Development of the ground-based radar data assimilation capability within the HWRF hybrid ensemble-variational system to improve the land-falling hurricane prediction

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In collaboration with
EMC and HRD

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Background and Objectives

- ❑ Implement ground based radar (GBR) data assimilation capability into HWRF hybrid EnVar system

- ❑ Perform experiments to determine the best DA configuration for GBR data

- ❑ Comprehensive evaluation of the impact of GBR data

(i) on track, intensity, precipitation forecast
(ii) on predictability of tropical cyclone dynamic processes
(iii) relative to other inner core observations (e.g. TDR)

- ❑ Document the development and results in peer reviewed papers

- ❑ Transition the development into HWRF operational data assimilation system

Major milestones

- Developed the GBR radial velocity (Vr) assimilation capability in HWRF

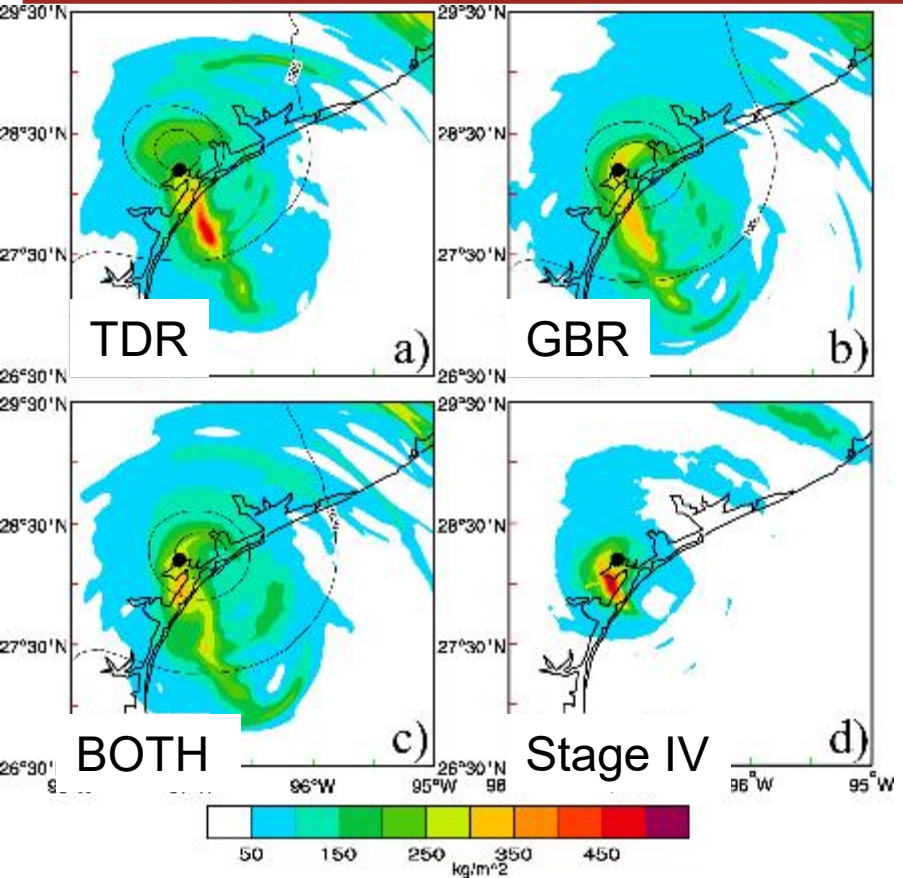
- Successfully transitioned the GBR Vr assimilation capability in operational HWRF since 2020 (in collaboration with J. Sippel) : (1) add capability to homogeneously superob/thin the GBR observations, (2) add capability to select certain radar sites instead of all sites, (3) account for vertical component in radial wind observation operator

- Performed detailed case studies (Harvey 2017; Matthew 2016) to optimize the hourly GBR DA configuration and to comprehensively examine the impact of the GBR data assimilation

