

Tropical Cyclone Modeling and Data Assimilation



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2022 WMO Workshop at NHC

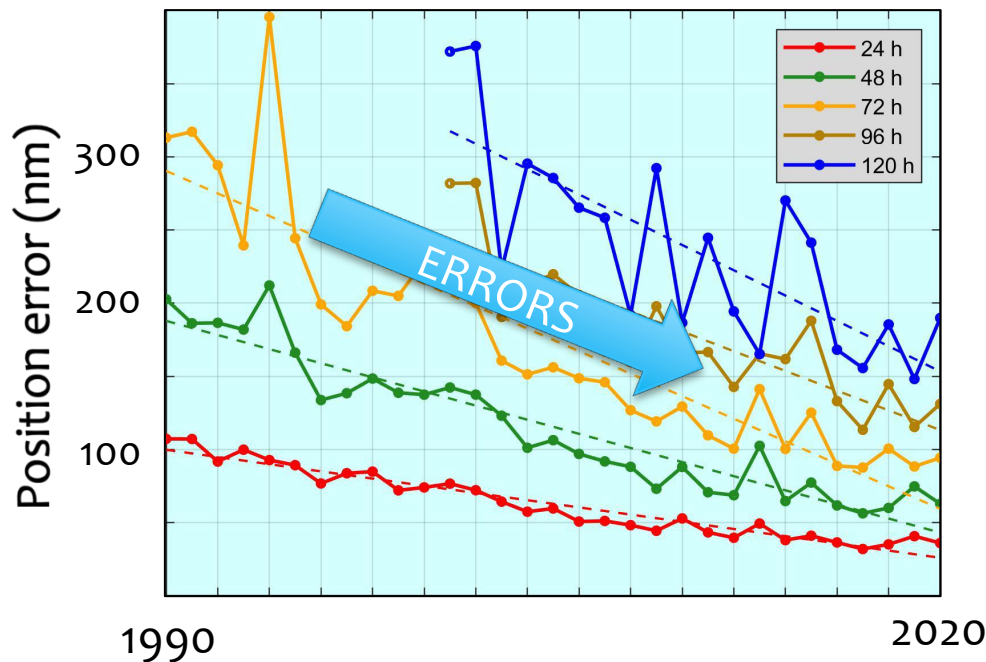


Outline

- History of TC forecast improvements in relation to model development
- Future direction: A new path forward

History: Error trends

**Official TC Track Forecast Errors:
1990-2020**



- 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

History: Error trends



NCEP Operational Forecast Skill 36 and 72 Hour Forecasts @ 500 MB over North America [100 * (1-S1/70) Method]



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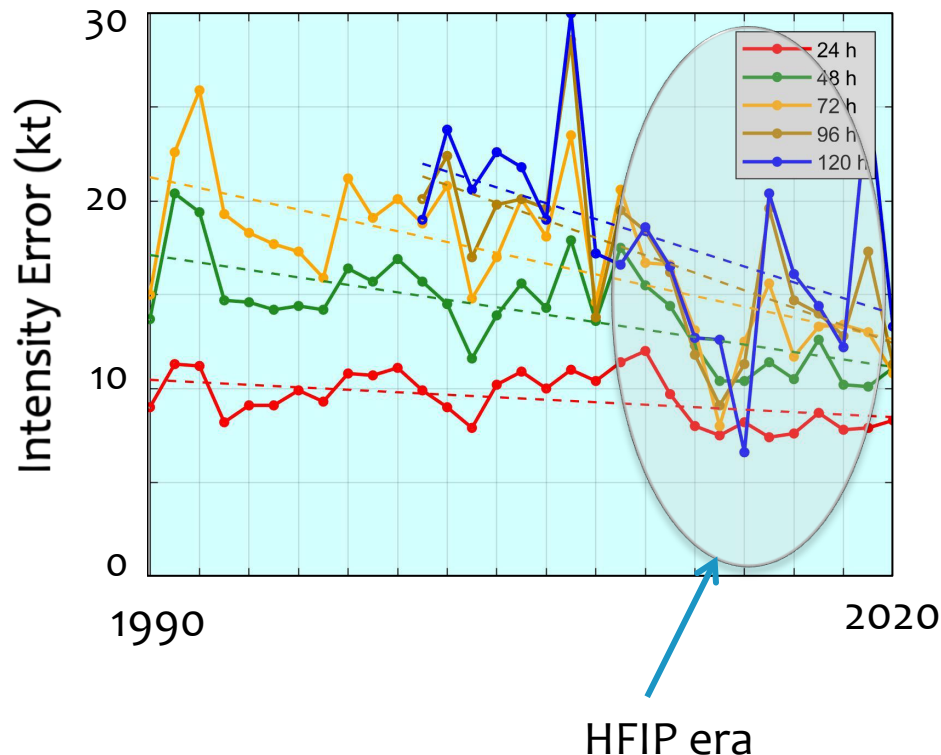
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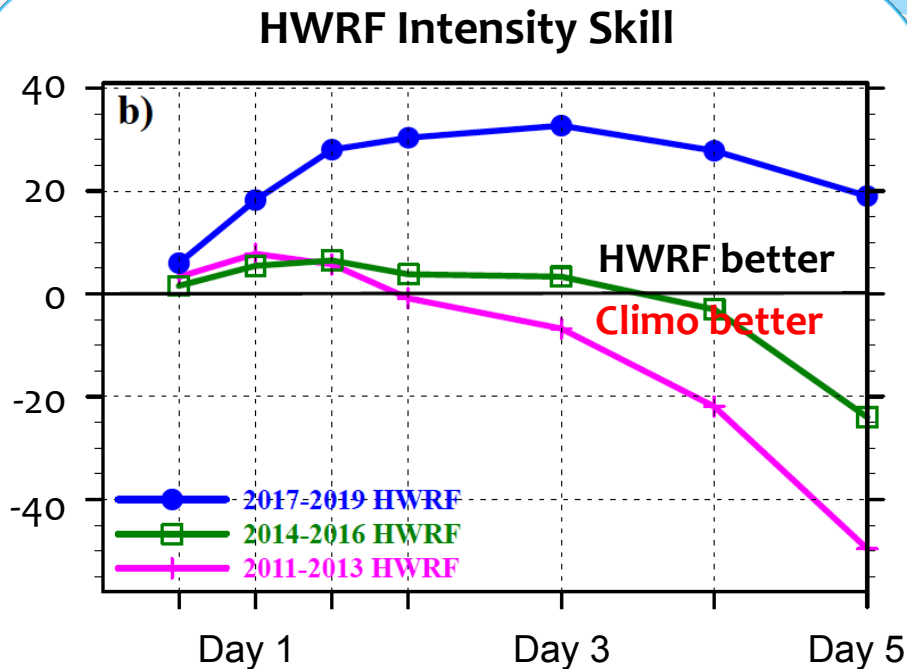
History: Error trends

**Official TC Intensity Forecast
Errors: 1990-2020**



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

History: Error trends



HWRF skill has improved up to 60%!

