

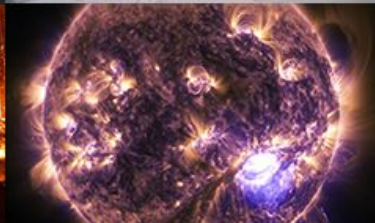
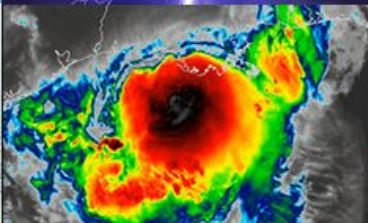
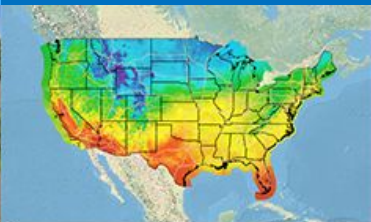


OAR

# Tropical Cyclone Modeling and Data Assimilation

Jason Sippel  
NOAA AOML/HRD

WMO RA-IV Workshop  
April 9, 2024





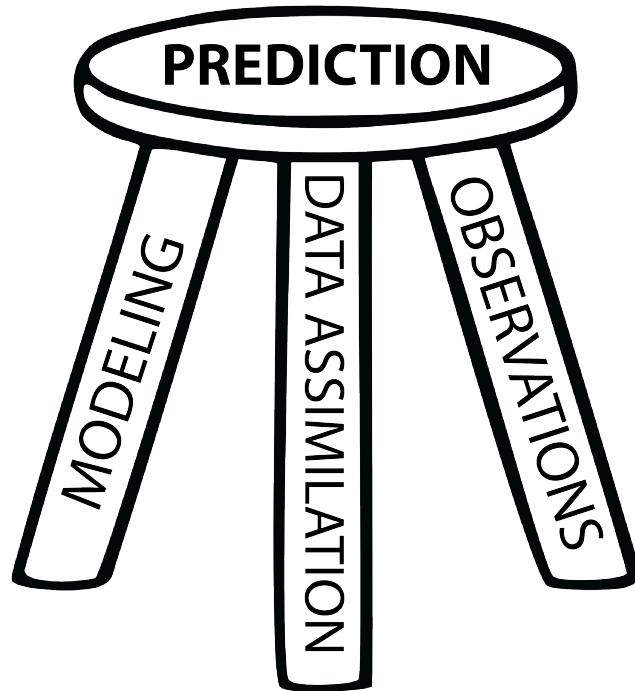
# Outline

- Background: Observations, modeling and data assimilation
- History: Forecast errors, data assimilation, and recon data
- Now: Where we stand with HAFS
- Future: A path forward

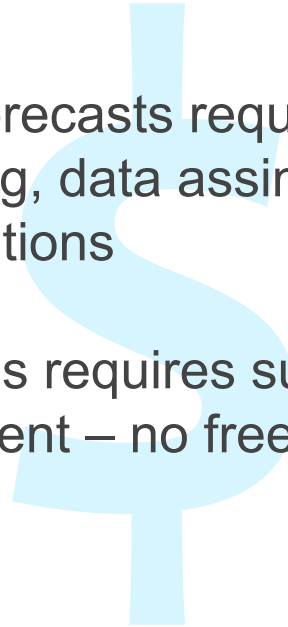




# Background: Improving Forecasts



- Good forecasts require good modeling, data assimilation, and observations
- All of this requires substantial investment – no free lunch!