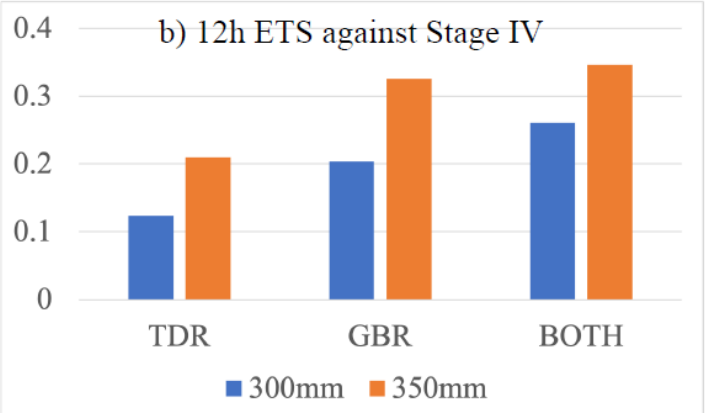
- Prepared peer reviewed papers

Harvey 2017: Accumulated Precipitation Prediction (Lu and Wang 2021)

~12-h Accumulated Precipitation @ 201708260600 UTC



- The 12-hour accumulated precipitation is best predicted with both TDR and GBR assimilated, immediately followed by GBR alone.
- Statistics with 31 12-hour forecasts show consistent improvements.



Impact of Assimilating Ground-Based and Airborne Radar Observations for the Analysis and Prediction of the **Eyewall Replacement Cycle** of Hurricane Matthew (2016) using HWRF Hybrid 3DEnVar System

❑ Motivations

- Dynamical models continue to struggle with the prediction of large intensity fluctuations associated with processes such as **Eyewall Replacement Cycles** (ERC) and Rapid Intensification

- Modeling studies with real cases have not focused on the accuracy of timing and structural evolution of ERC forecasts compared to observations

- In order to obtain more realistic forecasts for ERC events, more accurate analyses of TC structure are expected to be needed to initialize the forecast

- No/limited published studies comparing the assimilation of the two types of inner core Doppler Radar observations from GBR and TDR, including assimilation of them simultaneously.

Green, Wang and Lu 2021

Objectives

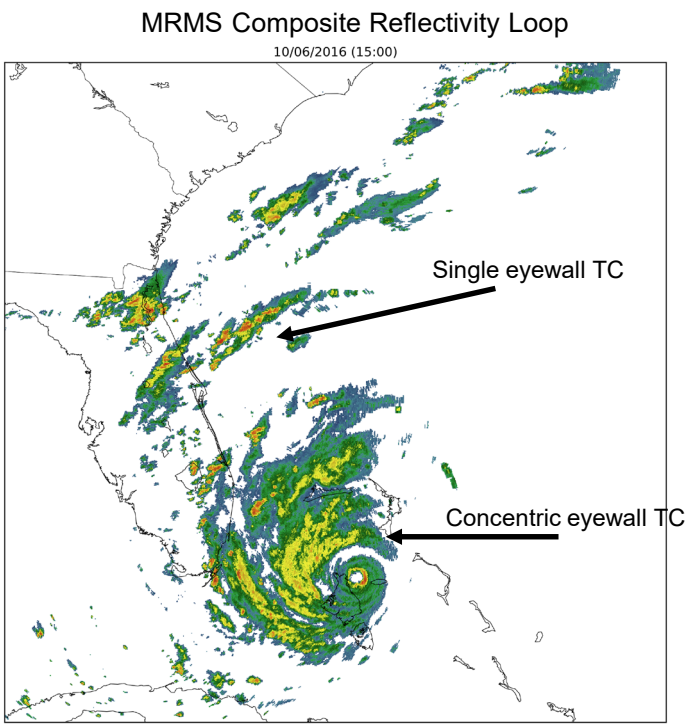
- Assess the impacts of assimilating GBR and TDR radial velocity observations individually, and in combination, on:

