Tropical Cyclone Modeling and Data Assimilation

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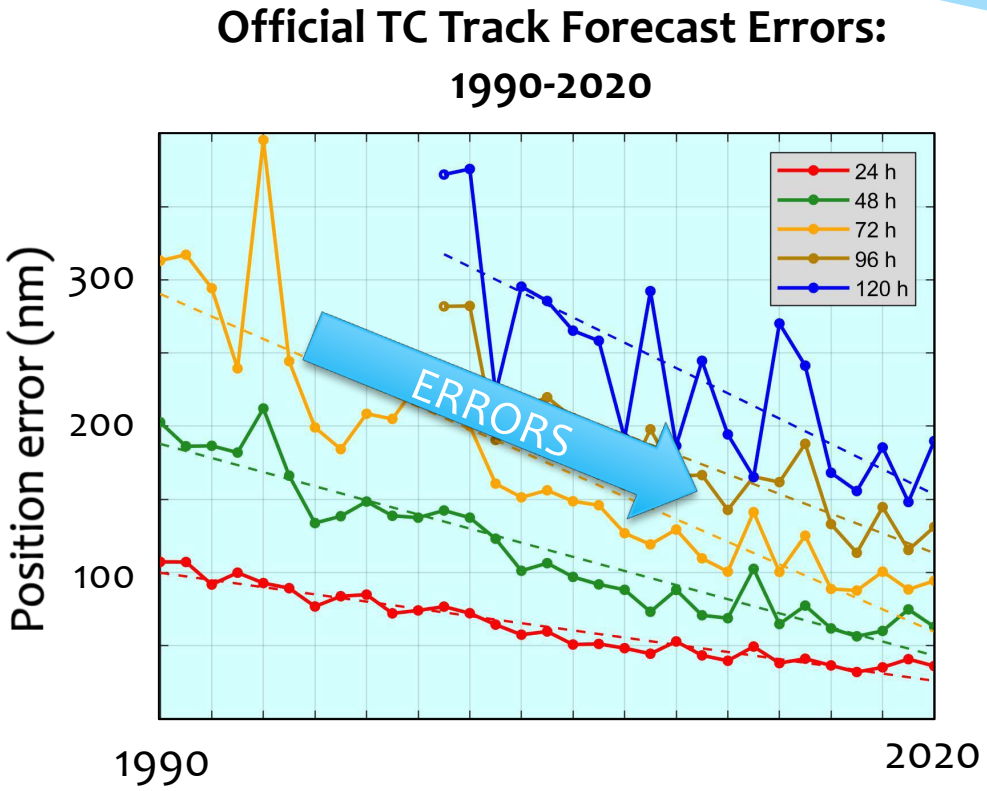
2021 WMO Workshop at NHC

Outline

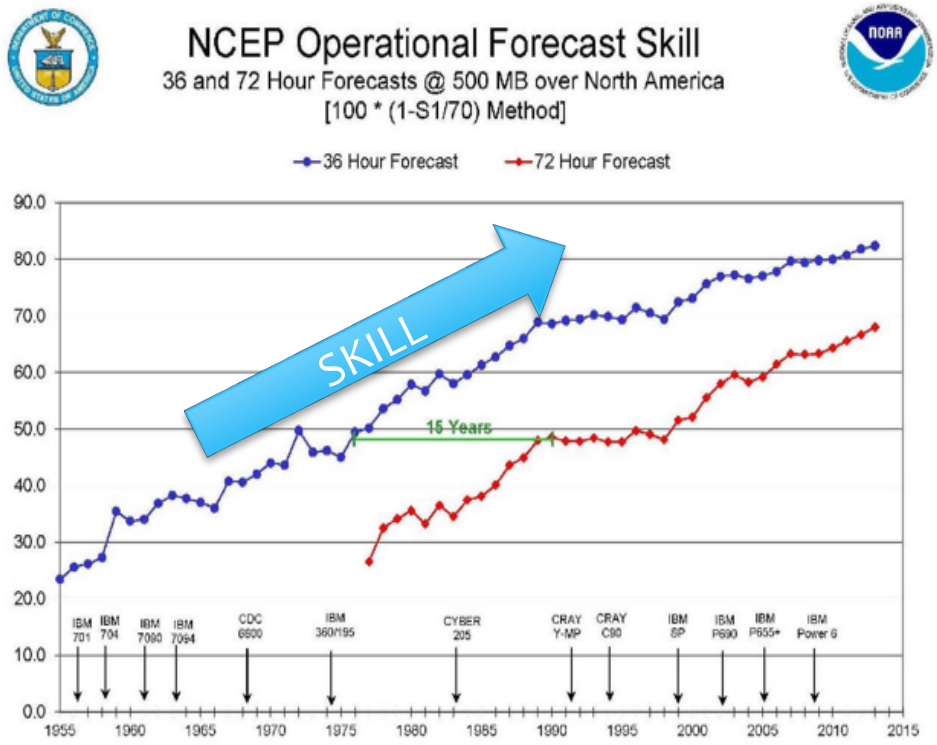
- History of TC forecast improvements in relation to model development
- Ongoing developments
- Future direction: A new model

History: 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

History: Error trends



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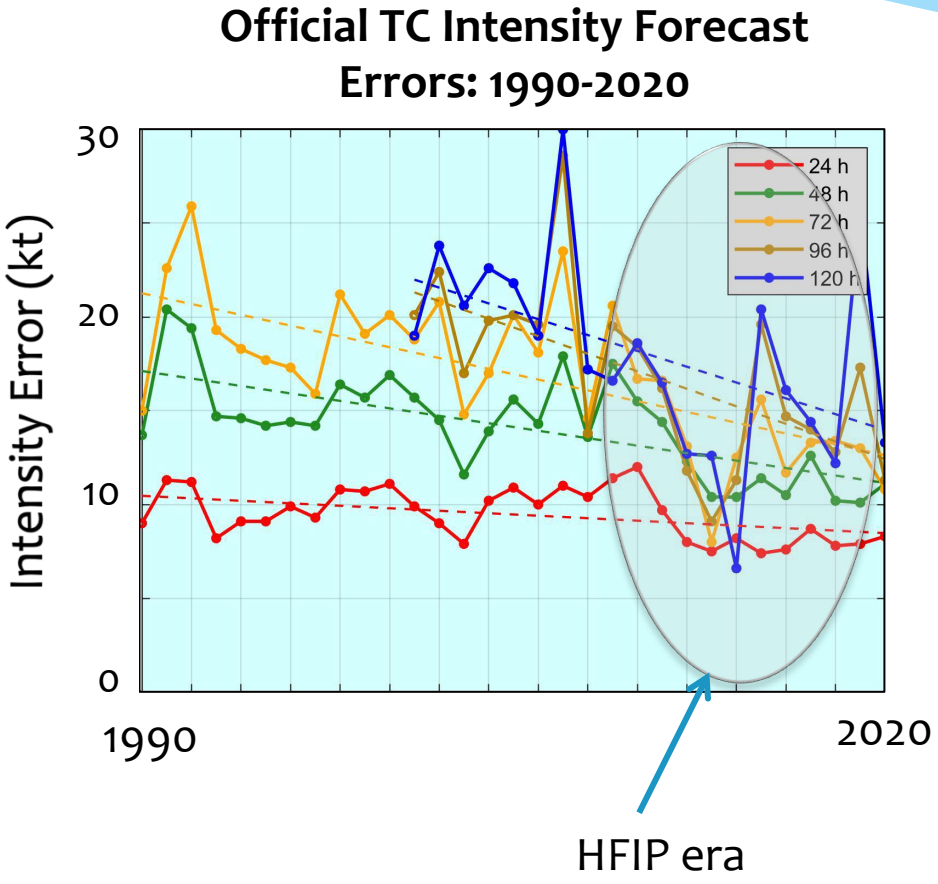
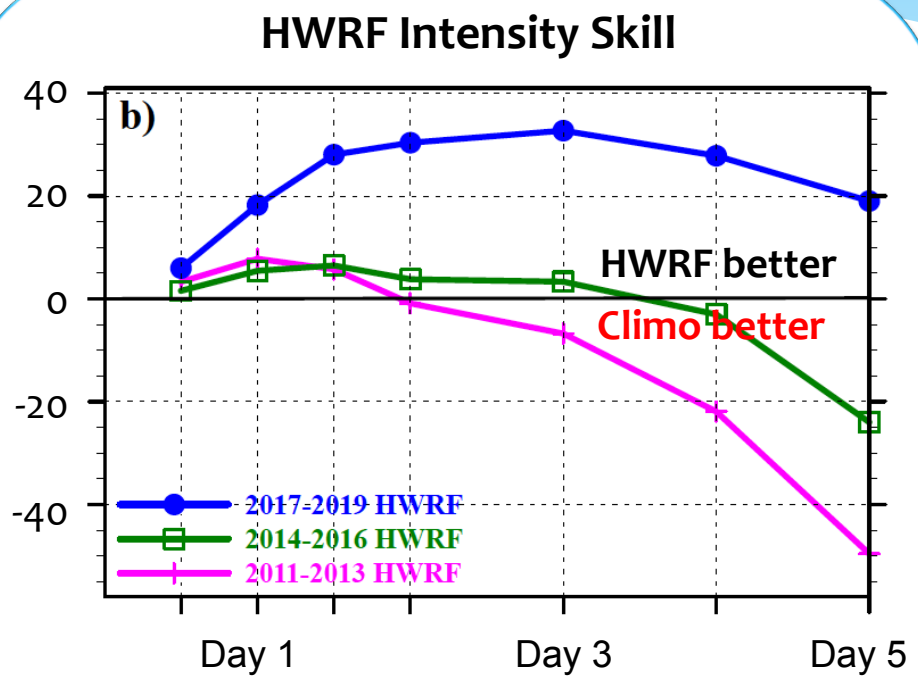


