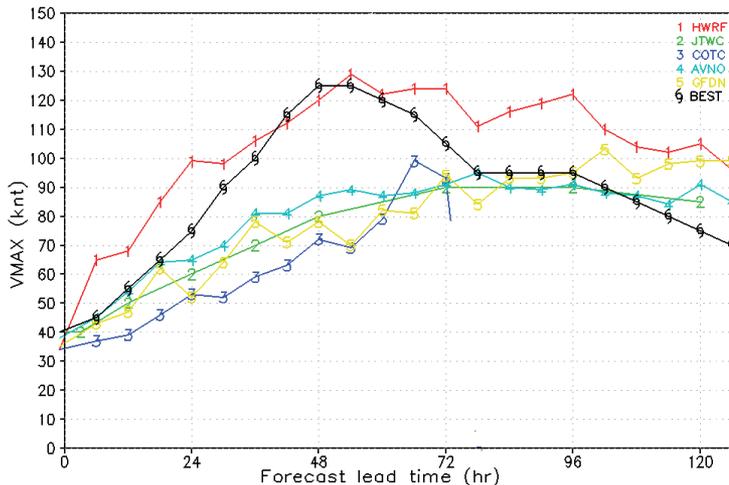
Humidity



Temperature

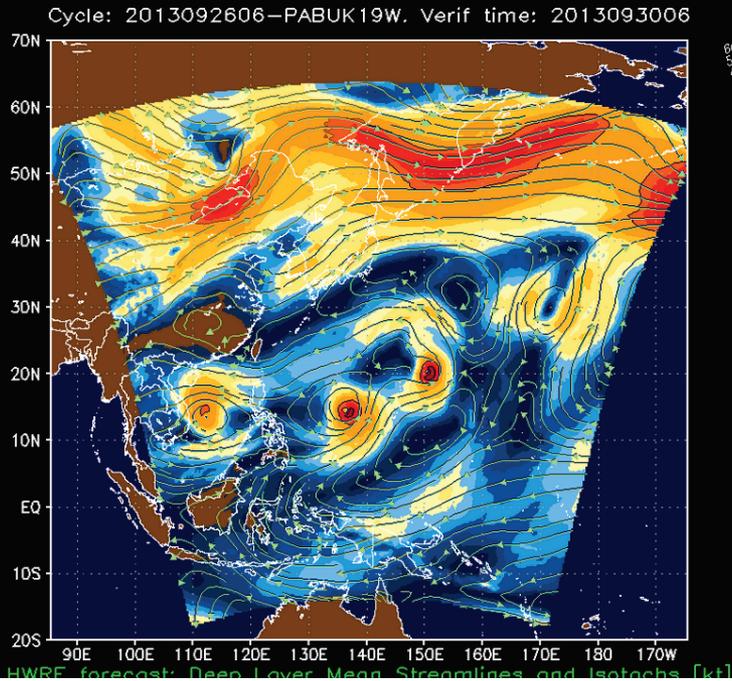


HWRF Forecast of SOULIK07W at 2013070800
Maximum 10-m wind time series

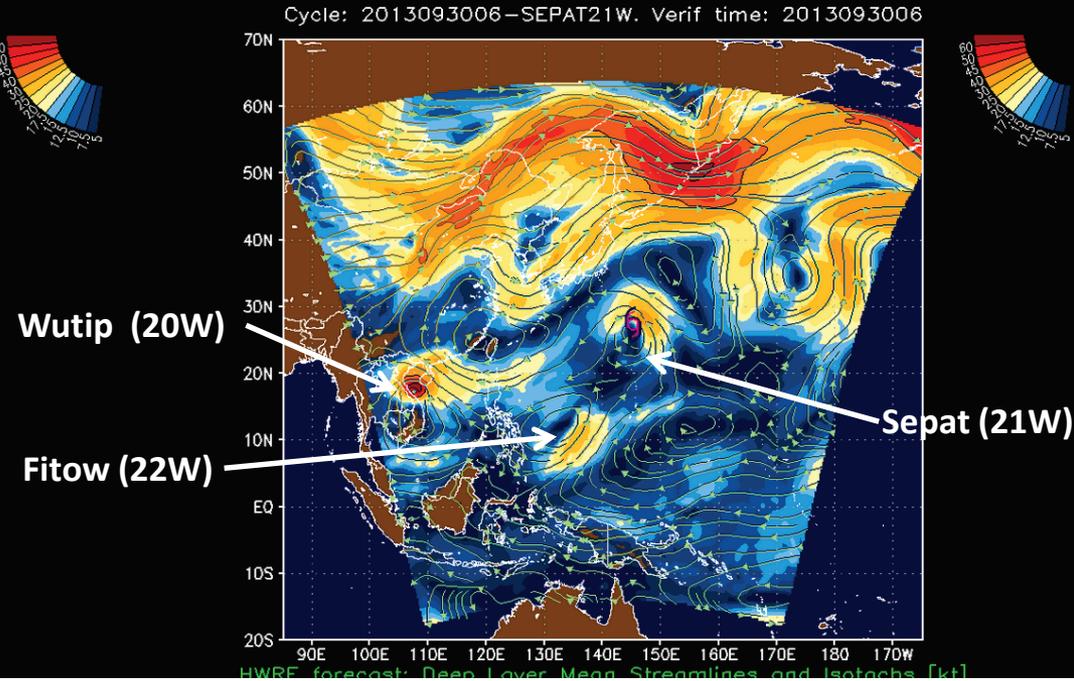


- Vortices with different vertical structure all share the same features at the time of onset of RI (moist inner core with >95% saturation; Vmax larger than 14 m/s; warm core anomaly >3-5 K at the time of onset)
- Model vortex does not grow if such structure is not seen

TC genesis capability: 4-day genesis forecast



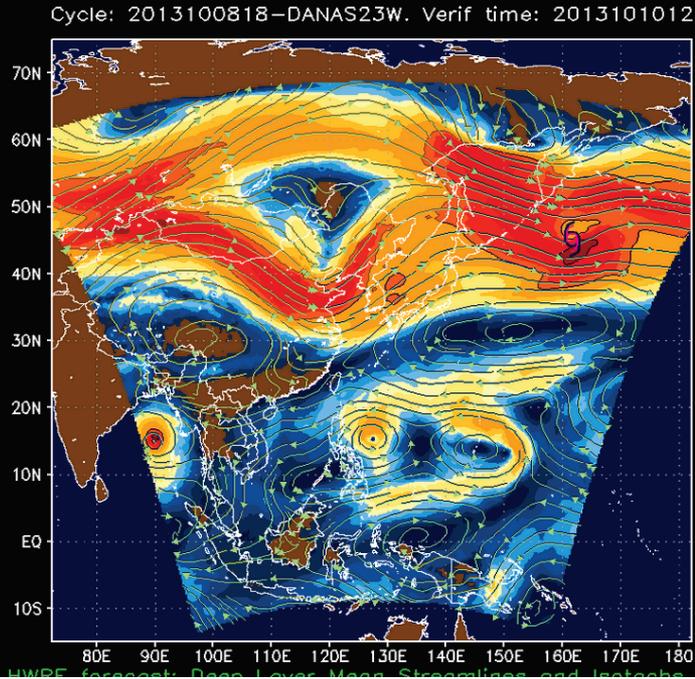
4-day forecast



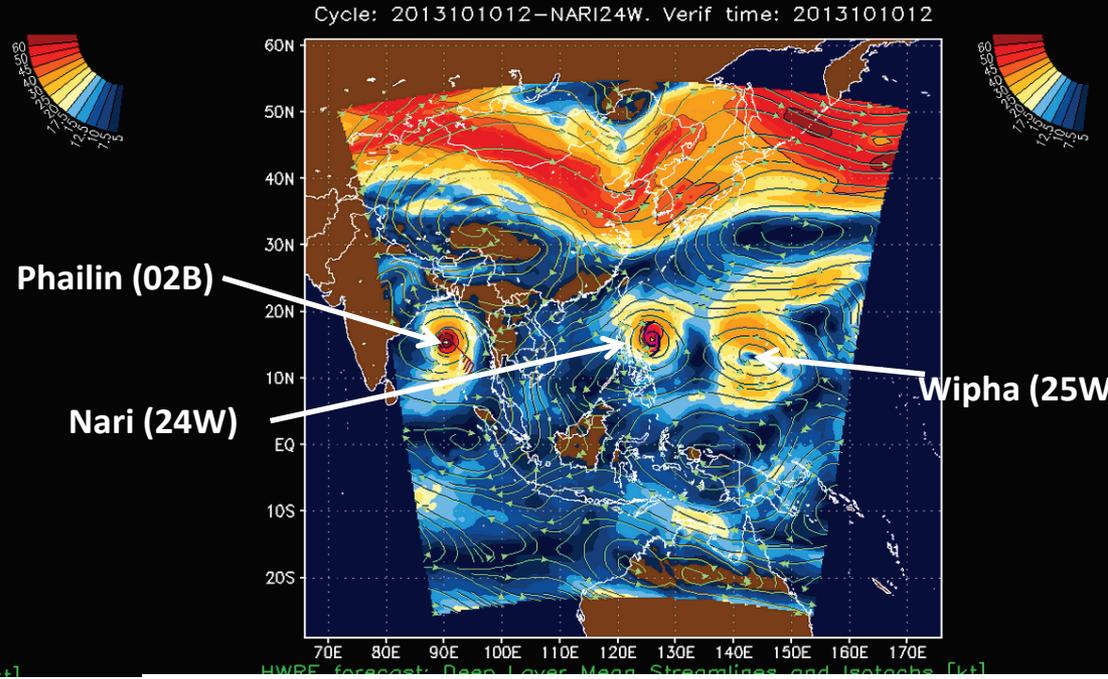
Verification

- String of 3 TCs developed at 96-h lead time from forecast of Pabuk (19W) was verified with observation valid 4 days later.
- Intensity is not exactly match but genesis locations were well captured.

TC genesis capability: 2-day genesis forecast



2-day forecast



Verification

- Another string of 3 TCs developed after 2 days into integration from forecast of Danas (23W) was verified with observation valid 2 days later.
- Intensity is again not exactly match but it is promising to note that the genesis locations were well captured.