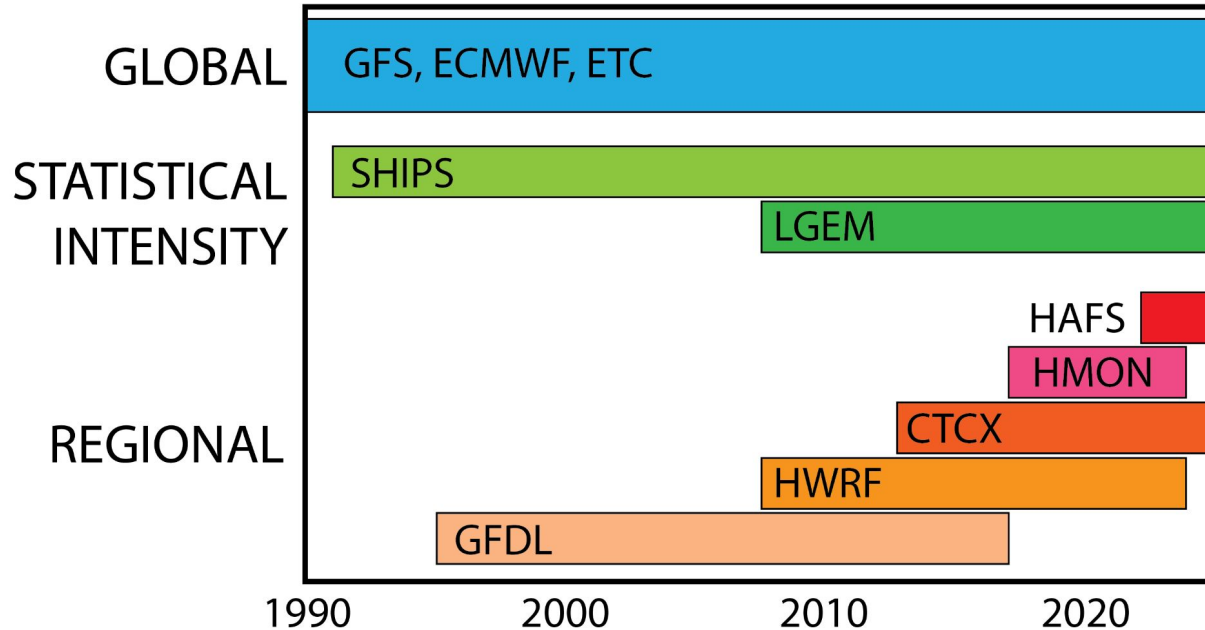




# Background: Modeling



## OPERATIONAL TC MODELING SINCE 1990



Models used by NHC since 1990





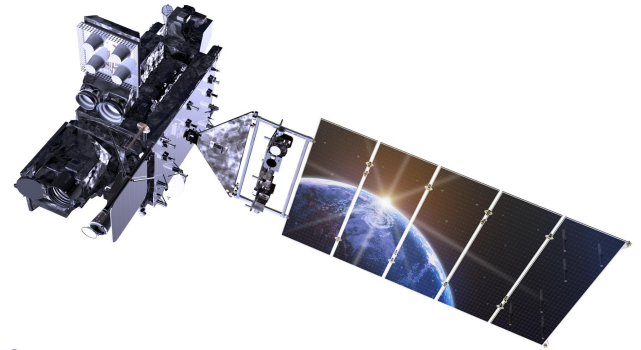
# Background: Observations



TERRESTRIAL



SATELLITES

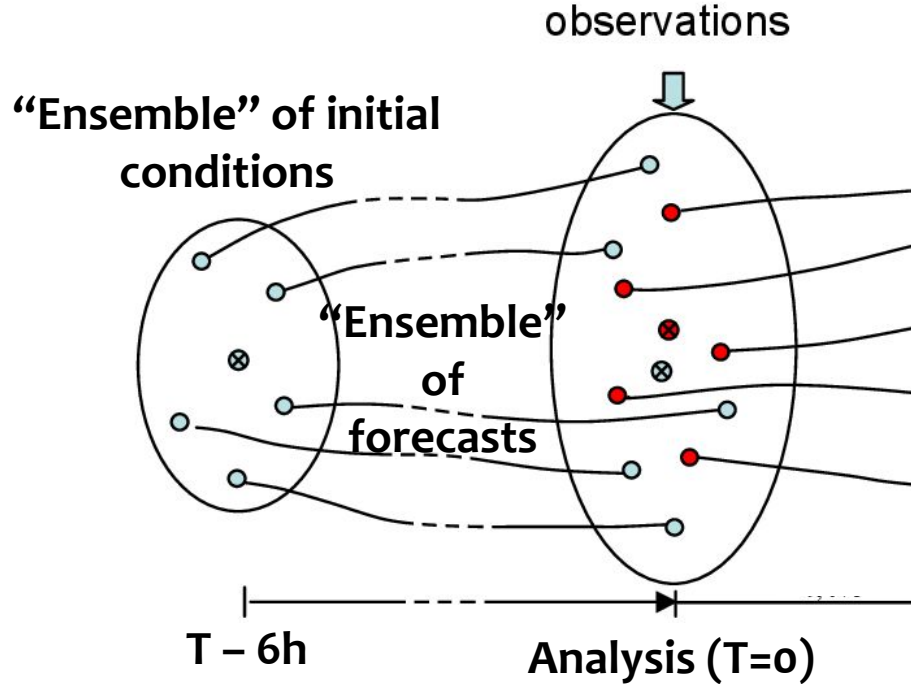


AIRBORNE





# Background: Data Assimilation Concepts



- DA provides initial conditions for a forecast (**analysis**)
- Update relies upon **covariance** derived from a prior short-term ensemble forecast

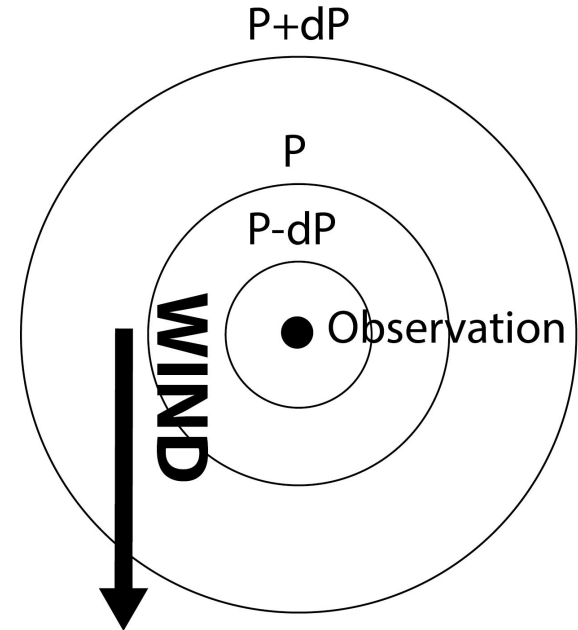
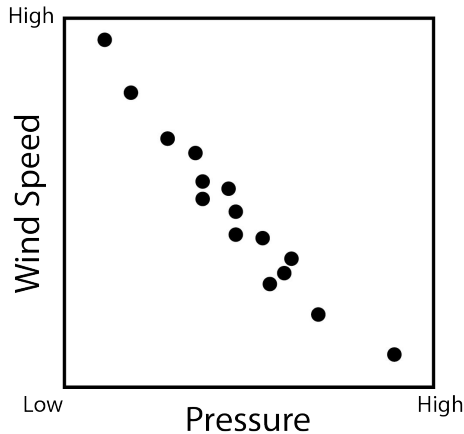




# Background: Data Assimilation Concepts



Example: Low pressure system

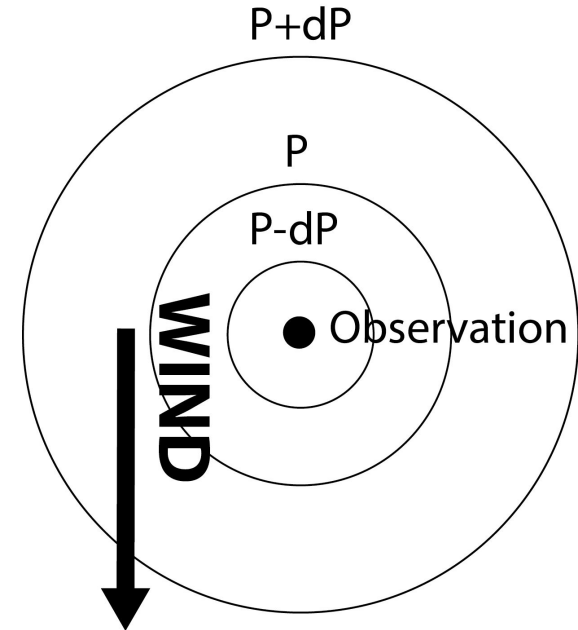


“Ensemble” of short-term forecasts provide covariance for DA

# Background: Data Assimilation Concepts

Example: Low pressure system

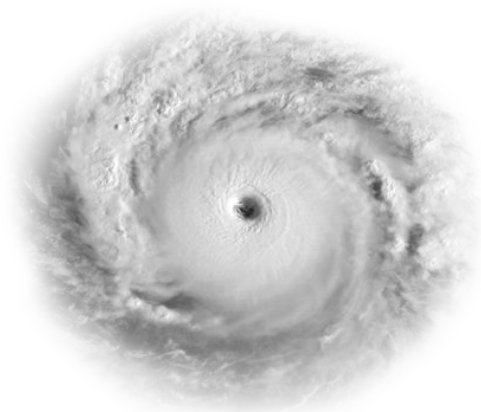
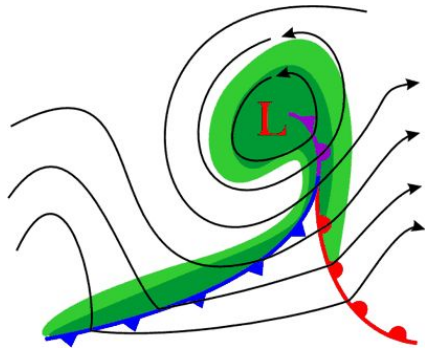
- Only pressure is observed
- Observed pressure is *lower* than the short-term forecast
- A *lower* pressure corresponds with a correction to *stronger* winds in the analysis







# Background: Data Assimilation Concepts



- Accurate analyses require good covariance and observations
- Covariance from a global ensemble is not great for hurricanes and is terrible for tornadoes





# Outline

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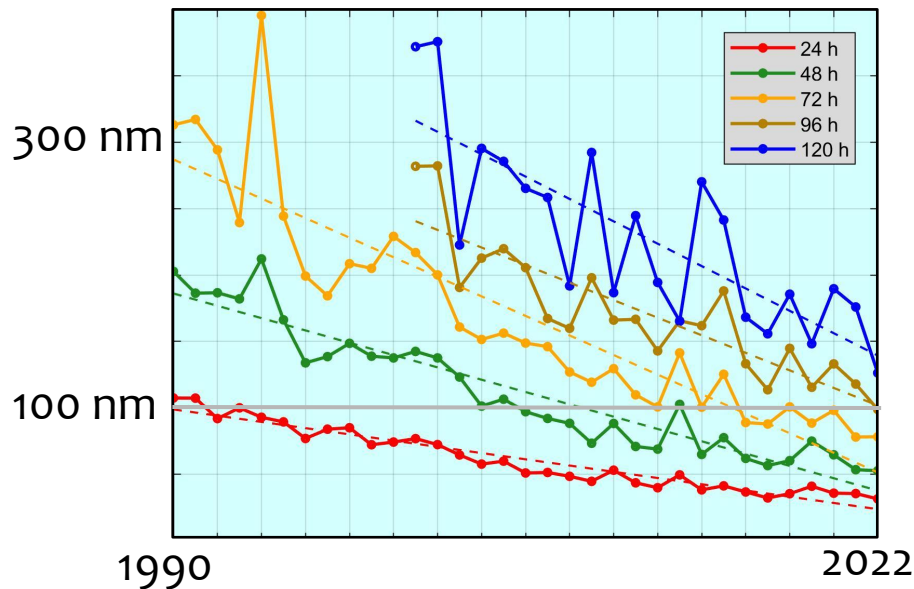