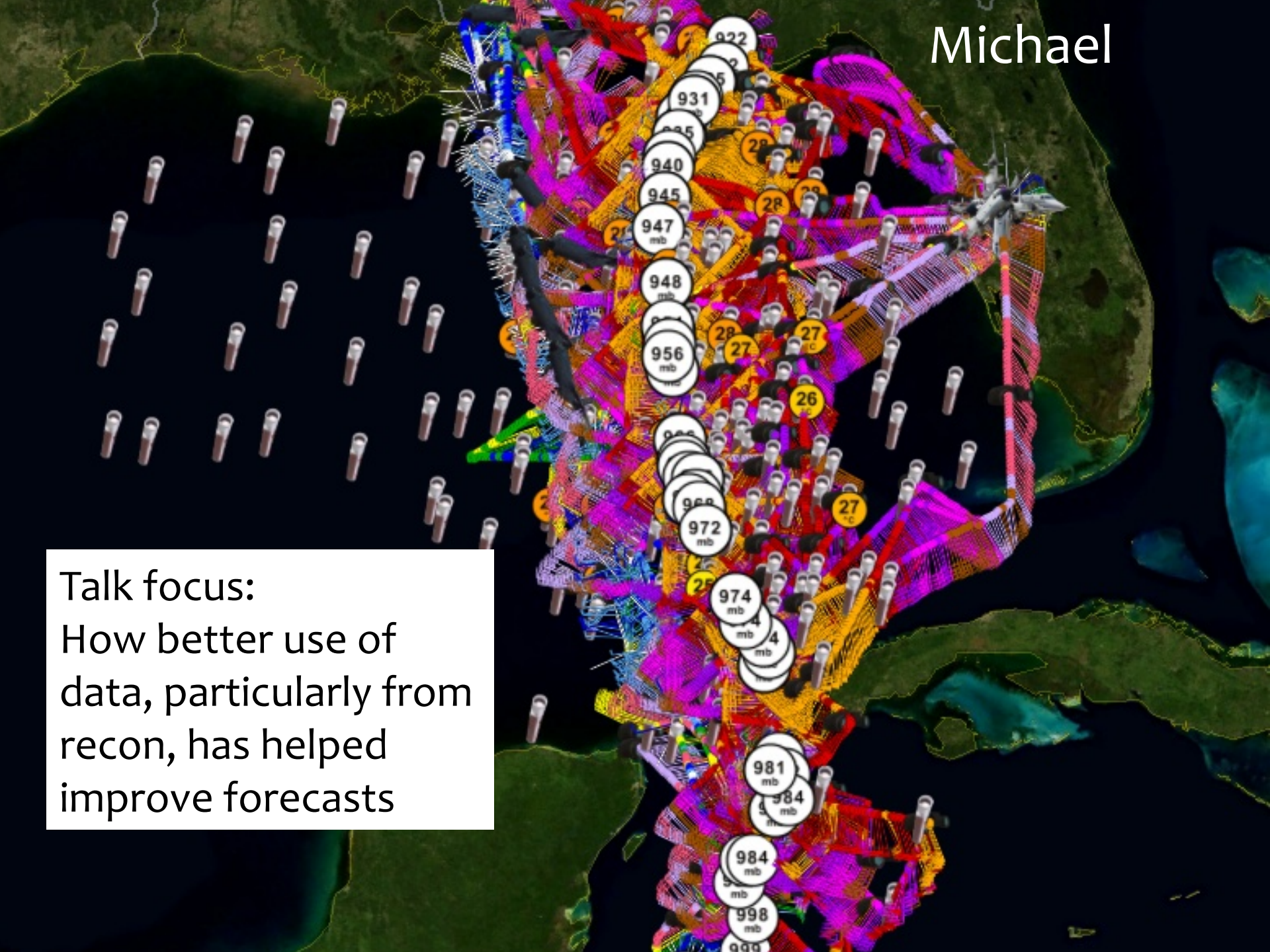
- Hurricane intensity forecasts have only recently improved
- Improvement in intensity forecast largely corresponds with commencement of Hurricane Forecast Improvement Project

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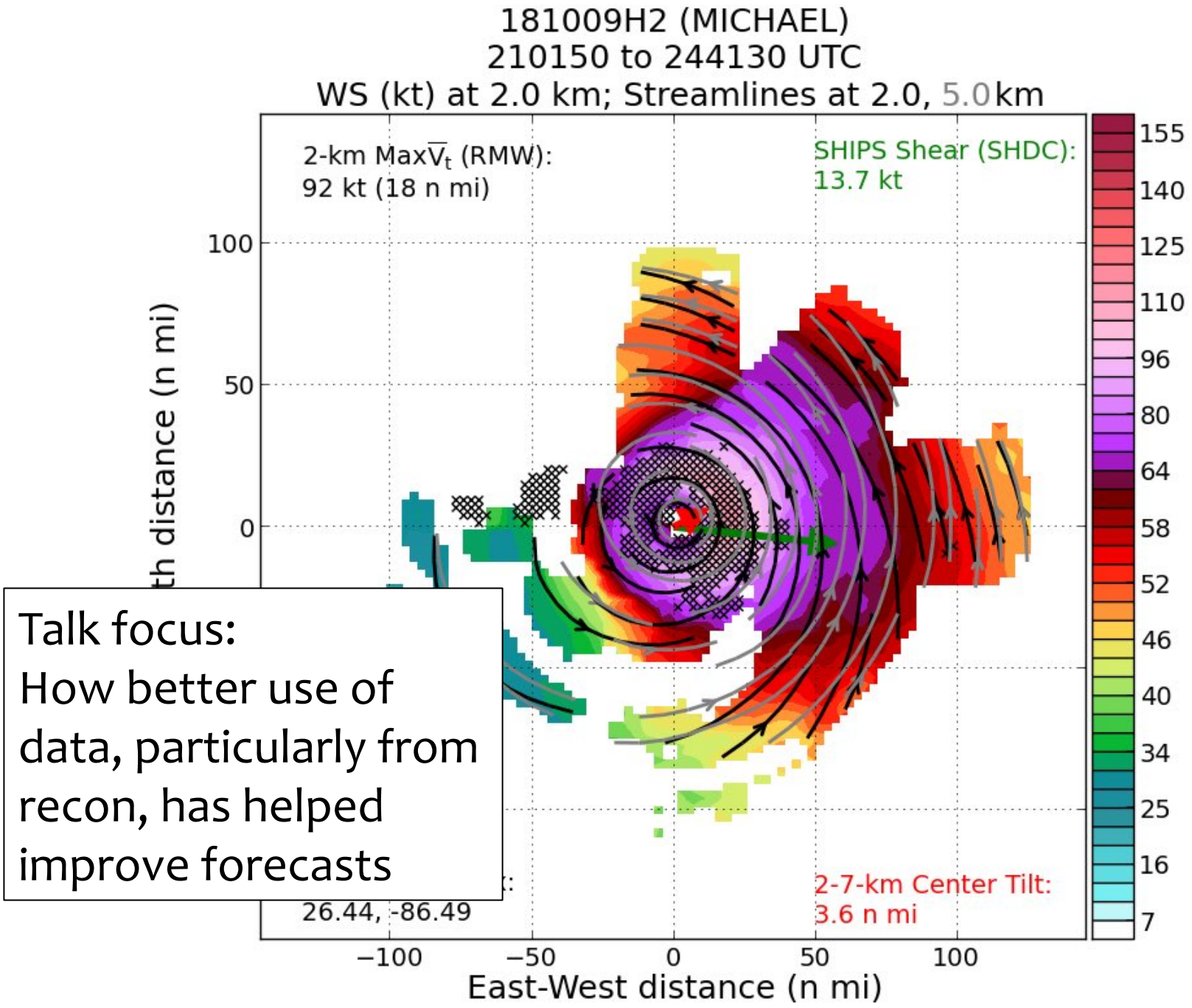
Talk focus:
How better use of data, particularly from recon, has helped improve forecasts