  1. The analysis of Matthew's concentric eyewall structure and evolution throughout the weakening and reintensification phases

  2. The forecasts of the ERC during the weakening and reintensification phases

Data and Methods

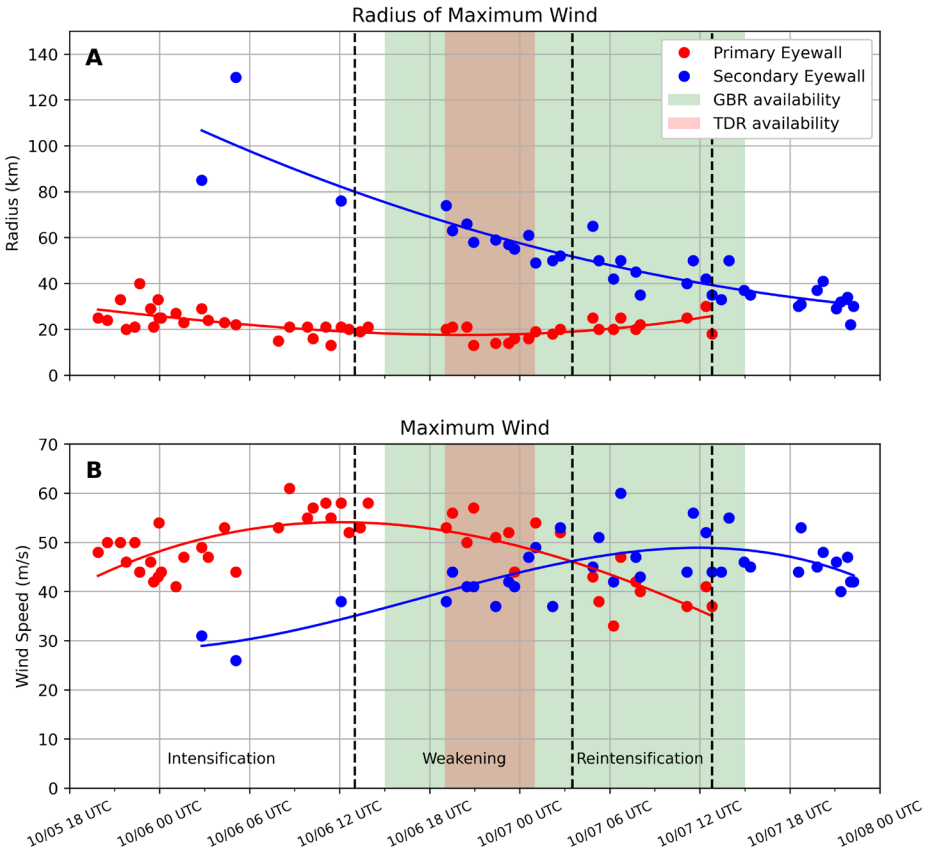
Hurricane Matthew



- On October 6-7, 2016 Matthew paralleled Florida's east coast while completing an ERC
- Event was sampled by coastal radars in Miami (KAMX), Melbourne (KMLB), and Jacksonville (KJAX) from 1500 UTC October 6 and onward
- Also sampled by TDR for about a 7-hour period from 1900 UTC October 6 to 0100 UTC October 7

Data and Methods

Quantitative Description of Matthew's ERC



- Created using the methodology of Sitkowski et al. (2011)
- Tracks the evolution of eyewalls' strength and radial locations throughout the ERC from Flight Level (FL) wind observations
- Cubic fits are shown to illustrate trends, which will be used as proxies for radial location of eyewalls and intensity trends in the study

