Tropical Cyclone Modeling and Data Assimilation

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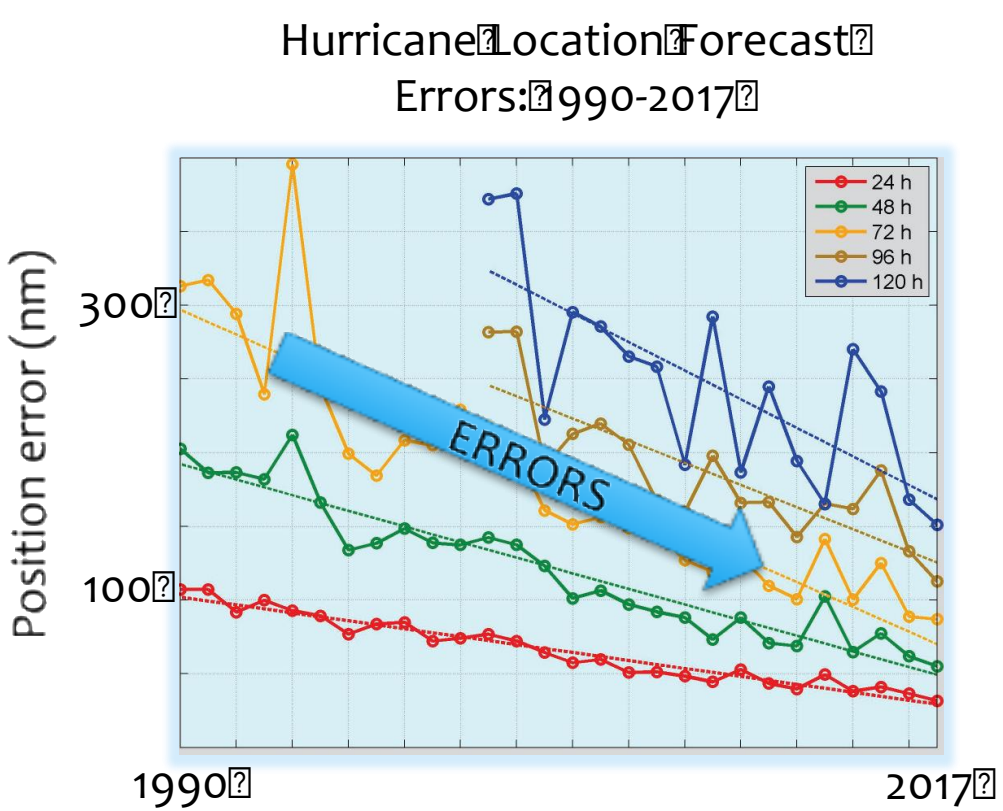
2019 WMO Workshop at NHC

Outline

- History of TC forecast improvements in relation to model development
- Ongoing modeling/DA developments
- Future direction

History of improvements: Error trends



- Hurricane track forecasts have improved markedly
- The average Day-3 forecast location error is now about what Day-1 error was in 1990
- These improvements are largely tied to improvements in large-scale forecasts

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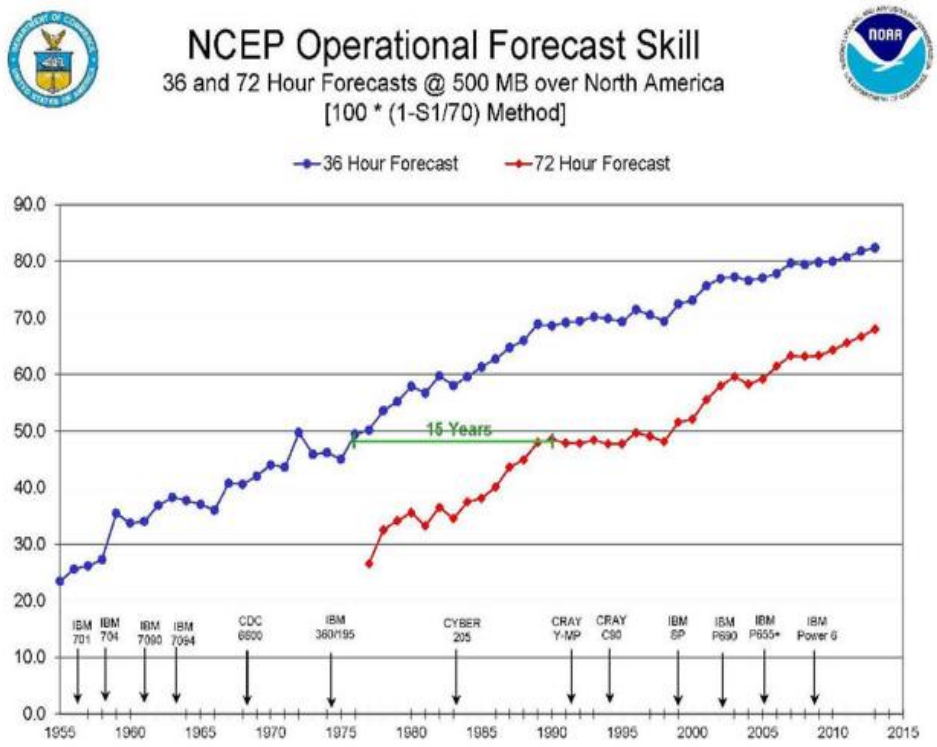

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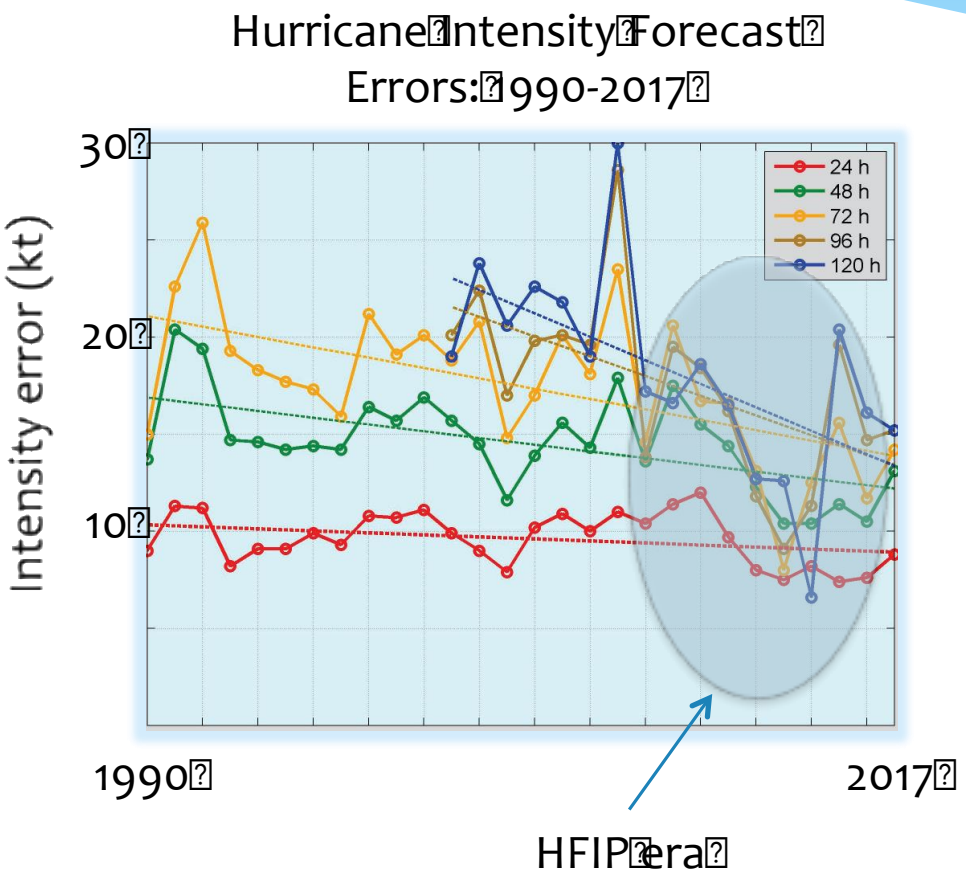
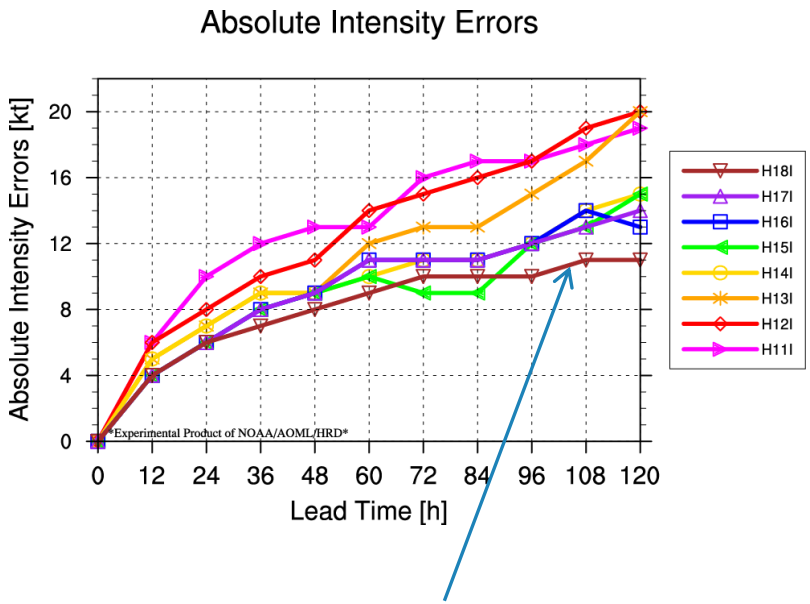