# History: Improving TC Forecast Errors



## NHC Track Errors in NATL basin



- Continuously improving track errors
- 3-day gain in lead-time
- This is tied to better large-scale forecasts





# History: Improving TC Forecast Errors



## NCEP's Large-scale Forecast Quality



- Continuously improving track errors
- 3-day gain in lead-time
- This is tied to better large-scale forecasts

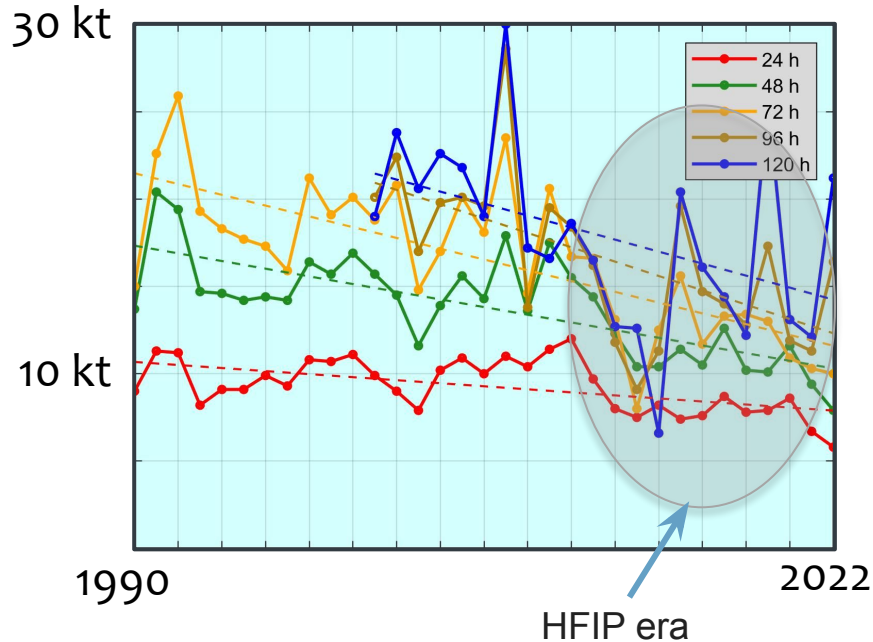




# History: Improving TC Forecast Errors



## NHC Intensity Errors in NATL basin



- Hurricane intensity forecasts have only recently improved
- Improvement a result of Hurricane Forecast Improvement Project
- BIG financial investment