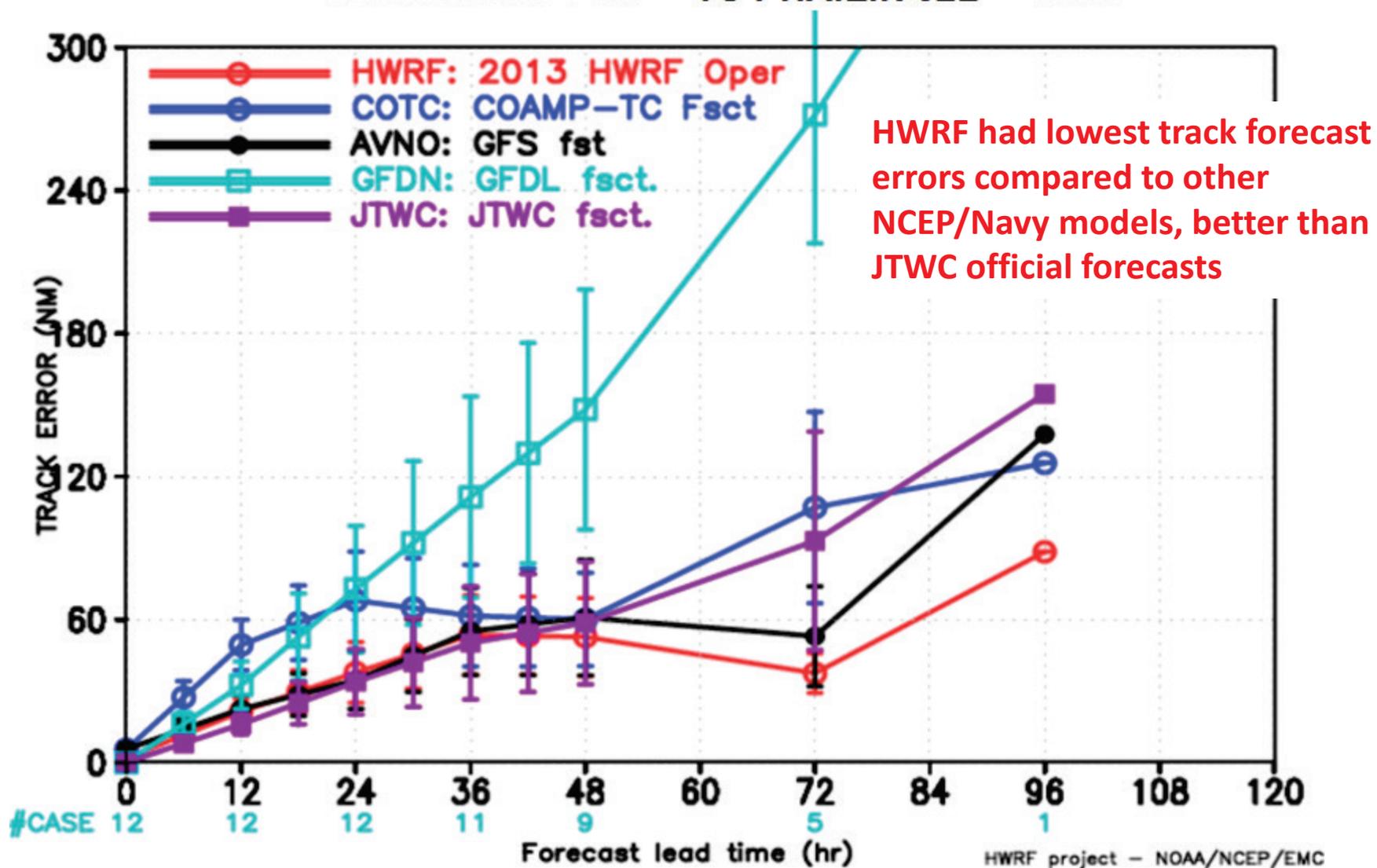
Real-Time HWRF Forecasts for Super Cyclone* Phailin 02B

- **126-hr HWRF Forecast Guidance for all cycles of Phailin 02B Provided to JTWC and IMD⁺ at 6-hr interval, starting from genesis stage to dissipation (October 7, 00Z to October 12, 18Z)**
- **This is the first time we extended real-time forecast guidance support to JTWC for the Indian Ocean basin using the West-Pac HWRF experiments run on HFIP Jet machines**

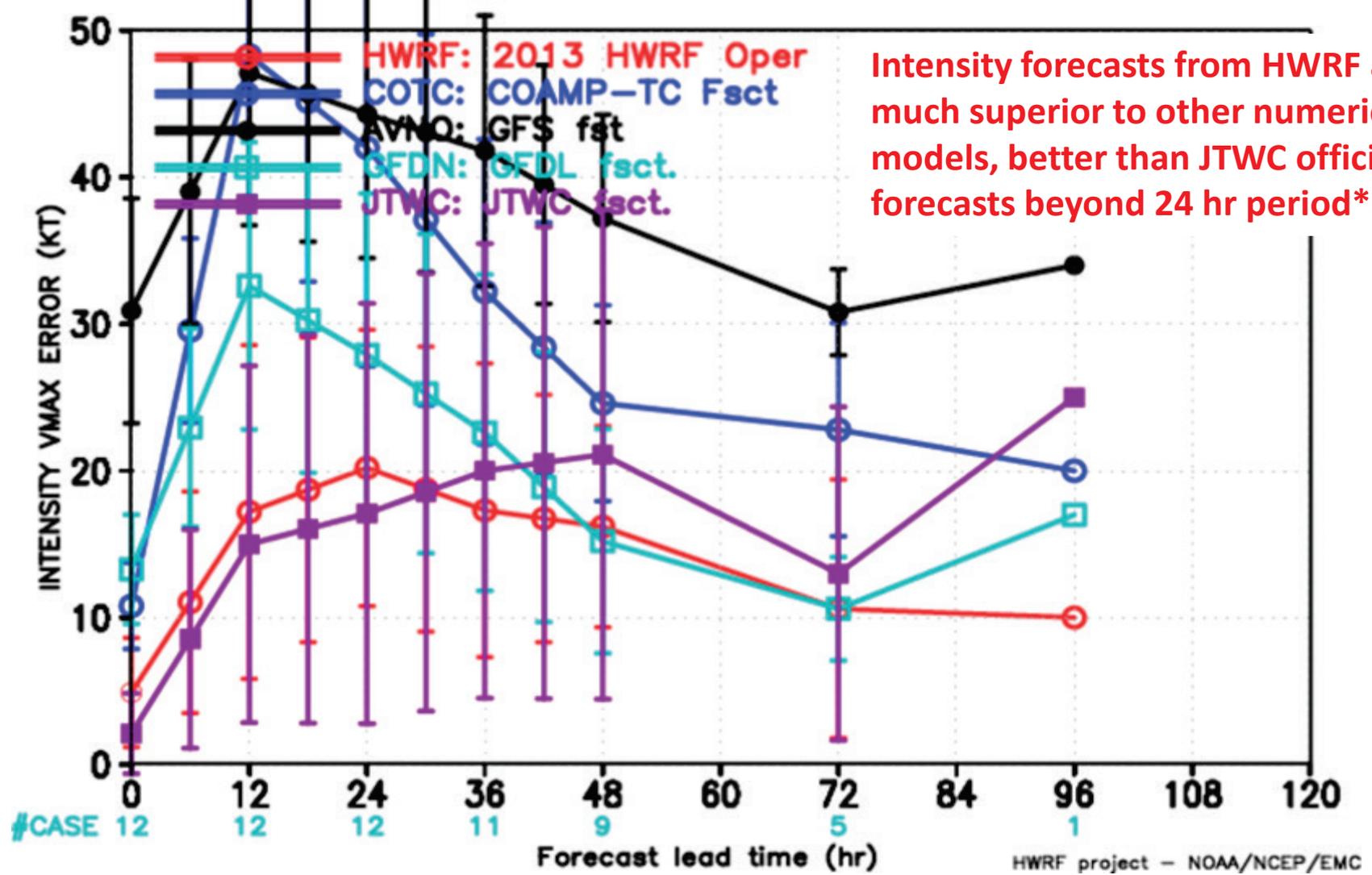
**IMD did not declare Phailin as Super Cyclone, however, JTWC estimates called for a Cat.5 hurricane strength for Phailin 24 hrs before landfall. This could be due to difference in standards adopted for intensity estimates (3min sustained wind, WMO criteria for IMD vs. 1min sustained wind, NHC/JTWC criteria)*

+IMD runs it's own version of HWRF (9km, 2010 version of operational HWRF) at 12-hr interval, without vortex cycling. NCEP HWRF is latest 2013 operational configuration. Both are uncoupled. IMD scientist Mr. Das is currently visiting EMC to adopt the latest version of HWRF for implementation at IMD.

HWRP FORECAST – TRACK ERROR (NM) STATISTICS VERIFICATION FOR TC PHAILIN 02B 2013



HWRF FORECAST – INTENSITY VMAX ERROR (KT) STATISTICS
 VERIFICATION FOR TC PHAILIN 02B 2013

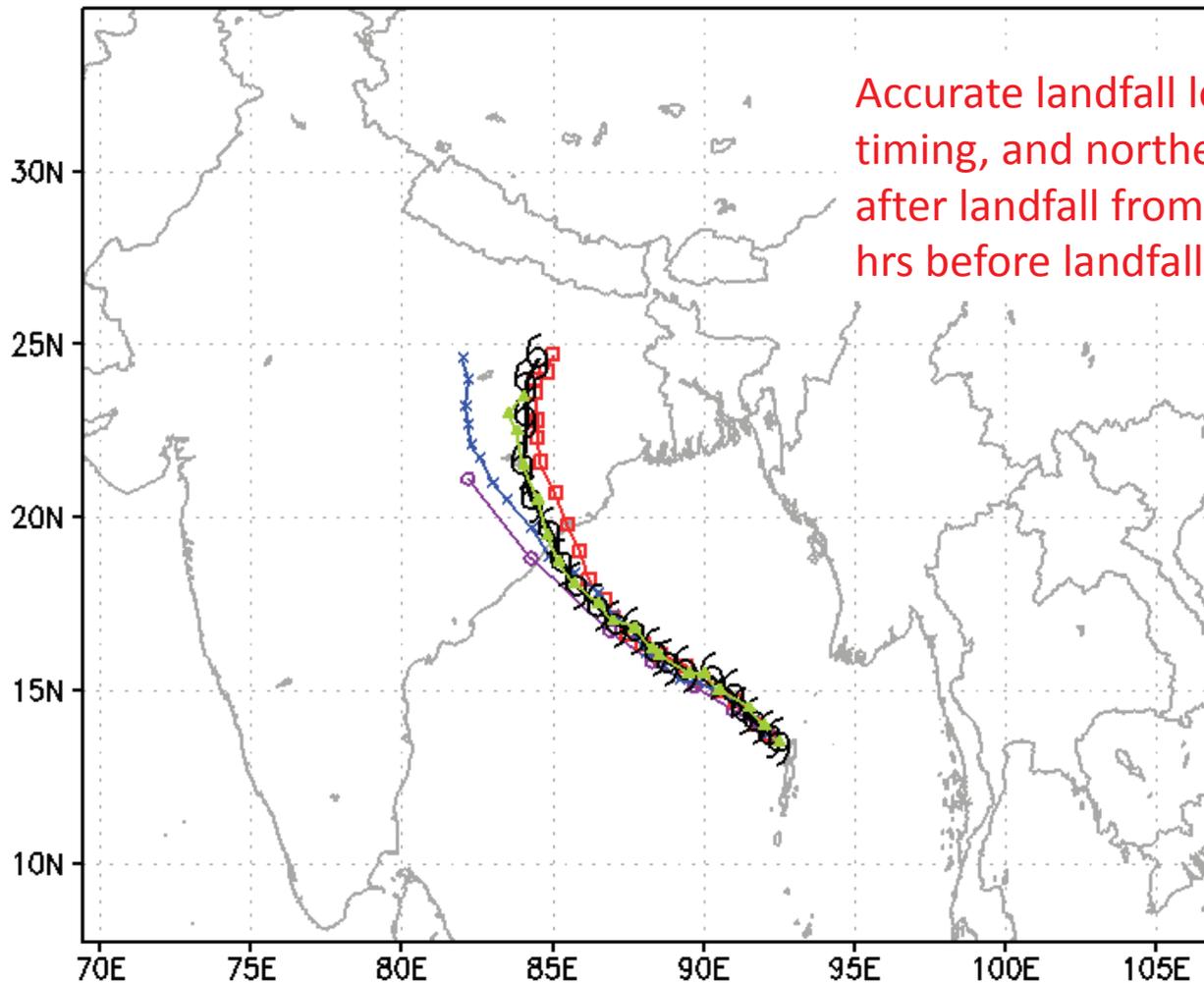


* Errors computed against JTWC best track data.