- Hurricane intensity forecasts have only recently improved
- Improvement in intensity forecast largely corresponds with commencement of Hurricane Forecast Improvement Project

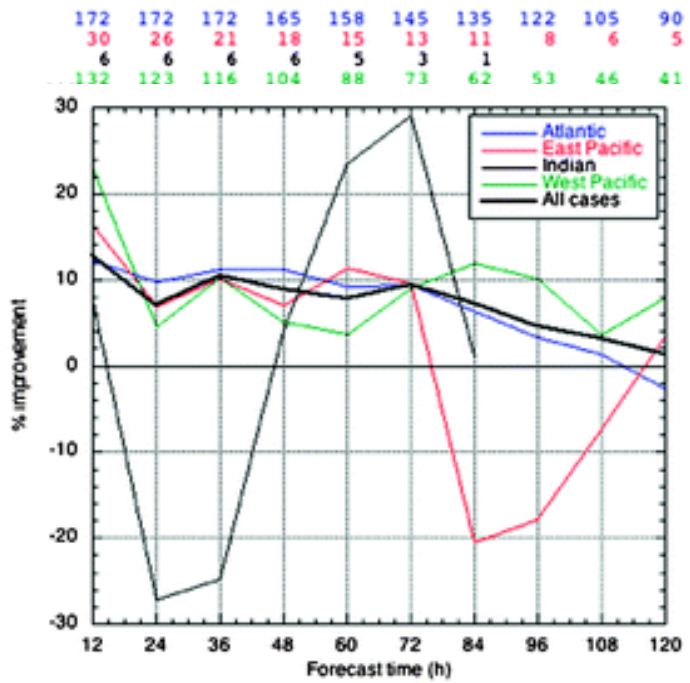
History of improvements: Error trends



HWRF median intensity error at long lead times have decreased by almost 50% in last decade!

- Significant focus of HFIP has been the development of the HWRF model
- As a result, HWRF intensity errors have decreased significantly over the past decade

History of improvements: Using TC Observations

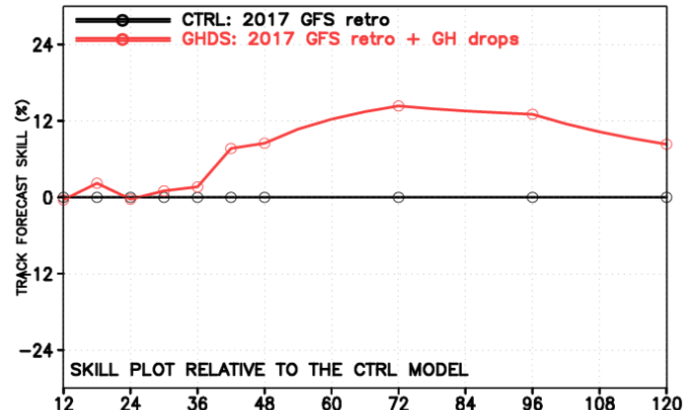


Percent improvement as a result of assimilating NOAA, DOTSTAR, and THORPEX dropsondes in September 2008 (Aberson 2011)

- US has used dropsondes for TC model forecast improvement since 1997
- Aberson (2010, 2011) examined impact of dropsondes in GFS
- Significant track improvement globally

History of improvements: Using TC Observations

Track skill - 2016 NATL



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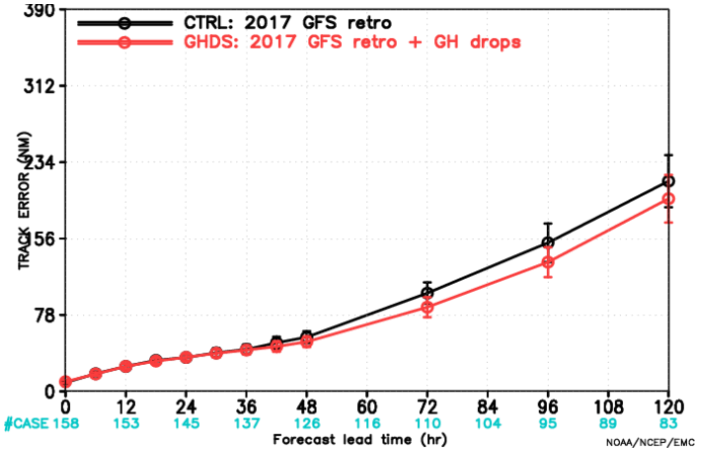
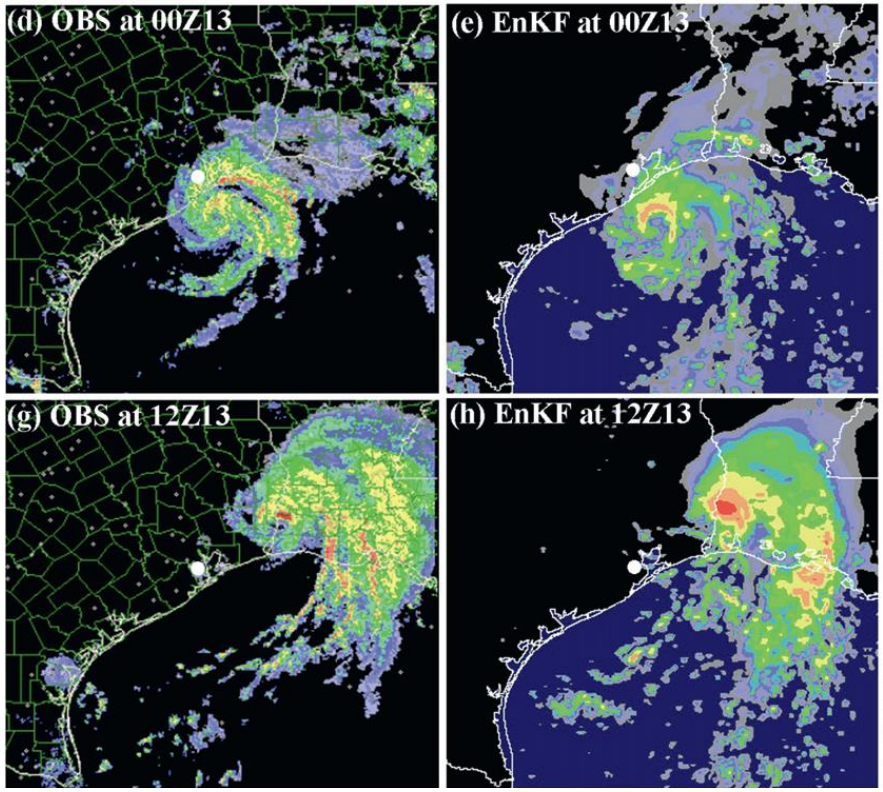