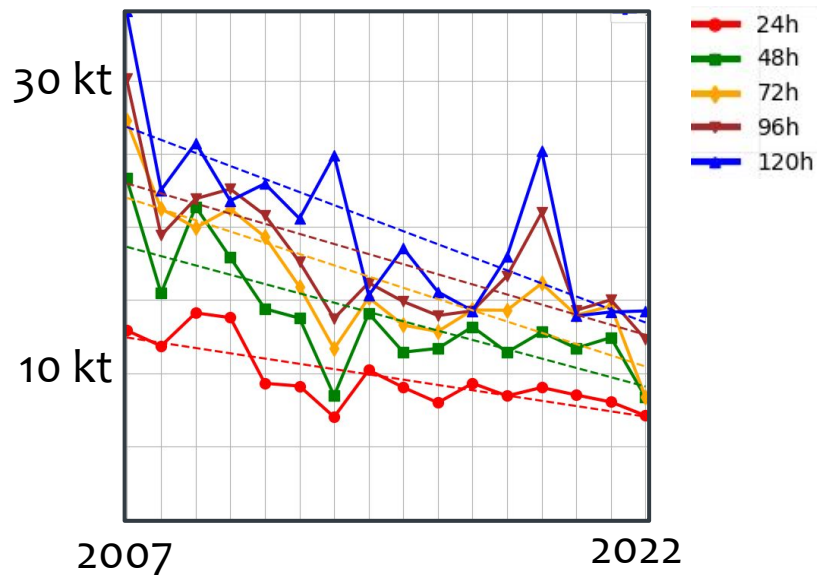




# History: Improving TC Forecast Errors



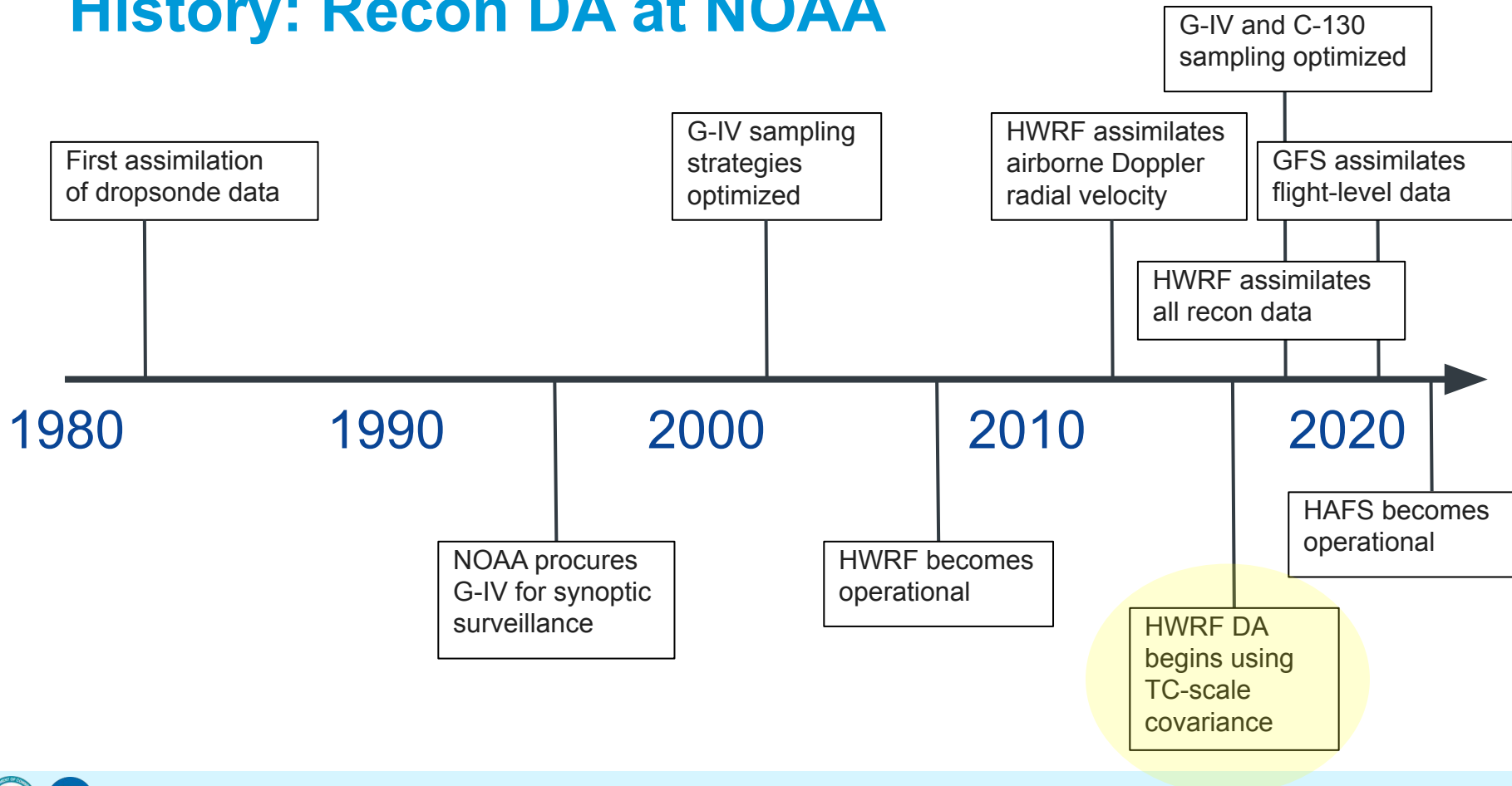
## HWRF Intensity Error Trends



- Improving dynamic guidance has improved intensity forecasts
- Dynamic models have improved due to advances in resolution, physics, and **data assimilation**



# History: Recon DA at NOAA

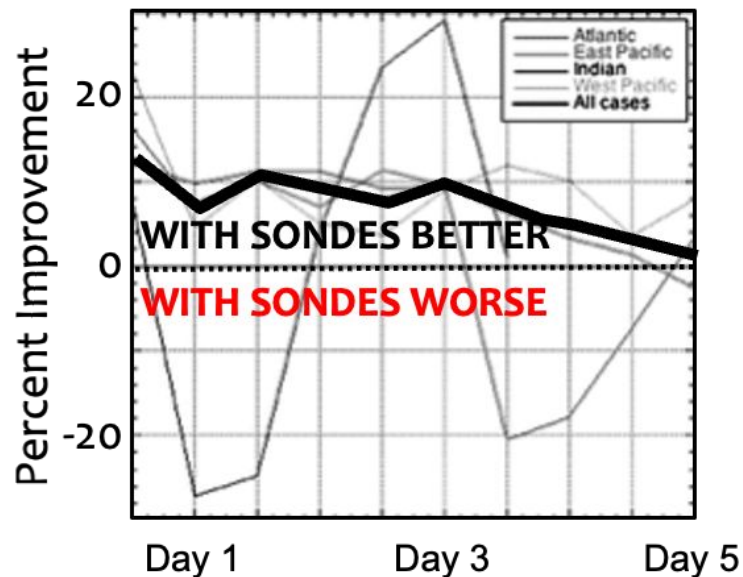




# History: Assimilating Dropsonde Data



Dropsonde Impact on GFS TC Track



Impact of dropsondes in September 2008

- US has used dropsondes in weather models for ~40 years
- “Environmental” data easier to deal with than “in-vortex” data
- Many studies have shown dropsondes improve TC track forecasts





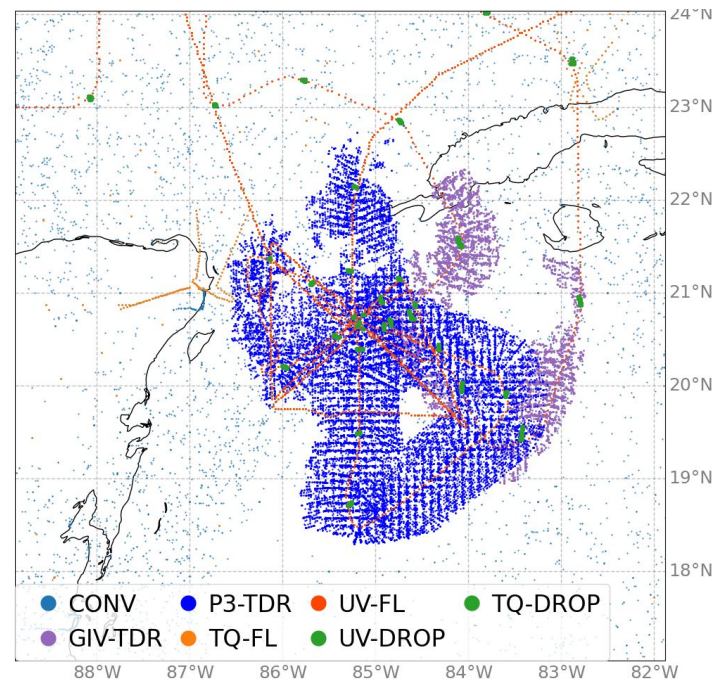
# History: Assimilating In-vortex Data



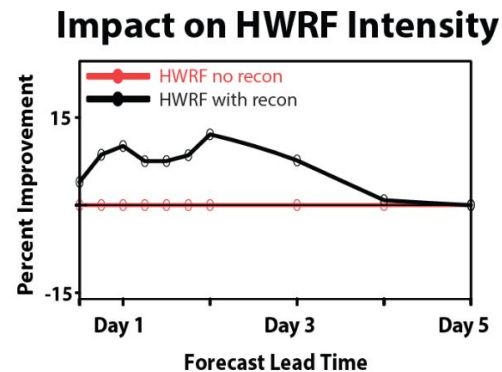
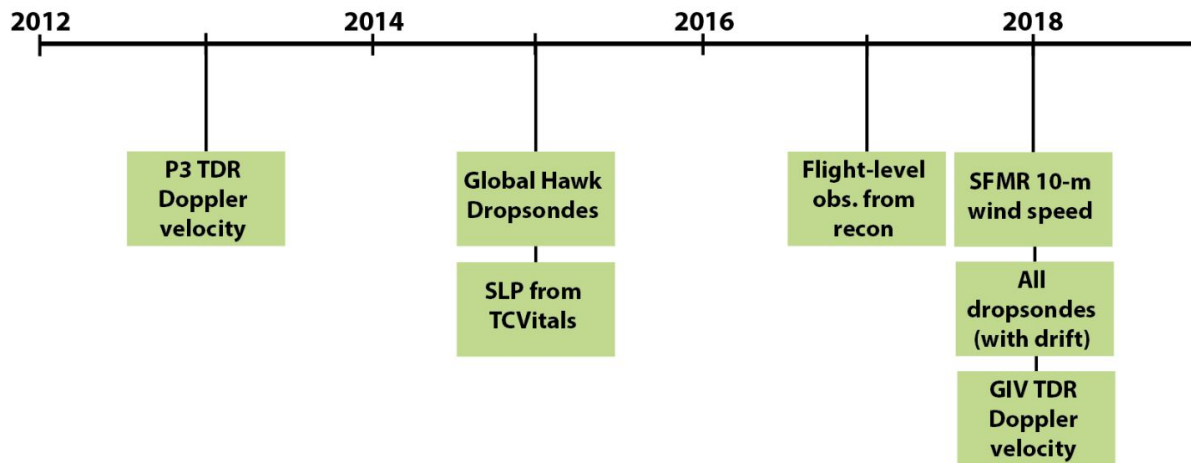
- DA research with Doppler velocity (88D) in TCs began ~15 years ago
- Operational assimilation of airborne Doppler velocity (TDR) begin ~10 years ago
- Use has expanded greatly over past decade