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

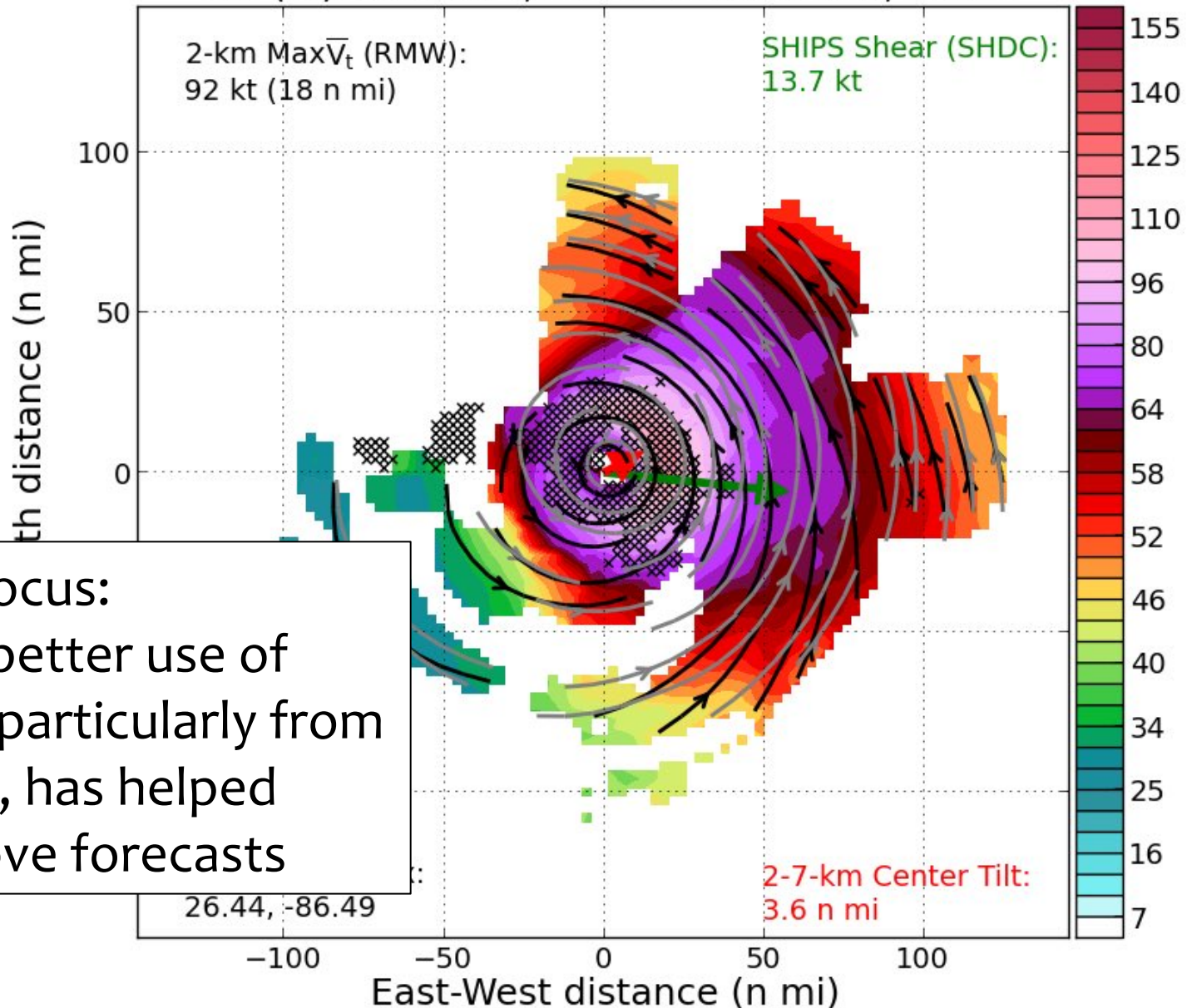
Michael

Talk focus:
How better use of
data, particularly from
recon, has helped
improve forecasts



181009H2 (MICHAEL)
210150 to 244130 UTC

WS (kt) at 2.0 km; Streamlines at 2.0, 5.0 km

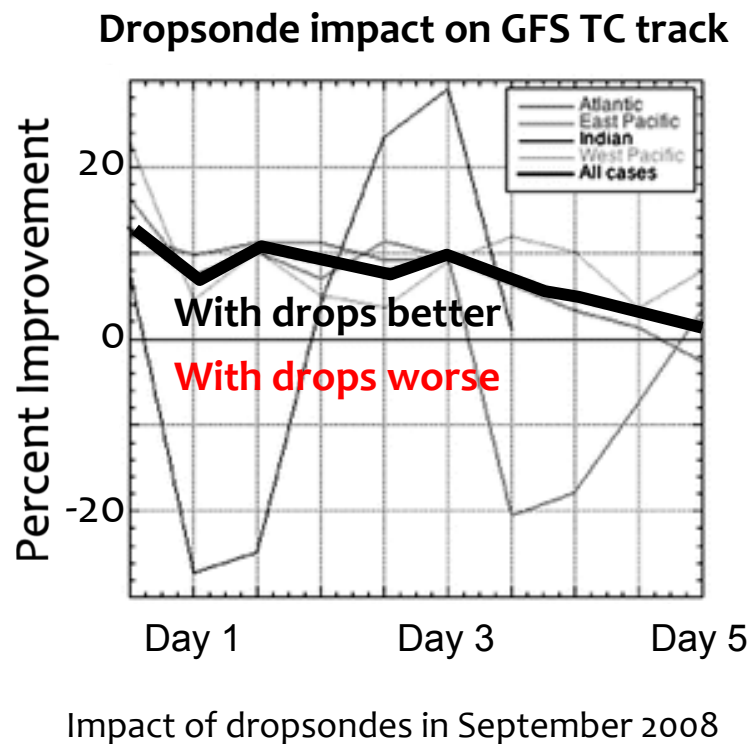


Talk focus:
How better use of
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26.44, -86.49

