Tropical Cyclone Modeling and Data Assimilation

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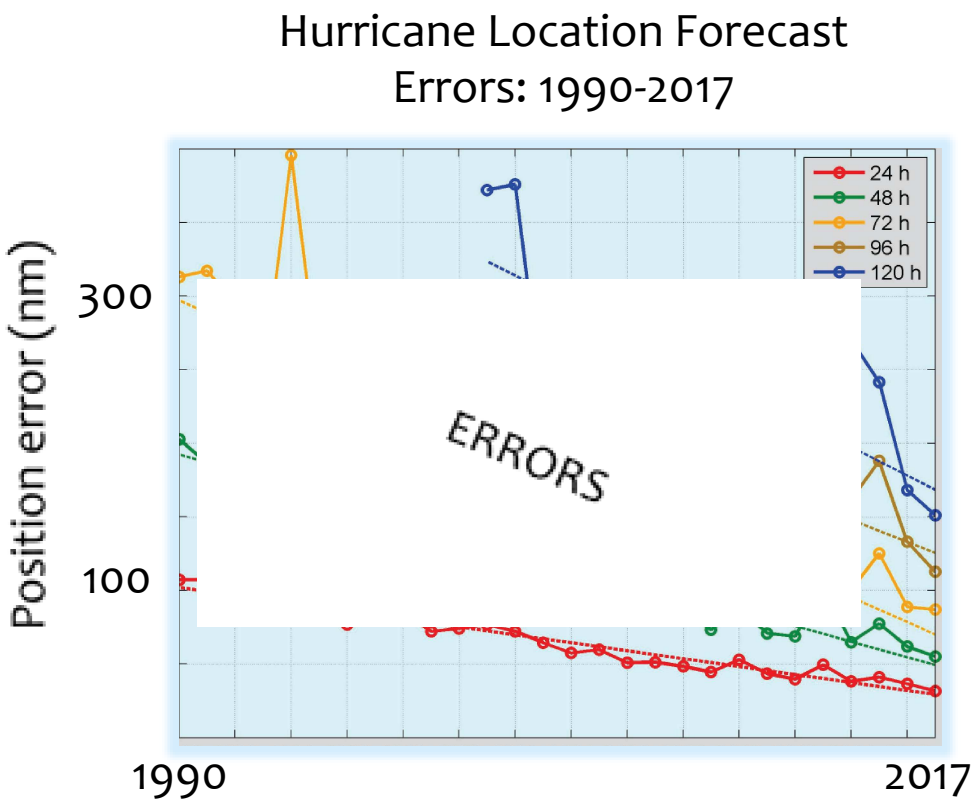
2018 WMO Workshop at NHC

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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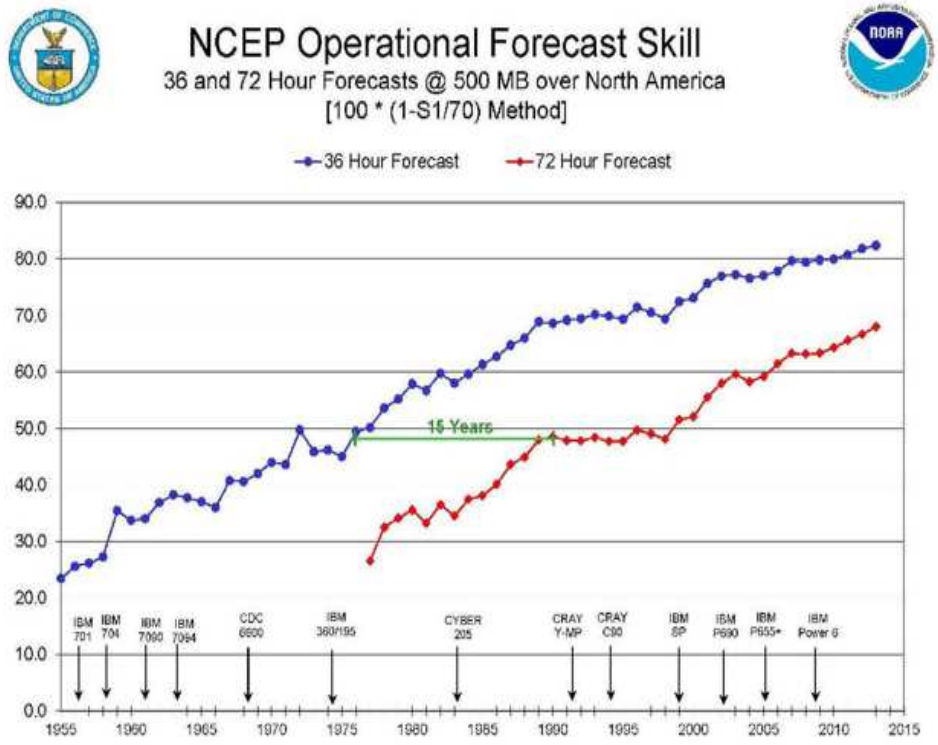

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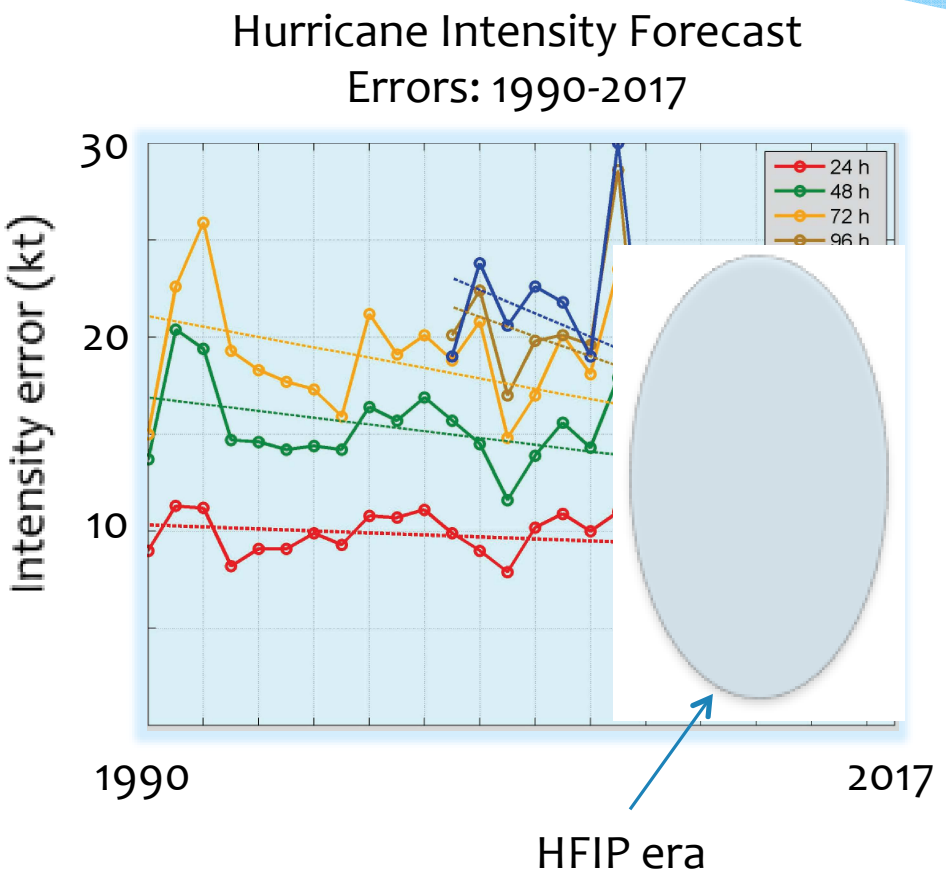
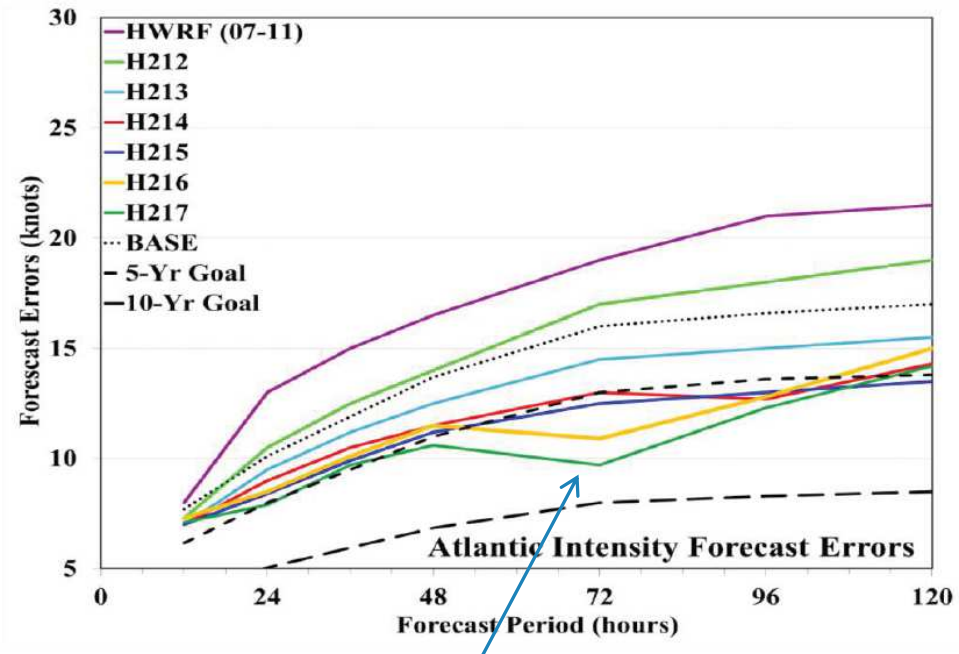