## Data Assimilated in Idalia



# History: Assimilating In-vortex Data



## RECONNAISSANCE DATA IN HWRF



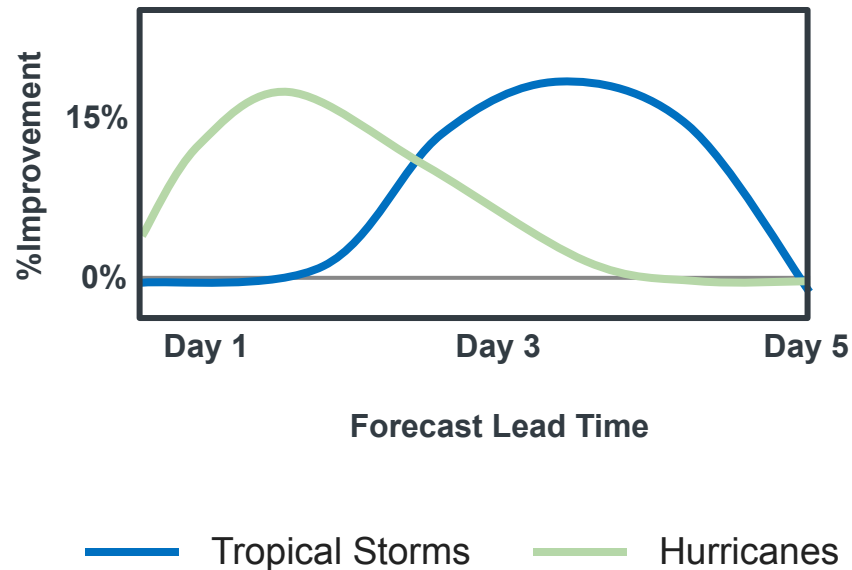
# History: Assimilating In-vortex Data



- For tropical storms, recon data improves long-term intensity forecasts
- For hurricanes, recon data improves short-term intensity forecasts
- This matches theoretical expectations



## Recon Impact on HWRF Intensity

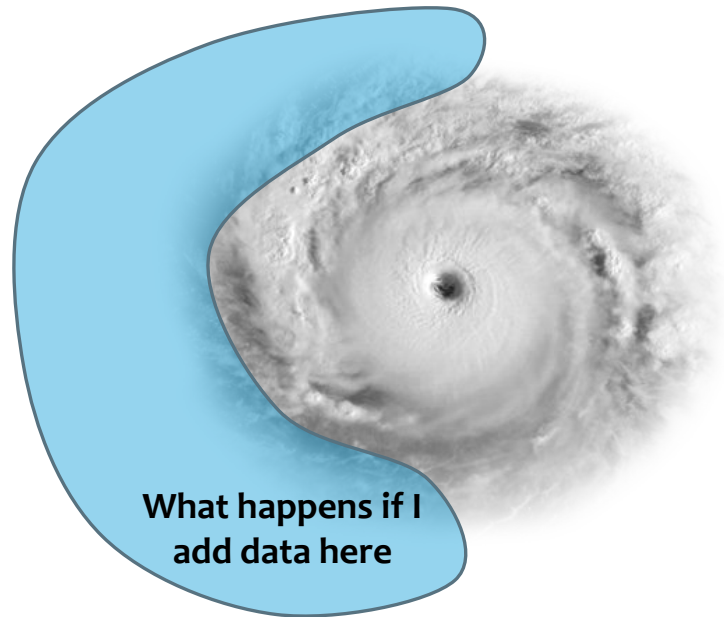




# History: Optimizing Sampling



With a model that performs well, one can more effectively evaluate observing-system experiments (OSEs)

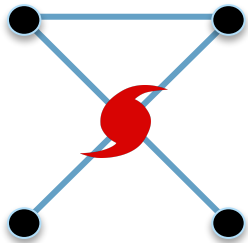


What happens if I  
add data here

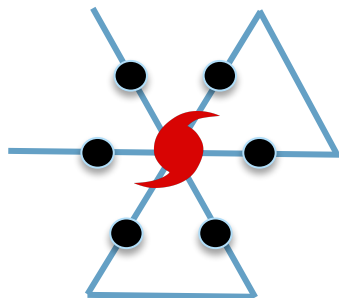




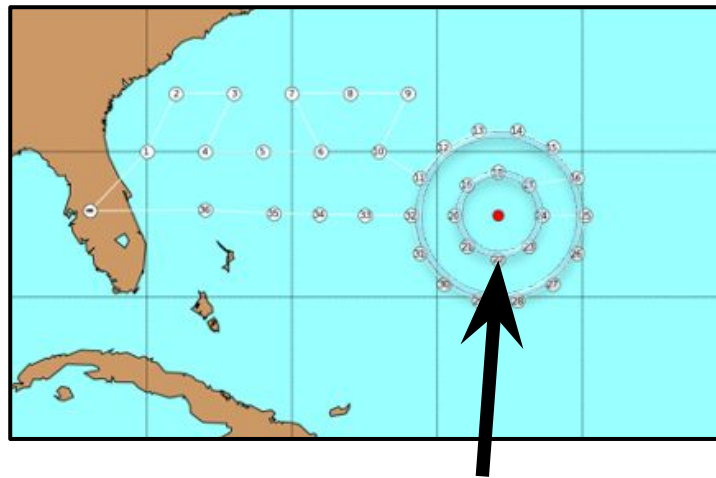
# History: Optimizing Sampling



**USAF C-130:**  
Added end-point  
dropsondes



**NOAA P3:**  
Added mid-point  
dropsondes



**G-IV:** Added Inner Circumnavigation

Sampling changes in 2017-18 have improved forecasts



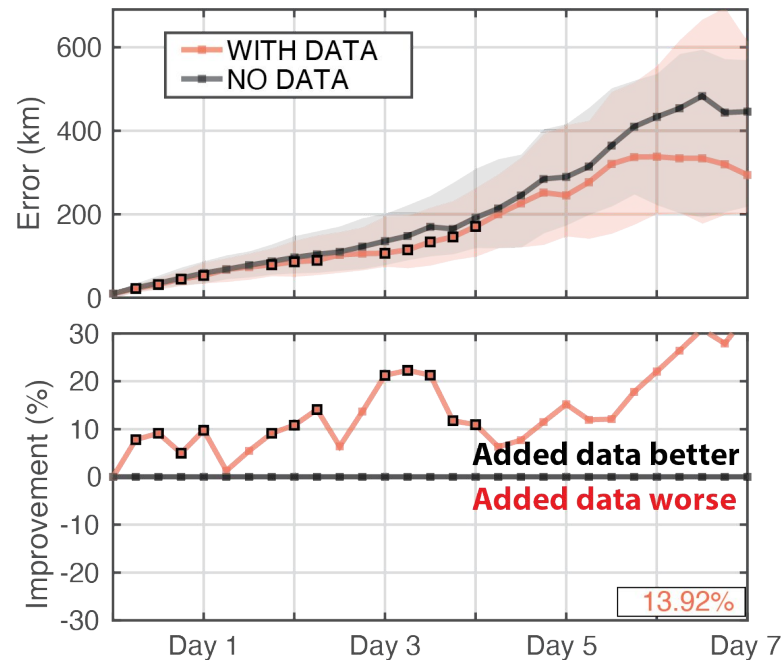
# History: Recent GFS Improvements



- GFSV16 upgrade in March 2021 included better use of dropsondes and flight-level data
- Added data improves track in sampled storms 10-20%