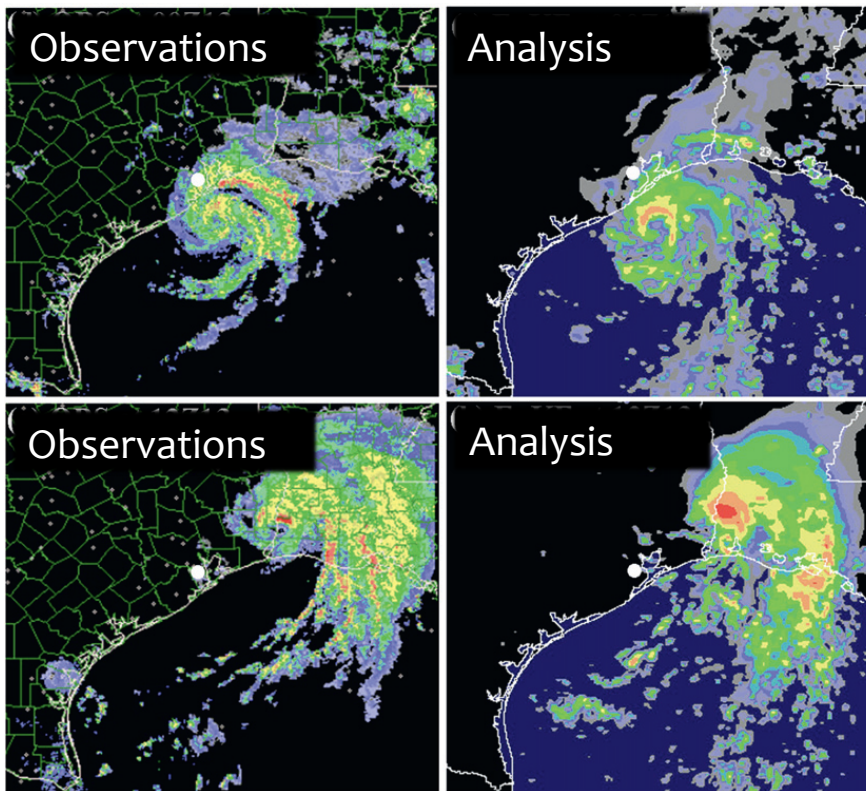
2-7-km Center Tilt:
3.6 n mi

History: Using TC Observations



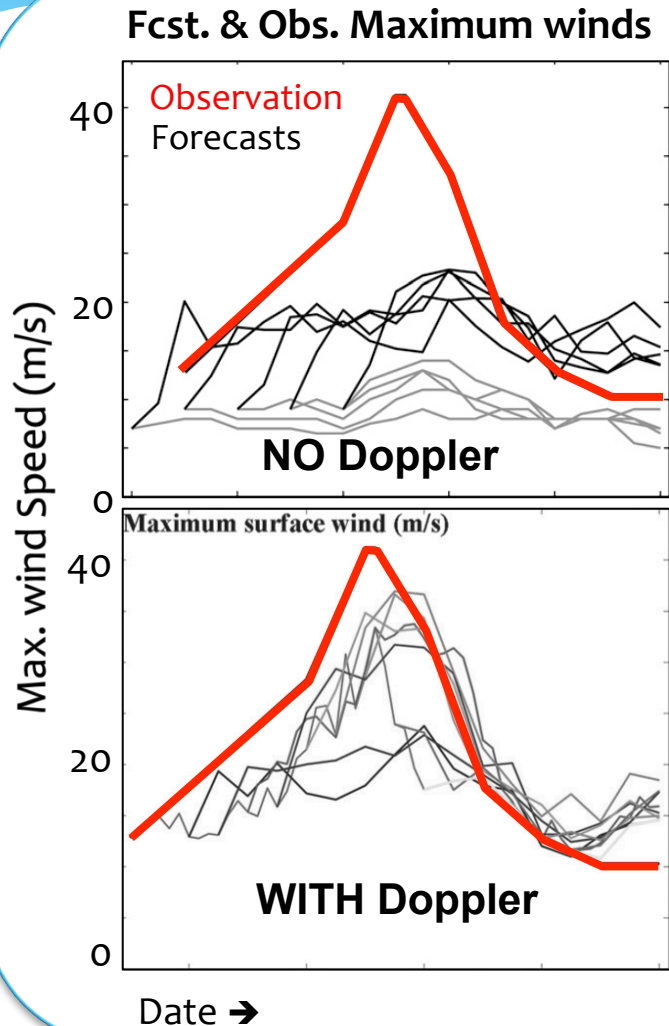
- US has used dropsondes for TC model forecast improvement since 1980
- Significant track improvement globally
- Consistent across many studies

History: Using TC Observations



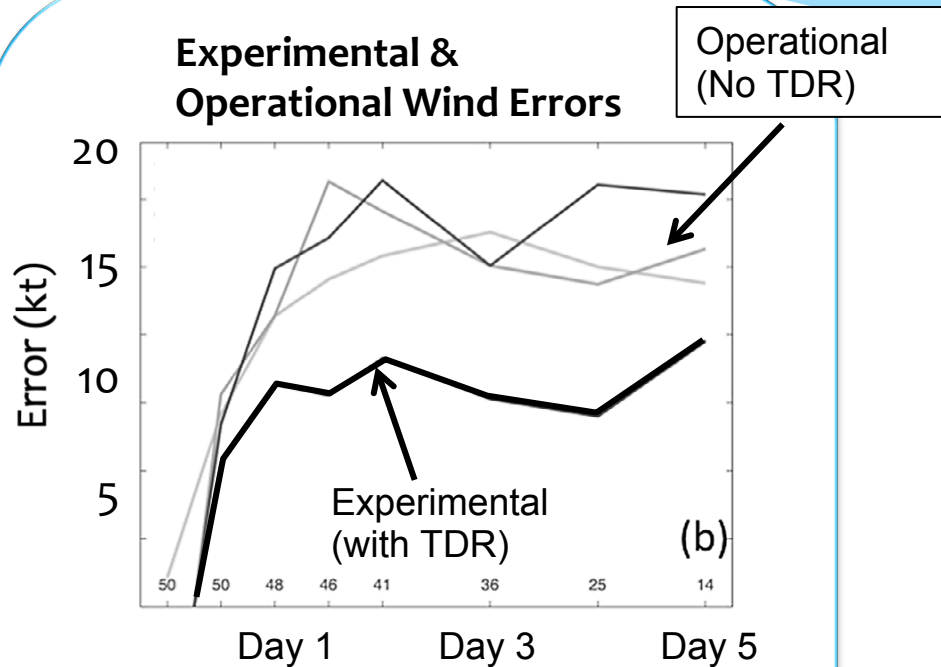
- Starting in 2008, it became apparent that assimilating 88D Doppler velocity could improve coastal TC forecasts
- Assimilating radar data significantly improved analyses and forecasts of Hurricane Humberto

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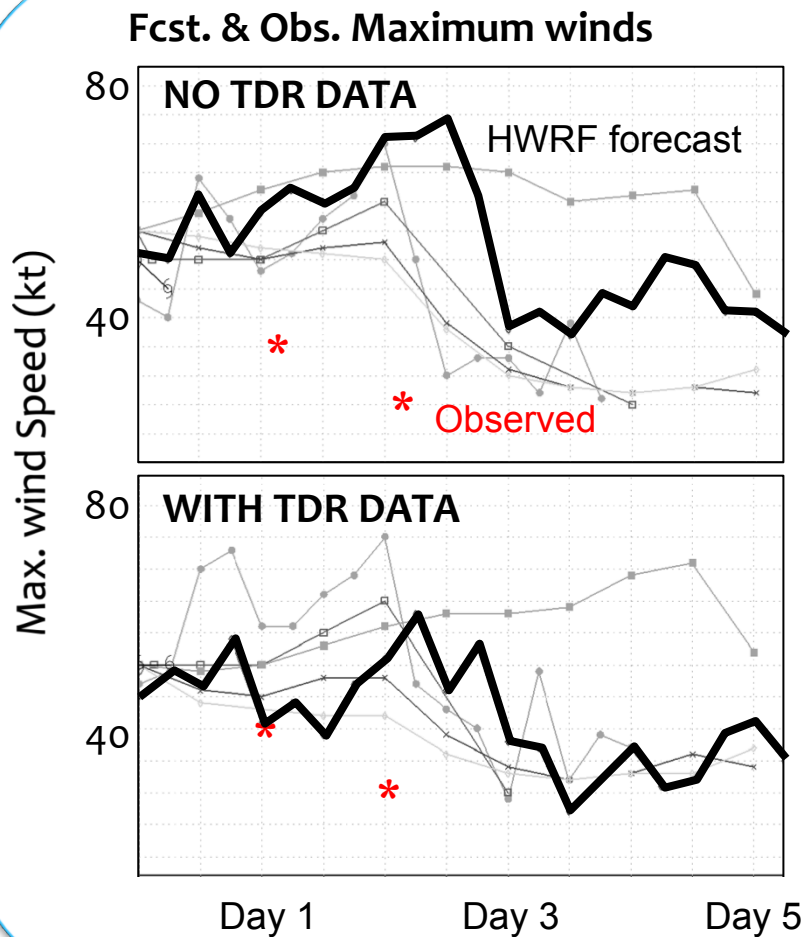
History: Using TC Observations



Maximum wind errors from operational forecasts (no TDR) and an experimental system that assimilated TDR data.

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

History: Using TC Observations

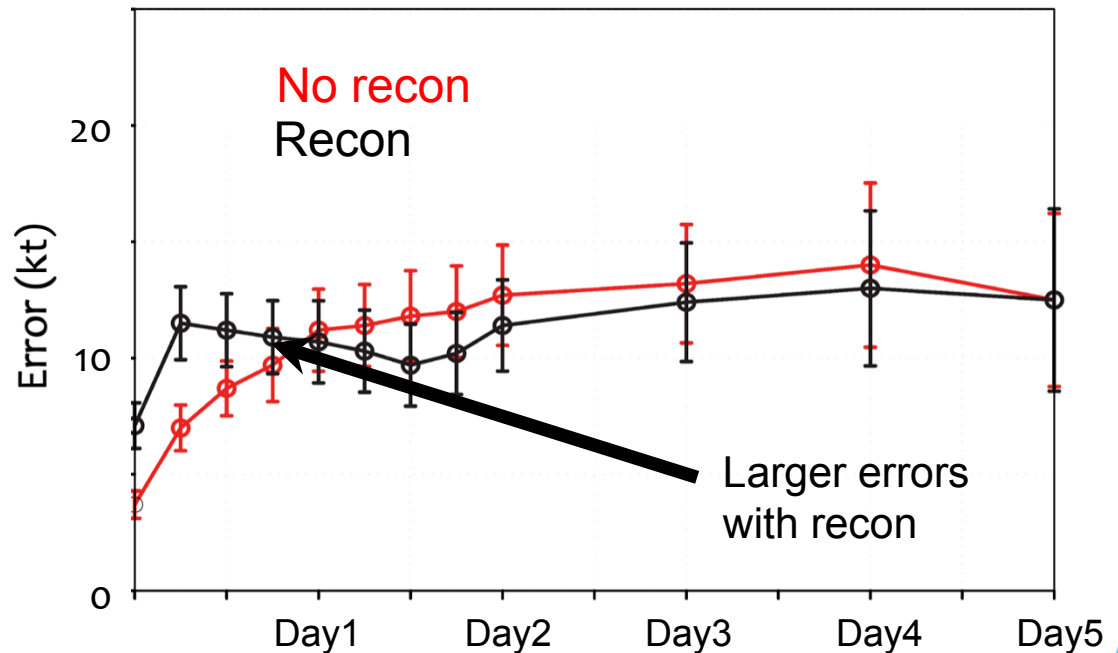


- TDR data began being assimilated in HWRf in 2013
- For weak storms like Karen (left), there was substantial improvement of a positive intensity bias in HWRf