HWRF 2013 Real time: TC Tracks

Storm: TWO (02B) valid 2013100912

- JTWC: JTWC Official
- HWRF: 2013 Oper.
- ×— AVNO: Oper. GFS
- BEST: Best Track
- NGPS: NGPS Forecast
- GFDN: GFDN Oper.
- ◇— COTC: COAMP Forecast
- ▲— HIMD: IMD best track

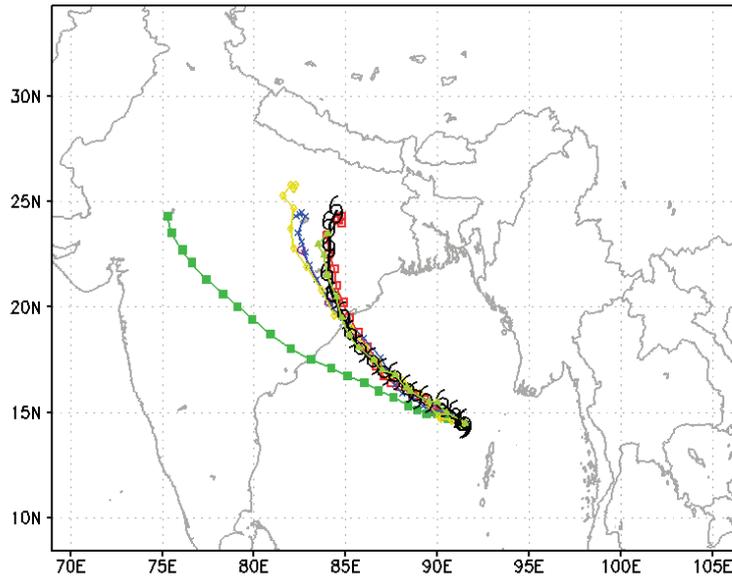


Accurate landfall location and timing, and northeastward turn after landfall from HWRF (72 hrs before landfall).

HWRF 2013 Real time: TC Tracks

Storm: PHAILIN (02B) valid 2013101000

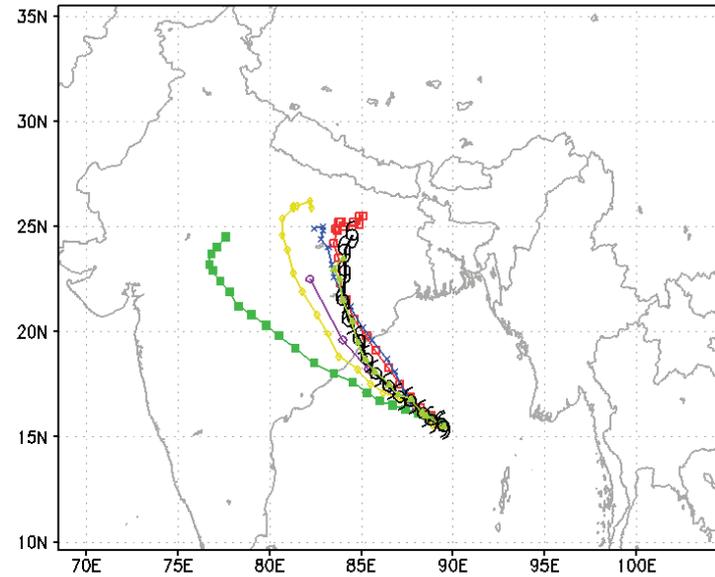
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- AVNO: Oper. GFS
- BEST: Best Track
- NGPS: NGPS Forecast
- GFDN: GFDN Oper.
- COTC: COAMP Forecast
- HIMD: IMD best track



HWRF 2013 Real time: TC Tracks

Storm: PHAILIN (02B) valid 2013101018

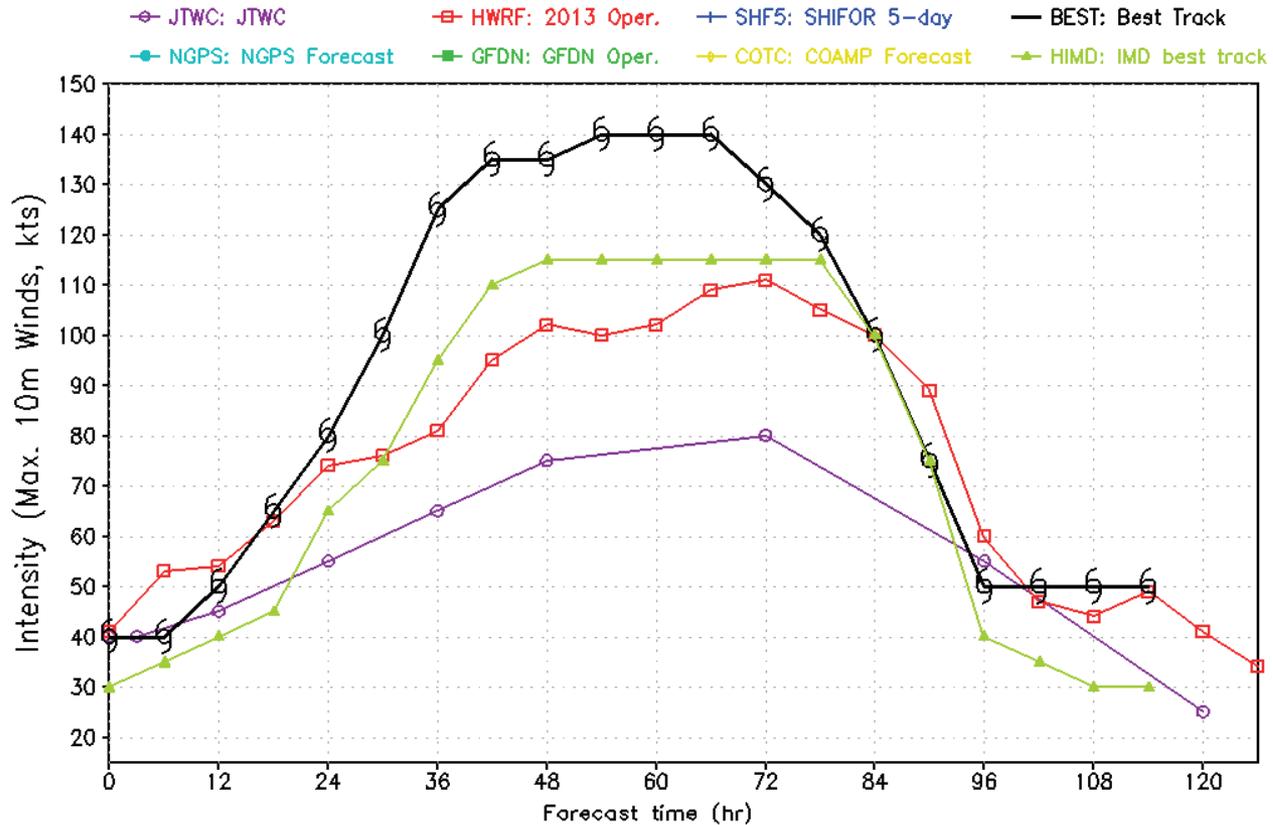
- JTWC: JTWC Official
- HWRF: 2013 Oper.
- AVNO: Oper. GFS
- BEST: Best Track
- NGPS: NGPS Forecast
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- COTC: COAMP Forecast
- HIMD: IMD best track



Consistently accurate forecast tracks from HWRF.

HWRF 2013 Real time: TC Intensity Vmax

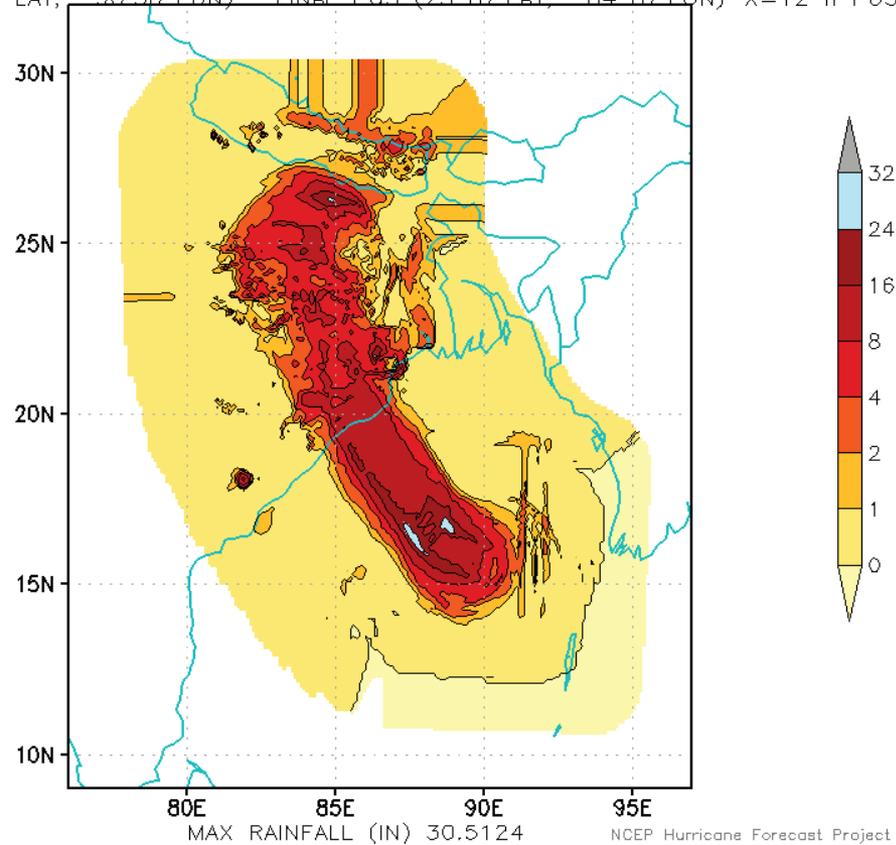
Storm: TWO (02B) valid 2013100906



HWRf underestimated the maximum winds, better match with the IMD best track intensity (HIMD)