## Additional recon impact on GFS track





# Outline

- Background: Observations, modeling and data assimilation
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# Where We Stand: HAFS vs. HWRF

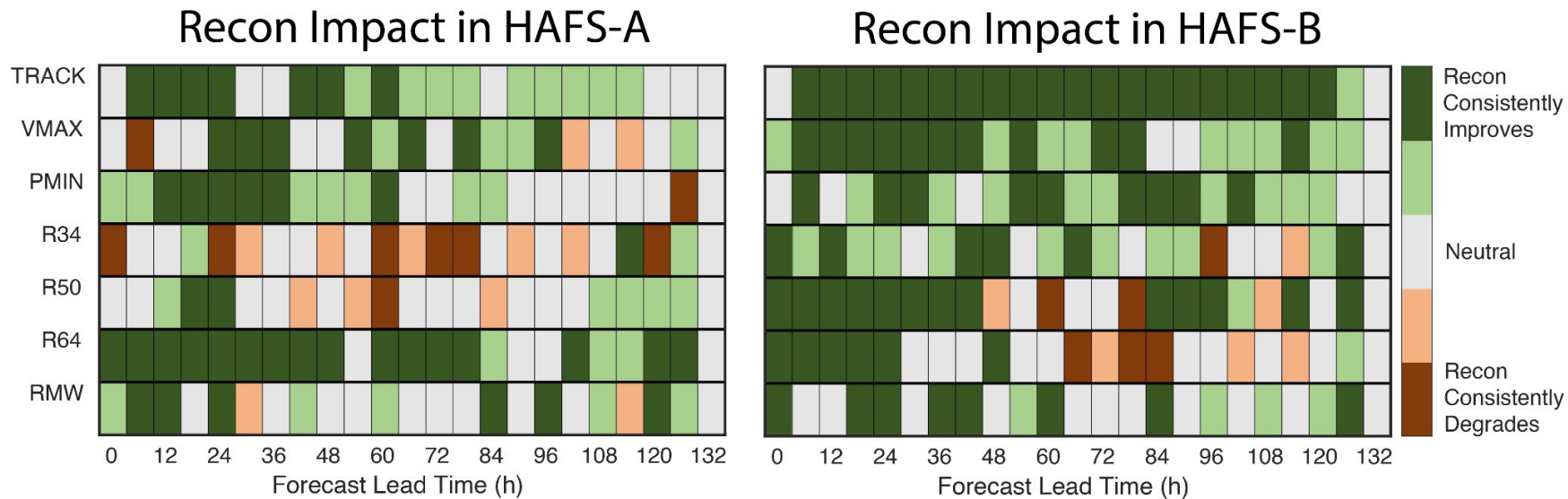
Metric	NATL	
	HAFS-A	HAFS-B
Track	<i>Mostly improved</i>	<i>Improved</i>
Intensity	Neutral to <i>improved</i>	<i>Improved</i>
Storm Size	RMW neutral, mixed for 34 kt, <i>reduced</i> for 50 kt and 64 kt radii	RMW neutral, increased for 34 kt, <i>reduced</i> for 50 kt and 64 kt radii
RI Metrics	Slightly behind HWRF	Slightly behind HWRF
P-W relationship	Neutral	Neutral

Negative
Neutral
Positive





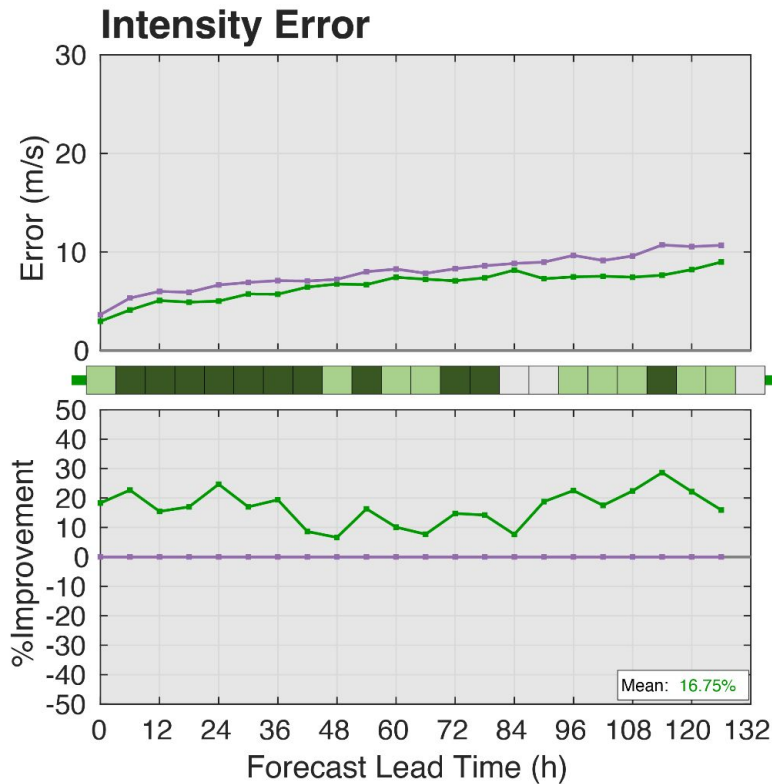
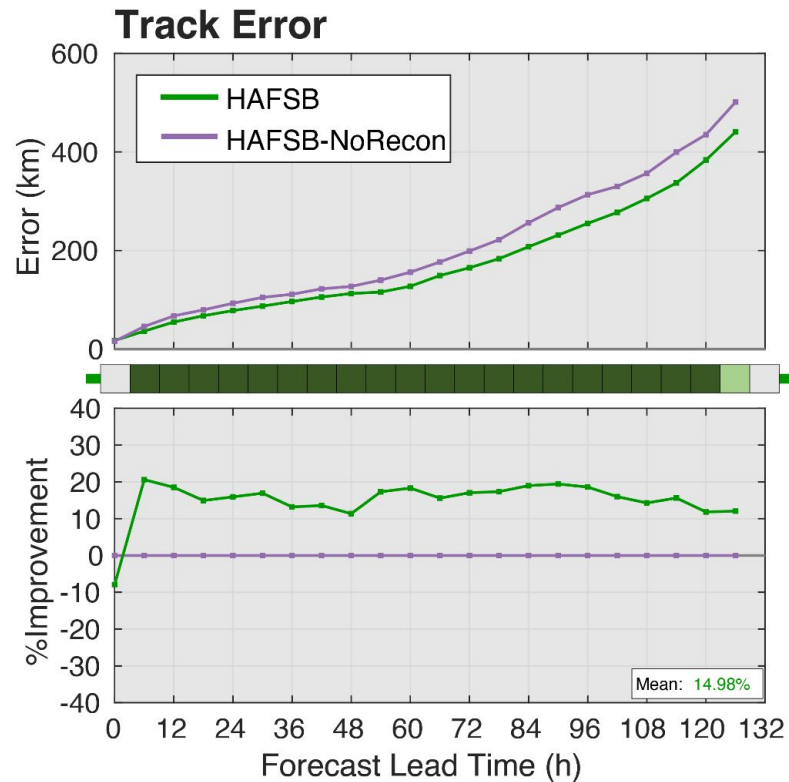
# Where We Stand: Recon Impact in HAFS