- Recent GFS (v2017) retrospectives assimilated Global Hawk dropsondes
- SUBSTANTIAL benefits for GFS track!!!
- Ongoing work suggests very high altitude of GH sondes is important

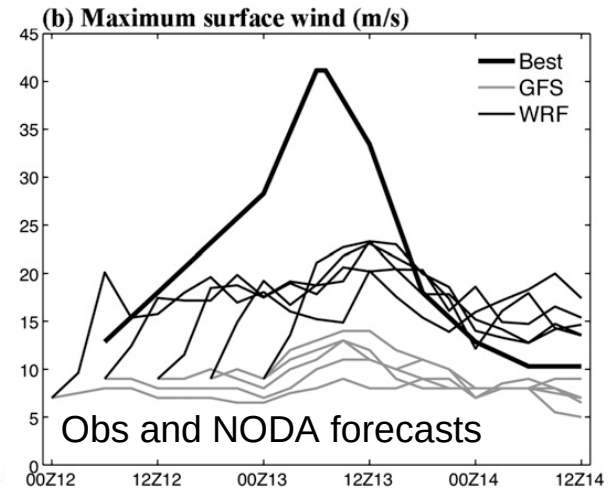
History of improvements: Using TC Observations

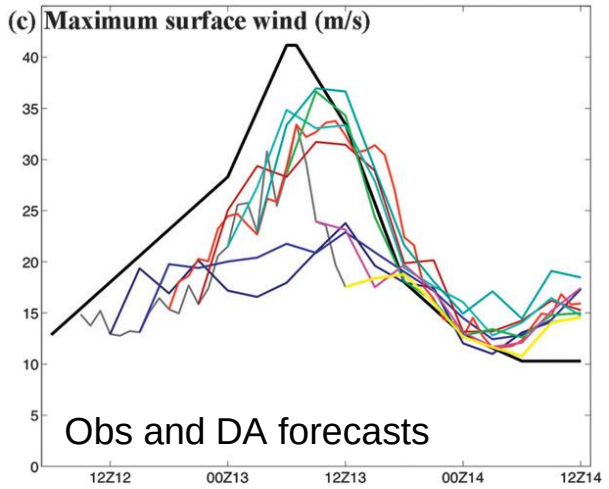


Observations (left) and analyses (right) of reflectivity from Hurricane Humberto with an experimental system

- Starting in 2008, it became apparent that assimilating Doppler velocity data had potential for forecast improvement
- Assimilating radar data significantly improved analyses and forecasts of Hurricane Humberto

History of improvements: Using TC Observations





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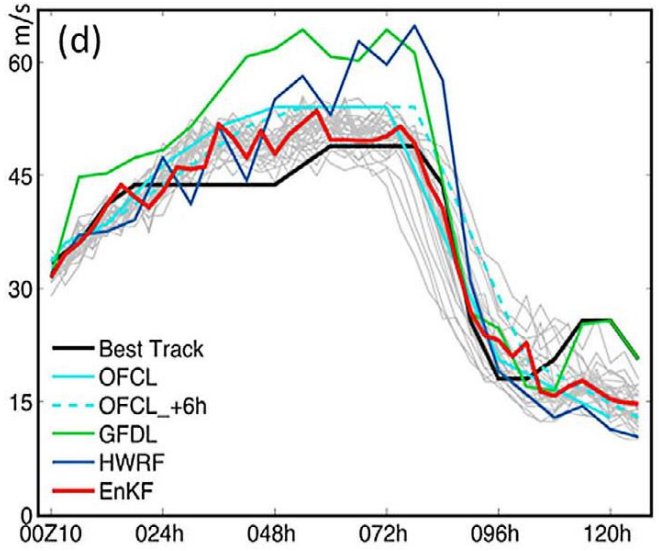
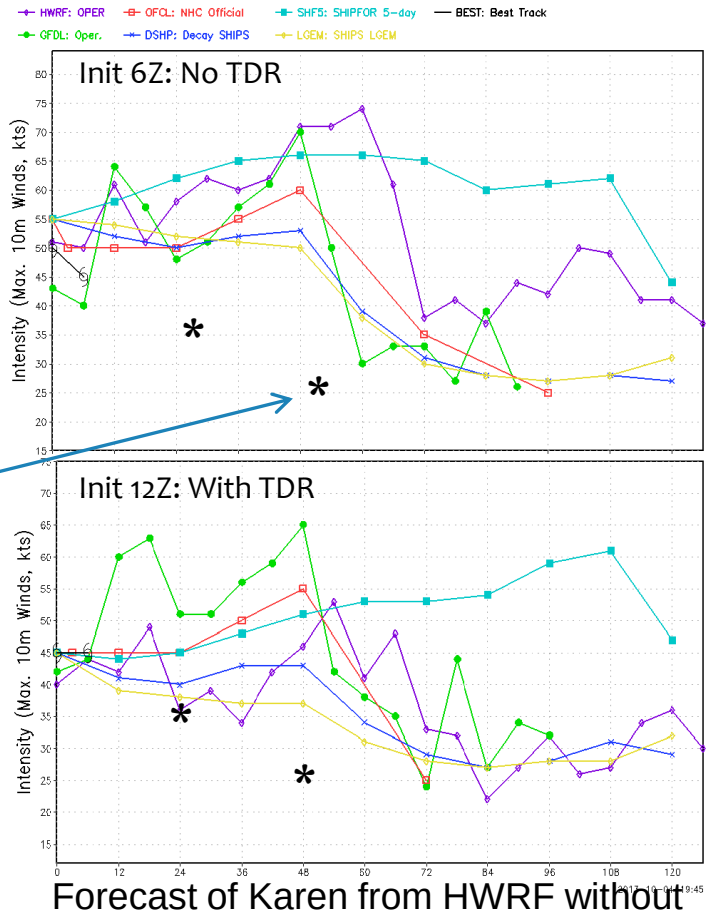


Operational and experimental intensity forecasts of Hurricane Ike (2008) prior to landfall near Houston. The forecast from EnKF used assimilation of TDR velocity data.