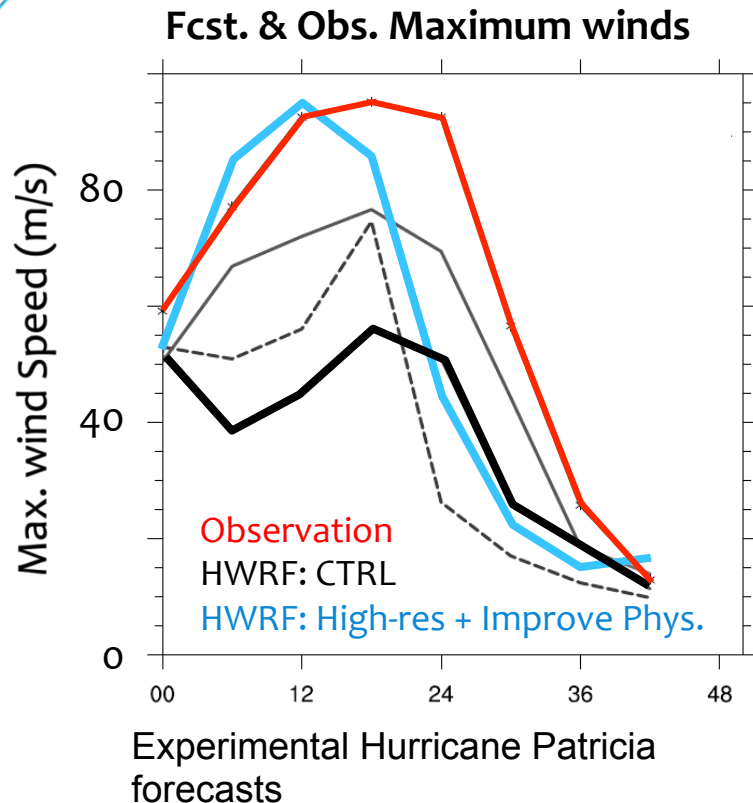
History: Using TC Observations

- Results worse over larger sample
- Major problem was short-term forecast degradation
- Cause was physics and data assimilation deficiencies for strong storms

2013 HWRF recon impact: Intensity



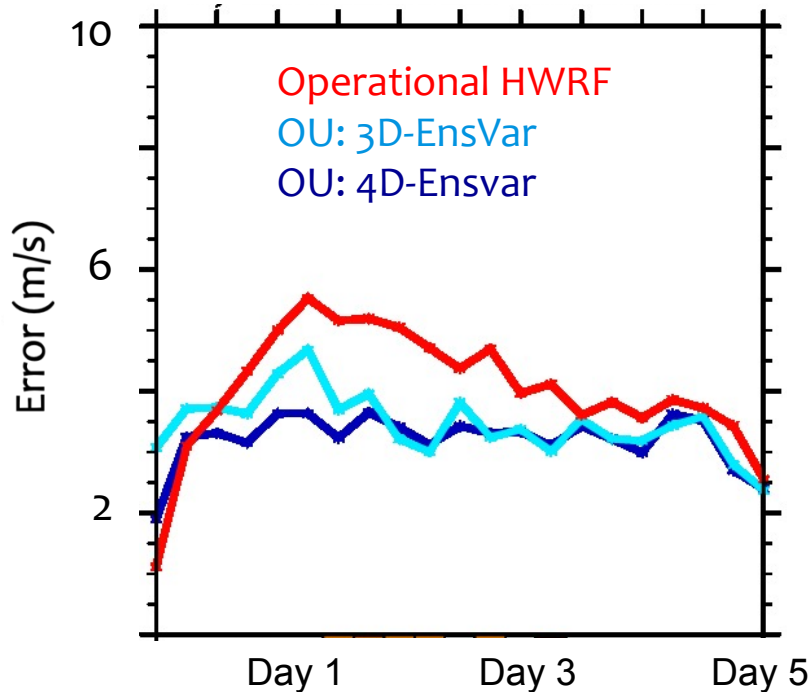
History: HWRF improvements



- Increasing resolution AND improving physics (diffusion/mixing) are necessary
- The challenge is to make physics changes that don't make every TD a Cat 5

History: HWRF improvements

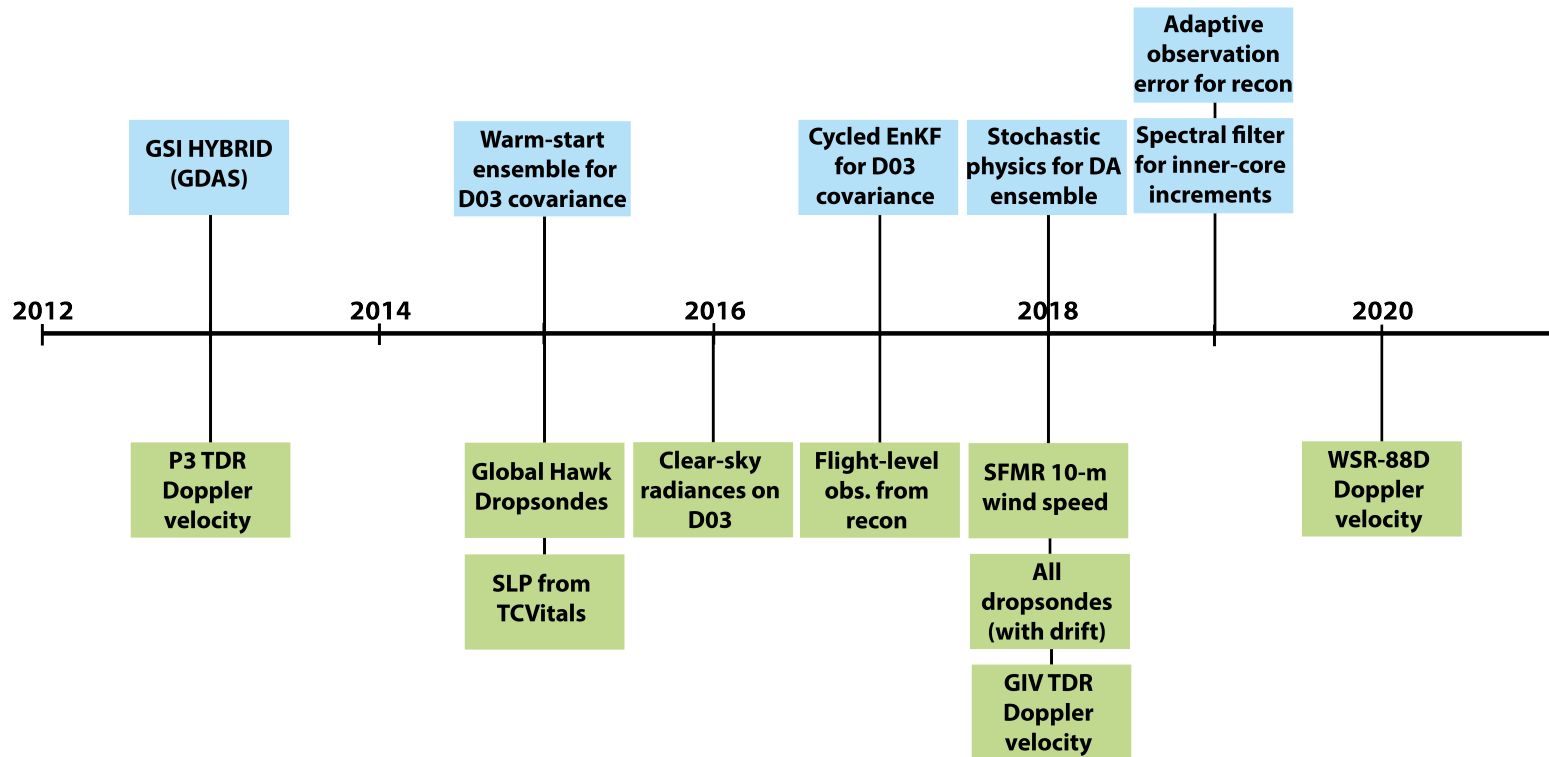
Experimental & Operational Intensity Errors