- Recon data impacts positive in both versions of HAFS
- Not as good in HAFS-A due to a setting in TS (improving in 2024)

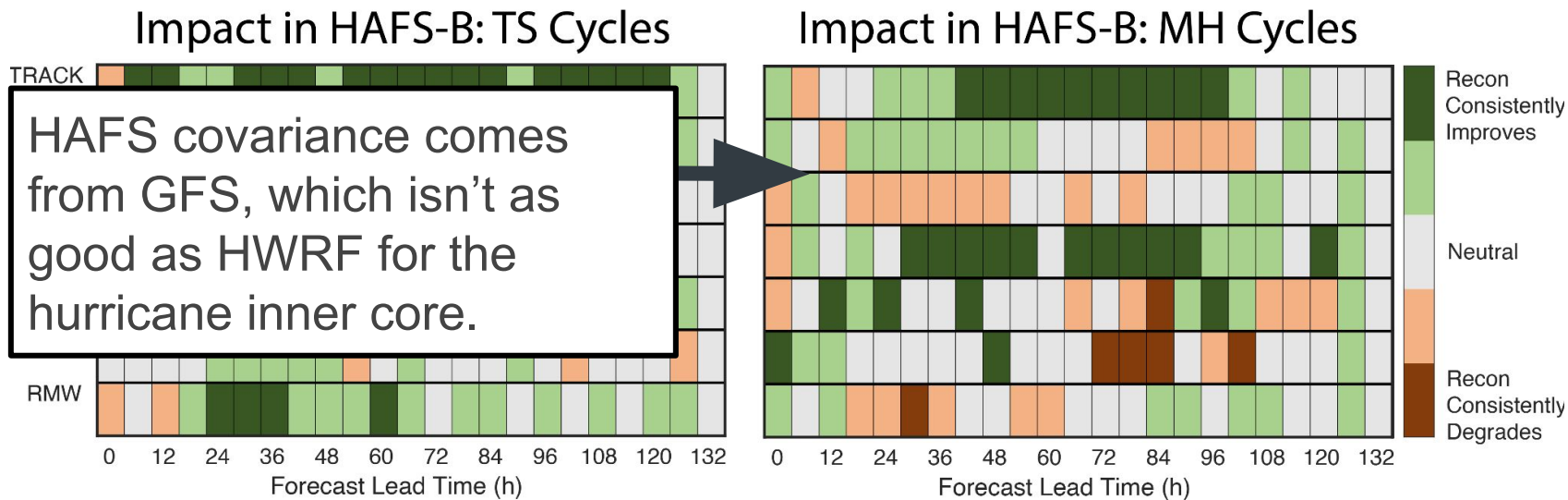


# Where We Stand: Recon Impact in HAFS





# Where We Stand: Recon Impact in HAFS



## Recon Impacts Compared with HWRF

- Better impact on track than in HWRF
- Impact on intensity varies: better for weak storms, worse for strong storms



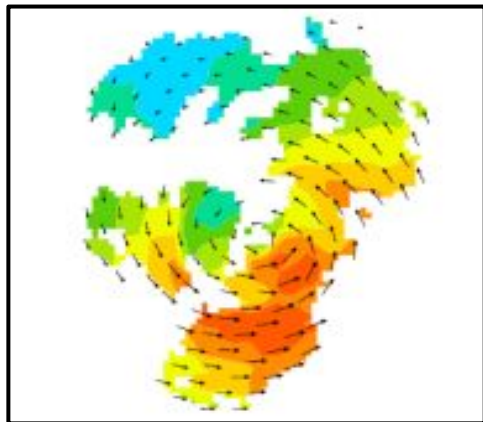
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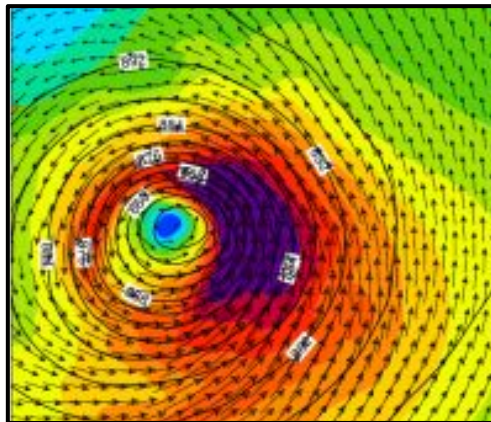