Data and Methods

Description of Experiments

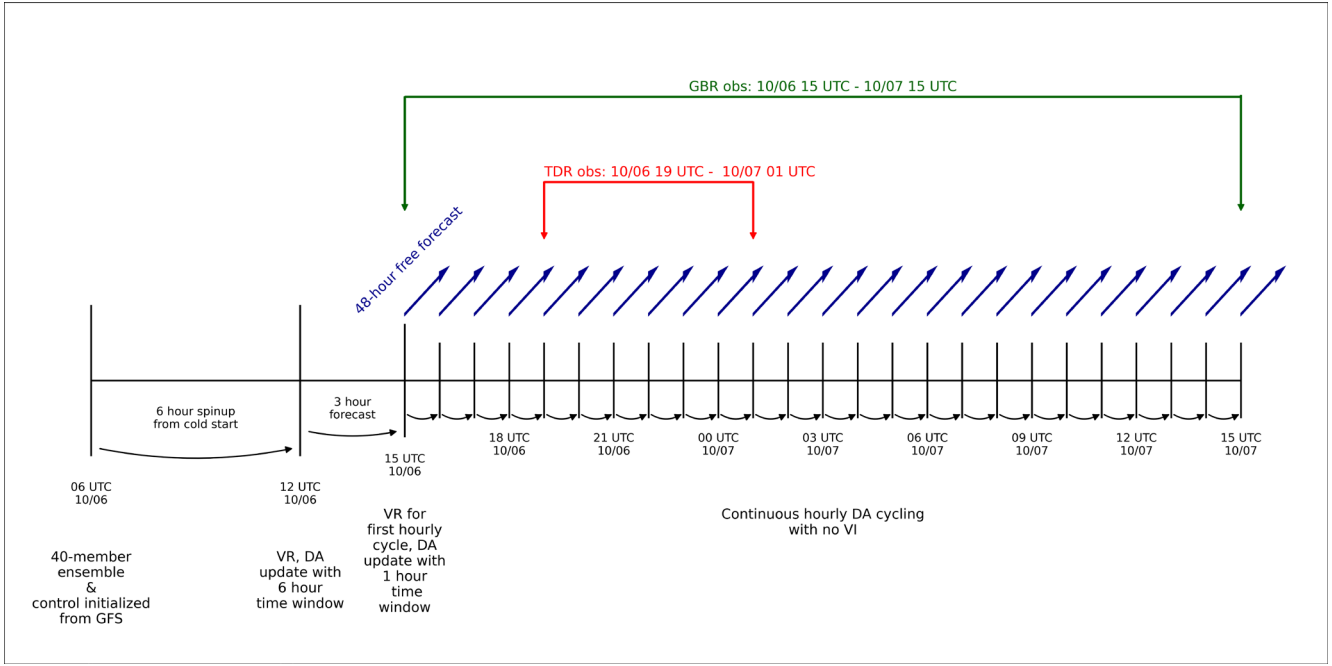
- Four different cycling experiments are performed

- Baseline observations include:
  1. Conventional in-situ observations (prepbfur file)
  2. Satellite clear air radiances
  3. TCVital MSLP
  4. Satellite winds

Observations /Experiment	Baseline	TDR	GBR
Control	✓	×	×
TDR	✓	✓	×
GBR	✓	×	✓
GBTDR	✓	✓	✓