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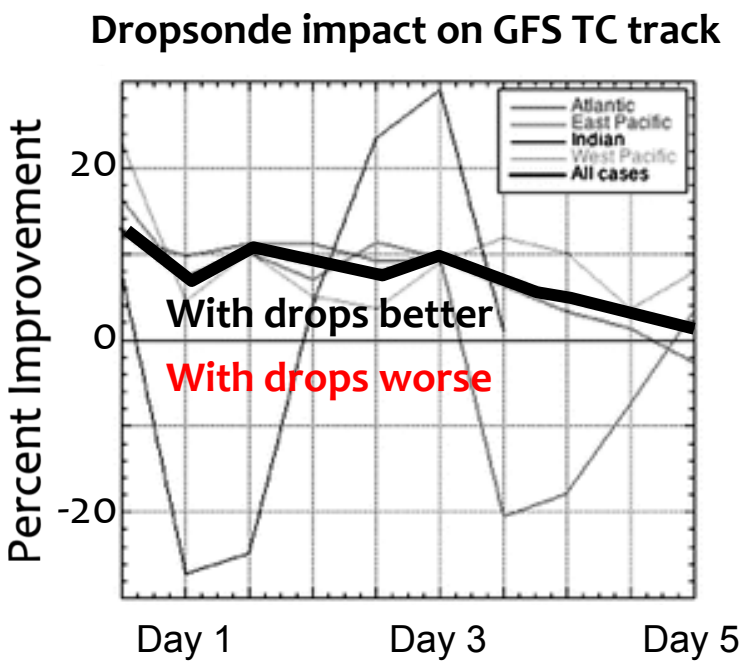
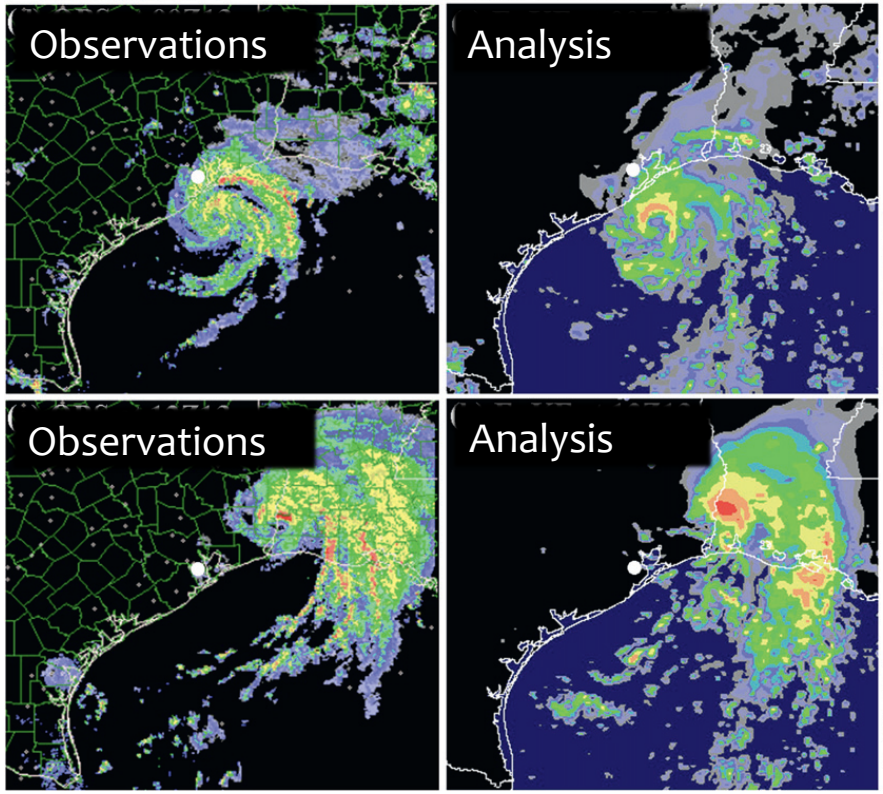
History: Using TC Observations



Impact of dropsondes in September 2008

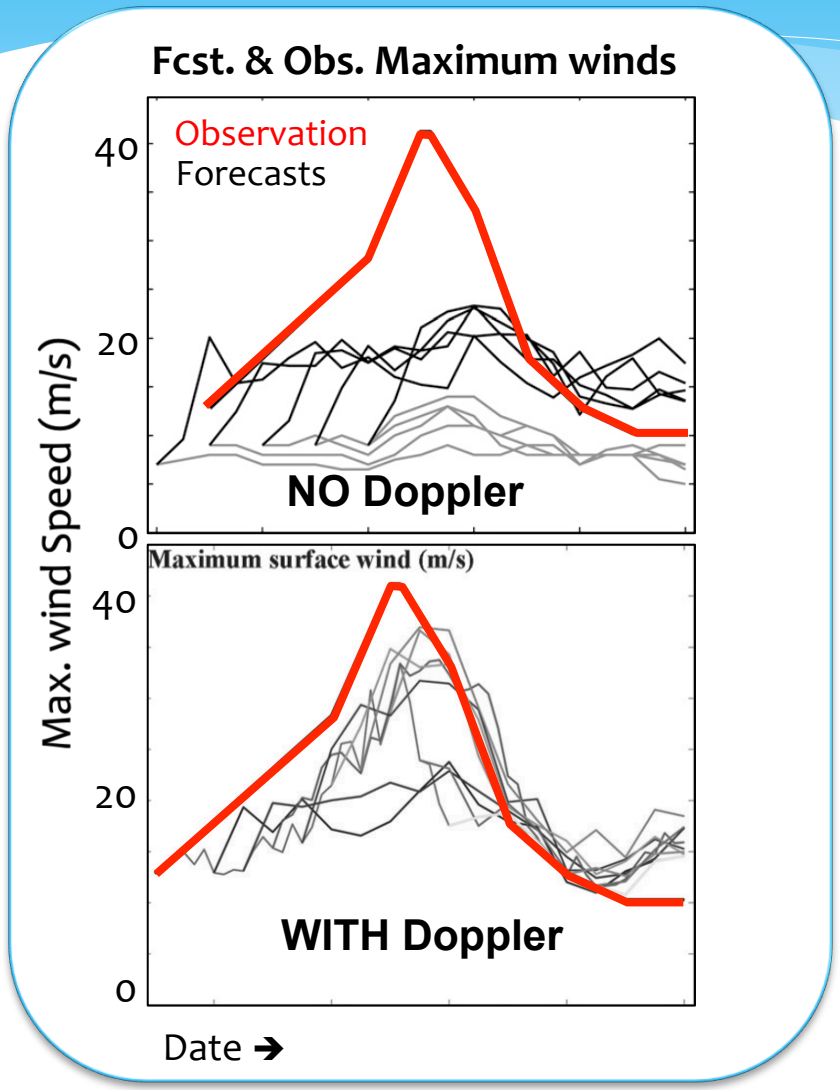
- US has used dropsondes for TC model forecast improvement since 1997
- Aberson (2010, 2011) examined impact of dropsondes in GFS
- Significant track improvement globally