- Subsequent work showed forecast improvements from assimilating Doppler velocity from recon (TDR)
- These results led to a dedicated effort to assimilate TDR operationally

History of improvements: Using TC Observations



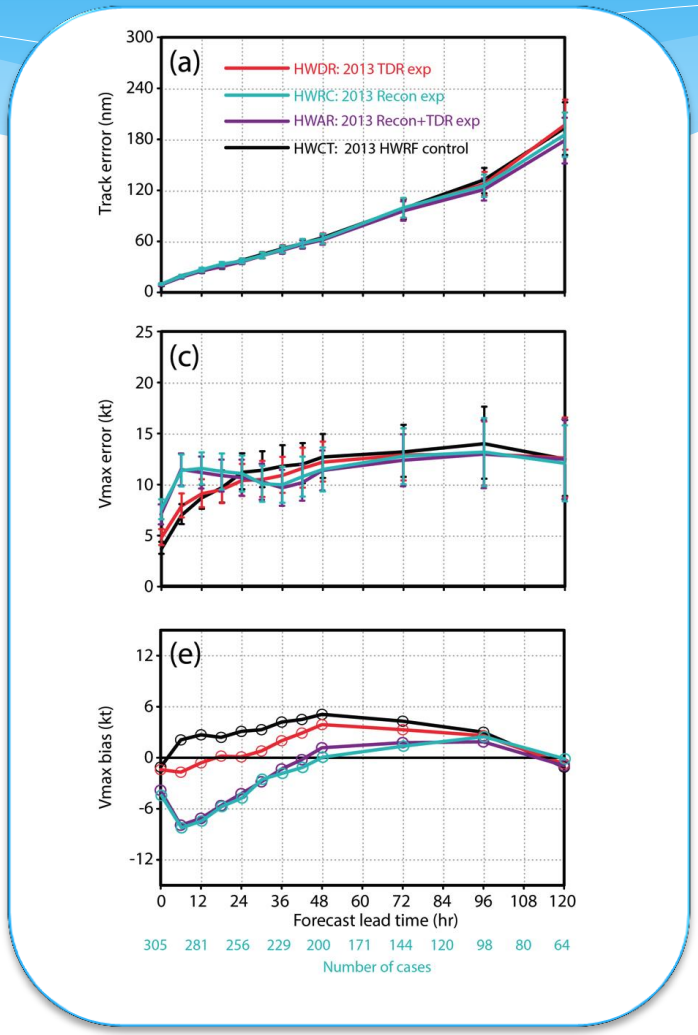
Reality

Forecast of Karen from HWRF without (top) and with (bottom) TDR DA

- TDR data began being assimilated in HWRF in 2013
- For weak storms like Karen, there was substantial improvement of a positive intensity bias in HWRF (purple)

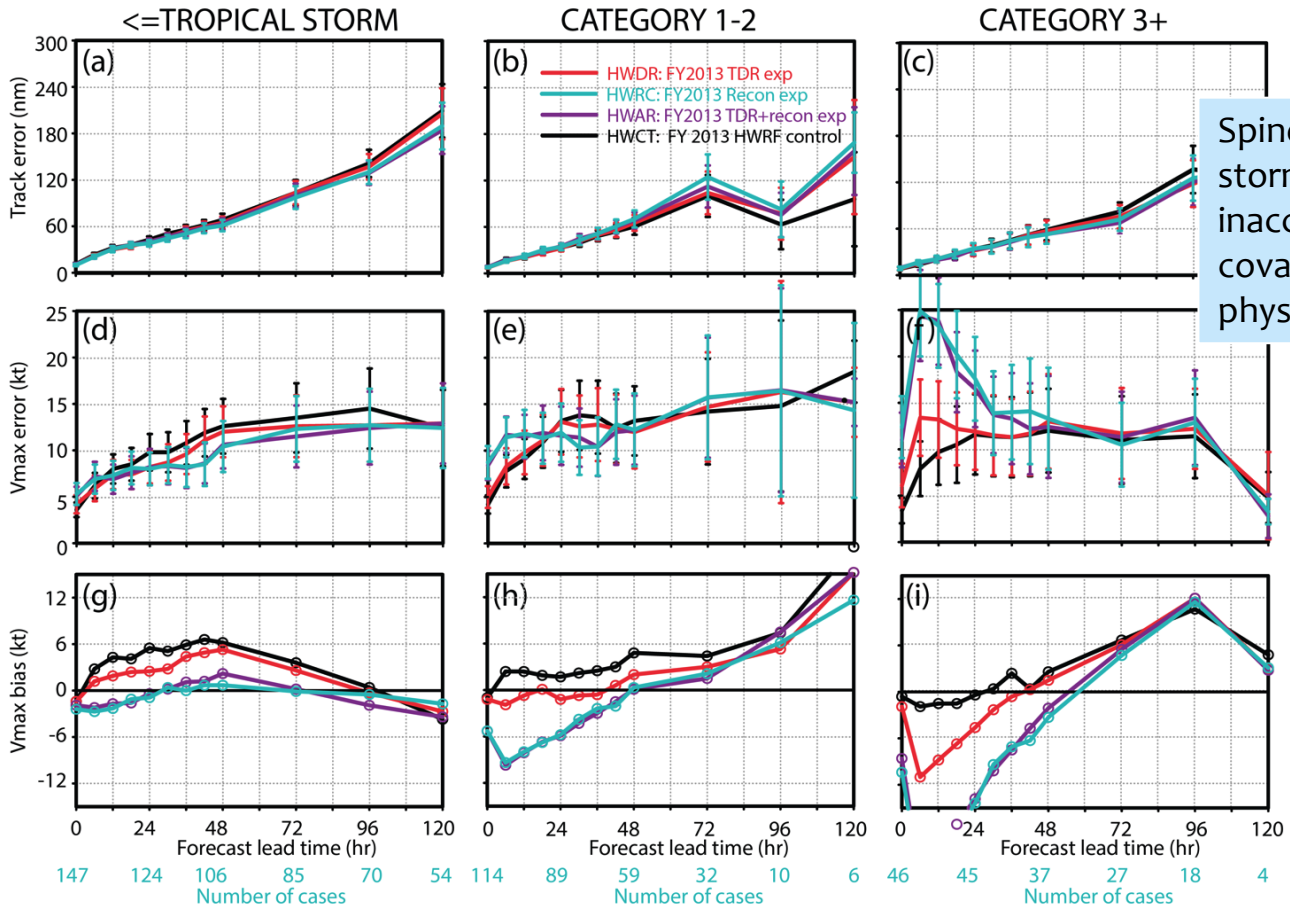
History of improvements: Using TC Observations

- Results diminished over a larger sample (cf red & black lines)
- Major problem was a substantial negative bias in the first 24 h
- The problem is worse for stronger storms and is the result of physics and DA deficiencies



History of improvements: Using TC Observations

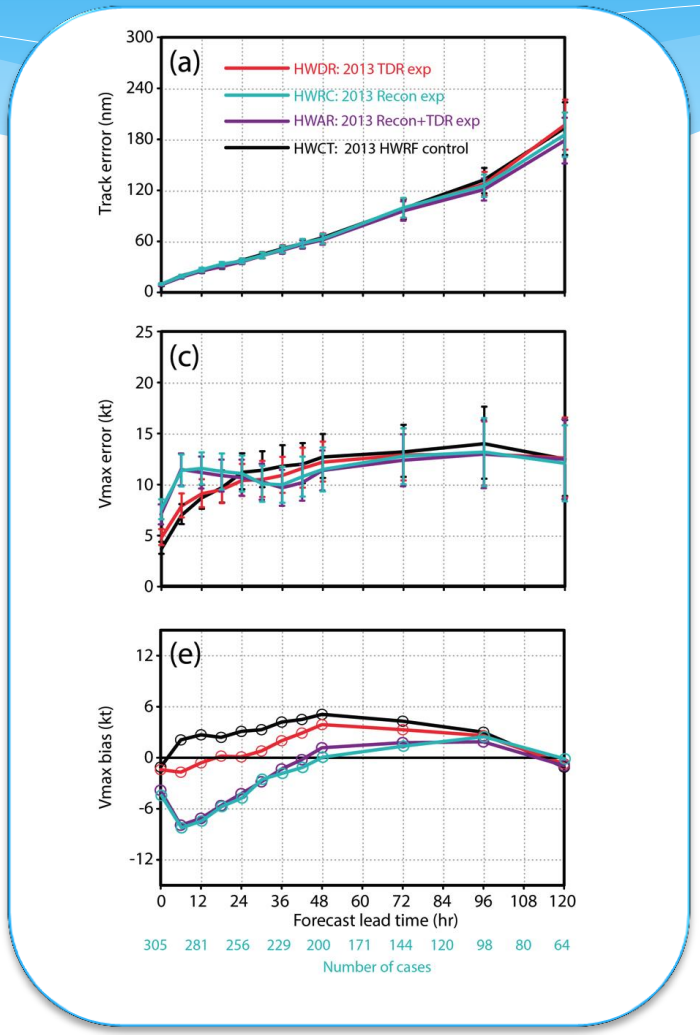
Consistent Vmax benefit for TS cycles



Spindown for strong storms due to inaccurate error covariance and physics deficiencies