INIT 2013101012 Z for 126 h FCST VALID 2013101518 Z
HWRF TOTAL RAINFALL(IN) PHAILINO2B

START POS (15.40 LAT, -90.30 LON) FINAL POS (25.10 LAT, -84.10 LON) X=12 h POS



Impressive rainfall totals predicted by HWRF (20 inches at landfall)

Concluding Remarks

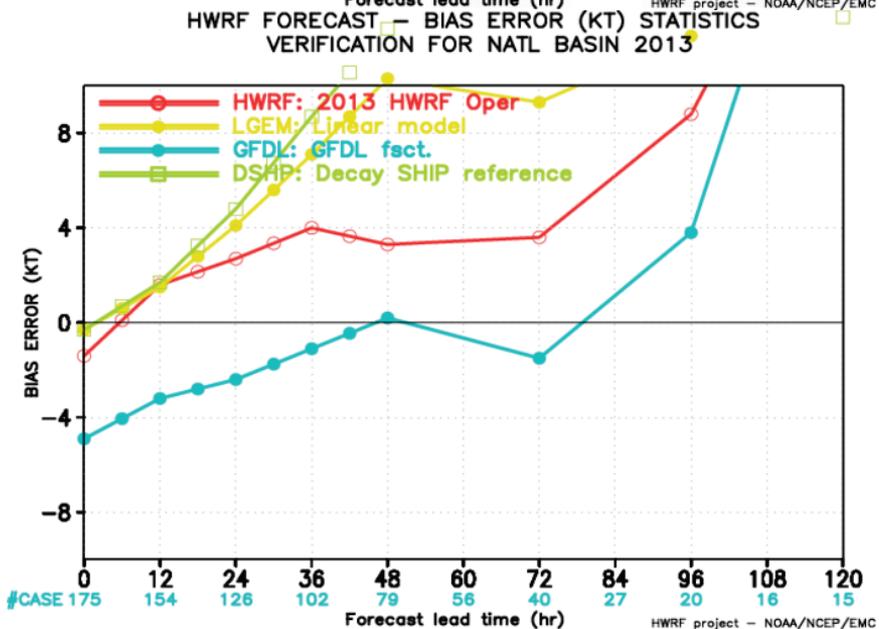
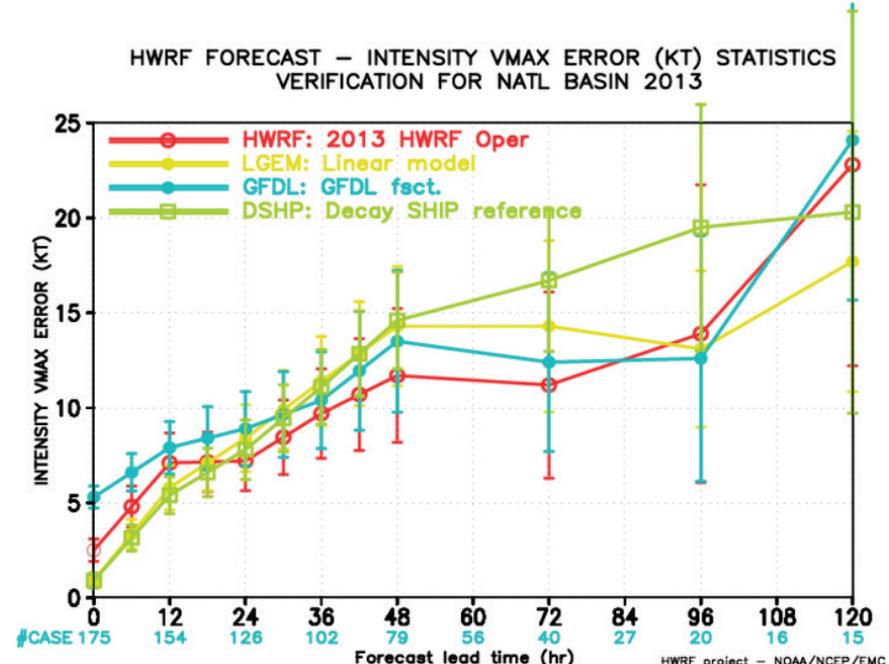
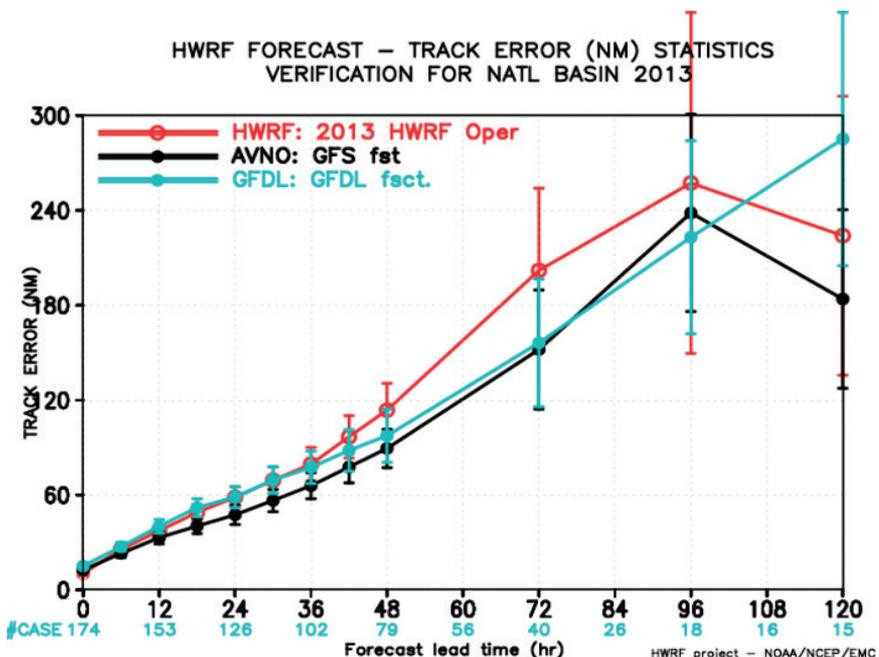
- HWRF has been performing consistently better than other regional models in the WPAC so far despite no major tuning specific to that basin;
- Retrospective evaluation of WPAC HWRF forecasts and feedback from JTWC helped further improve the operational HWRF modeling system
- HWRF still has issues with overestimation of the storm intensity for strong storms, and underestimate intensity for weak storms; potential issues with large-scale environmental control
- Ocean coupled HWRF for WPAC is under development, and could improve HWRF's forecast skill in future;
- Continue providing support for JTWC 2013 season and beyond (resources permitting)
- Plan for implementation of HWRF for Southern Hemisphere in January 2014, making HWRF a truly global tropical cyclone model

Publications

1. Tallapragada V., Y. Kwon, Q. Liu, S. Trahan, Z. Zhang, E. Aligo, C. Kieu, W. Wang, J. Oconnor, R. E. Tuleya, S. Gopalakrishnan, X. Zhang, B. Lapenta, F. D. Marks Jr., and R. L. Gall, 2012: Operational Implementation of High-Resolution Triple-Nested HWRF at NCEP/EMC - A Major Step Towards Addressing Intensity Forecast Problem. *AMS 30th Conference on Hurricanes and Tropical Meteorology*. Florida, USA.
2. Tallapragada, V., C. Kieu, Y. Kwon, S. Trahan, Q. Liu, Z. Zhang, and I.-H. Kwon, 2013: Evaluation of storm structure from the operational HWRF model during 2012 implementation. *Mon. Wea. Rev.* accepted.
3. Tallapragada, V., C. Kieu, Y. Kwon, S. Trahan, Q. Liu, Z. Zhang, and Brain Stral, 2013: Experimental, Real-Time Forecasts for the 2012 North-Western Pacific Typhoon Season using the NCEP Operational HWRF. *Weather and Forecasting*. in revision.
4. Several more to be submitted (including BAMS paper on HWRF)