- Data assimilation (DA) improvements are also necessary
- Experimental University of Oklahoma system with better data assimilation system performs much better

History: HWRF improvements

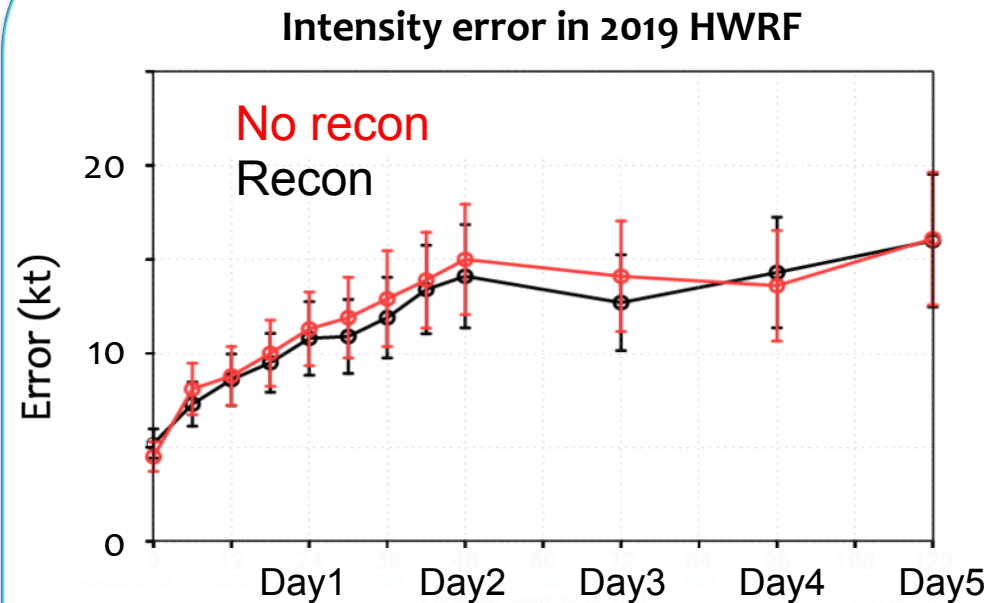
DA INFRASTRUCTURE ADVANCES



DA DATA ADDED

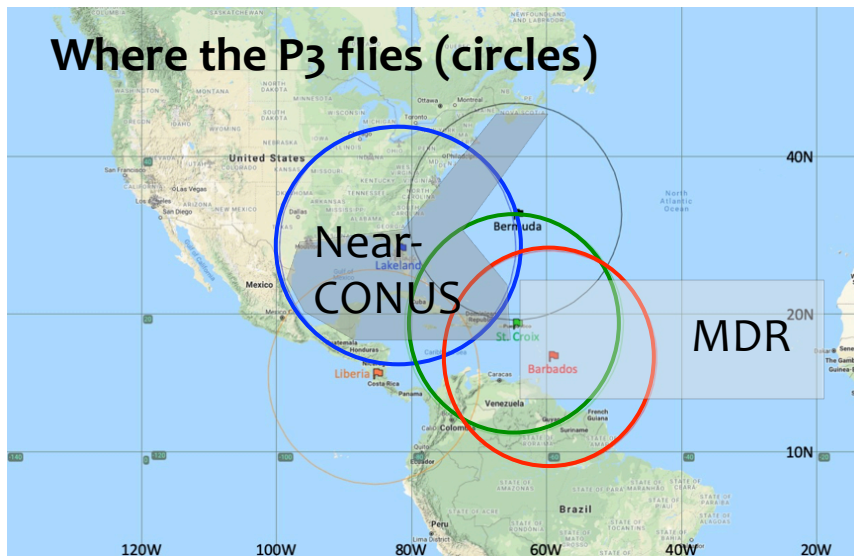
History: HWRF improvements

- Recon benefit assessed in 2016-2018 high impact storms
- Many major hurricanes in this sample
- Recon has a clear positive impact on intensity, 10-15% improvement through 72h

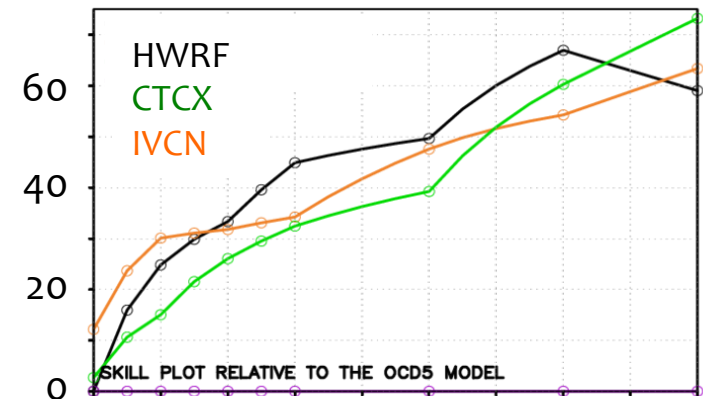


History: Recent Performance

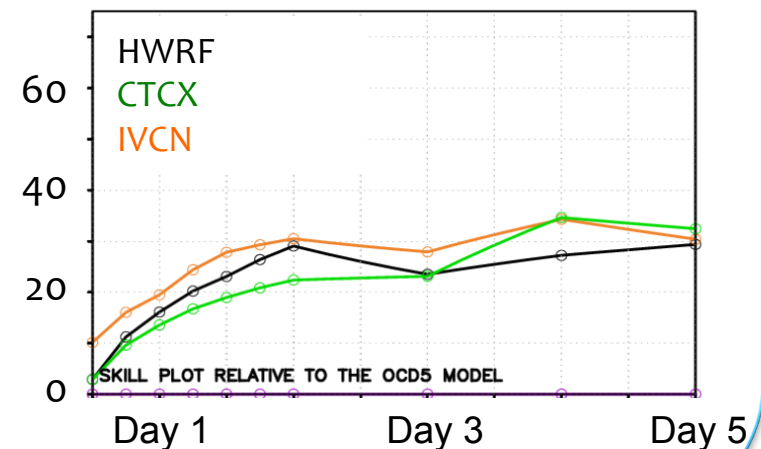
- Model intensity skill varies greatly by region
- Highest skill is where we have the most data (esp. HWRF)



Intensity skill: Near-CONUS



Intensity skill: MDR

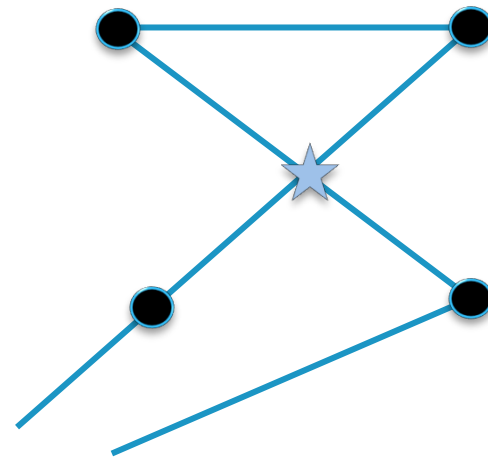


History: Recent Changes

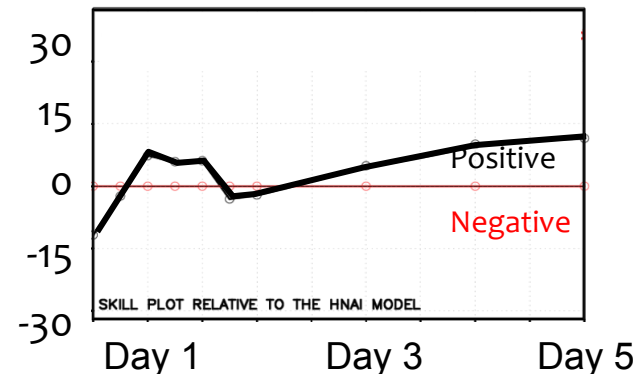
“End-point” dropsondes from USAF C-130 missions