History: 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

History: Using TC Observations



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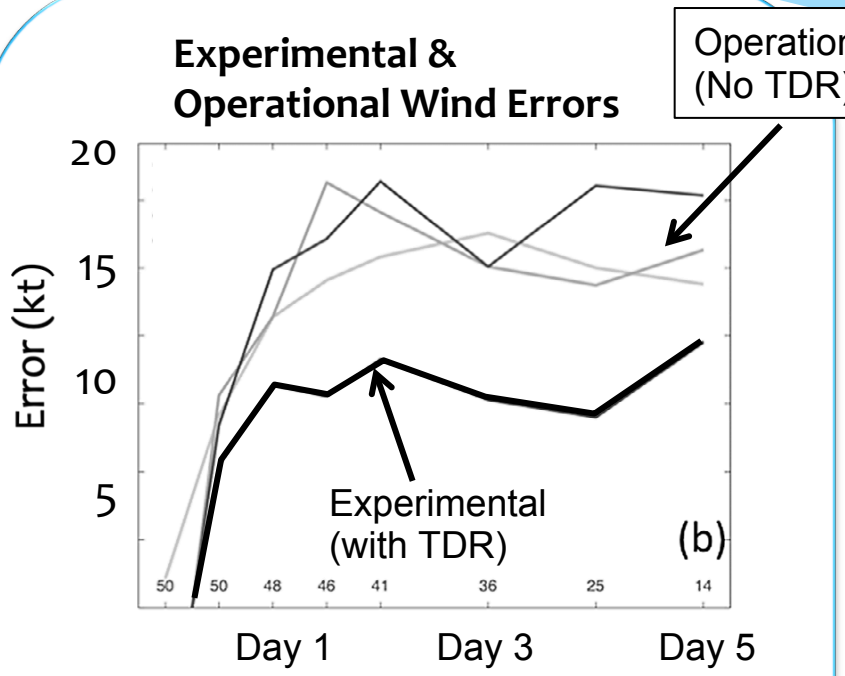
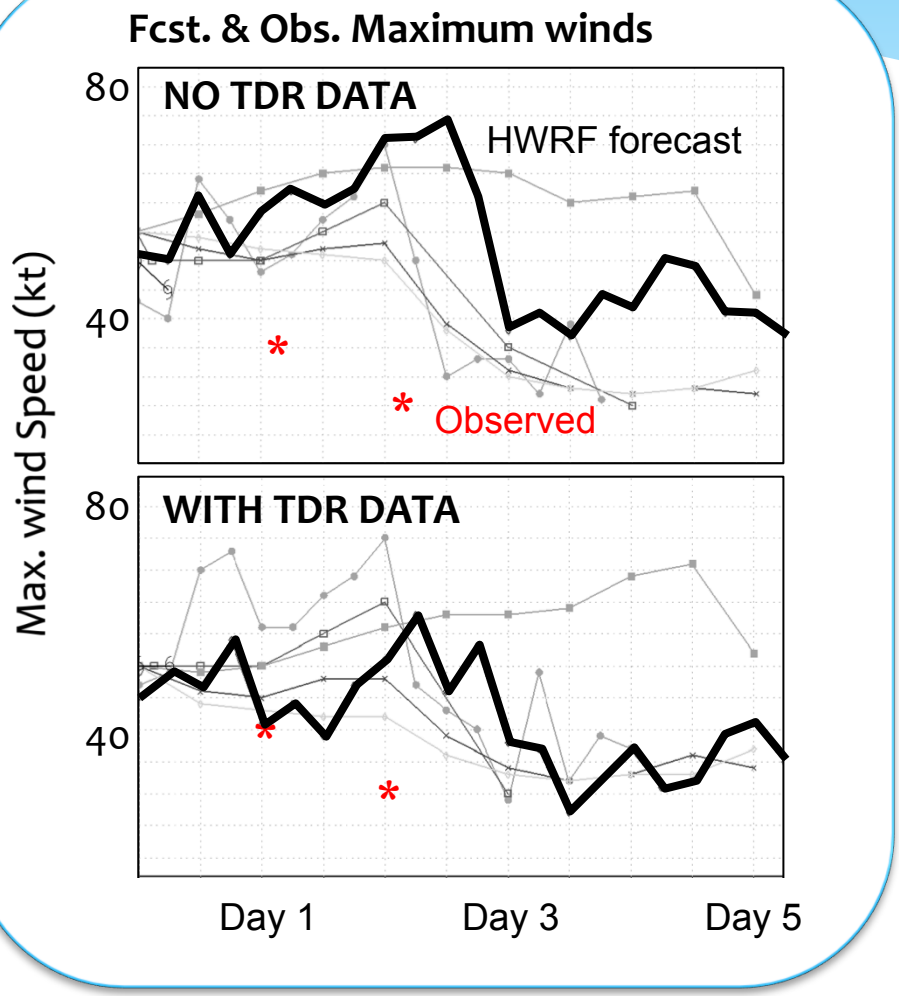


Maximum wind errors from operational forecasts (no TDR) and an experimental system that assimilated TDR data.

- 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

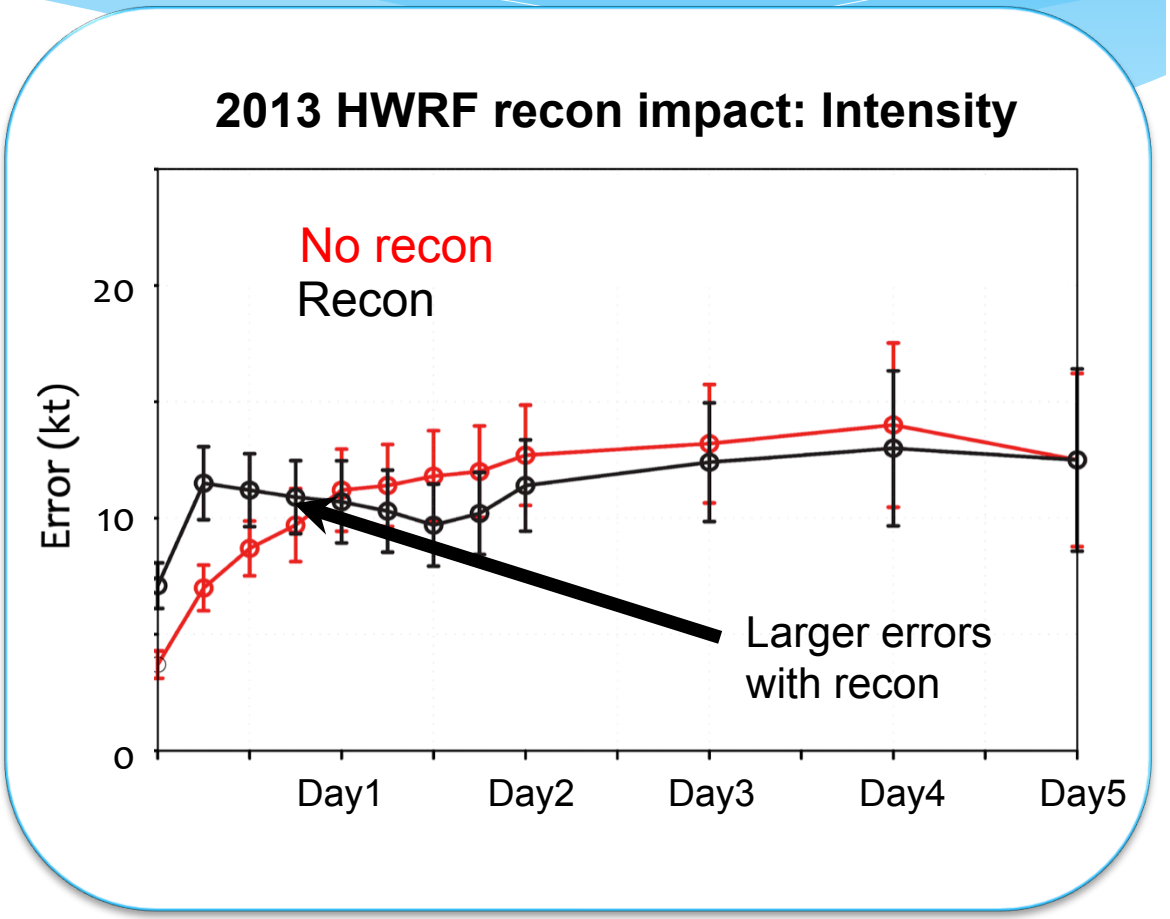
History: Using TC Observations



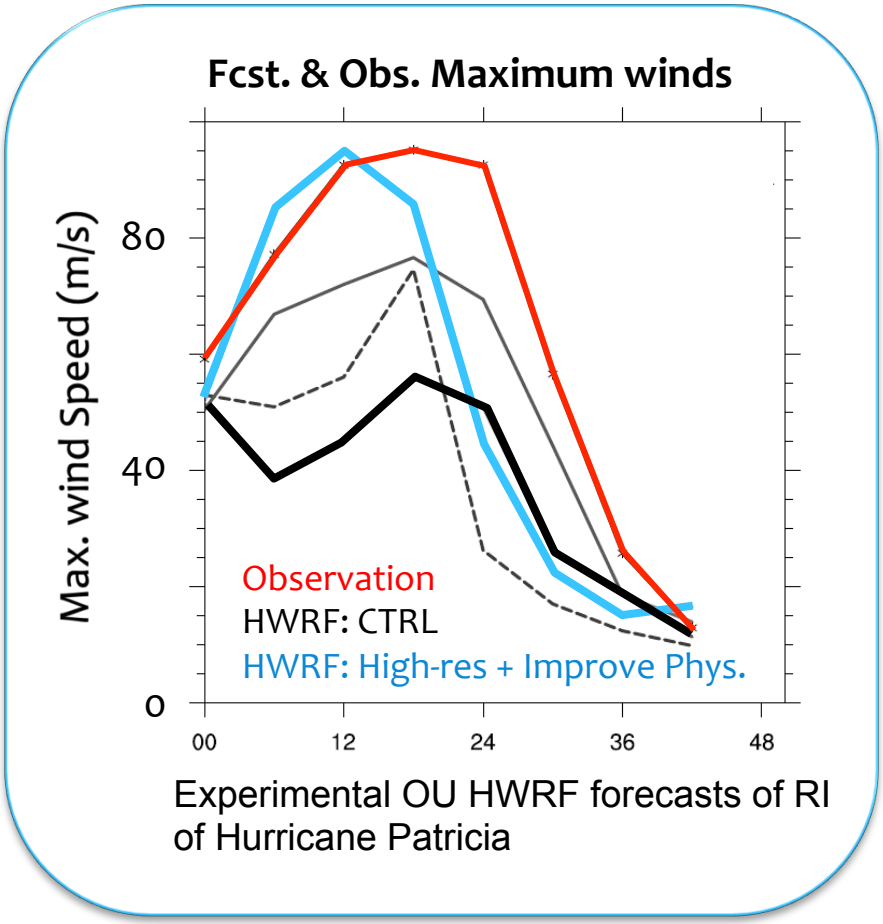
- TDR data began being assimilated in HWRF in 2013
- For weak storms like Karen (left), there was substantial improvement of a positive intensity bias in HWRF