History of improvements: Using TC Observations

- HDOB data (i.e., flight-level and SFMR) reduce track error more (more data continuity)
- Spindown problem worse for HDOB data
- Best results from using all data

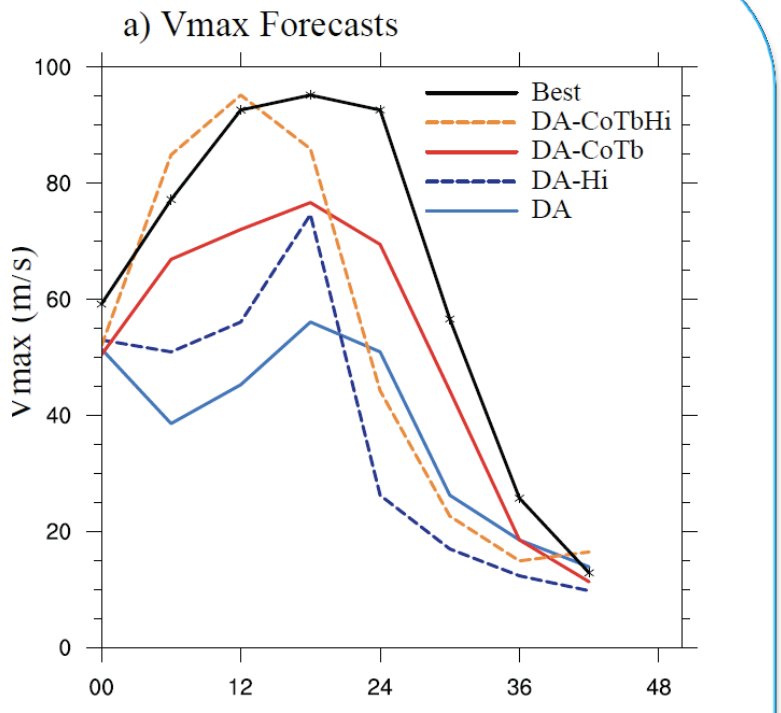


History of improvements: Using TC Observations

CURRENT OBSERVATIONS ASSIMILATED BY HWRF INCLUDE:

- Conventional observations (radiosondes, dropwindsondes, aircraft, ships, buoys, surface observations over land, scatterometer, etc)
- ALL reconnaissance (HDOB, TDR)
- Atmospheric motion vectors
- Clear-sky satellite radiance observations

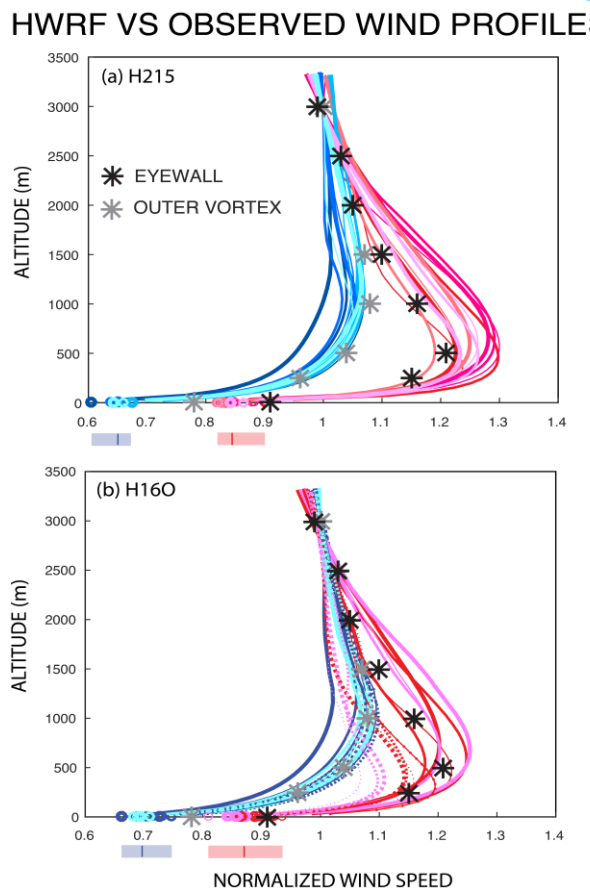
History of improvements: Battling spindown



Experimental HWRF forecasts of RI of Hurricane Patricia

- Recent work showed that increasing resolution AND improving physics (diffusion/mixing) are necessary to reduce spindown
- The challenge is to make physics changes that don't make every TD a Cat 5

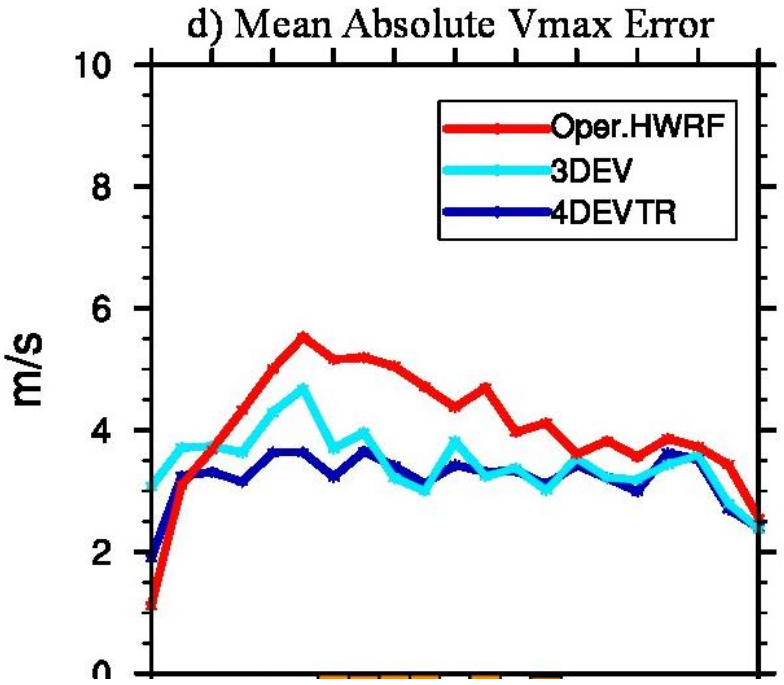
History of improvements: Battling spindown



Old (top) and new (bottom) HWRF wind profiles as a result of changing Cd

- It was found that unrealistic wind profiles were causing DA problems in HWRF
- Lowering the drag coefficient produces better wind profiles and improves DA
- Other PBL changes have been made, more needed