- Hurricane intensity forecasts have only recently improved
- Improvement in intensity forecast largely corresponds with commencement of Hurricane Forecast Improvement Project

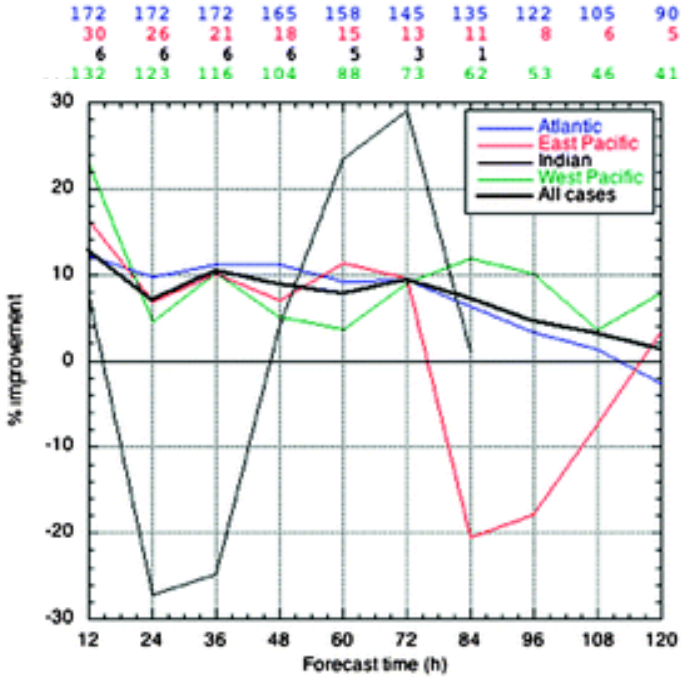
History of improvements: Error trends



HWRF intensity error at 72 h has 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

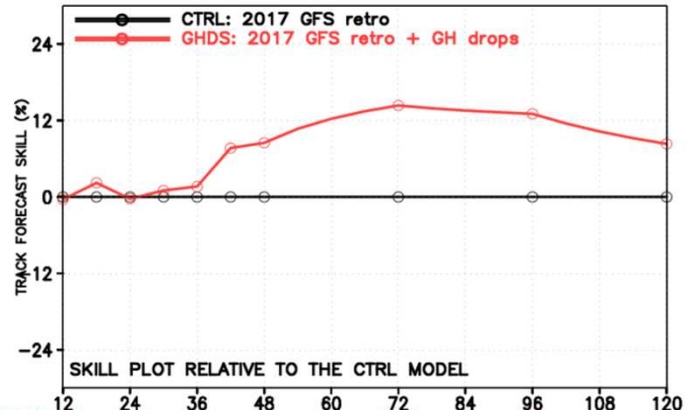


Percent improvement as a result of assimilating NOAA, DOTSTAR, and THORPEX dropsondes in September 2008 (Aberson 2011)

- 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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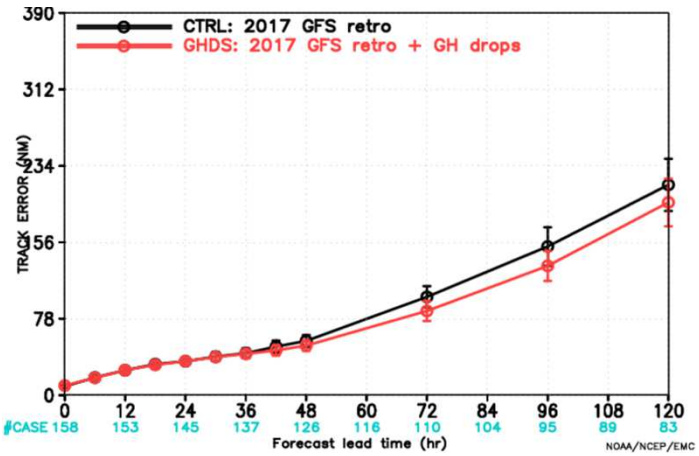
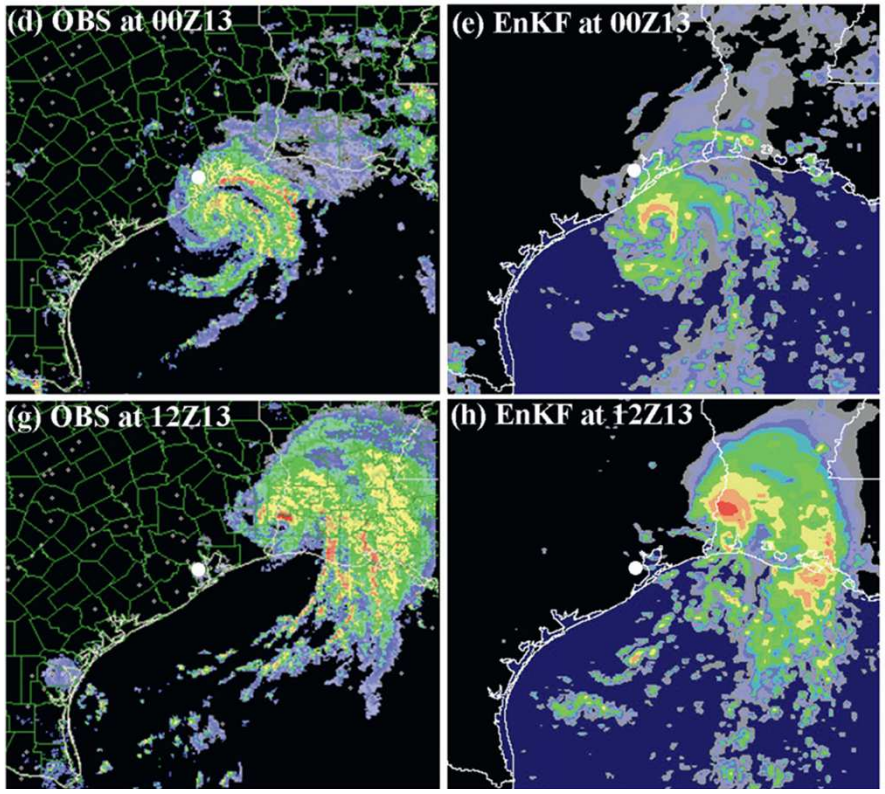


- Recent GFS (v2017) retrospectives assimilated Global Hawk dropsondes
- SUBSTANTIAL benefits for GFS track!!!
- Ongoing work suggests very high altitude of GH sondes is important