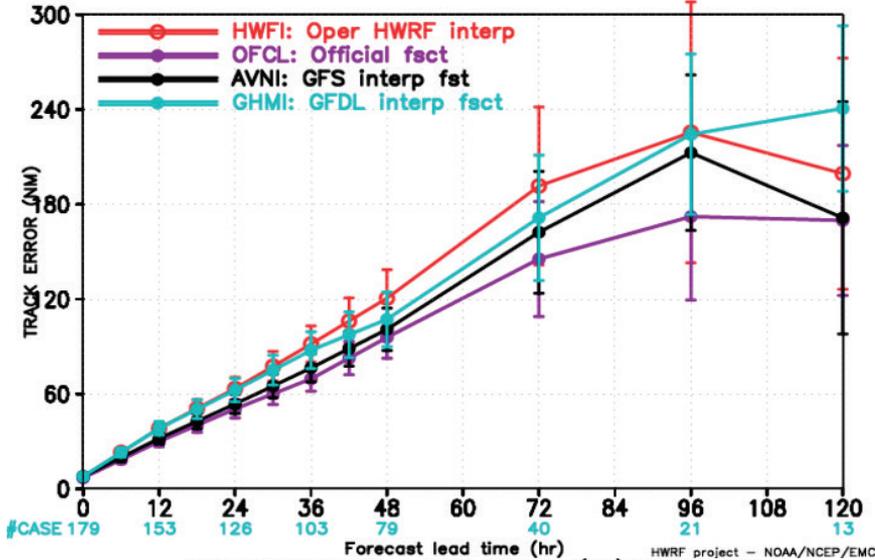
Appendix

2013 North Atlantic late model verification

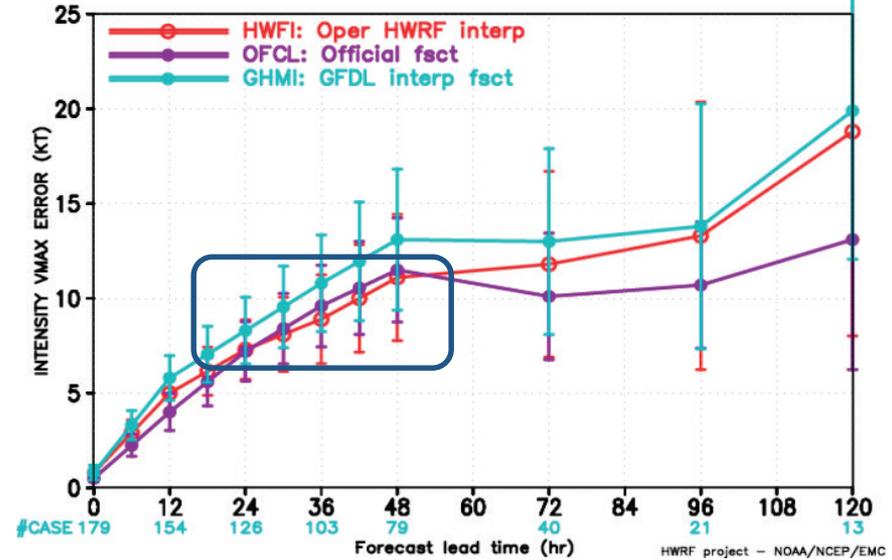


2013 North Atlantic early model verification

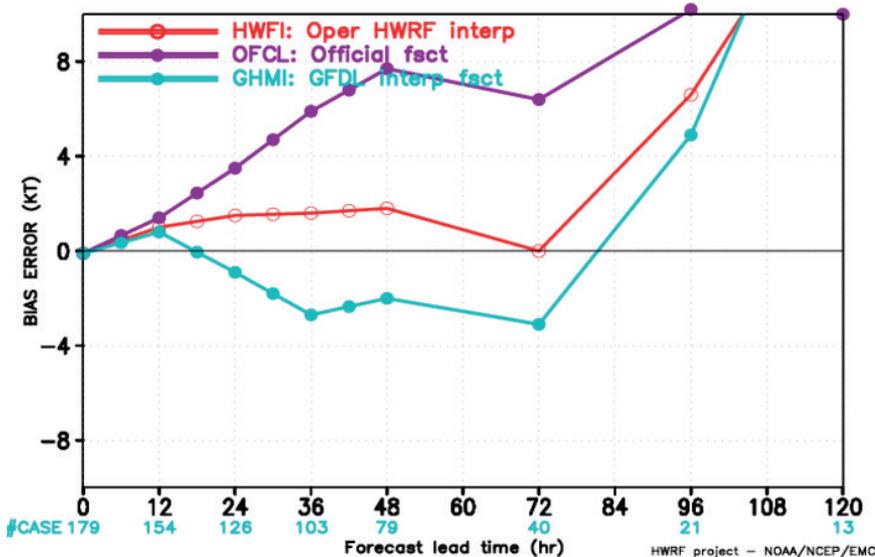
HWRP FORECAST – TRACK ERROR (NM) STATISTICS
VERIFICATION FOR NATL BASIN 2013



HWRP FORECAST – INTENSITY VMAX ERROR (KT) STATISTICS
VERIFICATION FOR NATL BASIN 2013



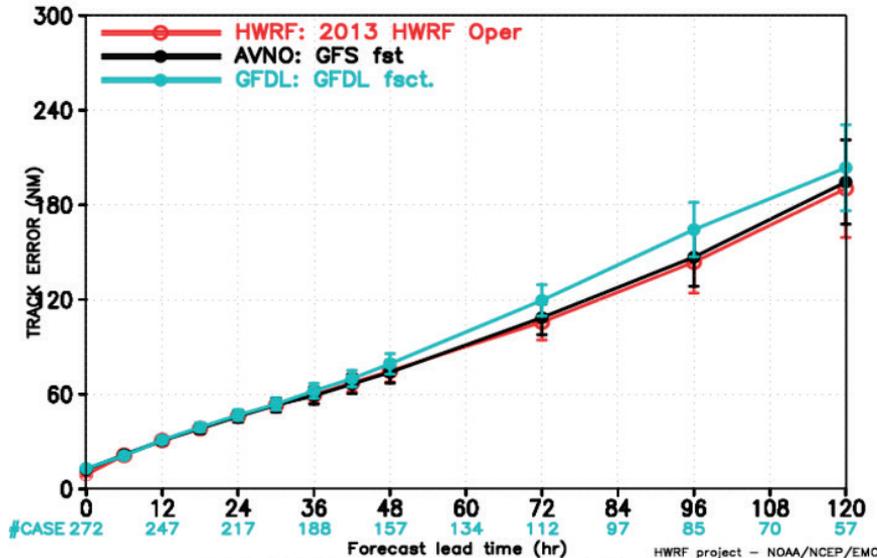
HWRP FORECAST – BIAS ERROR (KT) STATISTICS
VERIFICATION FOR NATL BASIN 2013



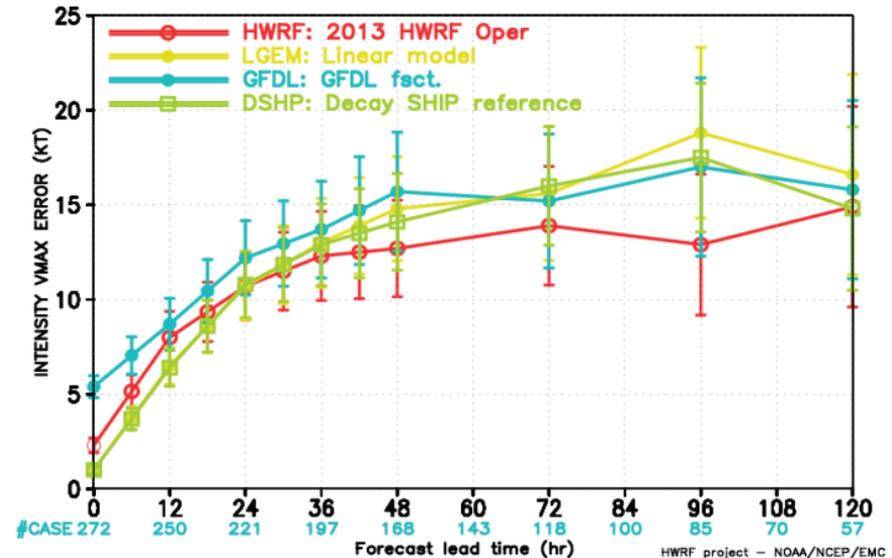
Intensity bias and errors from operational HWRP showed similar improvements noted in the retrospective evaluation.

2013 Eastern Pacific late model verification

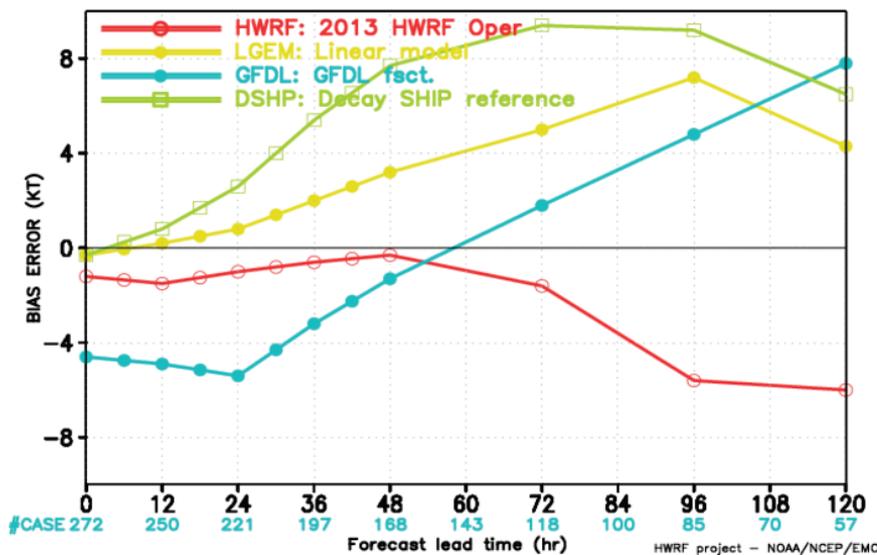
HWRF FORECAST – TRACK ERROR (NM) STATISTICS
VERIFICATION FOR EADT-PAC BASIN 2013



HWRF FORECAST – INTENSITY VMAX ERROR (KT) STATISTICS
VERIFICATION FOR EADT-PAC BASIN 2013



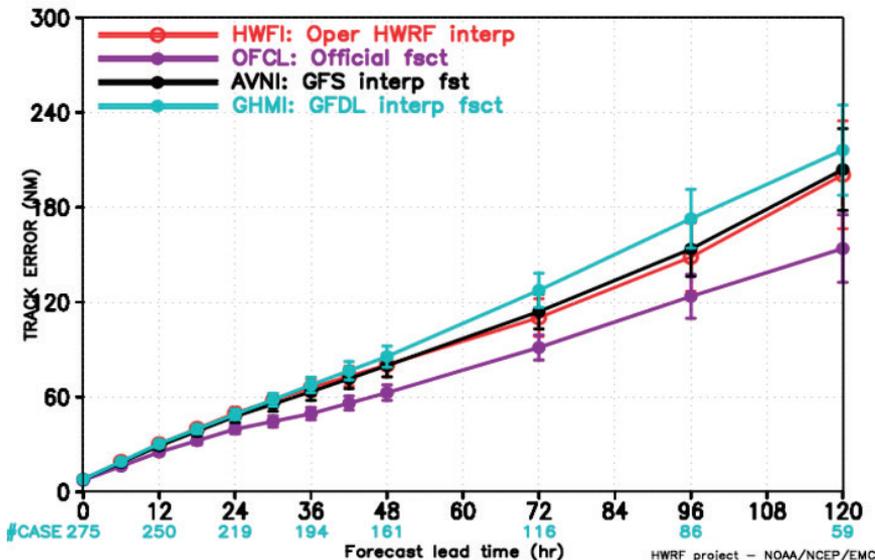
HWRF FORECAST – BIAS ERROR (KT) STATISTICS
VERIFICATION FOR EADT-PAC BASIN 2013



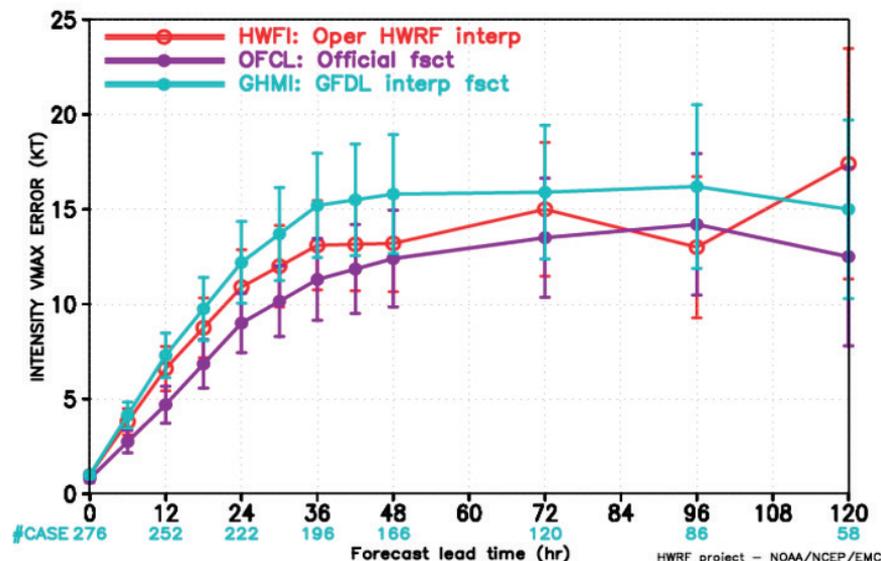
HWRF track and intensity forecasts for the Eastern Pacific basin have shown better skill compared to other NCEP models