- Dropsondes at end-points of “alpha” pattern from C-130 missions tested in 2017
- Data denial tests suggested a 10% impact on intensity skill
- Based on these results, this practice was implemented operationally in 2018

Example of end-point drop positions



Impact on intensity skill

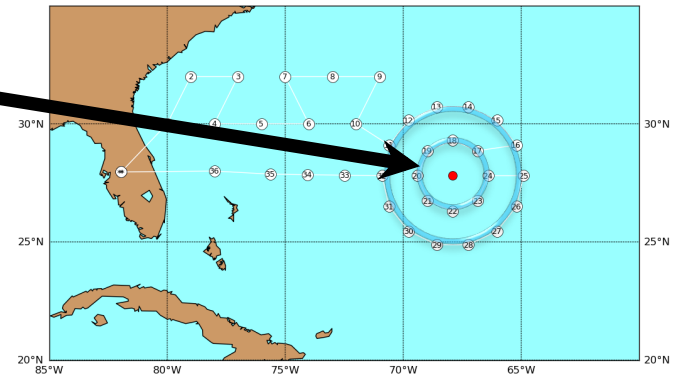


History: Recent Changes

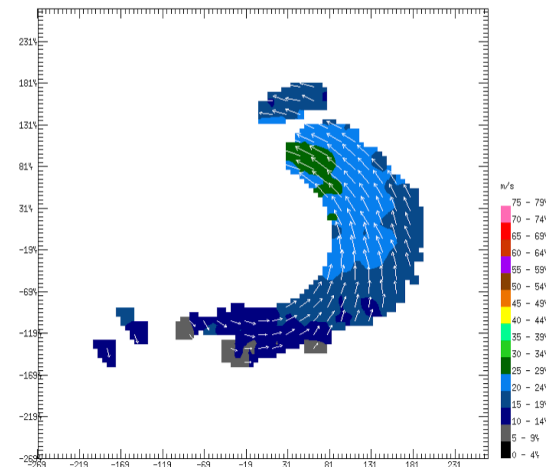
G-IV began two complete circumnavigations at ~90 and 180 nm

- Stronger impact on track than that from distant dropsondes
- Near-vortex data helps intensity/structure
- G-IV Doppler velocity data more extensive closer to the vortex

Planned G-IV flight track and dropsondes for Hurricane Florence



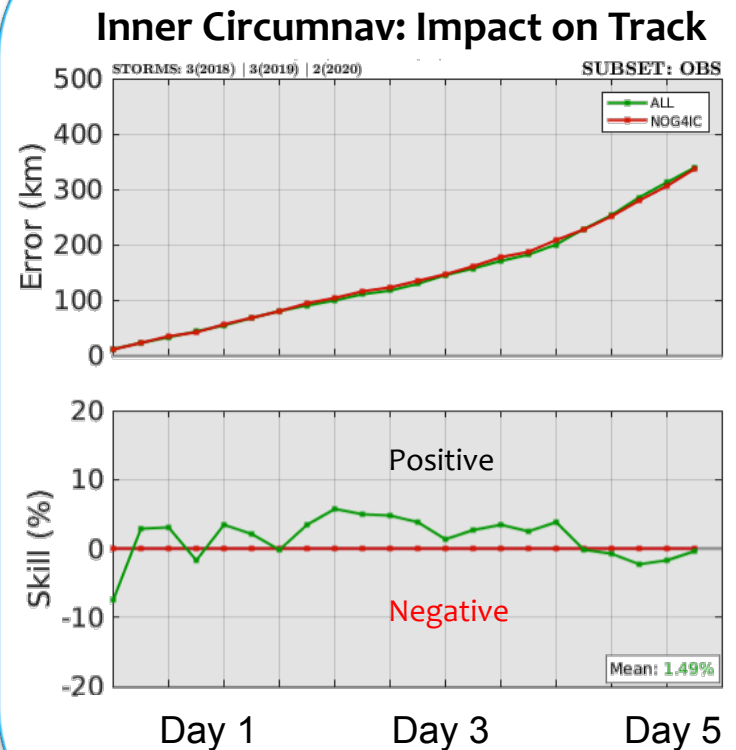
Analysis of horizontal winds from GIV TDR



History: Recent Changes

G-IV began two complete circumnavigations at ~90 and 180 nm

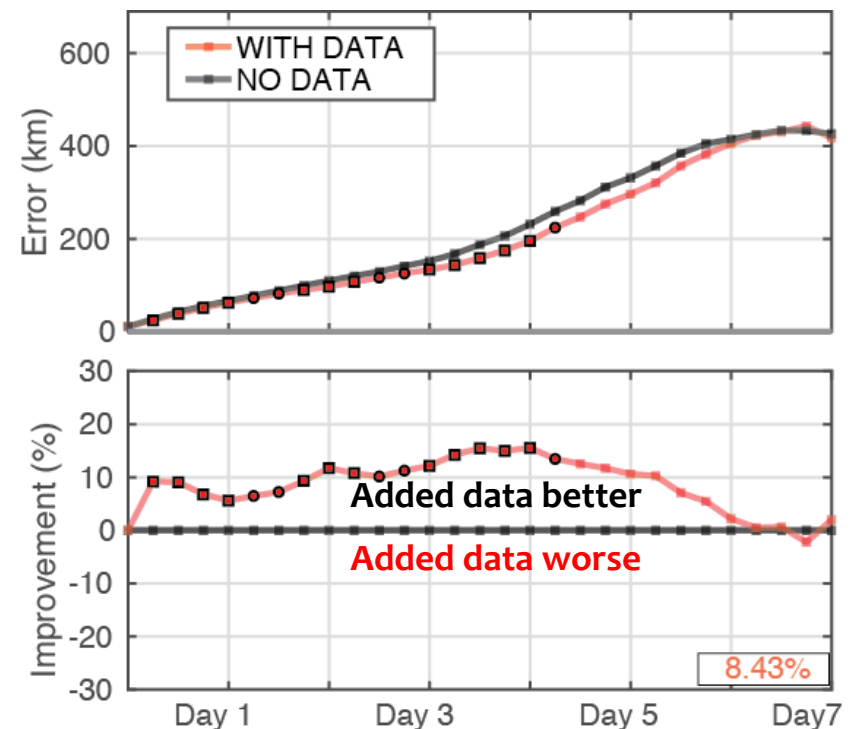
- Impact off inner-circle dropsondes evaluated in basin-scale HWRF
- Mostly positive track impacts from days 1-4 ~5%
- Neutral intensity impacts



History: Recent Changes

- Upgrade to GFSV16 in March 2021 included better use of dropsondes and flight-level data
- Added data improves track in sampled storms up to 15%
- Other stats suggest improvements on D6-7