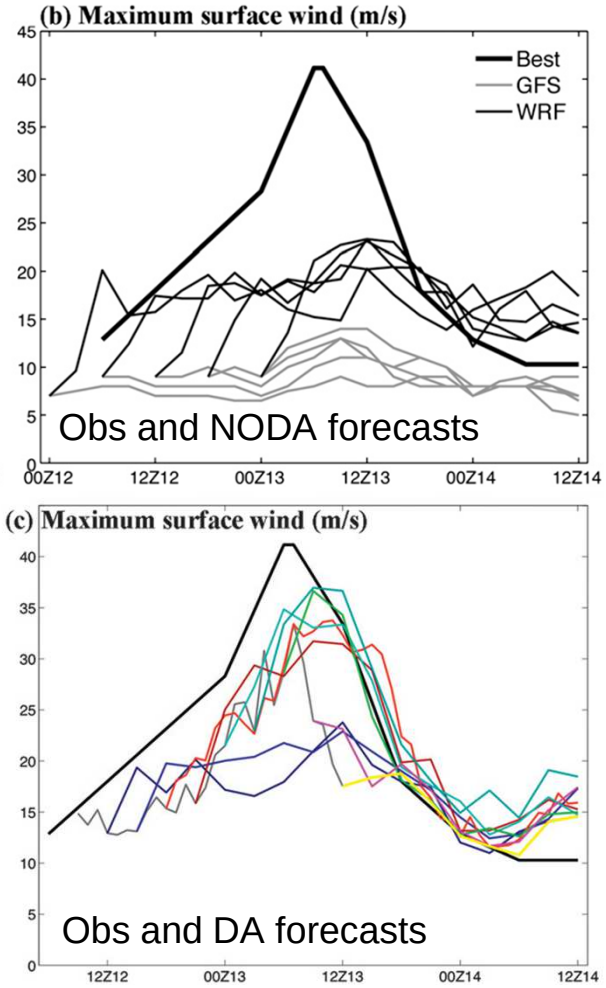
History of improvements: Using TC Observations



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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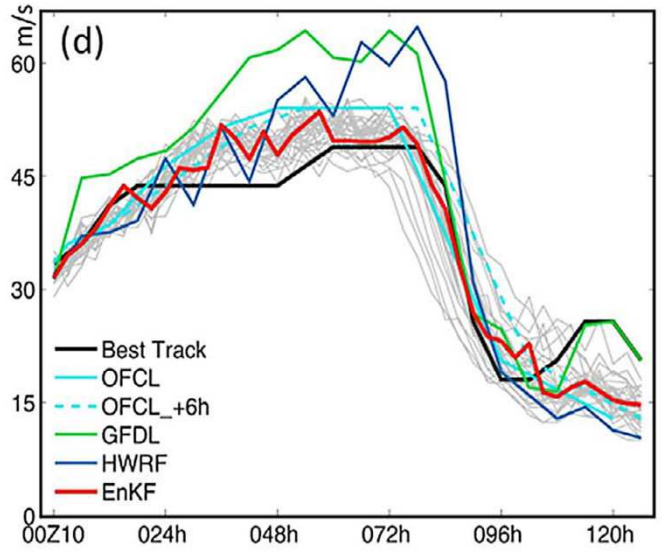
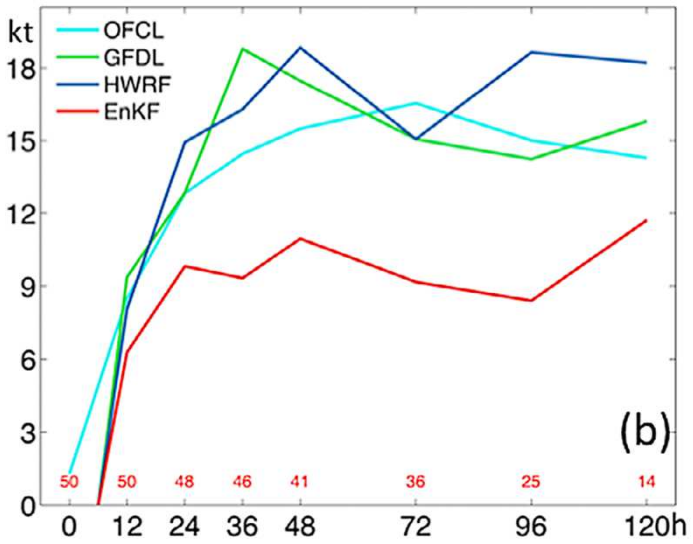


Operational and experimental intensity forecasts of Hurricane Ike (2008) prior to landfall near Houston. The forecast from EnKF used assimilation of TDR velocity data.

- Subsequent work showed forecast improvements from assimilating Doppler velocity from recon (TDR)
- For the sample examined, the forecast improvement was significant

History of improvements: Using TC Observations



Operational and experimental intensity forecasts of cases from 2008-2010. The forecast from EnKF used assimilation of TDR velocity data.

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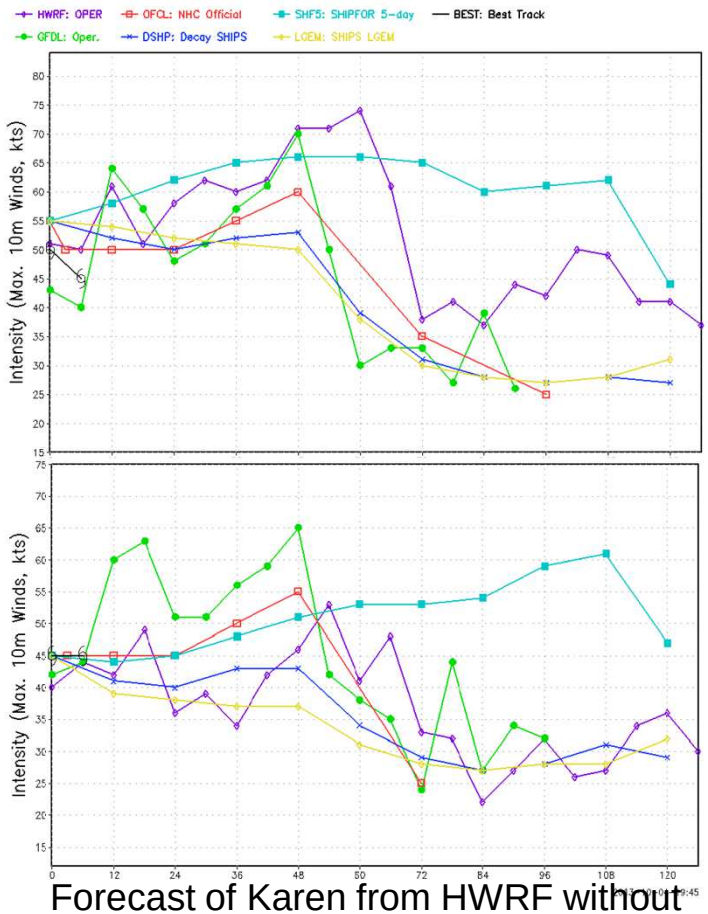
History of improvements: Using TC Observations