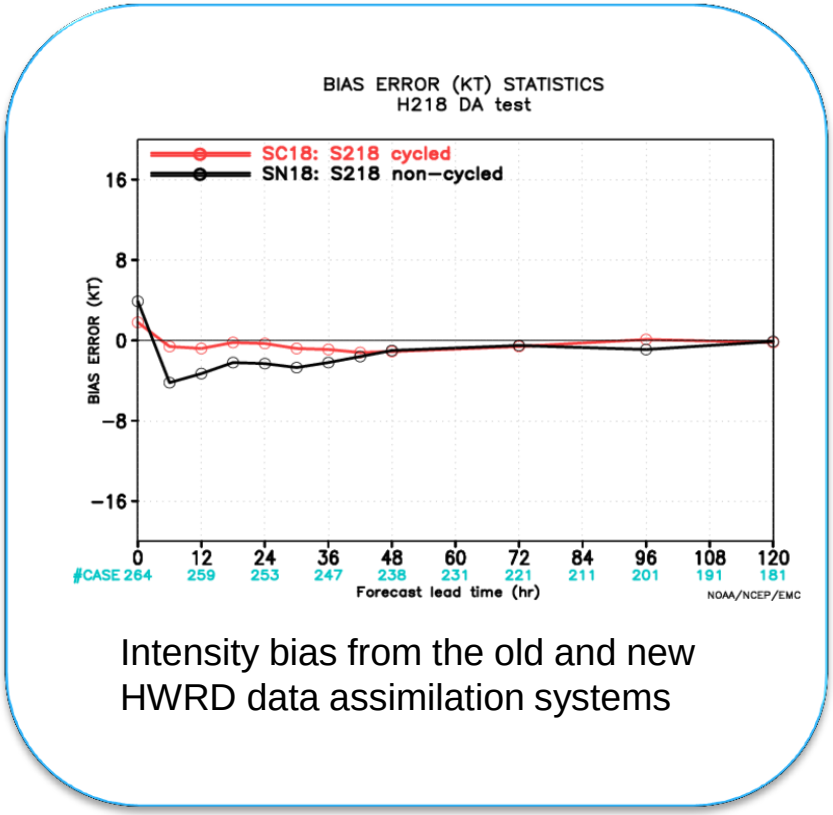
History of improvements: Battling spindown



Vmax errors for Hurricane Edouard in the operational HWRF vs the experimental OU HWRF system with fully-cycled covariance.

- It also was evident that DA system improvements were necessary to reduce spindown
- Results from experimental OU system showed significant improvements with use of self-cycled covariance

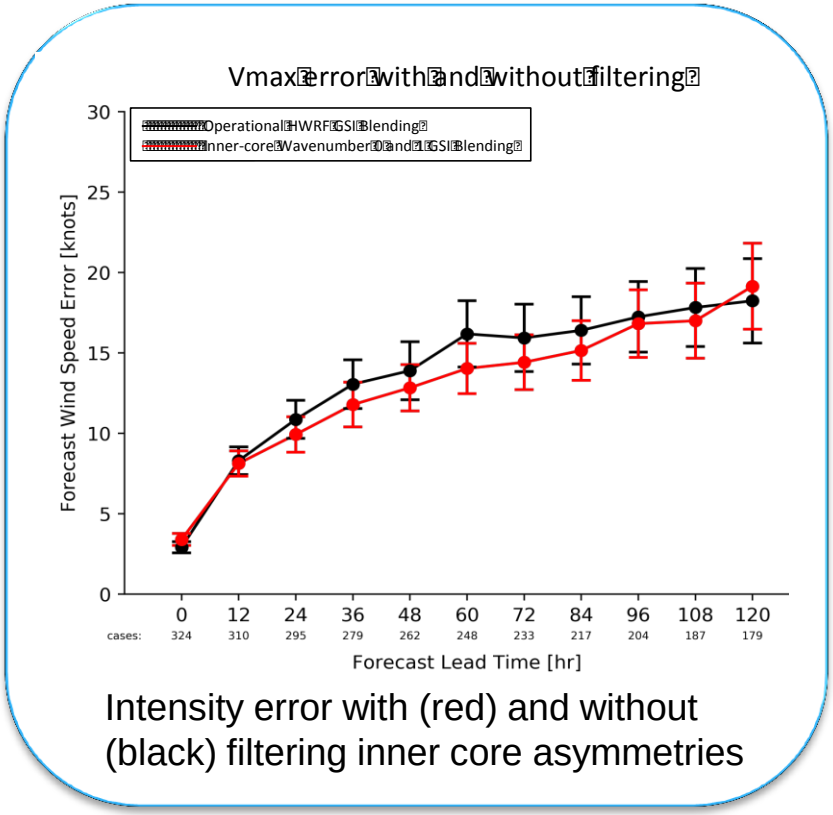
History of improvements: Battling spindown



Intensity bias from the old and new HWRD data assimilation systems

- New DA system shows less negative bias during early part of forecast
- To this point this does not improve intensity error later in forecast
- Ongoing tuning is improving performance

History of improvements: Battling spindown



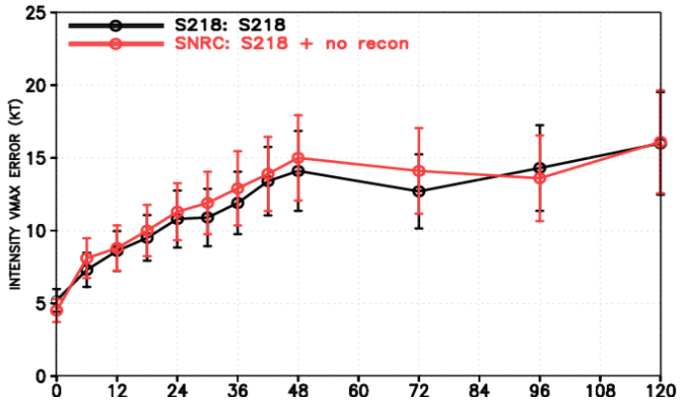
Intensity error with (red) and without (black) filtering inner core asymmetries

- Data assimilation can produce “fake” asymmetries in the inner core (just noise)
- Testing showed that removing these asymmetries with a filter significantly improves the forecast

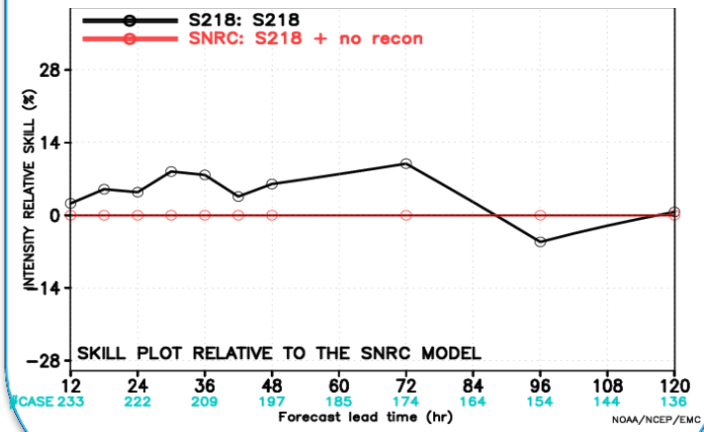
History of improvements: Current recon impact

- Impact of recon in 2016-2018 high impact storms was examined for HWRF
- Many major hurricanes in this sample, which are the hardest to improve
- Recon has a clear positive impact on intensity, about 10% improvement through 72h
- This does not include impacts on FV3

Recon test Vmax error in HWRF



Recon test Vmax skill in HWRF



Brief summary

- Track and intensity errors are both improving
- We are making great strides with HWRF and have significantly improved the DA system and data usage
- Battling spindown has been a major issue