2013 East Pacific early model verification

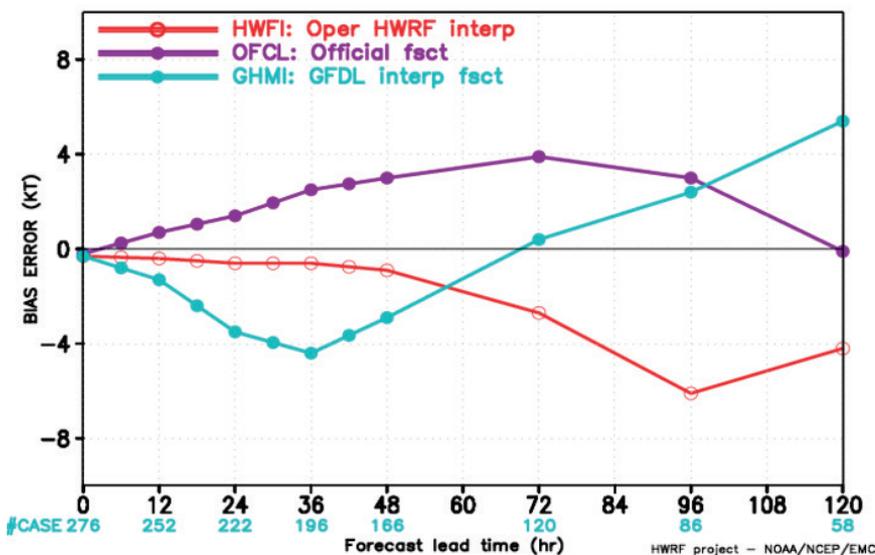
HWRP FORECAST – TRACK ERROR (NM) STATISTICS
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HWRP FORECAST – INTENSITY VMAX ERROR (KT) STATISTICS
VERIFICATION FOR EADT-PAC BASIN 2013



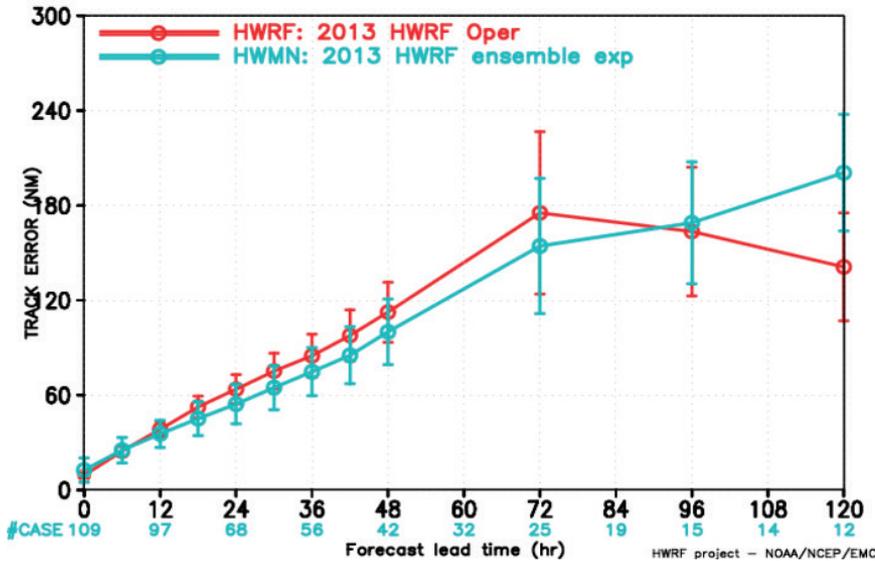
HWRP FORECAST – BIAS ERROR (KT) STATISTICS
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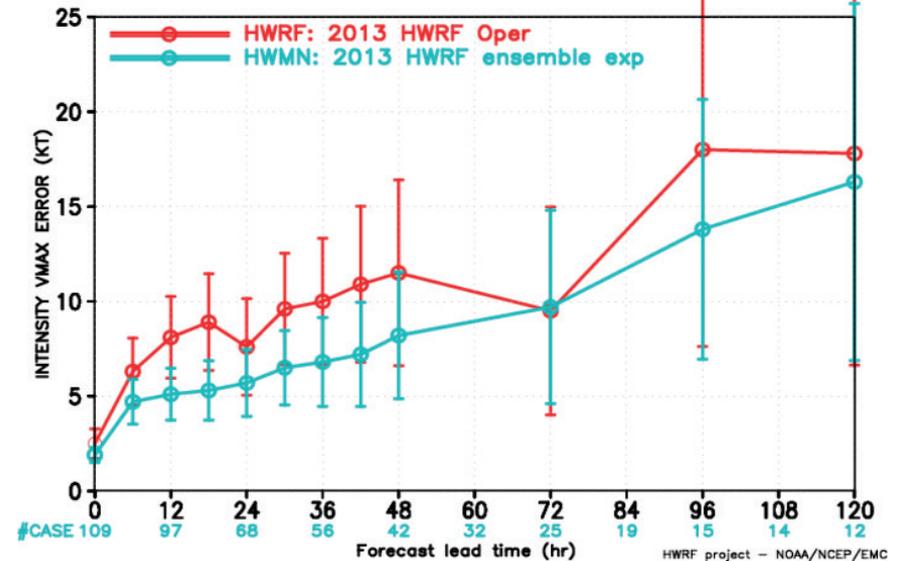
HWRP track and intensity forecasts for the Eastern Pacific basin have shown better skill compared to other NCEP models

HWRF-ensemble verification: North Atlantic 2013

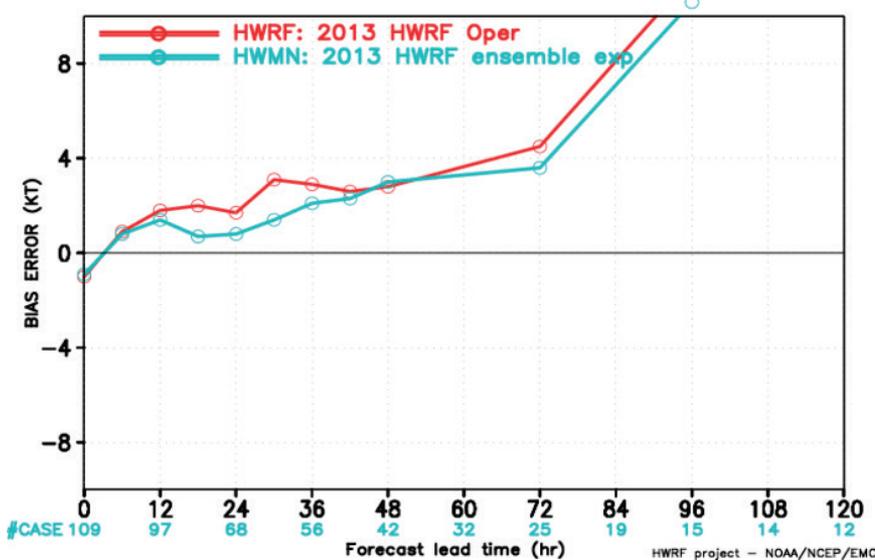
HWRF FORECAST – TRACK ERROR (NM) STATISTICS
VERIFICATION FOR NATL BASIN 2013



HWRF FORECAST – INTENSITY VMAX ERROR (KT) STATISTICS
VERIFICATION FOR NATL BASIN 2013



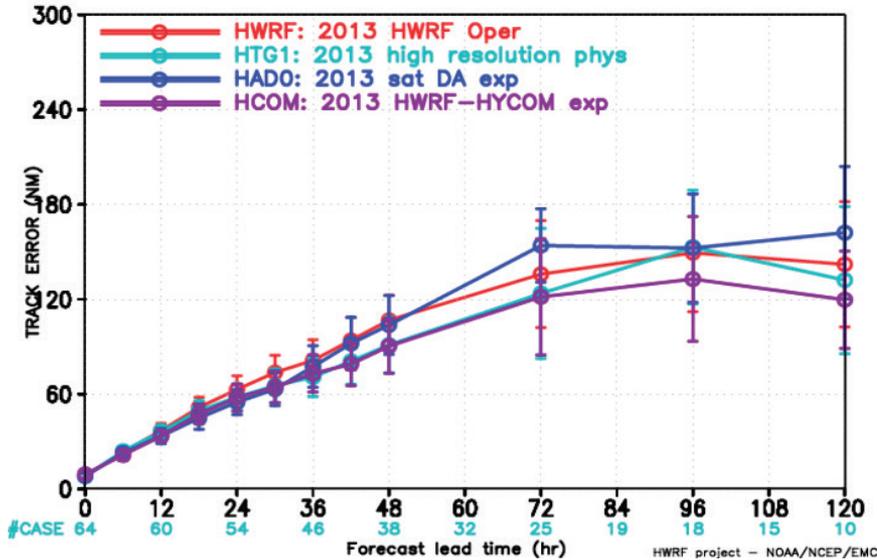
HWRF FORECAST – BIAS ERROR (KT) STATISTICS
VERIFICATION FOR NATL BASIN 2013



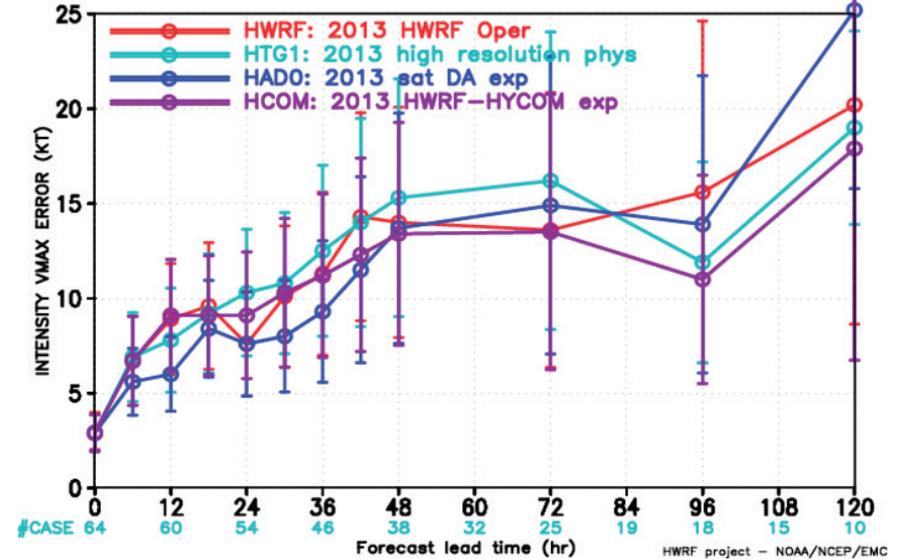
HWRf ensembles run in HFIP Stream 1.5 showed much improved track and intensity forecast skill compared to the deterministic model