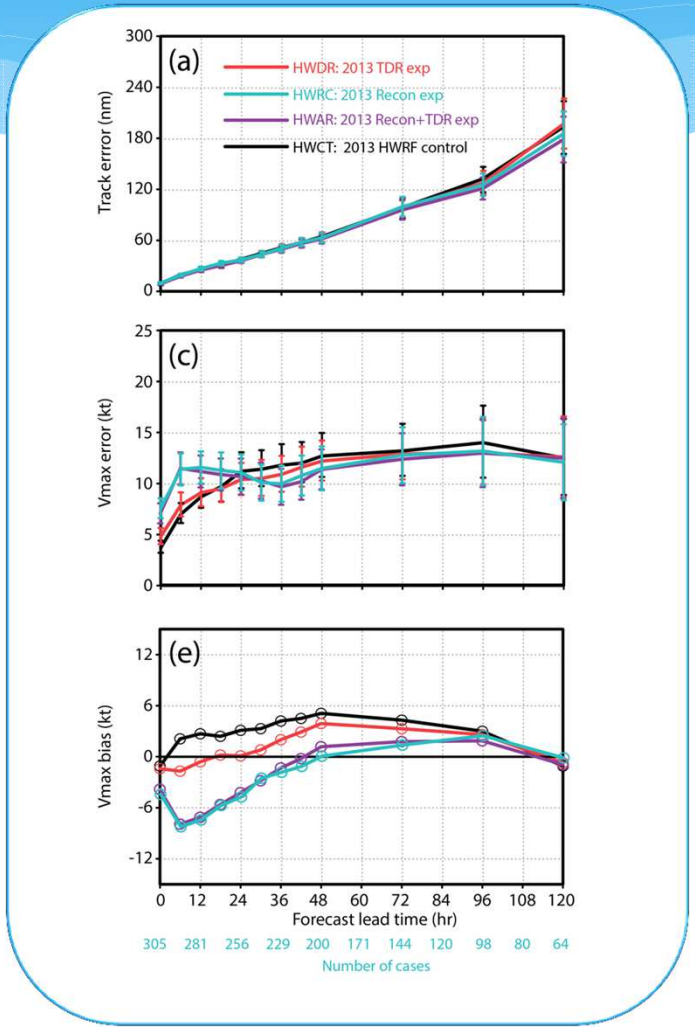


Forecast of Karen from HWRF without (top) and with (bottom) TDR DA

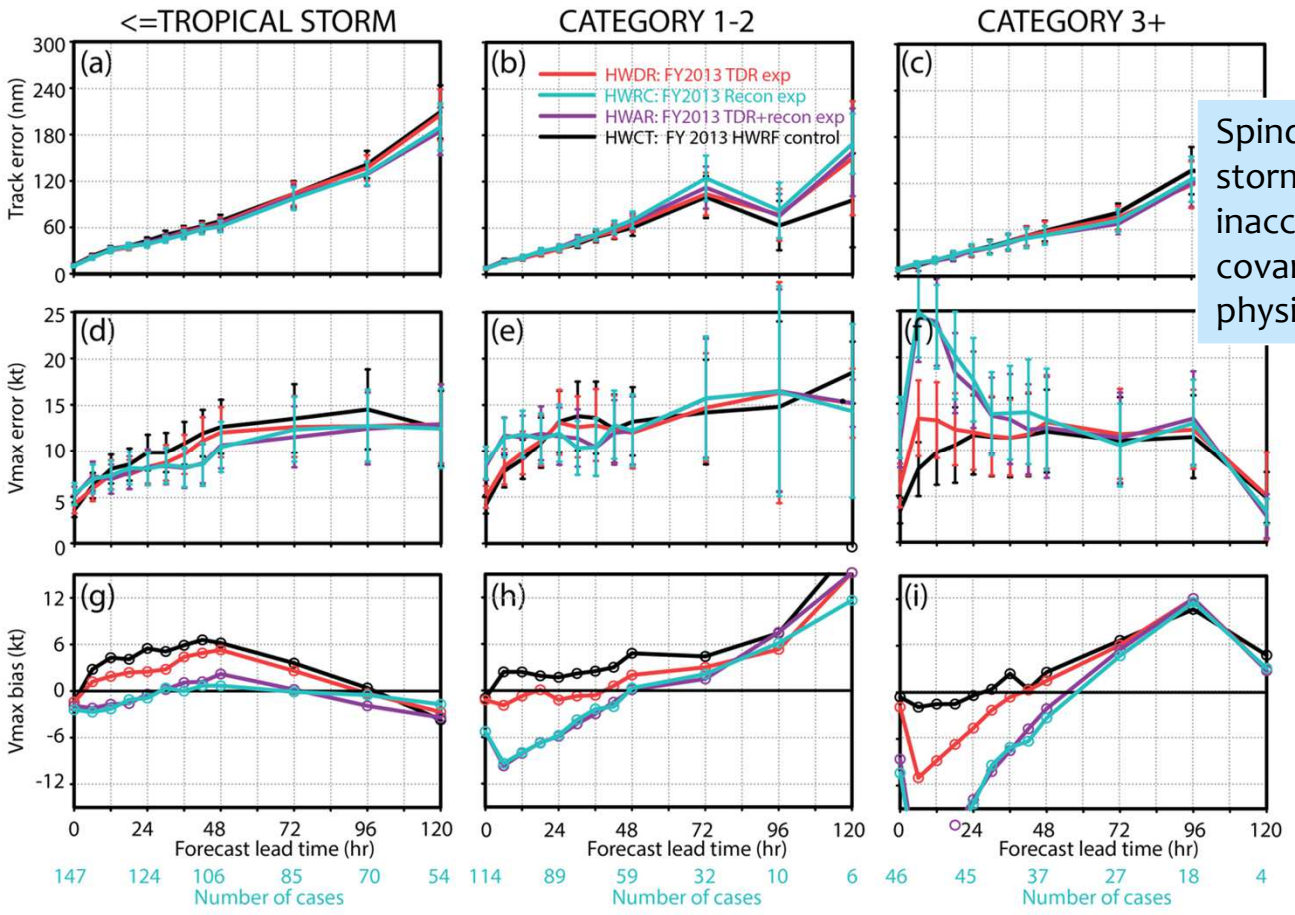
- As a result of this work, TDR data began being assimilated in HWRF in 2013
- For weak storms like Karen, there was substantial improvement of a positive intensity bias in HWRF (purple)

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

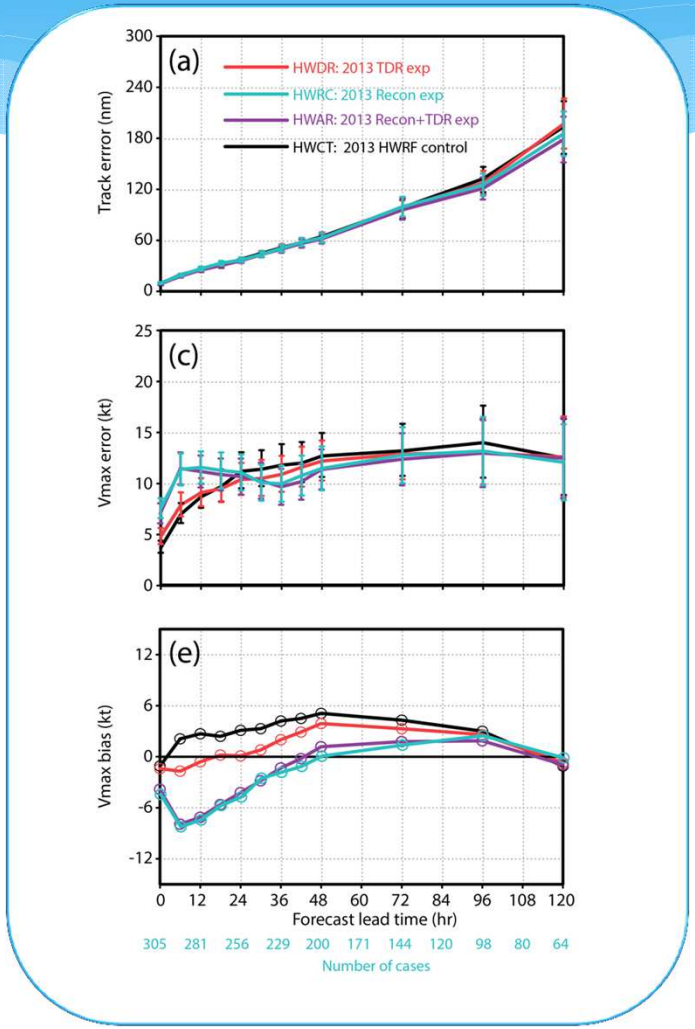


Consistent Vmax benefit for TS cycles

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

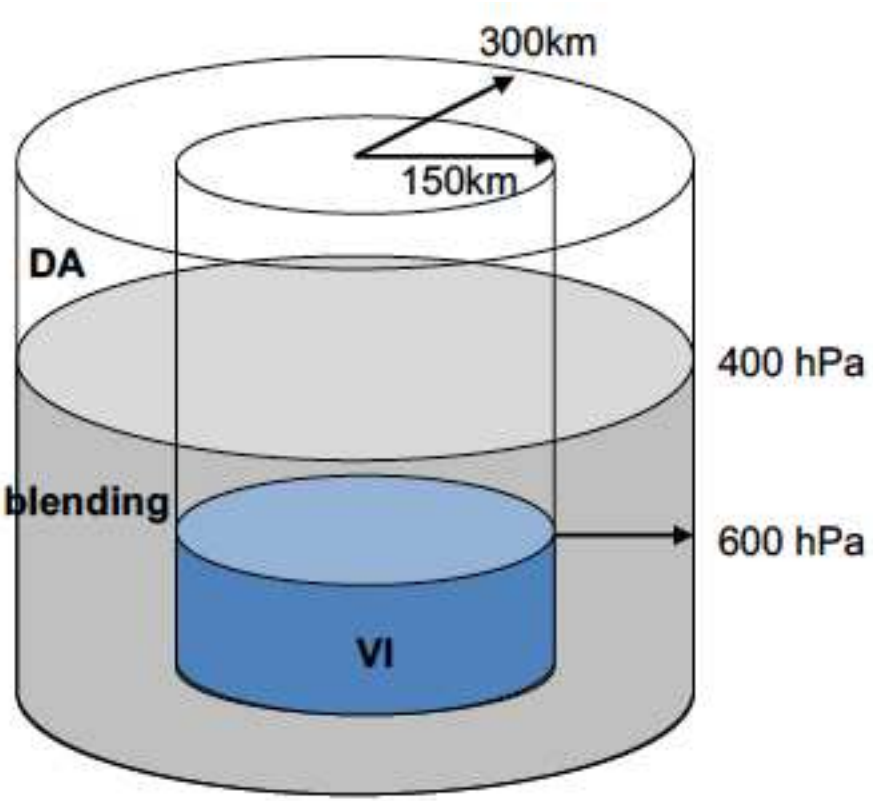


History of improvements: Using TC Observations

CURRENT OBSERVATIONS ASSIMILATED BY HWRF INCLUDE:

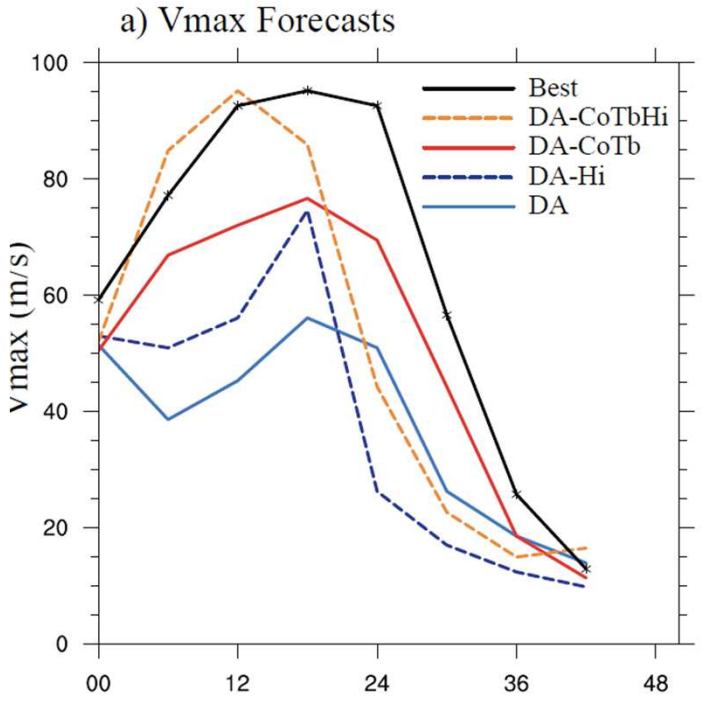
- Conventional observations (radiosondes, dropwindsondes, aircraft reports, ship and buoy obs, surface observations over land, pibal winds, wind profilers, VAD wind, WindSat scatterometer wins, PW derived from GPS)
- NOAA P3 aircraft Tail Doppler Radar
- Flight-level data from reconnaissance
- IR/VIS cloud drift winds and water vapor winds from GOES, EUMETSAT, MODIS, JMA
- Clear-sky satellite radiance observations including data from HIRS, AIRS, IASI, GOES Sounders, CrIS, SSMIS, Metop-B, AMSU-A, MHS and IASI

History of improvements: Battling spindown



- Vortex initialization (VI) procedure in HWRF produces less spindown than does DA
- Blending zero's DA increments near center for Vmax > 64 kt
- Not a long-term solution

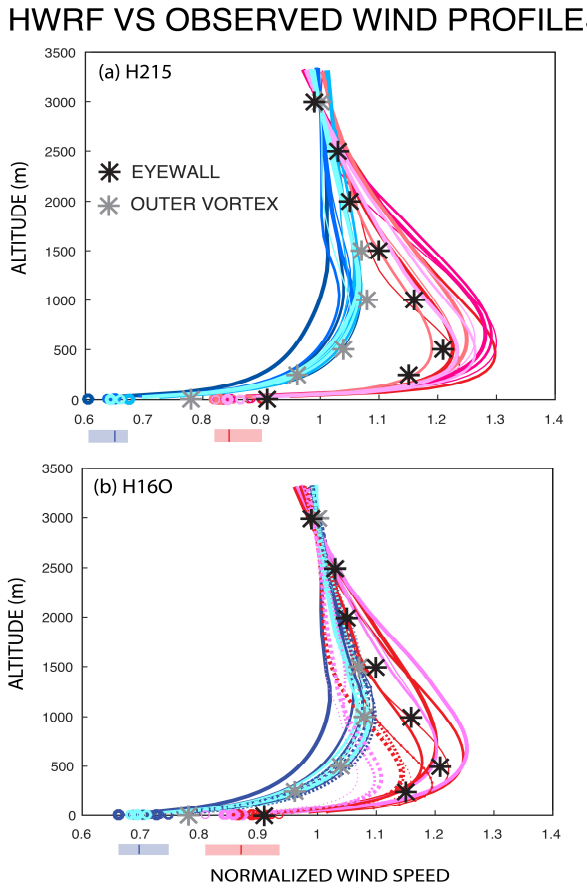
History of improvements: Battling spindown



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

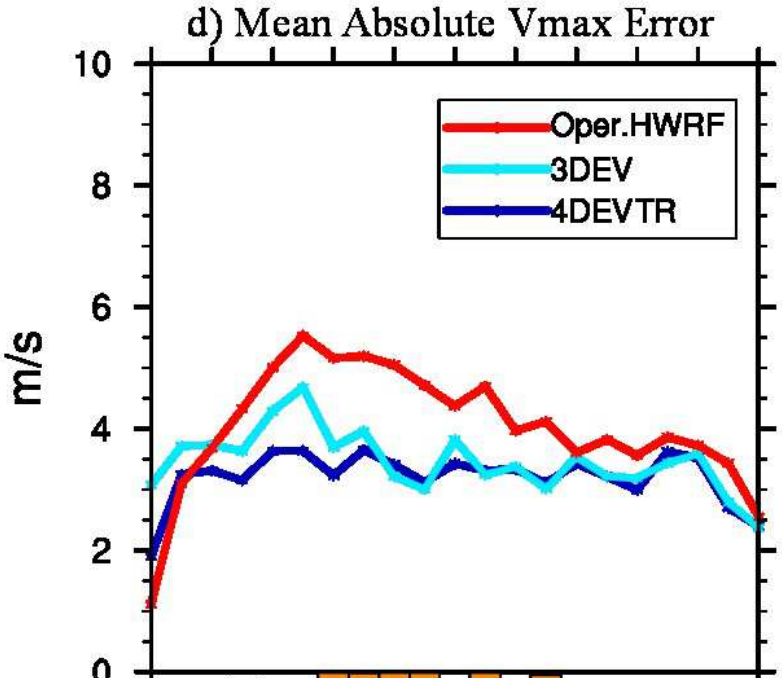
History of improvements: Battling spindown



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

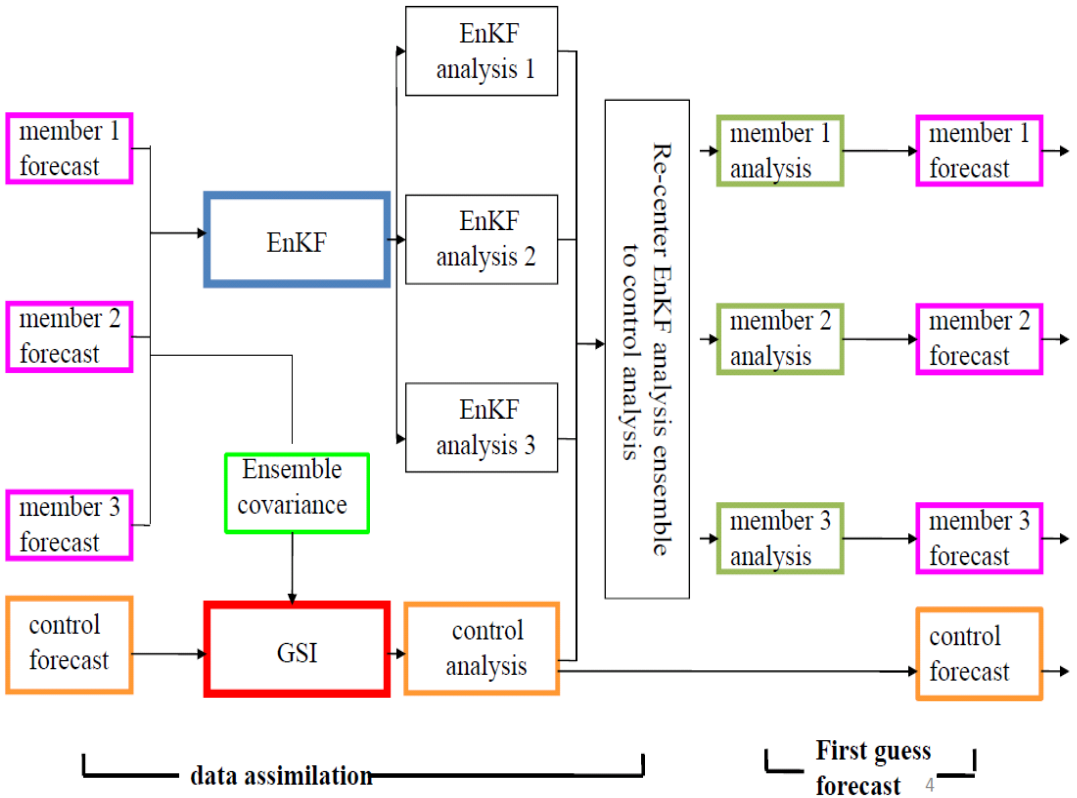


Vmax errors for Hurricane Edouard in the operational HWRF vs the experimental OU HWRF system with fully-cycled covariance.