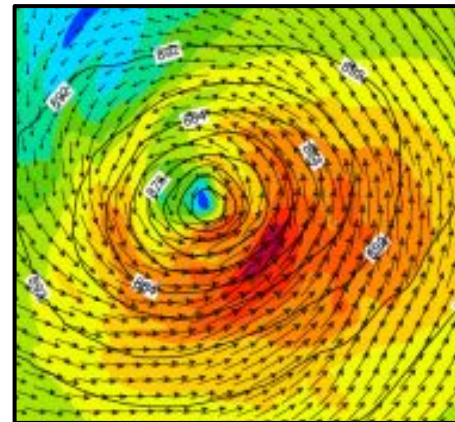
# Future: Improve DA in HAFS



**Observed Winds**



**Operational HWRf DA**



**Advanced HWRf DA**

Improving DA quality improves inner-core analyses

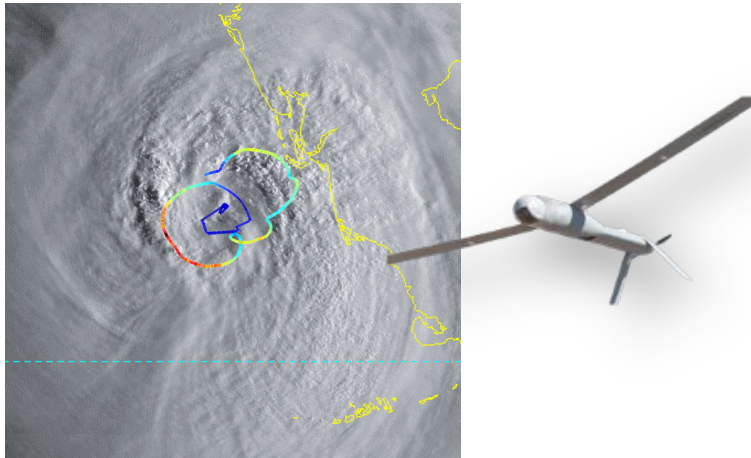




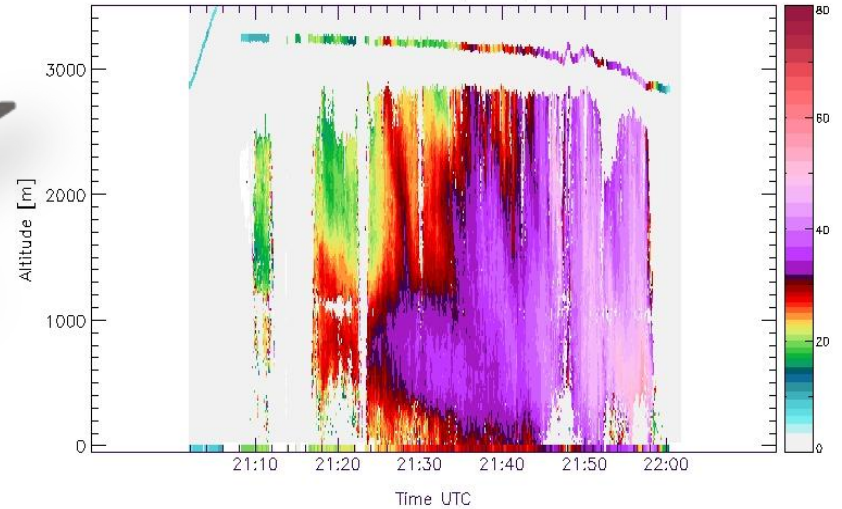
# Future: New Airborne Data



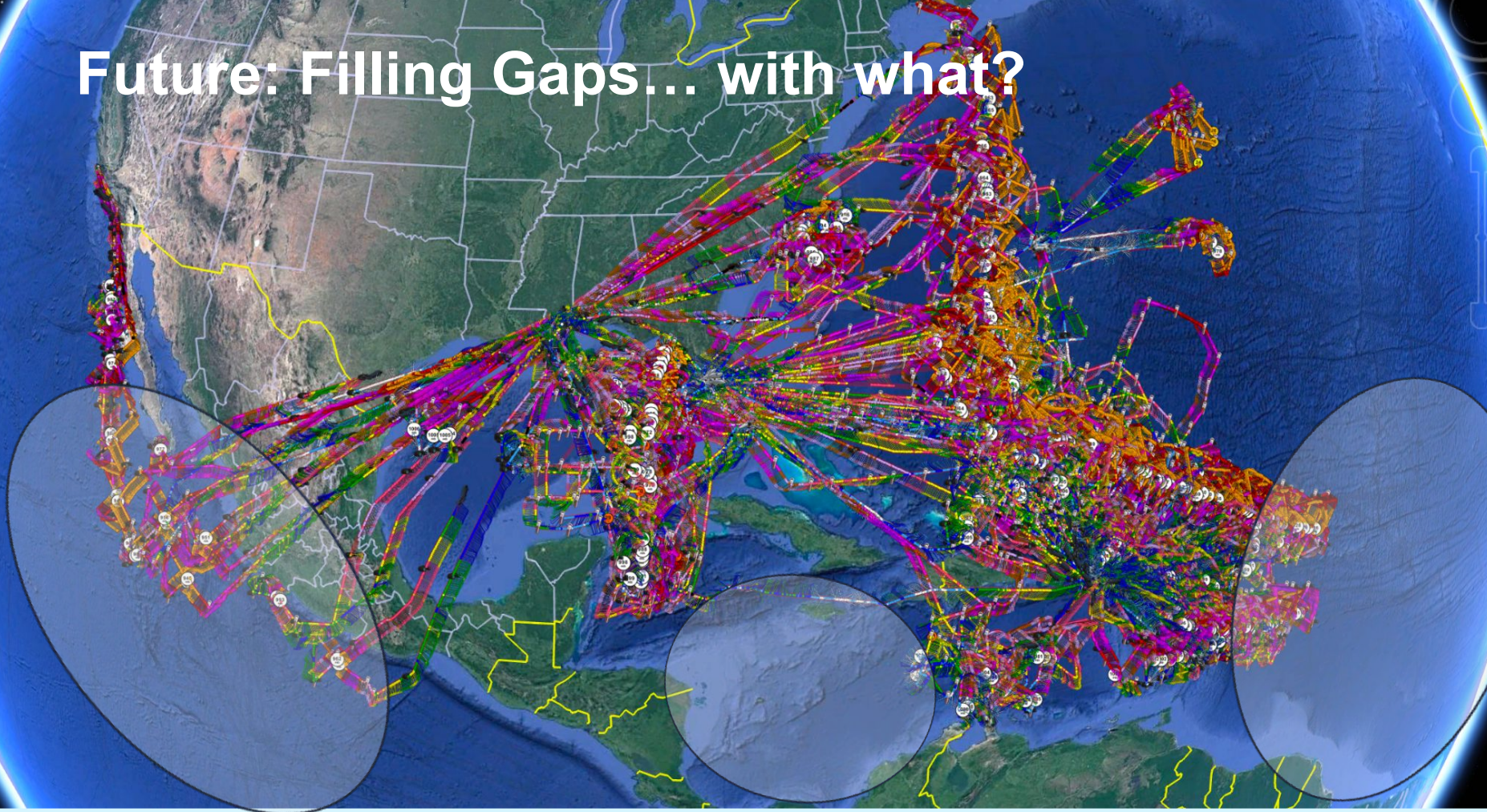
## SUAS track during Ian



## Horizontal Winds in Ian from IWRAP



# Future: Filling Gaps... with what?



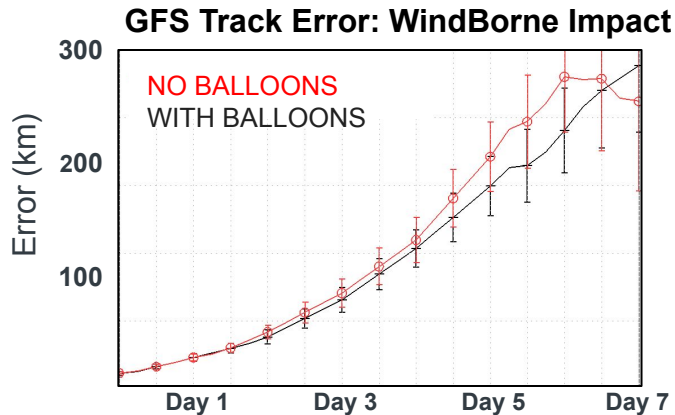




# Future: Uncrewed Systems to Fill Gaps



- WindBorne balloons have recently sampled NATL
- Surface to stratosphere profiles
- Wind obs fill a MAJOR gap (mid-levels)
- Improvements to large scale and TC track

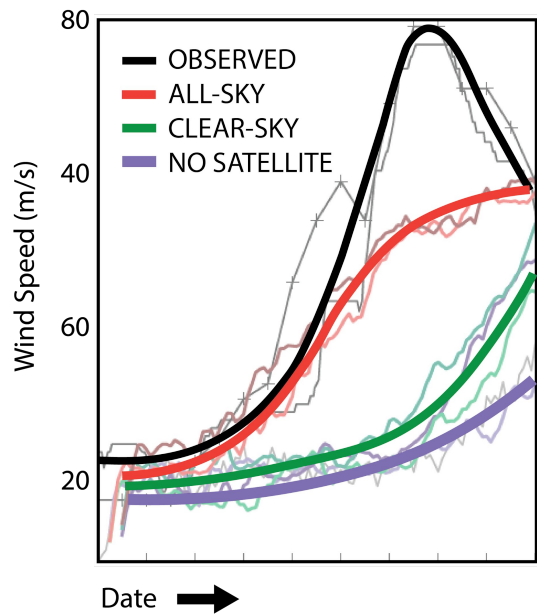




# Future: Improved Satellite DA to Fill Gaps



## Impact of Satellite DA on a TC Forecast



- Most storms do NOT have recon
- Satellite DA needs to help!
- Satellite DA for TCs is where recon DA was 10 years ago
- Initial results are showing amazing possibilities





# Summary



- NOAA TC prediction is undergoing dramatic advancements
- We are using more of the available data in DA, particularly from reconnaissance missions
- Long term plans address ongoing issues and allow for greater data usage
- The above factors should contribute to forecast improvement... BUT





# Summary



This will be contingent on how much our society wants to invest in it