Additional recon impact on GFS track



Brief summary

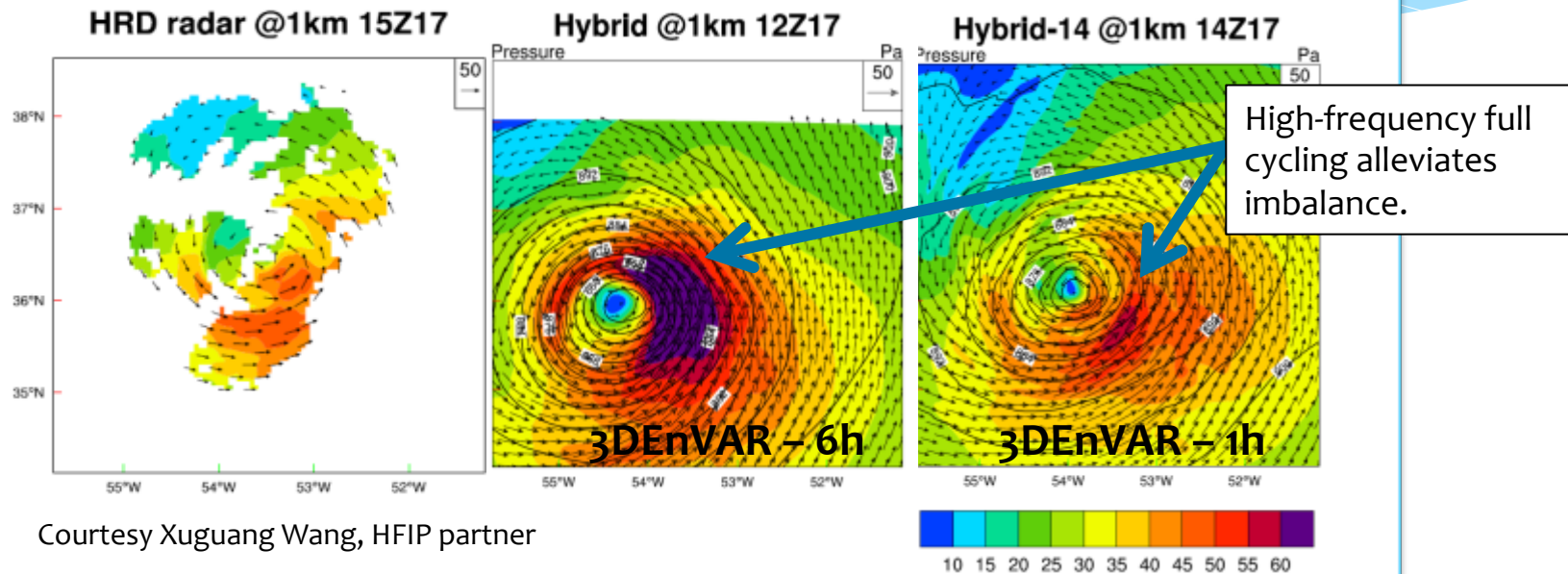
- Track and intensity errors are both improving
- DA & Physics improvements jointly improve model performance
- Significant improvements in HWRF, GFS, and approach to reconnaissance

Outline

- History of TC forecast improvements in relation to model development
- Future direction: A new path forward

Future Direction: Improving DA

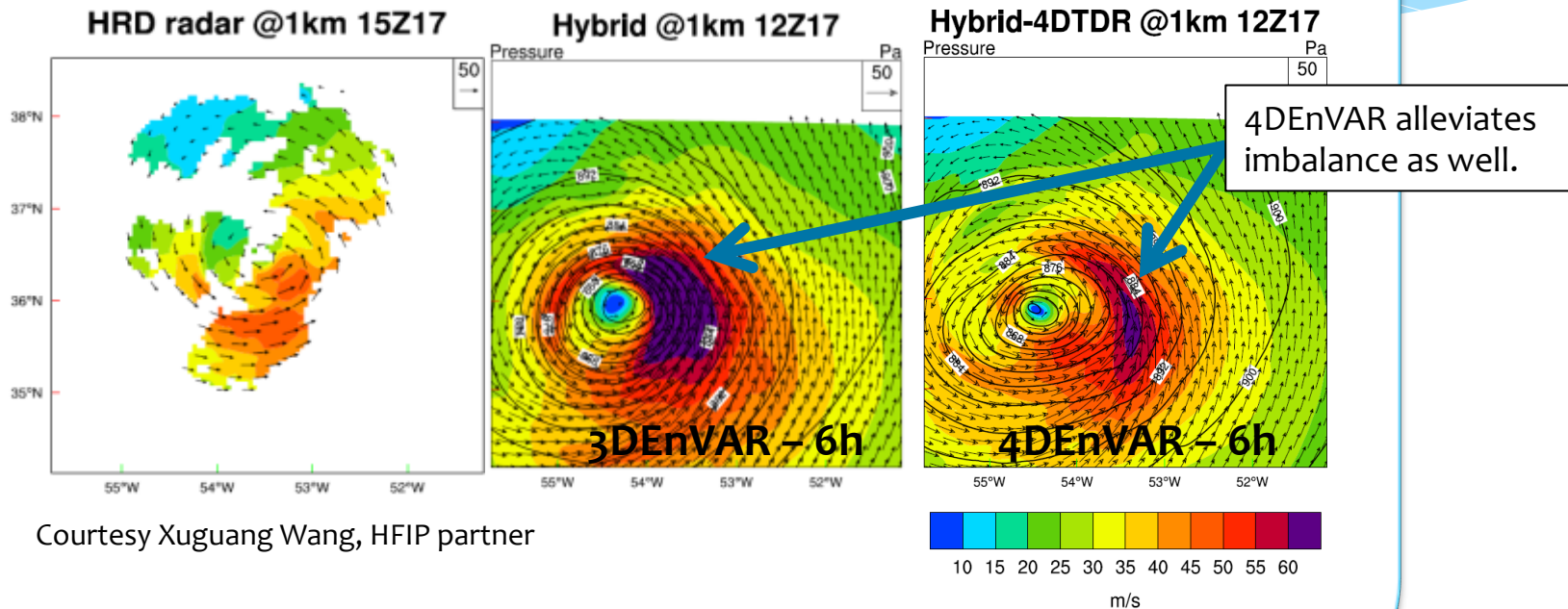
Improving the DA system improves analyses



Courtesy Xuguang Wang, HFIP partner

Future Direction: Improving DA

Improving the DA system improves analyses

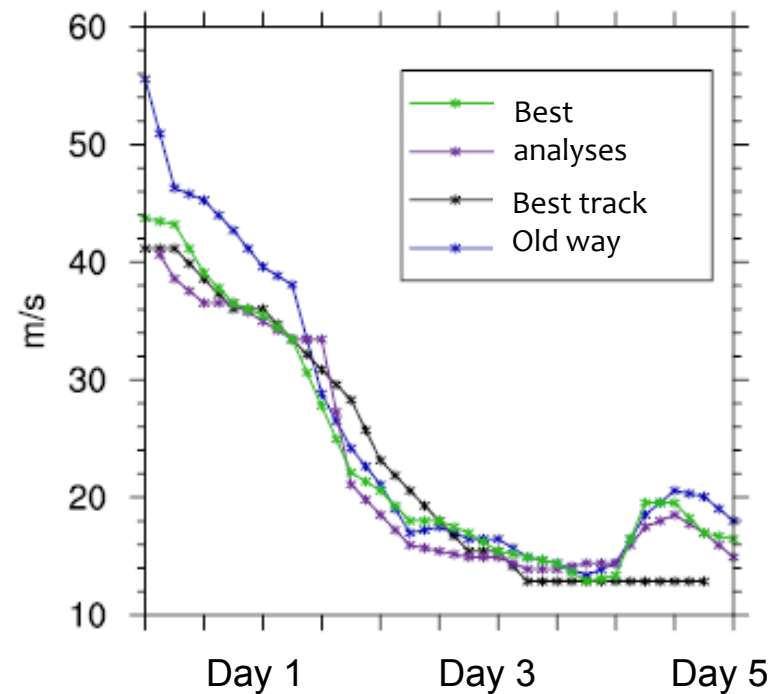


Courtesy Xuguang Wang, HFIP partner

Future Direction: Improving DA

- Intensity forecasts initialized off better analyses (pvs. slides) are better
- These capabilities are being developed for next-generation hurricane model
- This should appeal to researchers as well