HWRF stream 2 verification: North Atlantic 2013

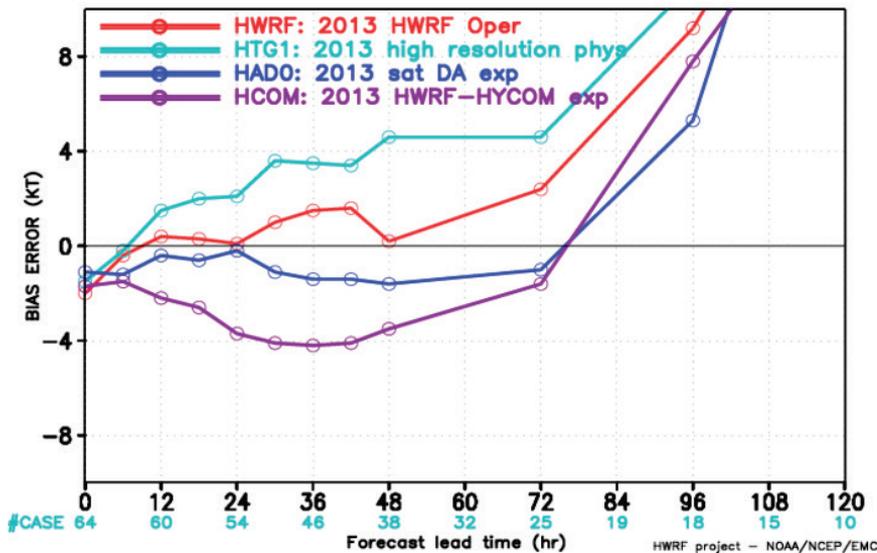
HWRF FORECAST – TRACK ERROR (NM) STATISTICS
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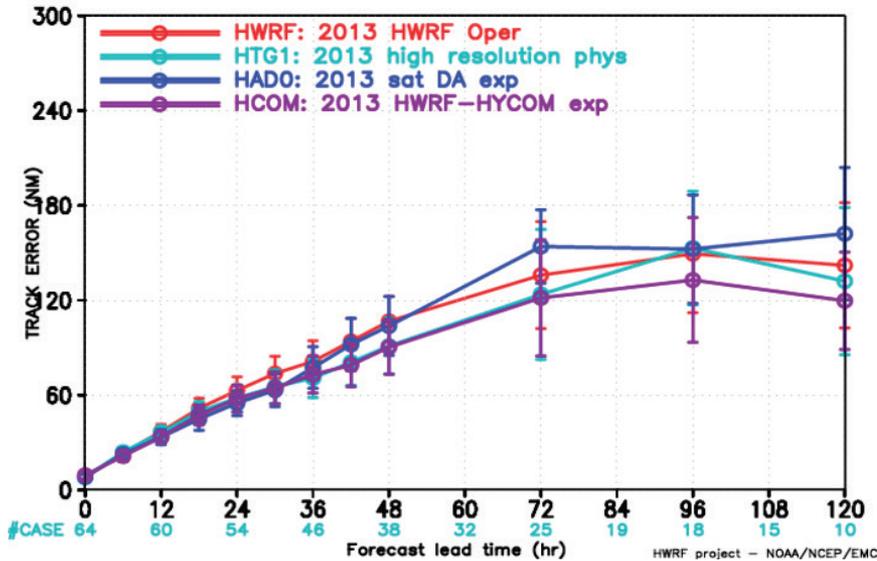
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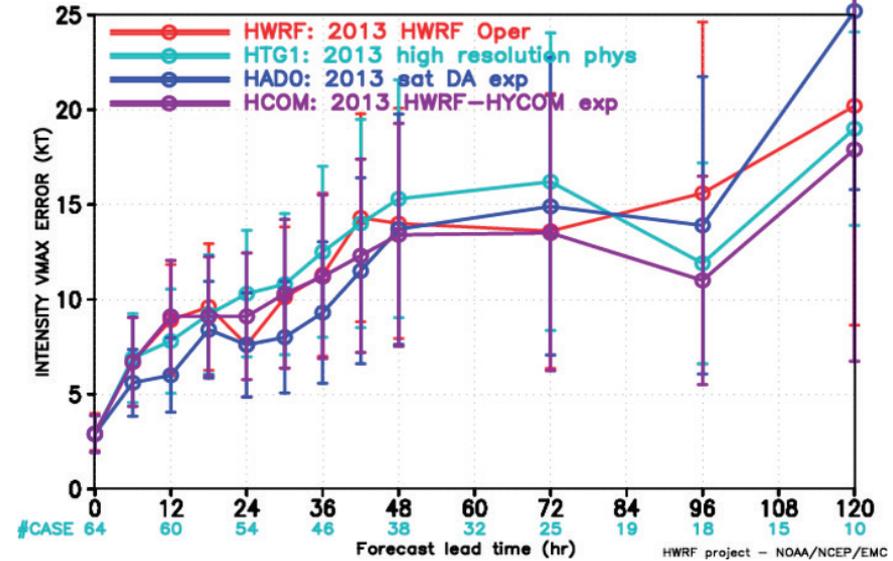
Satellite DA experiments with increased vertical levels showed desired impact on intensity forecasts.

HWRF stream 2 verification: East Pacific 2013

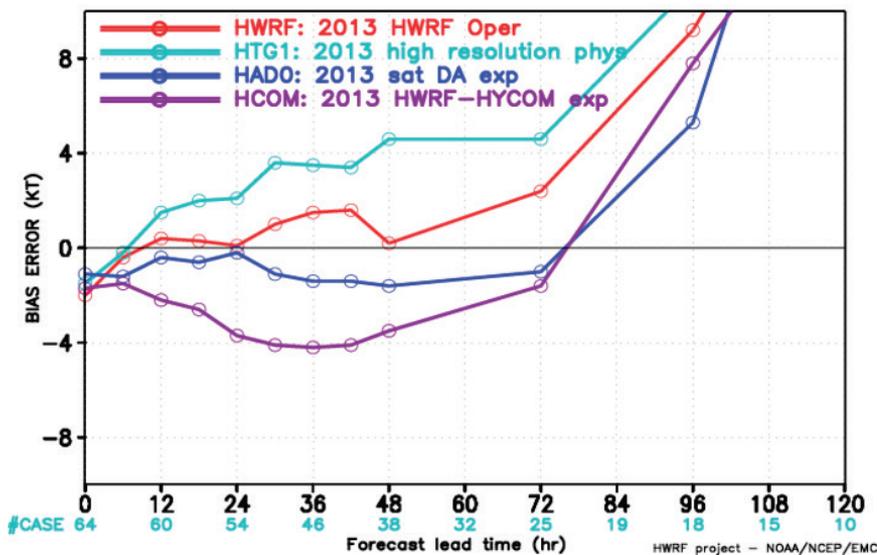
HWRF FORECAST – TRACK ERROR (NM) STATISTICS
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HWRF FORECAST – INTENSITY VMAX ERROR (KT) STATISTICS
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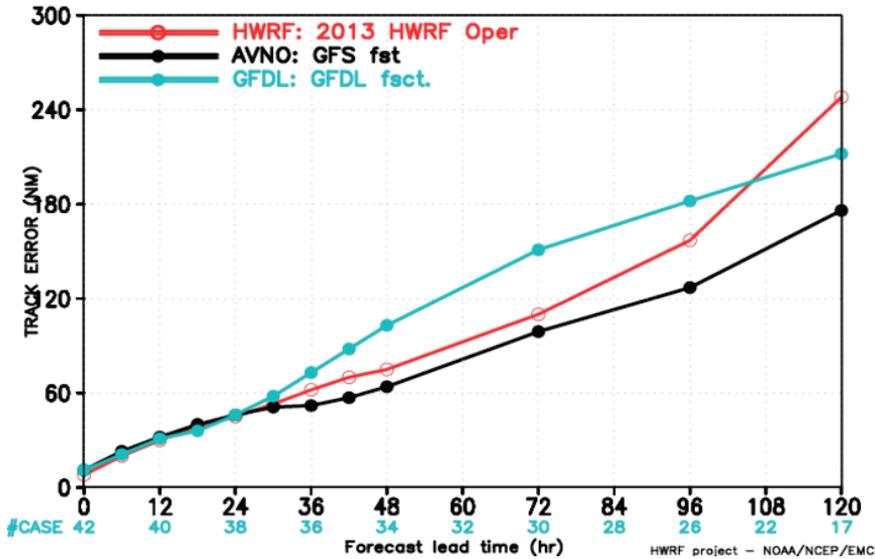
HWRF FORECAST – BIAS ERROR (KT) STATISTICS
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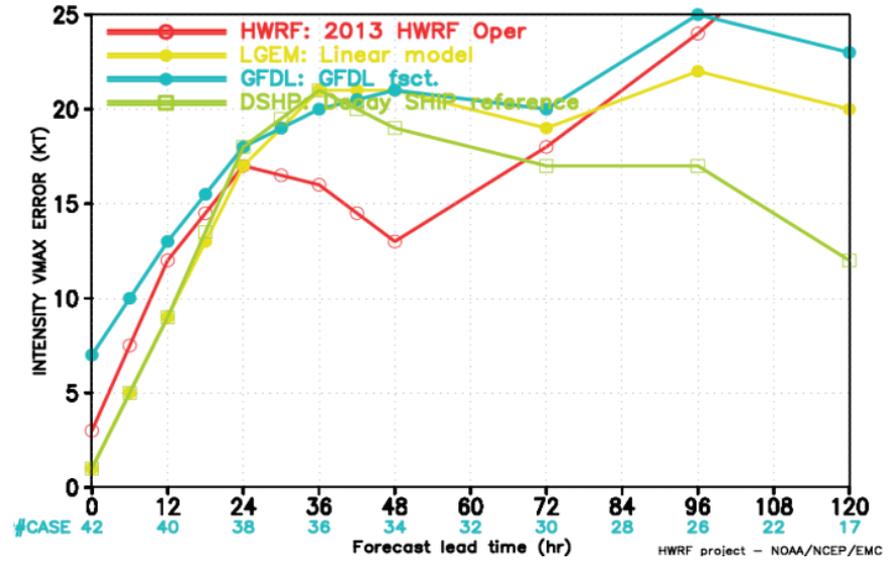
Satellite DA experiments with increased vertical levels showed desired impact on intensity forecasts.