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

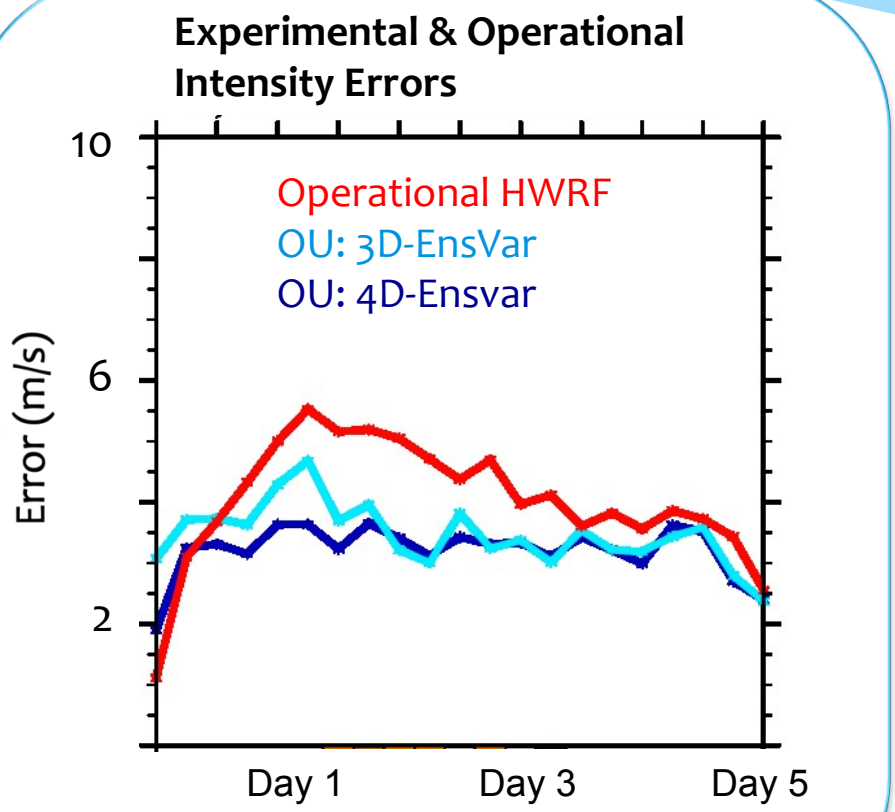


History: HWRF improvements



- 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

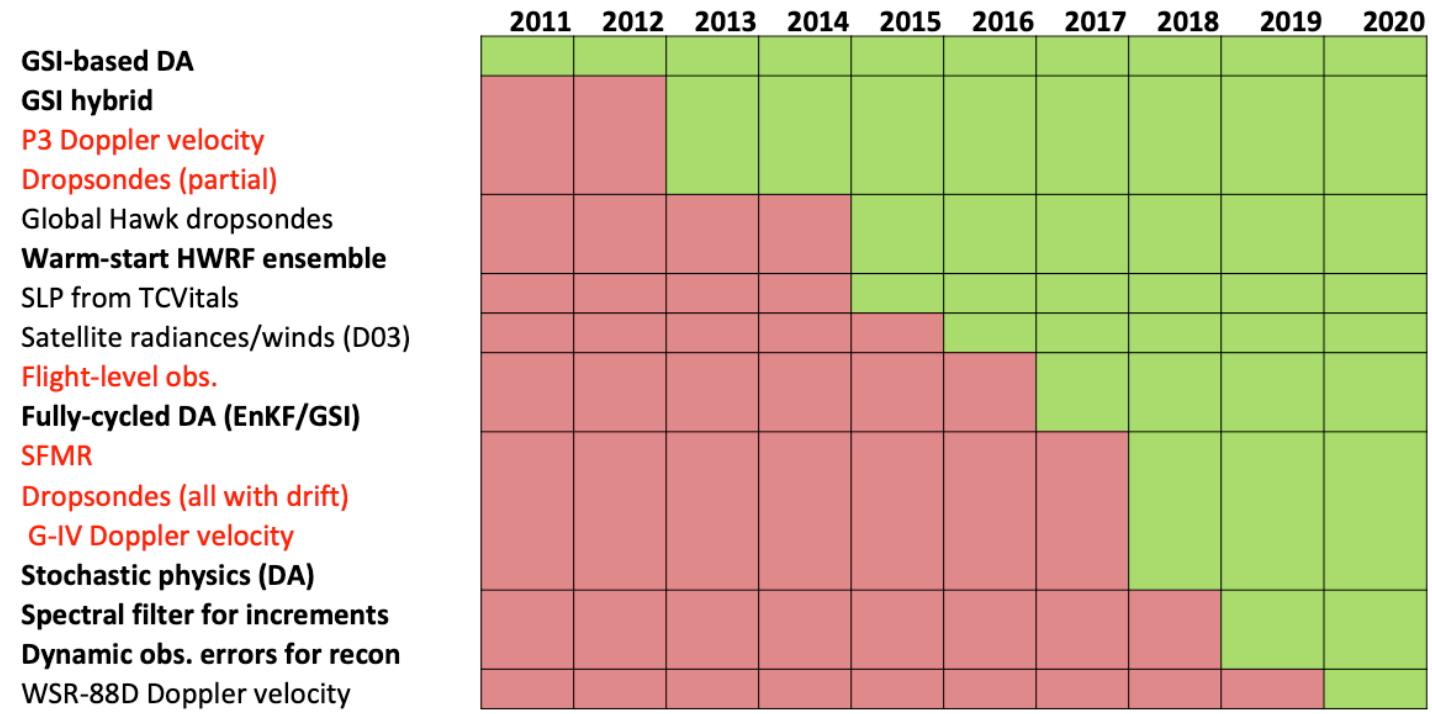
History: HWRF improvements



Vmax errors in operational HWRF vs the experimental OU HWRF system

- Data assimilation improvements are also necessary
- Experimental OU system with better data assimilation system performs much better

History: HWRF improvements



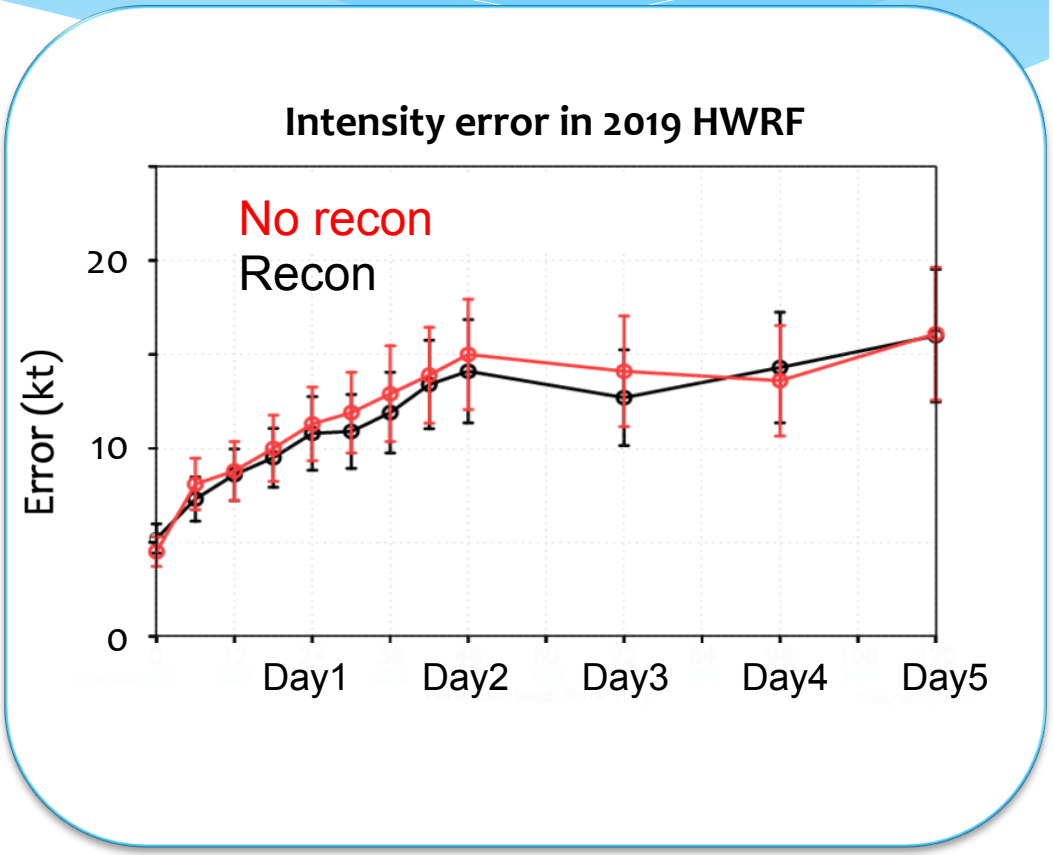
History: HWRF improvements

CURRENT OBSERVATIONS ASSIMILATED BY HWRF INCLUDE:

- Conventional observations (radiosondes, dropwindsondes, aircraft, ships, buoys, surface observations over land, scatterometer, etc)
- NEXRAD 88-D Doppler velocity
- ALL reconnaissance (HDOB, TDR)
- Atmospheric motion vectors
- Clear-sky satellite radiance observations

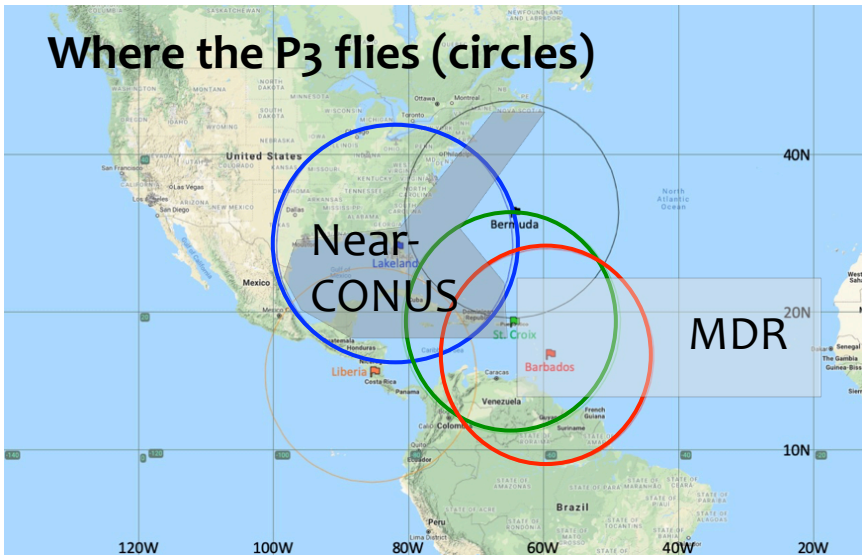
History: HWRF improvements

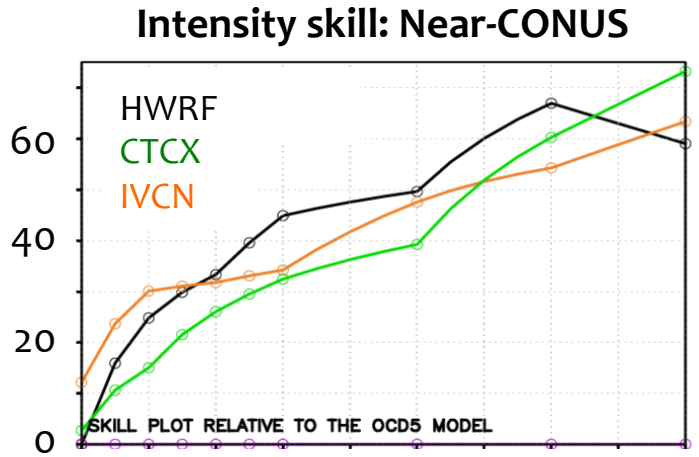
- Recon benefit assessed in 2016-2018 high impact storms
- Many major hurricanes in this sample
- Recon has a clear positive impact on intensity, 10-15% improvement through 72h

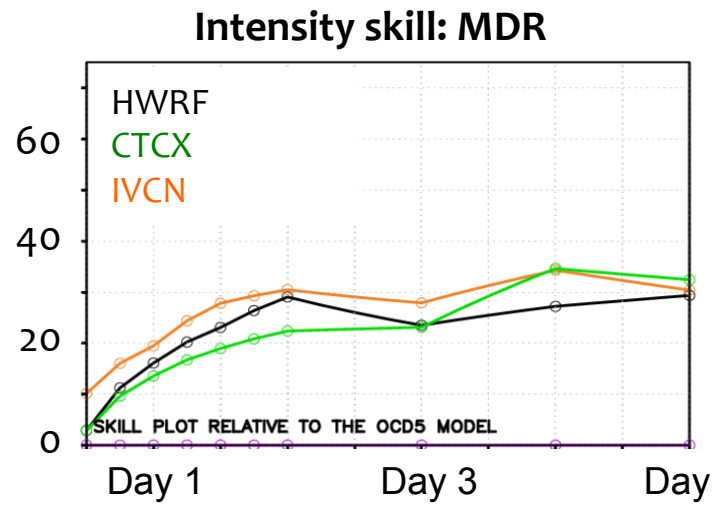


History: Recent Performance

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





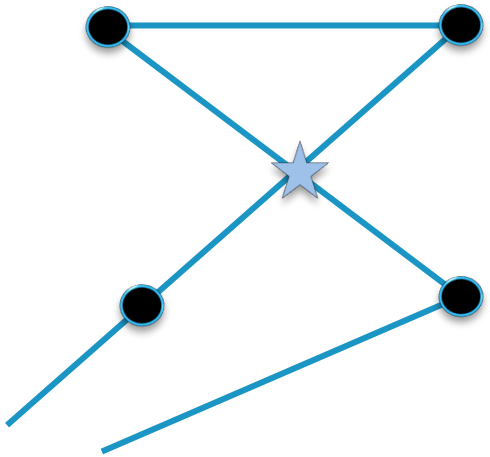


History: Recent Changes

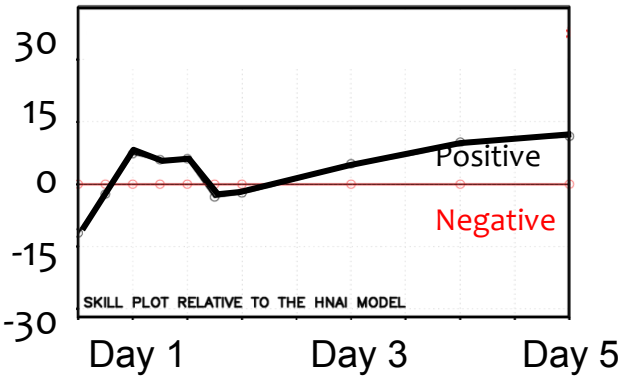
"End-point" dropsondes from USAF C-130 missions

- 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



Brief summary

- Track and intensity errors are both improving
- DA & Physics improvements jointly improve model performance
- Significant improvements in HWRF DA system and data usage

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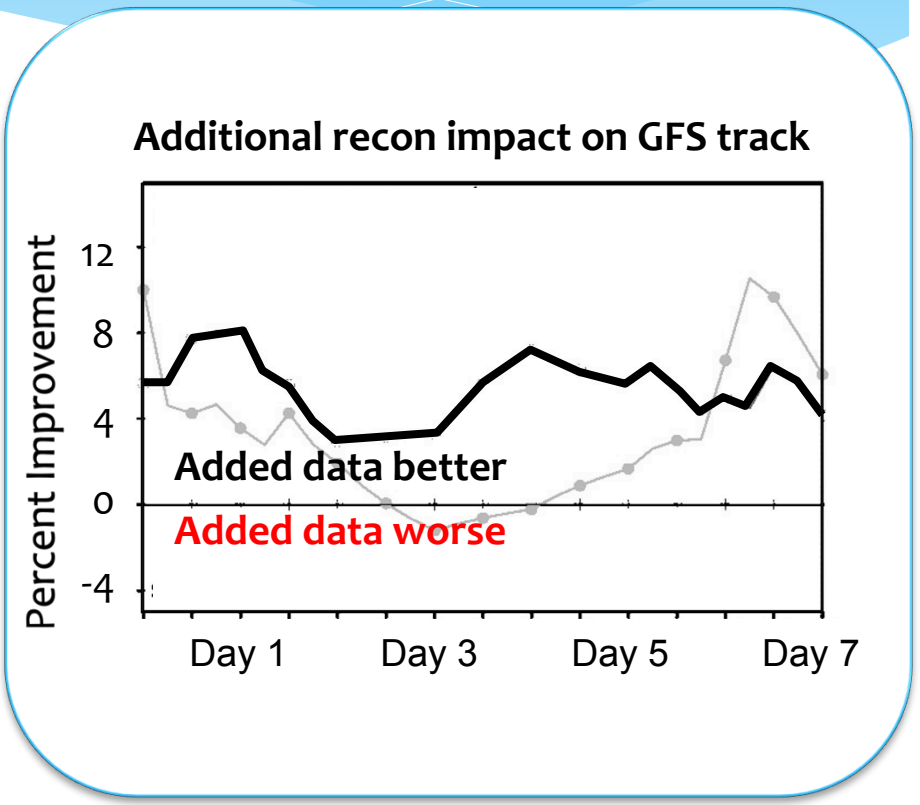
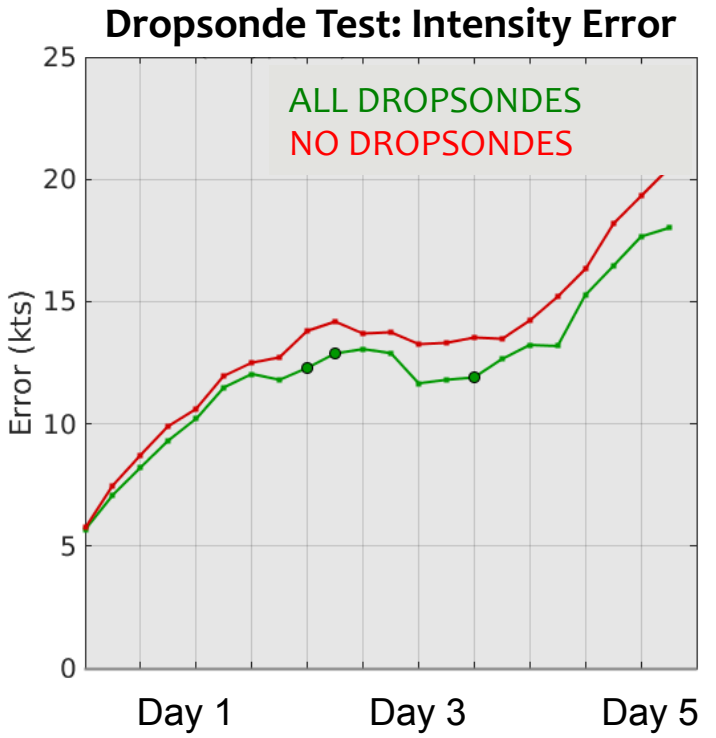
Ongoing developments