- 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

Hybrid EnKF-GSI DA system: 2 way coupling



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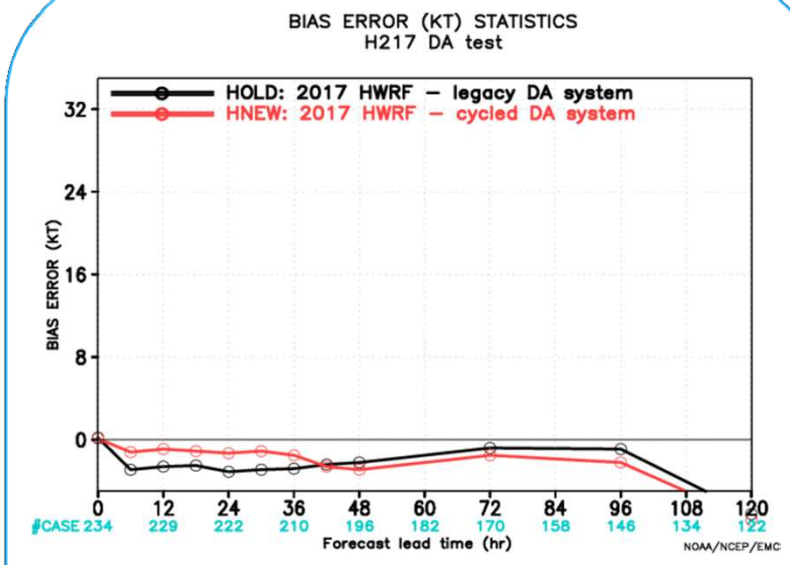

Intensity bias from the old and new HWRD data assimilation systems

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

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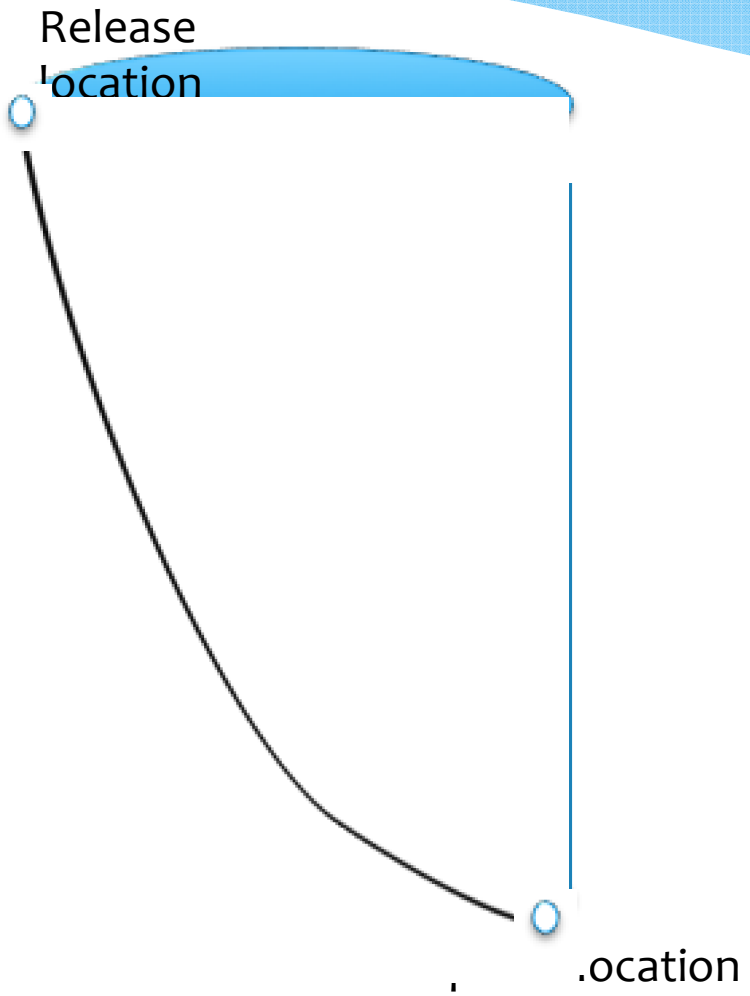
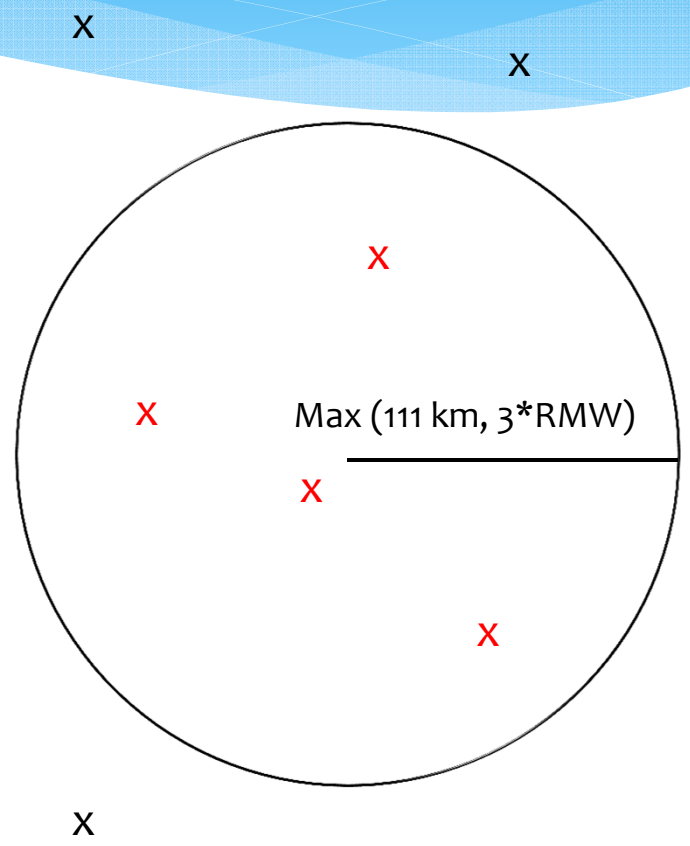
Ongoing developments: Using more observations



- Dropsonde observations currently transmitted in TEMPDROP format
- Only report release location in main body
- NCEP does not consider drift, which causes problems in the vortex

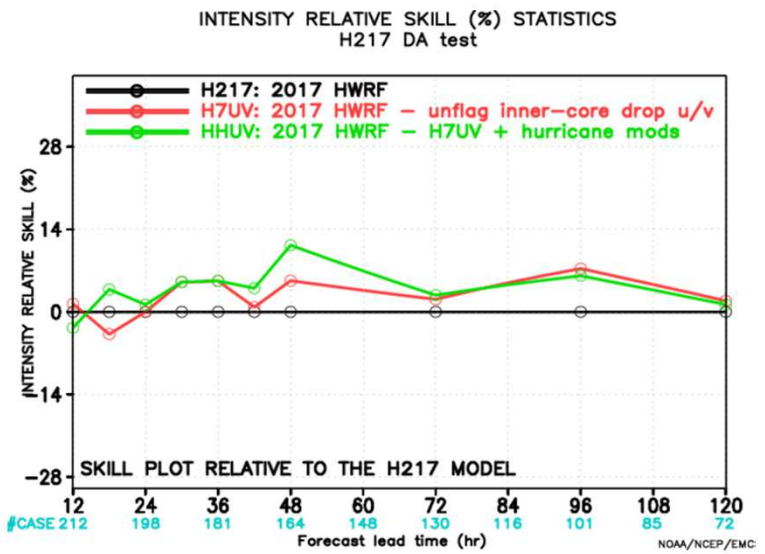
Ongoing developments: Using more observations

- U/V rejected in vortex due to concerns regarding drift
- Current rejection radius is max(111 km, 3*RMW)
- This gets rid of a lot of data (too much?)