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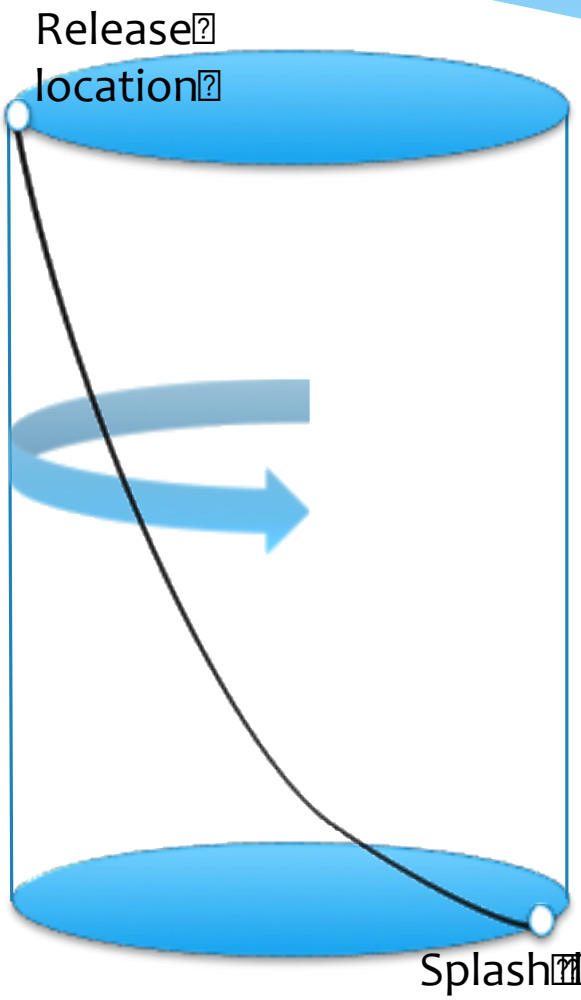
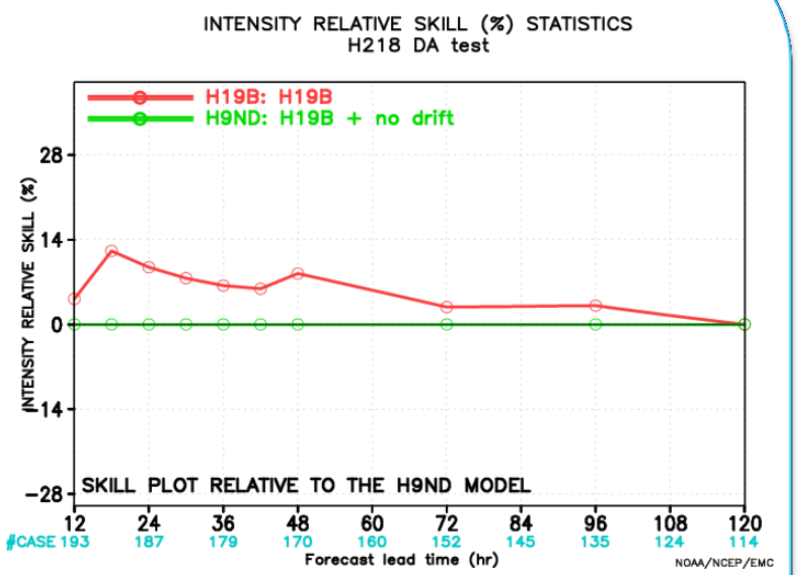
Ongoing developments: Using more observations



- Dropsonde observations currently transmitted in TEMPDROP format
- Only report release location in main body
- Not considering drift causes problems in the vortex

Ongoing developments: Using more observations

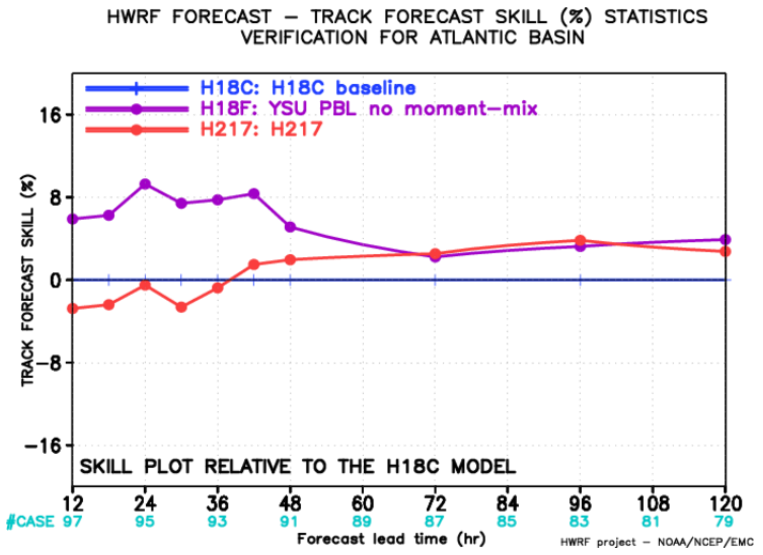
- Code has been developed to estimate dropsonde location
- Intensity improves over 10% when drift is included vs. no drift
- NOAA is also beginning to transmit full-resolution dropsonde data



Change in intensity skill due to considering dropsonde drift

Ongoing developments: Physics tests

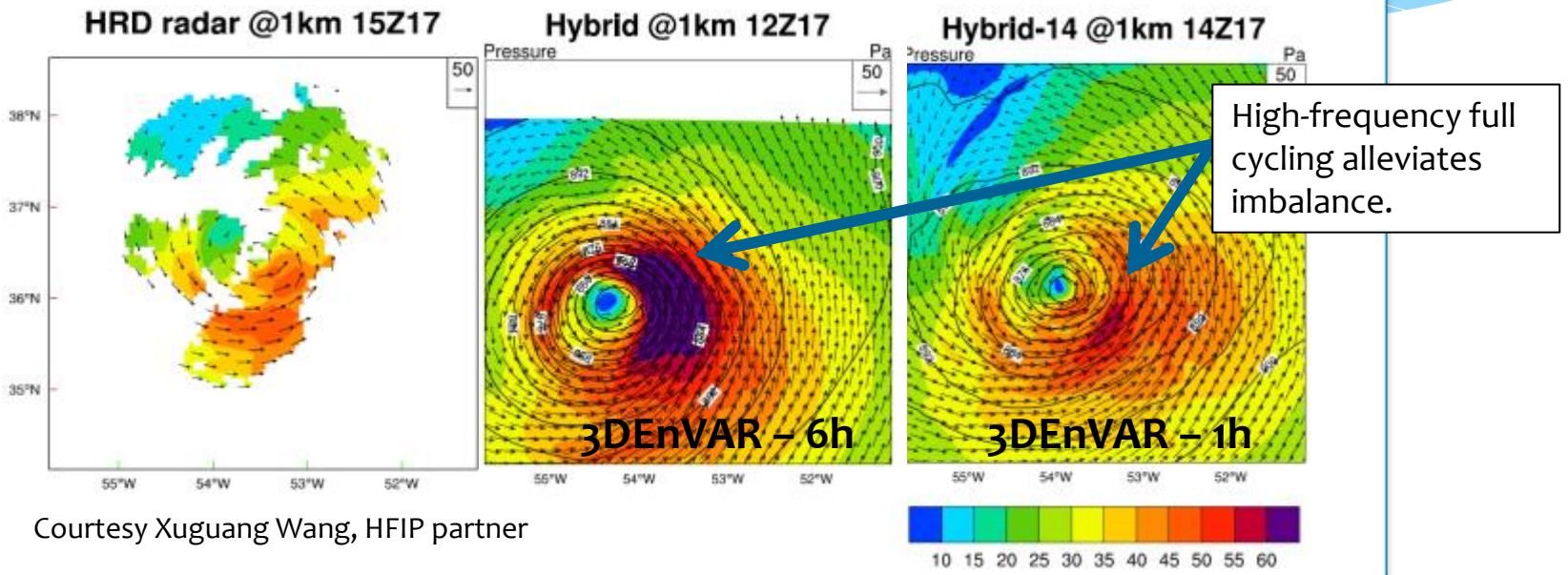
- Current HWRF PBL is GFS PBL + band aids + band aids
- Wholesale change likely needed, and YSU is one candidate
- Initial tests look very promising for both track and intensity!