- Upgrade to GFSV16 in March included better use of dropsondes and flight-level data
- Added data improves entire NATL sample track by ~5%
- Higher impact in cycles with data & strong storms



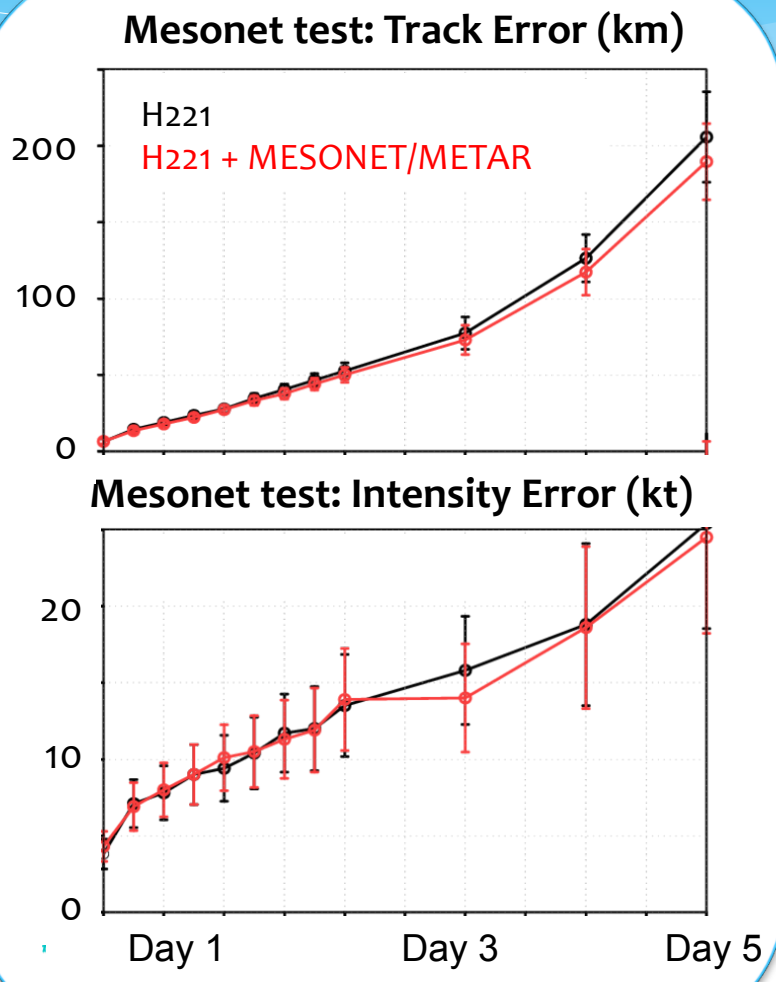
Ongoing developments

- Ongoing work assessing how best to deploy dropsondes using basin-scale HWRF
- Dropsondes directly benefit track by 5-10% and intensity by 10-15%
- Removing dropsondes *anywhere* (e.g., inner core vs. environment, etc.) has negative consequences



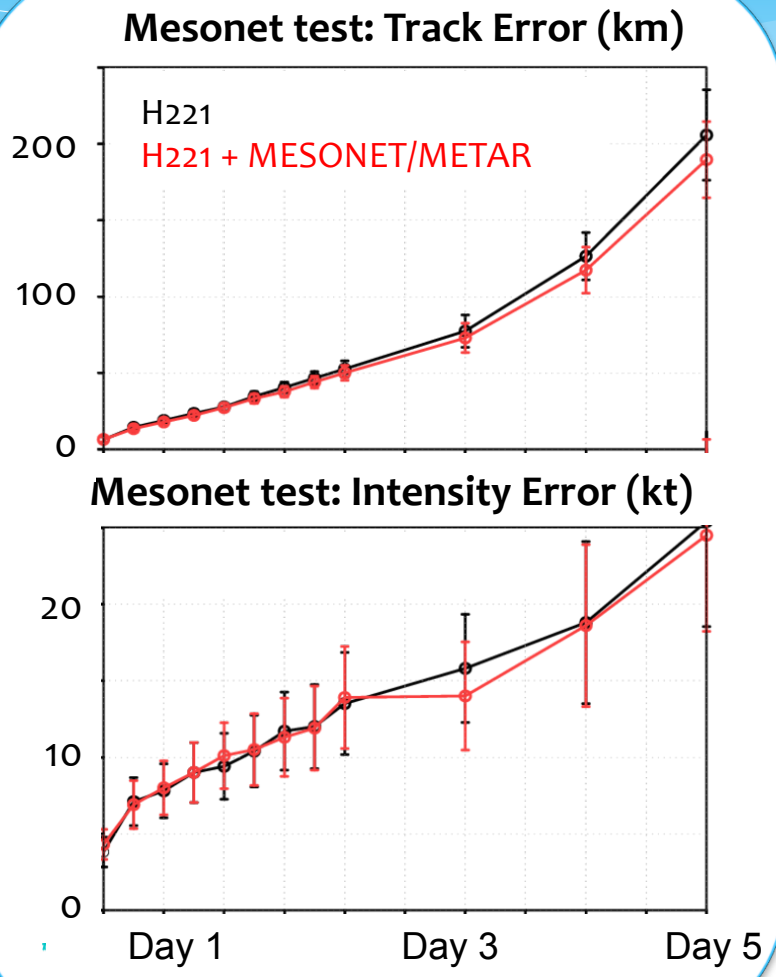
Ongoing developments

- Majority of HWRF development thus far has focused over ocean
- Known physics issues over land need to be addressed
- Major sources of data over land not currently assimilated