Raymond verification

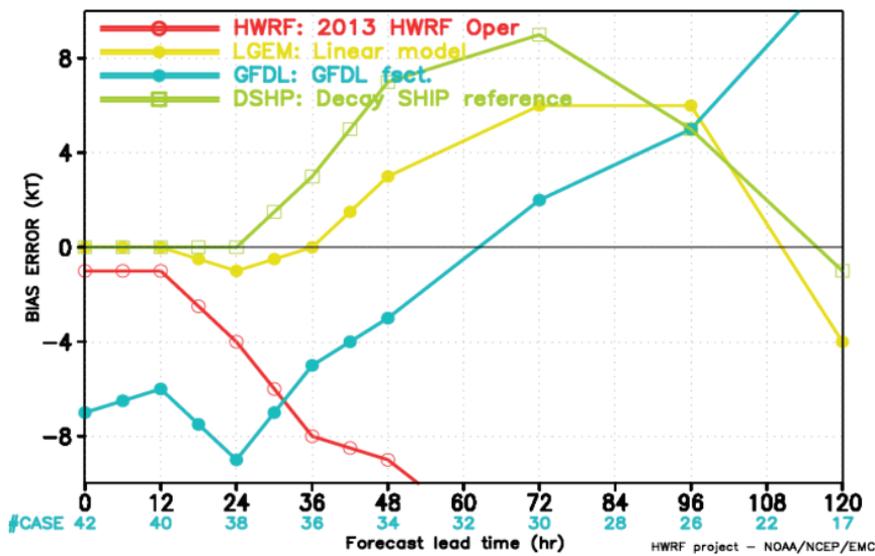
HWRF FORECAST – TRACK ERROR (NM) STATISTICS
STATISTICS FOR A SINGLE CASE – ep172013_RAYMOND



HWRF FORECAST – INTENSITY VMAX ERROR (KT) STATISTICS
STATISTICS FOR A SINGLE CASE – ep172013_RAYMOND



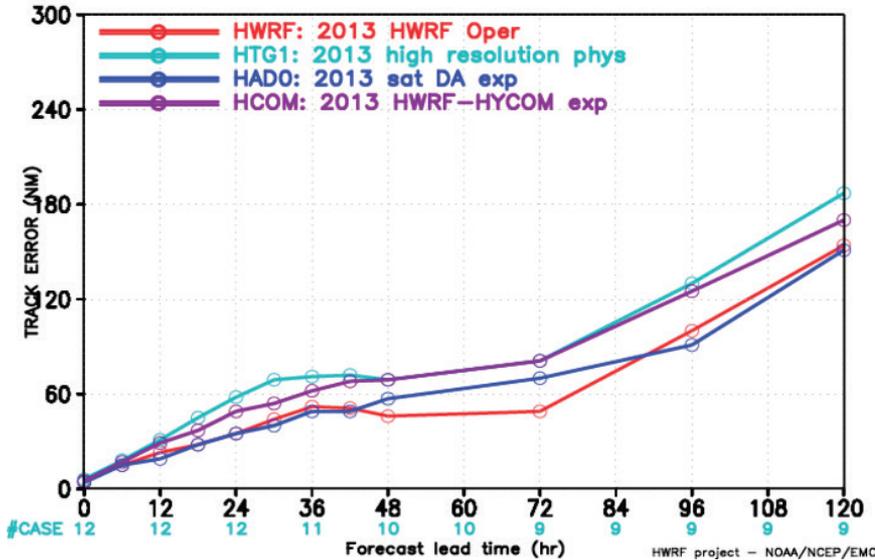
HWRF FORECAST – BIAS ERROR (KT) STATISTICS
STATISTICS FOR A SINGLE CASE – ep172013_RAYMOND



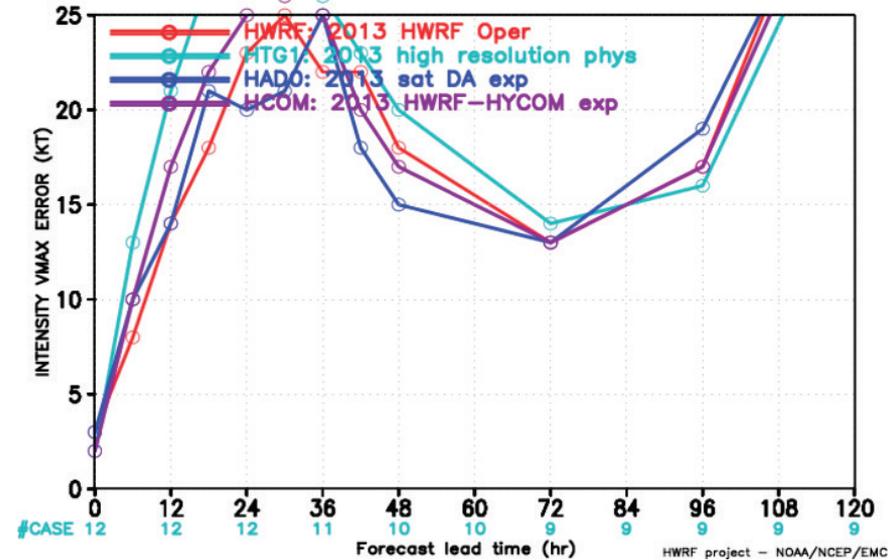
One of the most troubling storm for HWRF this season

Raymond verification

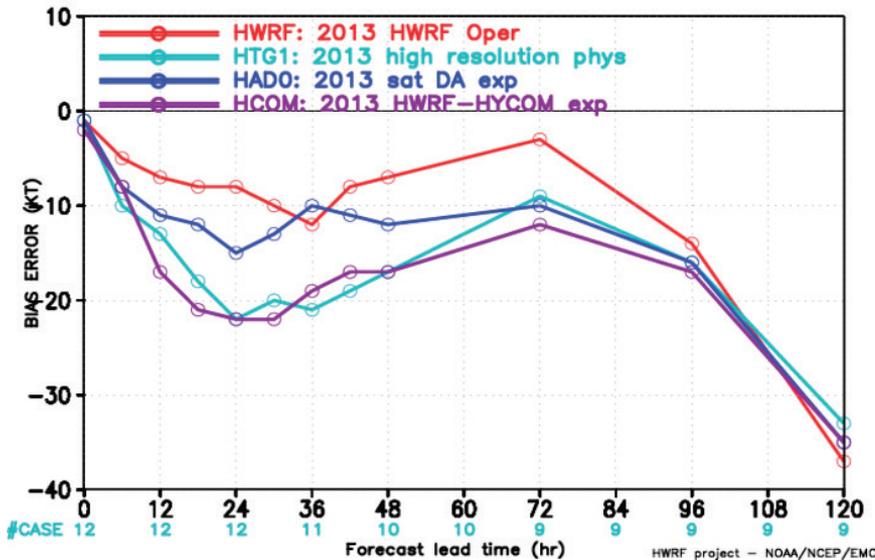
HWRF FORECAST – TRACK ERROR (NM) STATISTICS
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HWRF FORECAST – INTENSITY VMAX ERROR (KT) STATISTICS
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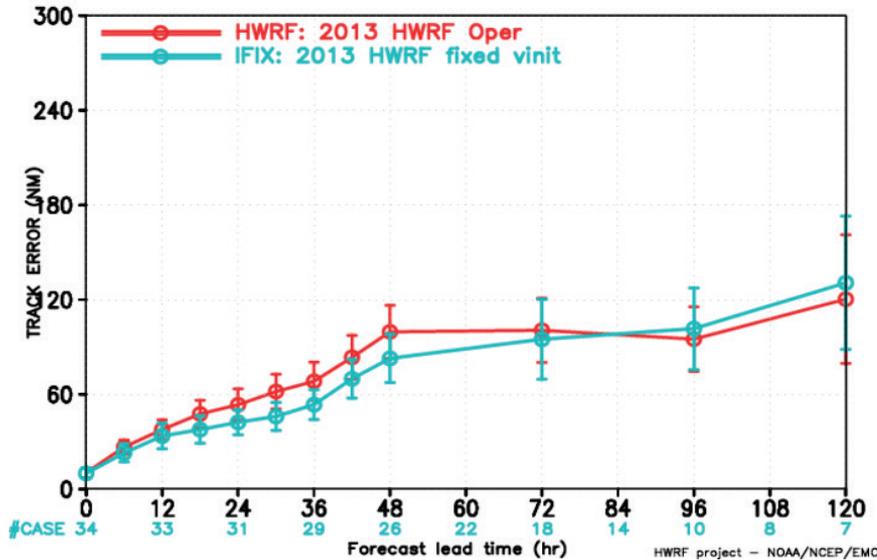
HWRF FORECAST – BIAS ERROR (KT) STATISTICS
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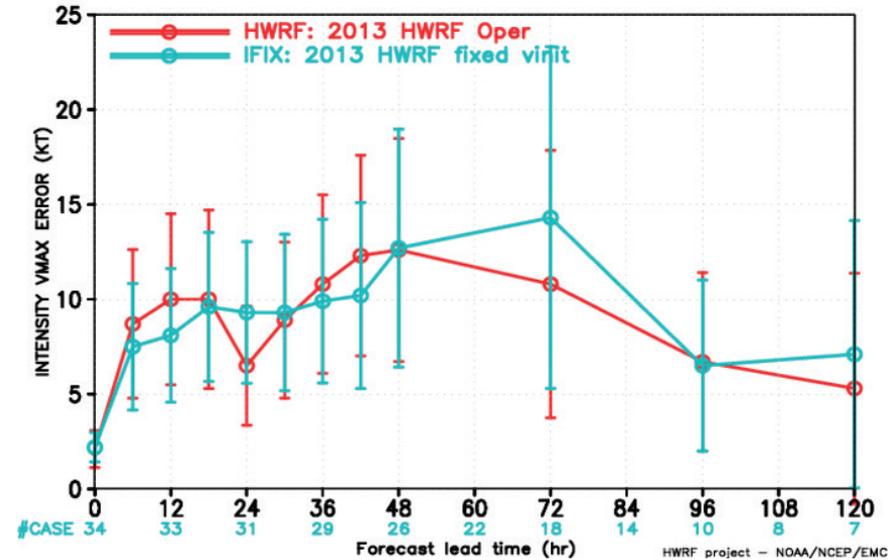
One of the most troubling storm for HWRF this season. None of the parallel experiments showed improvements in intensity forecasts

Further changes to vortex initialization

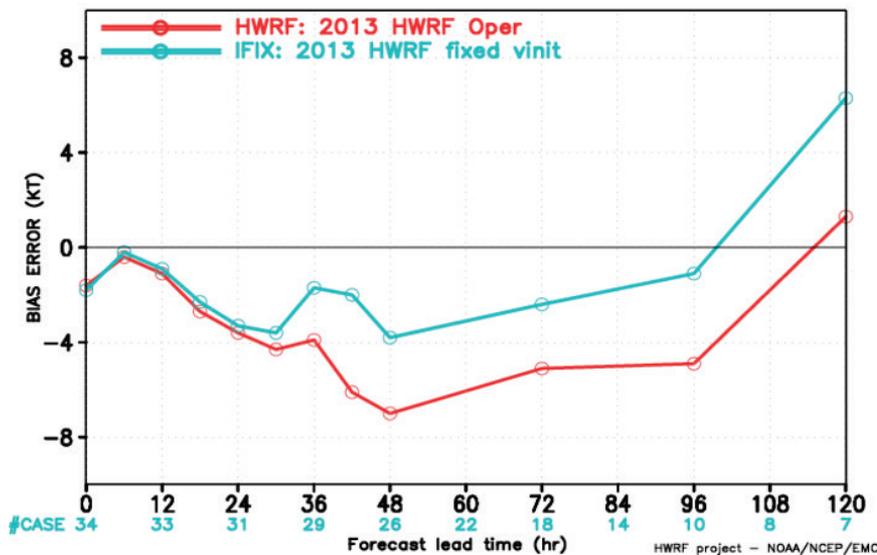
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A few additional changes to the vortex initialization for weaker storms showing promise (proposed FY14 HWRF configuration)