Change in track skill due to using YSU PBL

Ongoing developments: DA

Considering rapid error evolution reduces imbalance



Courtesy Xuguang Wang, HFIP partner

A comparison of the HRD TDR analysis with the OU 3DEnVar hybrid HWRF analysis from Edouard with 6-h and 1-h cycling.

Ongoing developments: DA

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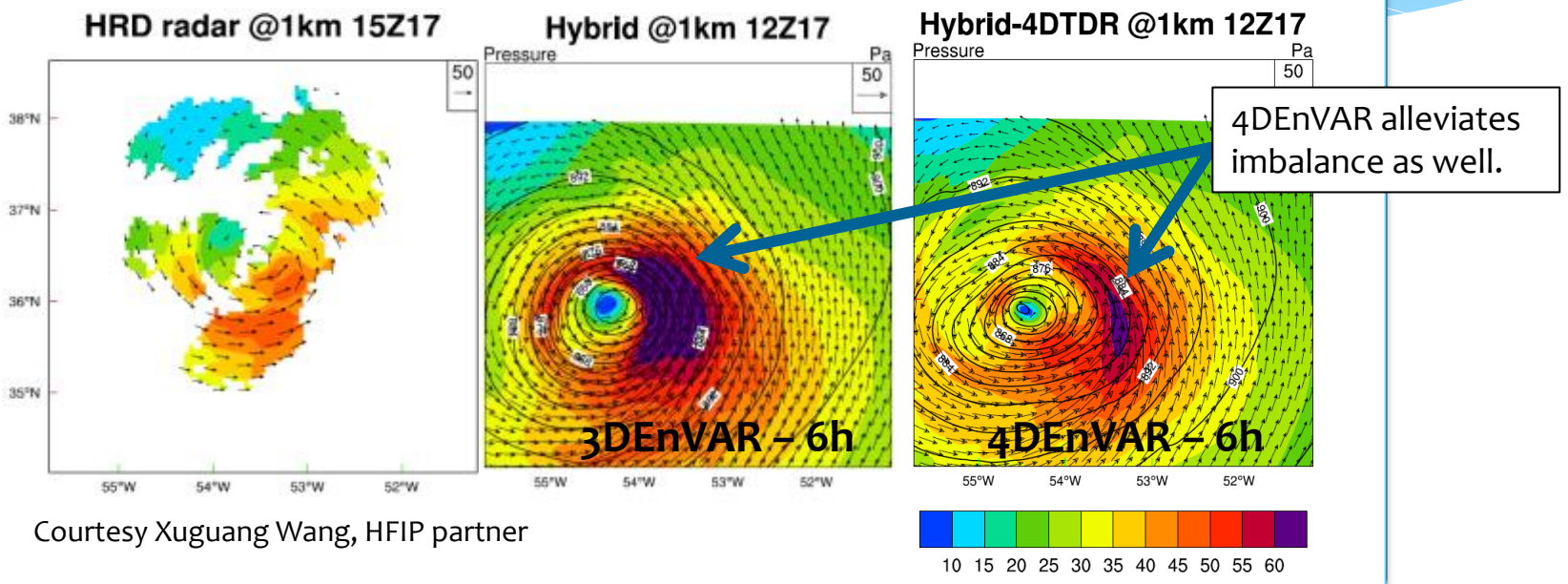

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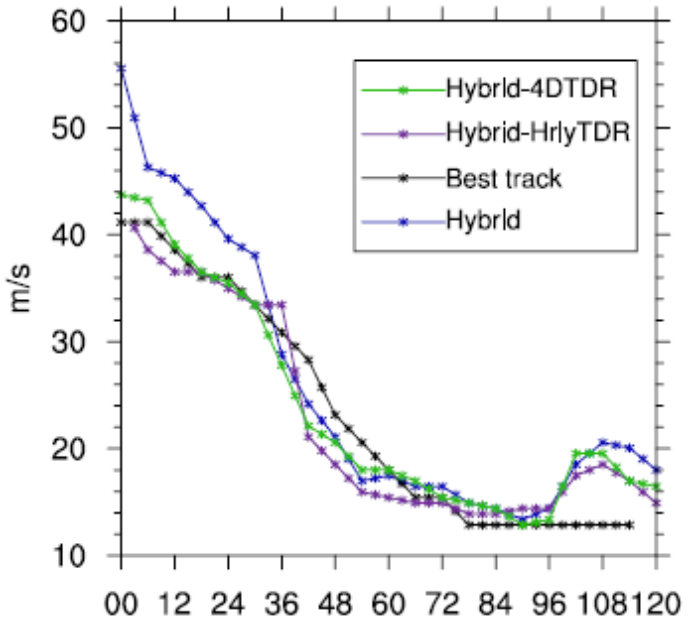
A comparison of the HRD TDR analysis with the OU 3DEnVar hybrid HWRF analysis from Edouard with 6-h and 1-h cycling.

Ongoing developments: DA

- Results from OU system show hourly cycling helps with inner core balance
- Similar capabilities are nearing completion for HWRF
- This should appeal to researchers as well



Vmax from the 12Z17 cycle of Edouard in the OU hybrid 3DVar and 4DVar systems. Courtesy Xuguang Wang, HFIP partner.

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Future direction: Other DA issues

- Improve initialization of vortex (e.g., any pre-processing before DA)
- Update condensate (and w?) with each cycle
- Assimilation of cloudy radiances
- Coupled atmosphere-ocean DA

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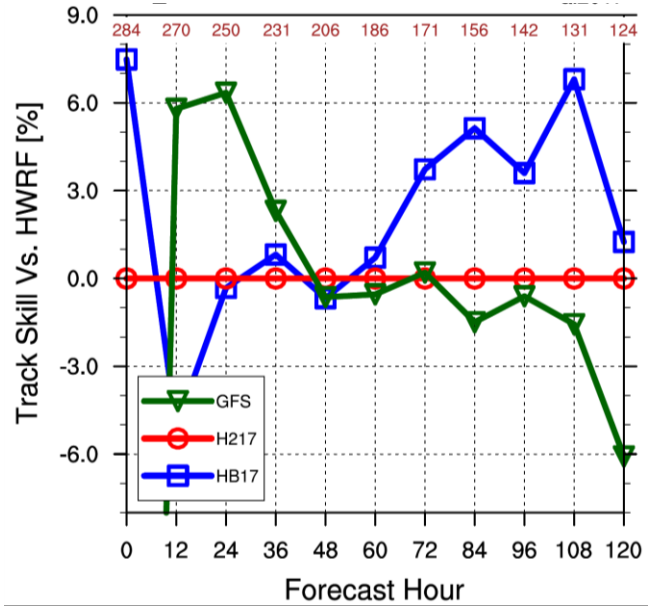
Hurricane Analysis and Forecast System (next-generation hurricane model)

Future direction: Other non-DA issues

- Intensity-dependent biases (overintensification of weak systems)
- Multi-storm approach (e.g., basin-scale)
- Probabilistic forecasting
- Targeting



Track skill of 2017 basin-scale HWRF as compared with operational HWRF and GFS

Conclusions

- NOAA TC prediction is undergoing dramatic advancements, lead by improvements in global models and HWRF
- We are using more of the available data in DA
- Long term plans address ongoing issues (e.g., spindown, bias) and allow for greater data usage
- The above factors should contribute to intensity improvement in particular