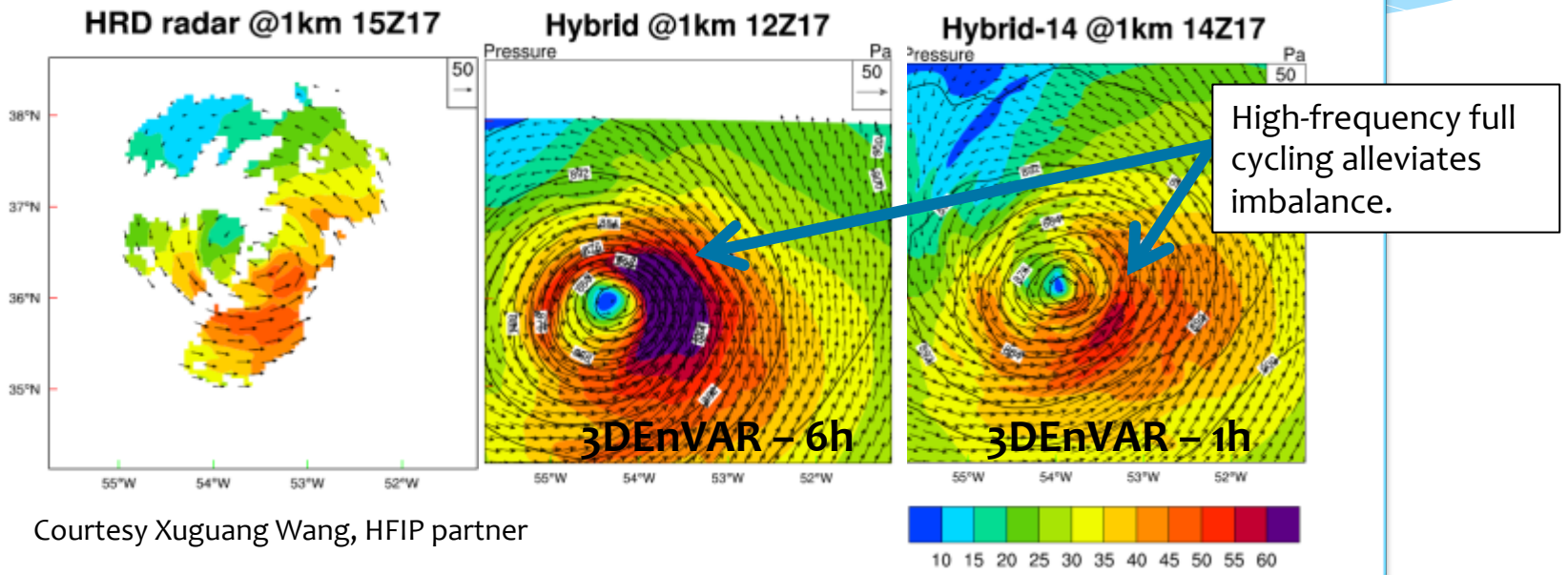
Ongoing developments

- Ongoing work is examining the impact of mesonet and METAR data on HWRF
- Initial results show a large positive track benefit and smaller benefit for intensity and other metrics



Ongoing developments

Improving the DA system improves analyses



Courtesy Xuguang Wang, HFIP partner

Ongoing developments

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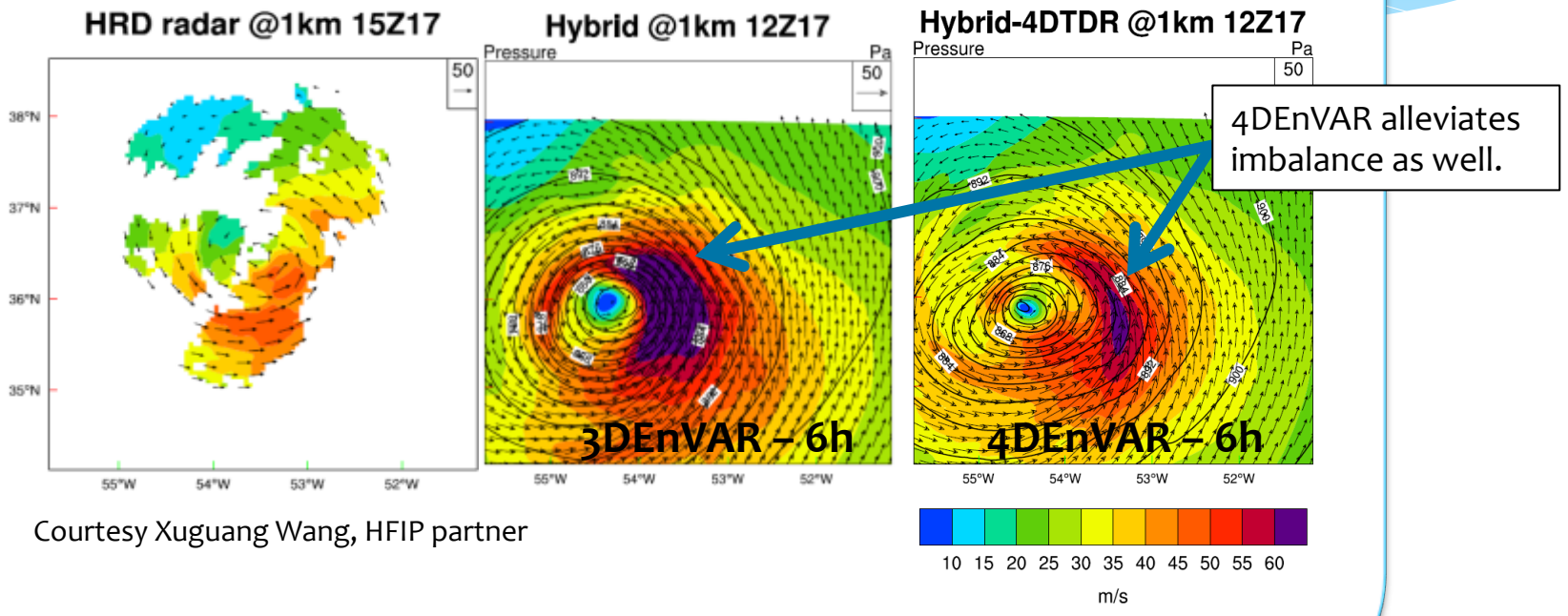

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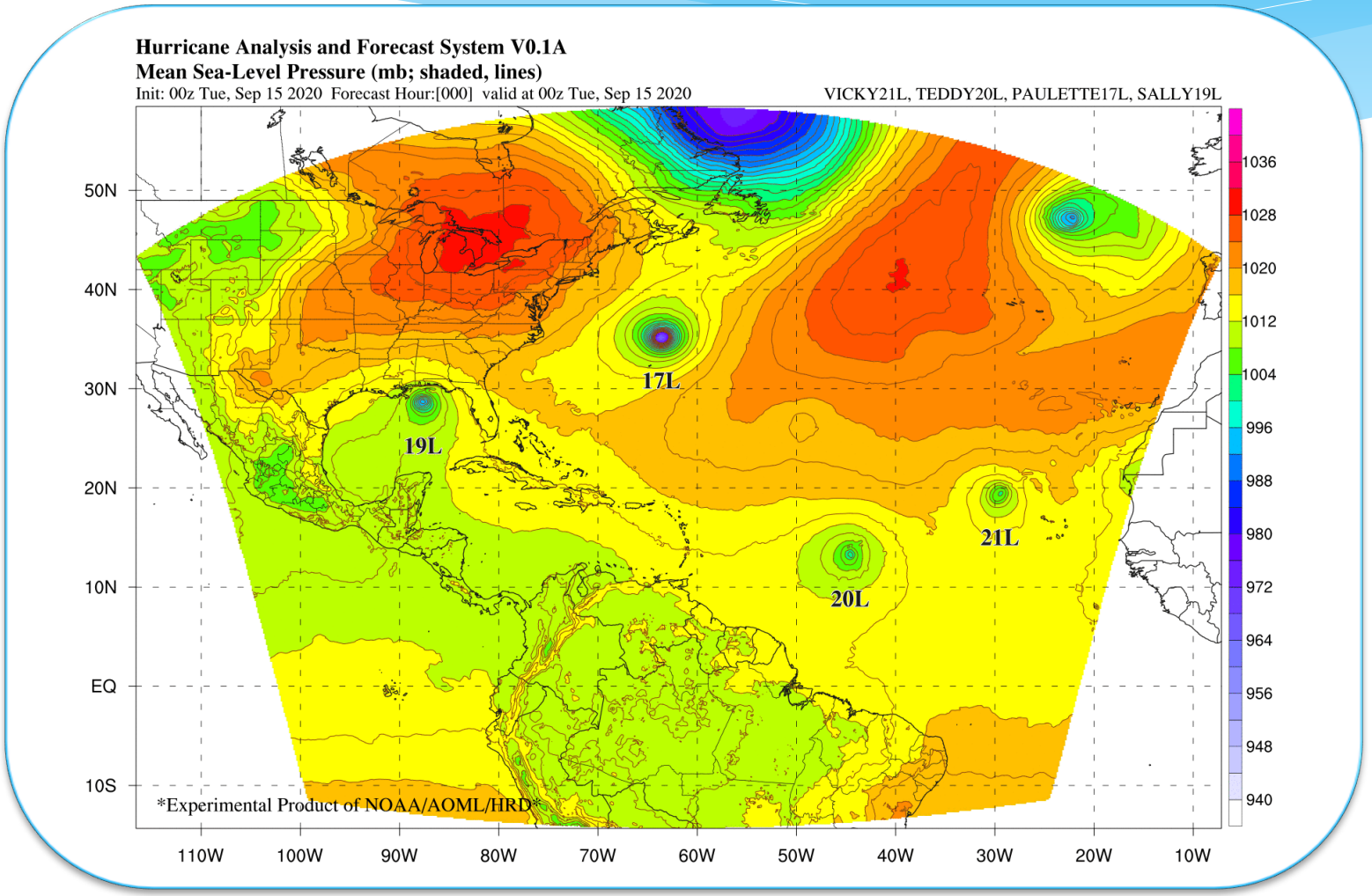
Future direction: HAFS

(Hurricane Analysis and Forecast System)



Future direction: HAFS
(Hurricane Analysis and Forecast System)

MAJOR 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

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