Data and Methods

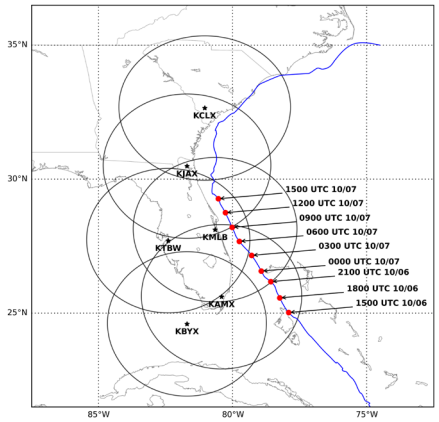
Experimental Setup

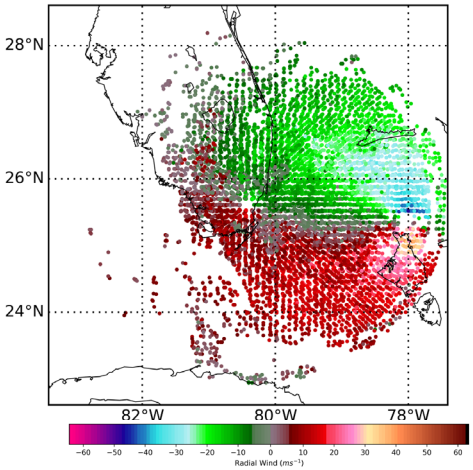


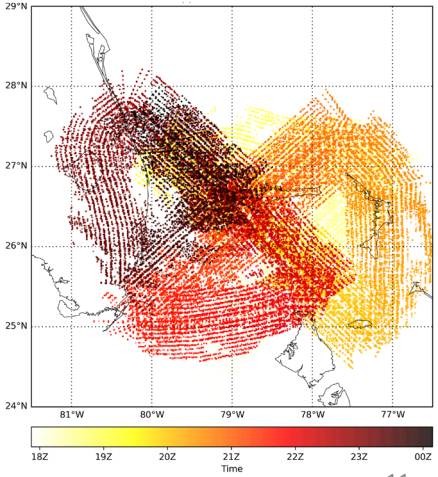
Data and Methods

GBR and TDR Observations

	Ground Based Radar Observations	Tail Doppler Radar Observations
Pros	Continuous availability near coasts	Superior lower level coverage during penetration legs, more available over oceans
Cons	Lower level coverage can be limited, when the storms are away from the land	Non uniform 3D coverage esp. in downwind legs, non uniform coverage in time