Intensity forecasts initialized from various analyses



Future direction: HAFS

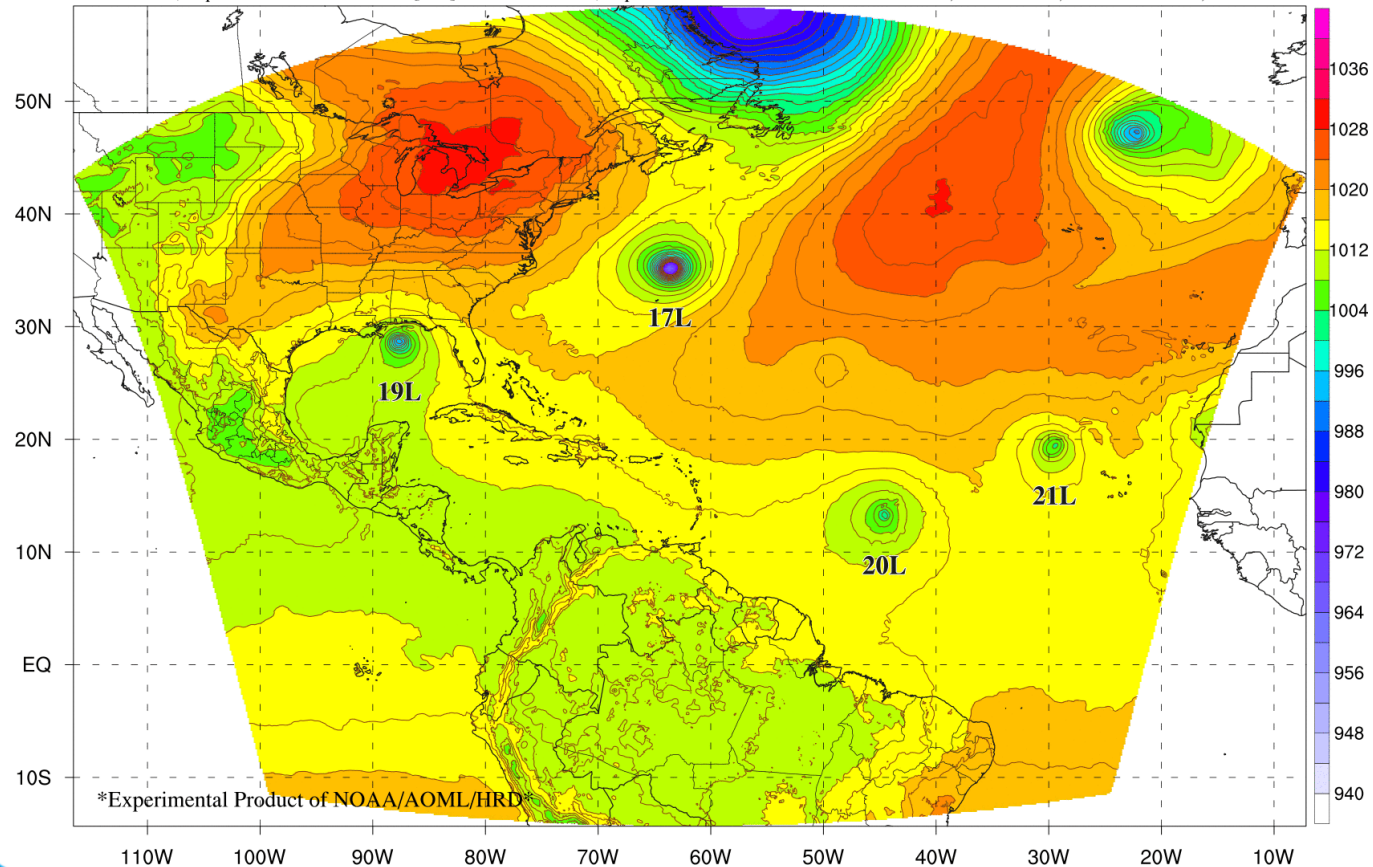
(Hurricane Analysis and Forecast System)

Hurricane Analysis and Forecast System V0.1A

Mean Sea-Level Pressure (mb; shaded, lines)

Init: 00z Tue, Sep 15 2020 Forecast Hour:[000] valid at 00z Tue, Sep 15 2020

VICKY21L, TEDDY20L, PAULETTE17L, SALLY19L



Future direction: HAFS

(Hurricane Analysis and Forecast System)

MAJOR POTENTIAL BENEFITS OF HAFS:

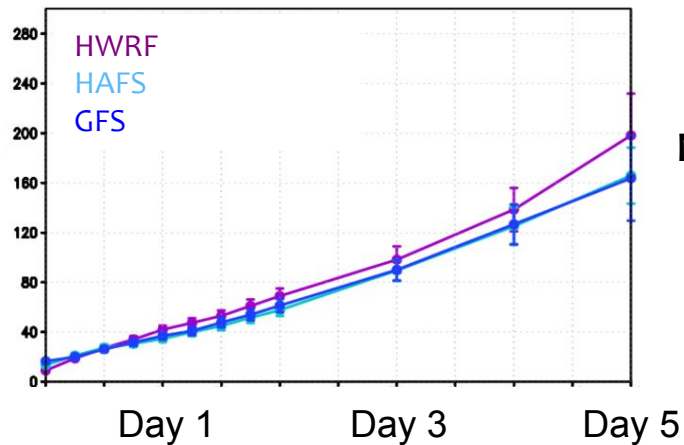
- More flexible / capable data assimilation system than HWRF
- Much better use of satellite data than HWRF
- Realistic storm interaction, not possible in HWRF

RESULT:

- Better initialization of vortex and environment
- Improved track and intensity forecasts

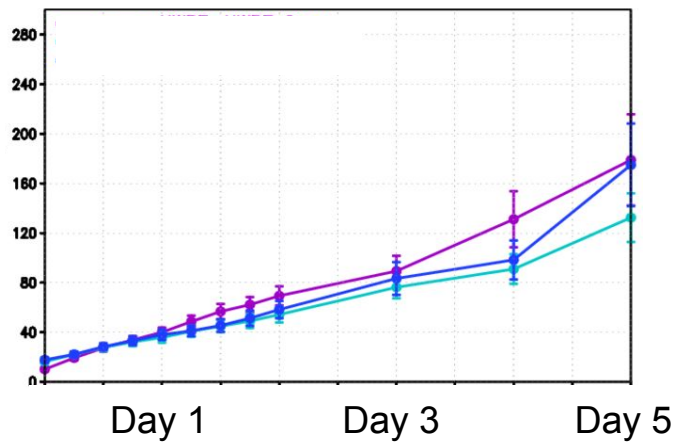
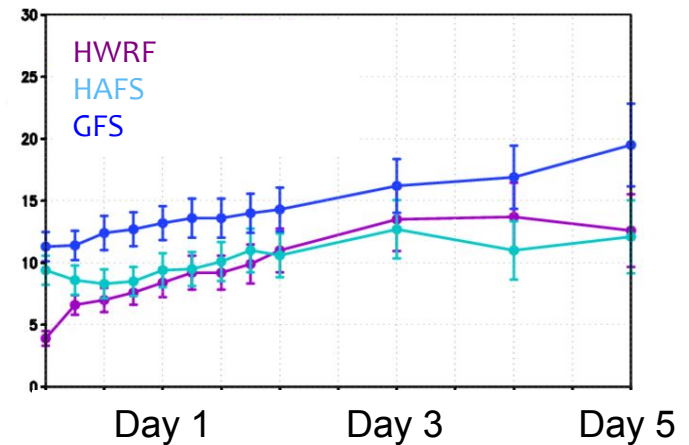
Initial HAFS results

Track Errors

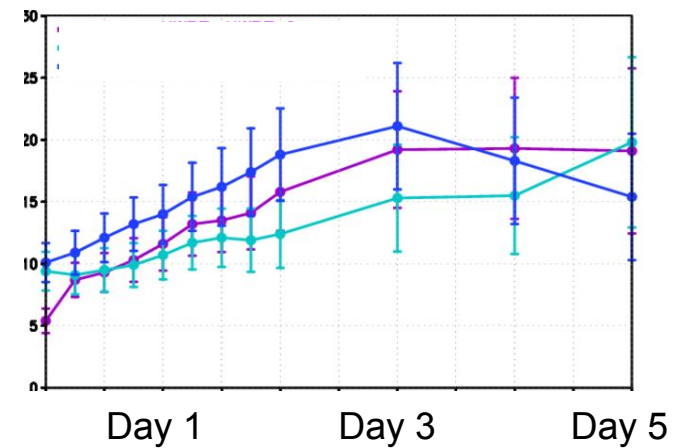


North Atlantic

Intensity Errors



Eastern North Pacific



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 and allow for greater data usage
- The above factors should contribute to intensity improvement in particular