Ongoing developments: Using more observations

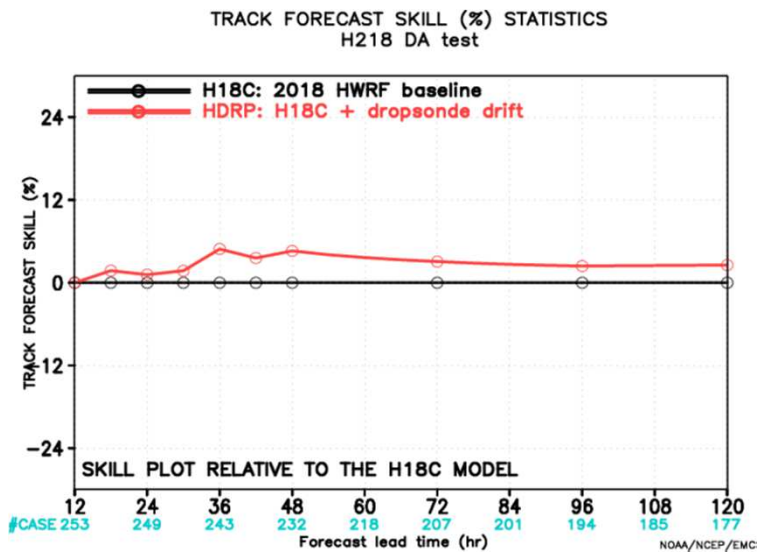
- Drift probably not an issue in all cases
- Unflagging u/v outside of R64 increases intensity skill by 5-10% (neutral track)
- Suggests we should be dropping far more in vortex



Change in intensity skill due to assimilating more dropsonde winds in the TC vortex

Ongoing developments: Using more observations

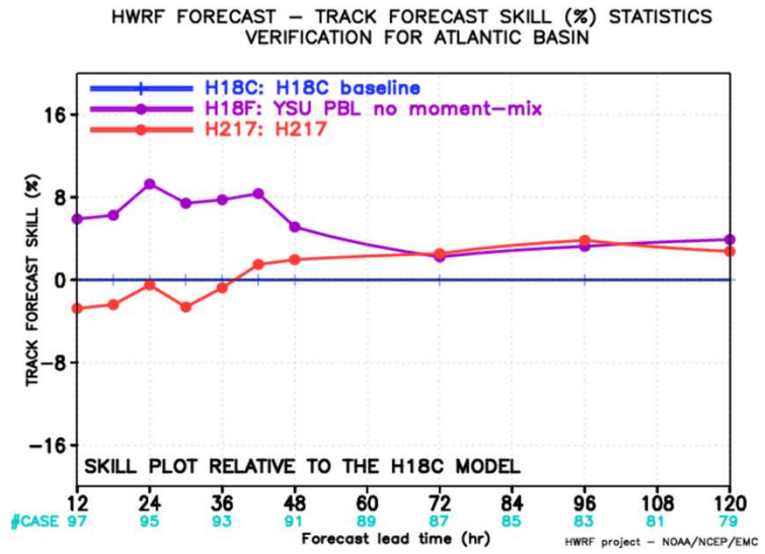
- Code has been developed to estimate dropsonde location
- Ongoing test uses all dropsonde observations with estimated location
- Track improves up to 5%, intensity neutral (different sample)



Change in track skill due to considering dropsonde drift and using all data

Ongoing developments: Physics tests

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



Change in track skill due to using YSU PBL

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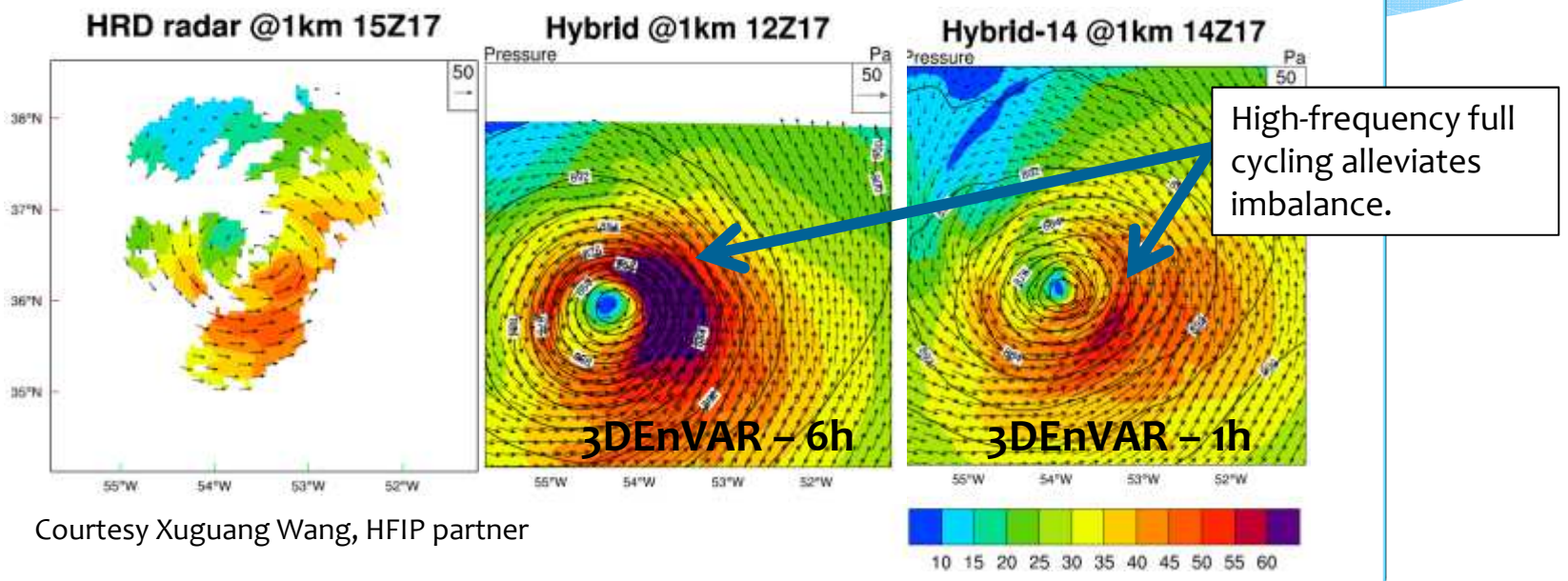
Future direction: DA

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.

Future direction: DA

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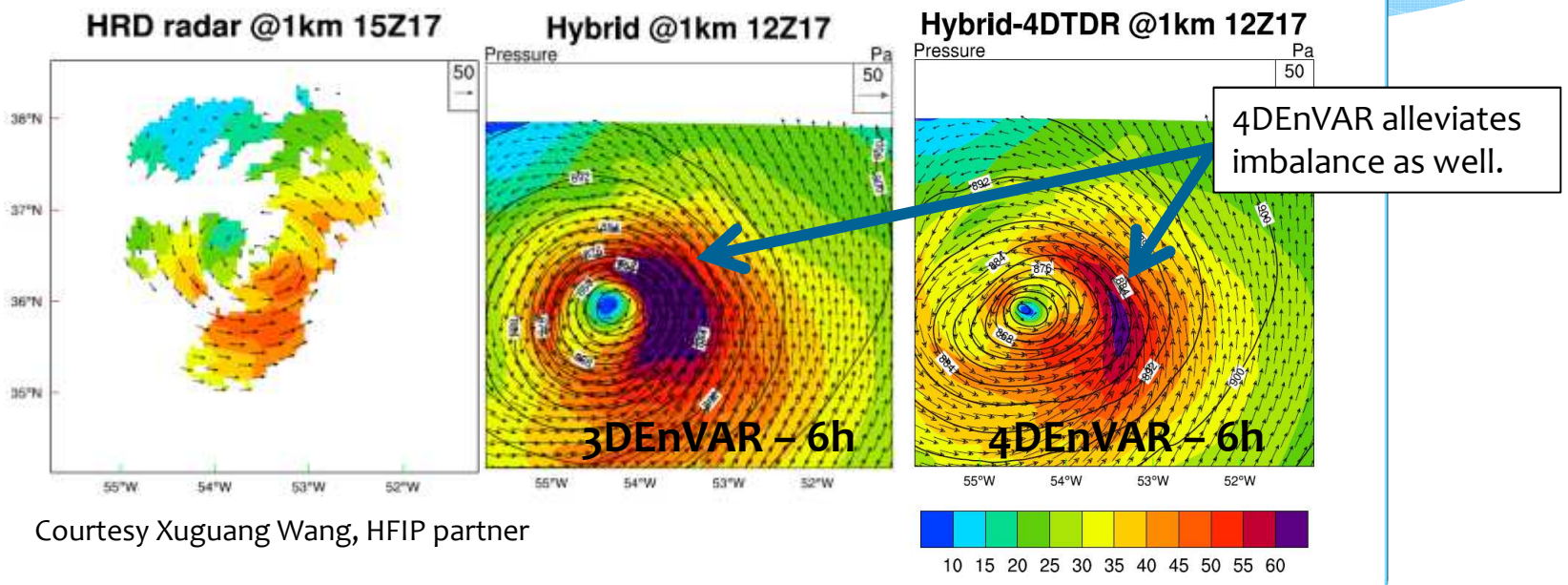