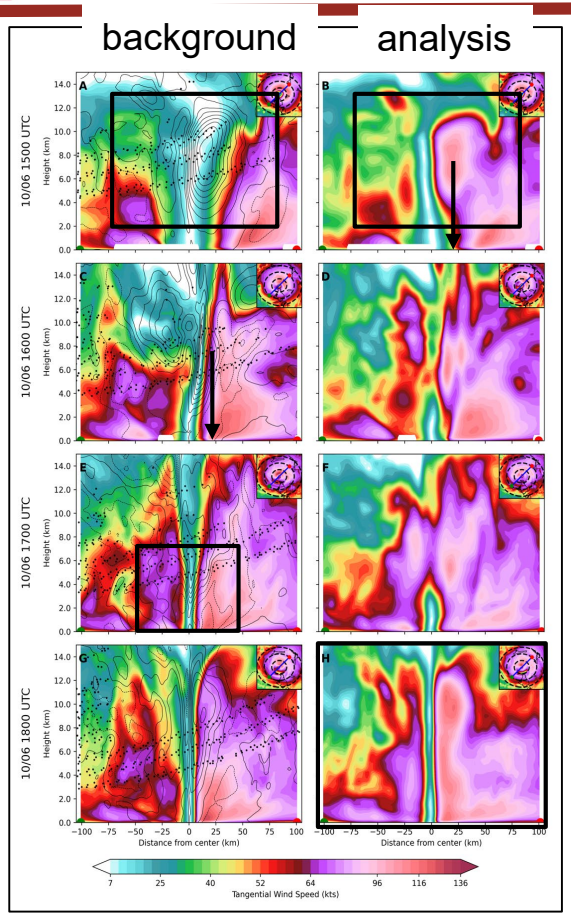






Results

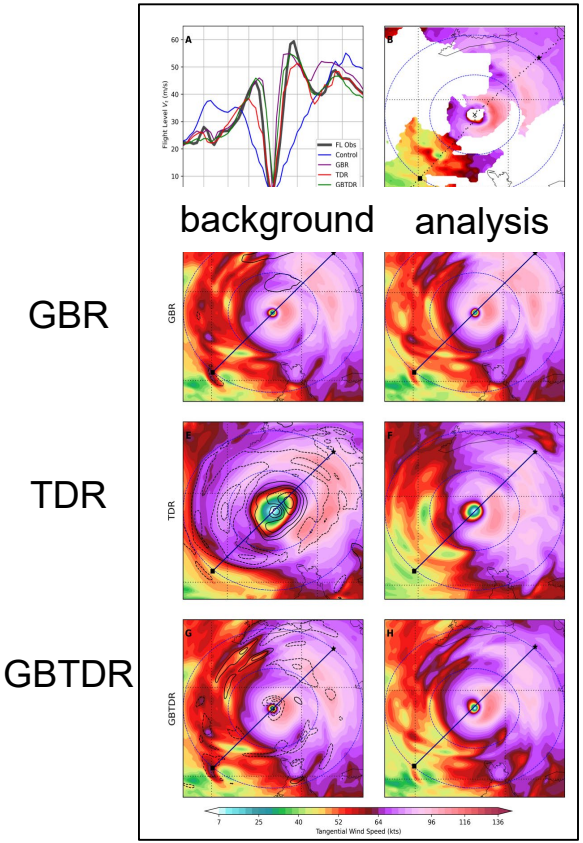
GBR DA cycling



- ❑ DA cycling with GBR observations is able to correct initially inconsistent storm structure in just 4 cycles, even with poor lower level coverage of observations
- Wind field is contracted at upper levels through initial DA
- Contracted wind field from DA is extended into the lower levels through background forecast
- As lower level GBR coverage improves, analysis increments start to extend to the surface
- By 1800 UTC, the DA cycling has established CE structure

Results

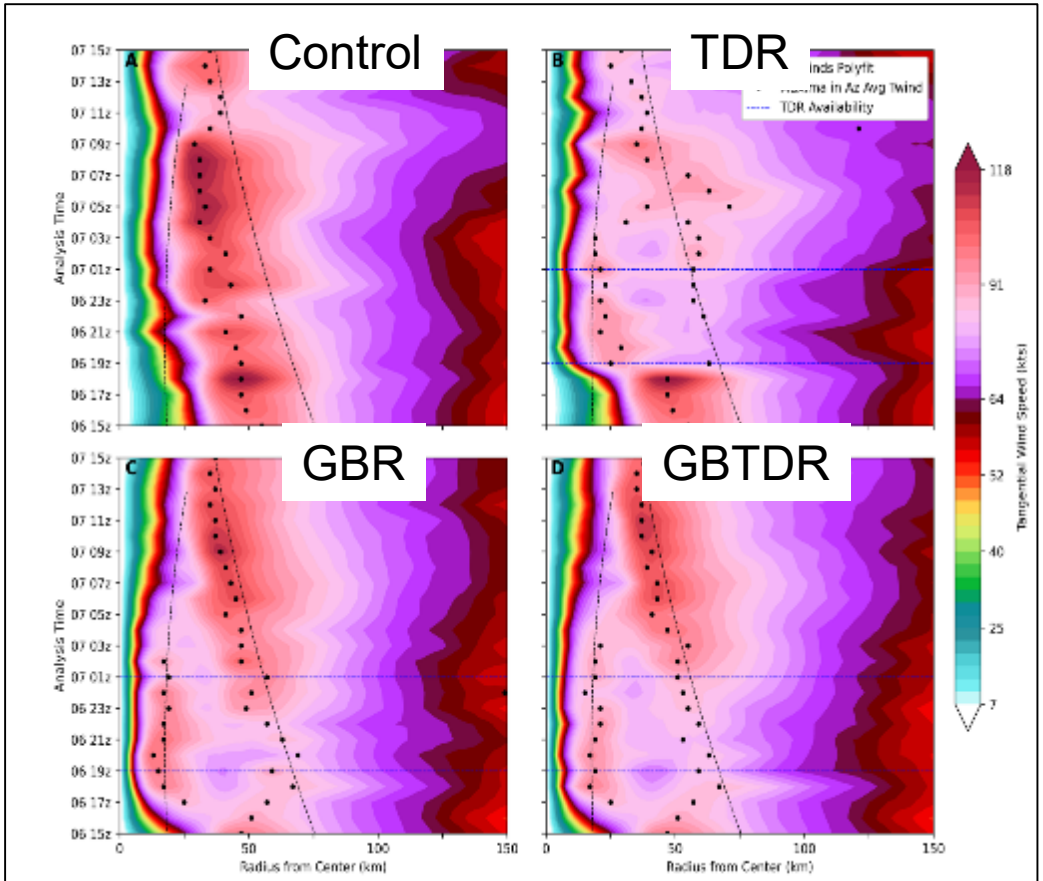
Relative Impacts of Assimilating TDR and GBR Observations: 1900 UTC cycle with TDR penetration leg