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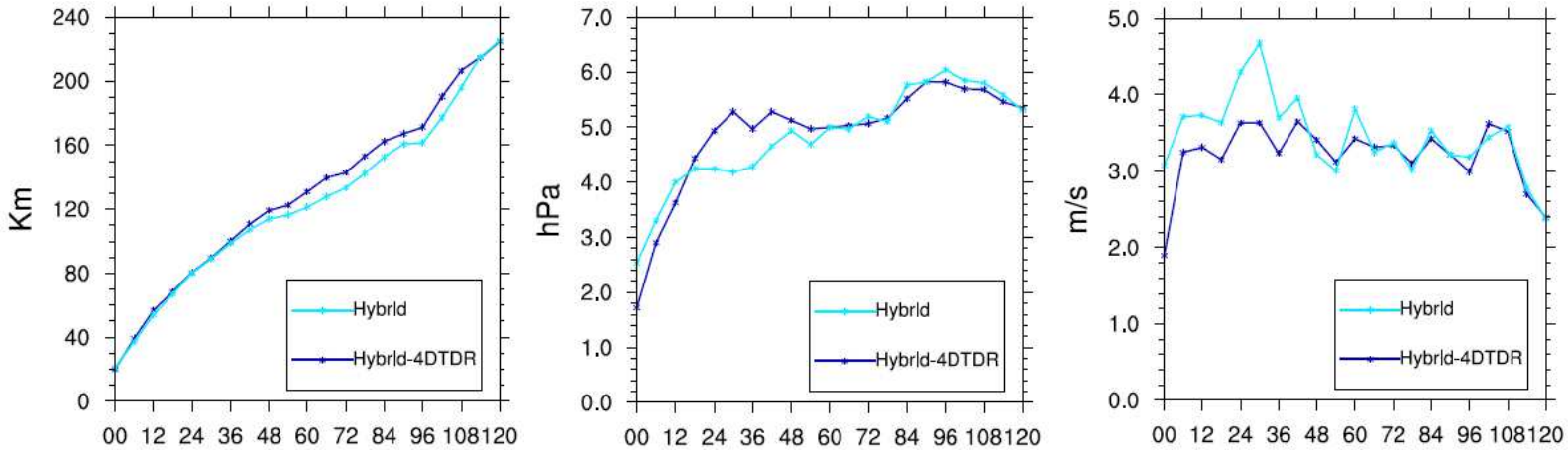


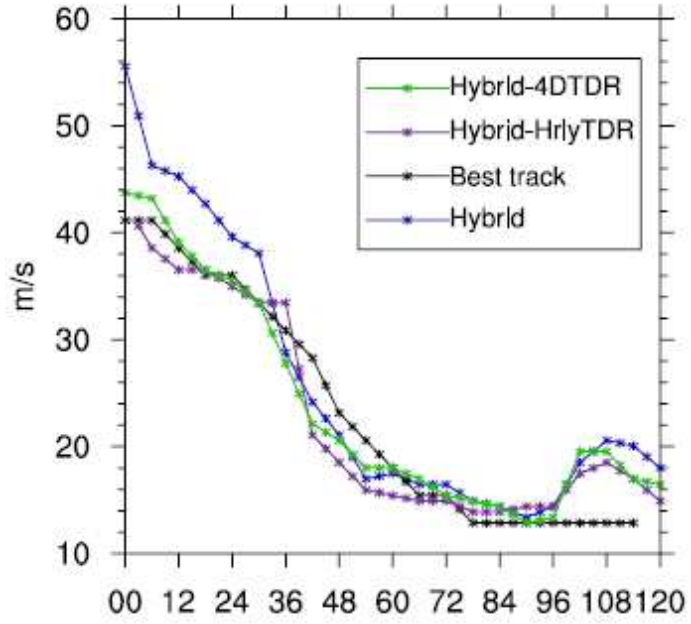
Track, SLP, and Vmax errors from Edouard in the OU hybrid 3DVar and 4DVar systems

Courtesy Xuguang Wang, HFIP partner

On average, forecasts initialized from 4DEnVAR have lower Vmax error for first 36h

Future direction: DA

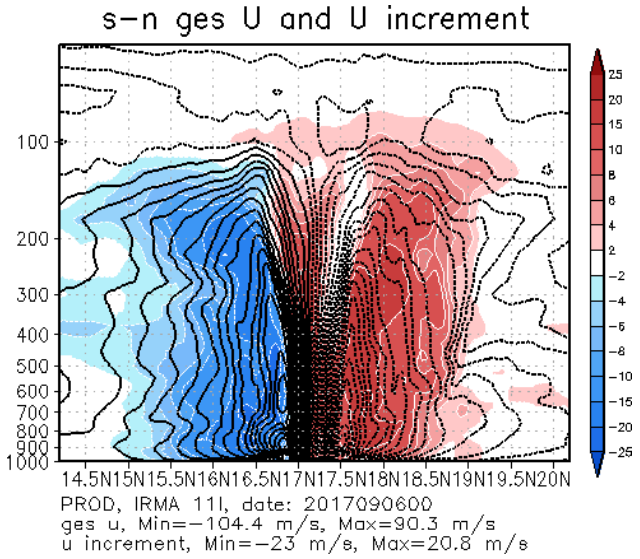
- Results from OU system show hourly cycling helps with inner core balance
- Current priority is to develop/test this for operational HWRF
- This should appeal to researchers as well



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

Future direction: Other DA issues

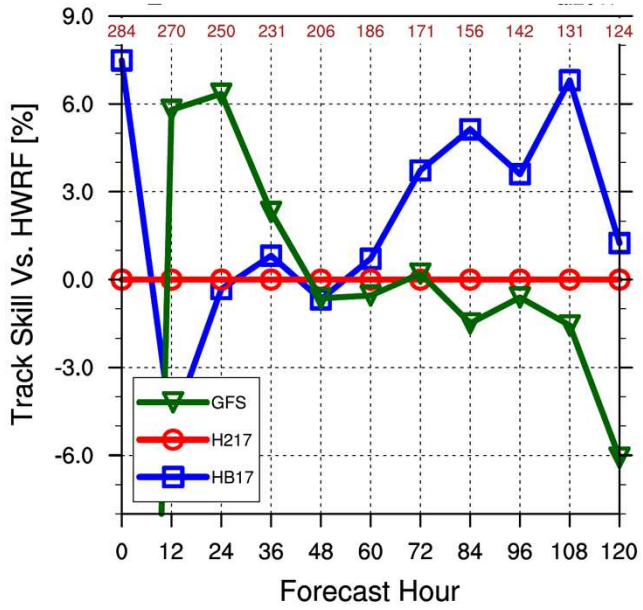
- Replace vortex initialization with self-consistent DA of something derived from TCVitals
- Update condensate (and w?) with each cycle
- Assimilation of cloudy radiances
- Coupled atmosphere-ocean DA



Vertical cross-section of U analysis increments (filled) and U wind (contoured) in a cycle of Irma. Note strong anticyclonic increments.

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