- GBR:
  - No major changes to GBR background → analysis has stabilized
  - Comparison with FL obs indicate eyewalls are located too far inward
  - Diagnostics suggest this is from lack of lower-level observational coverage
- TDR:
  - Analysis increments show contraction of the primary eye, and the establishment of a secondary eyewall
  - Correction to CE structure accomplished in 1 DA update (penetration leg)
  - FL obs comparison indicate primary eyewall has not contracted inward enough
- GBTDR
  - Increment structure shows an expansion of primary eyewall, and secondary eyewall on the right side
  - GBR and TDR can complement each other when e.g. vertical observation distributions vary

Results

Evolution of 1km Azimuthally Averaged Analysis Tangential Winds



- Control shows no ability to capture correct ERC structural changes
- GBR and GBTDR show most realistic ERC structural evolution
  - Quickly establish CEs
  - Have slight differences during TDR availability
  - Capture reintensification and have realistic analyzed secondary eyewall location
- TDR shows least realistic structure out of 3 DA experiments
  - CE establishment is delayed until obs become available
  - CE structure the rest of the cycling is less realistic than GBR and GBTDR
  - Hypothesized to be a result of inconsistent horizontal observation distribution
  - Reintensification not captured

Results

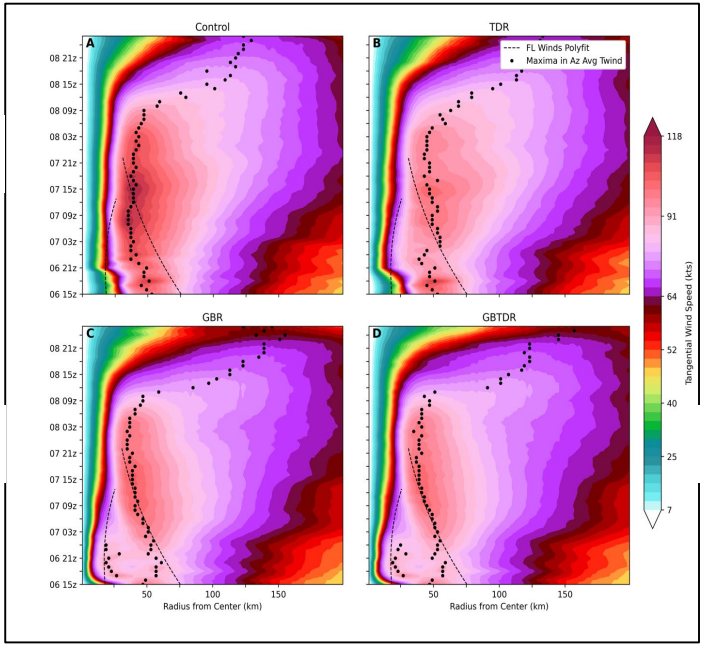
Structural Forecast

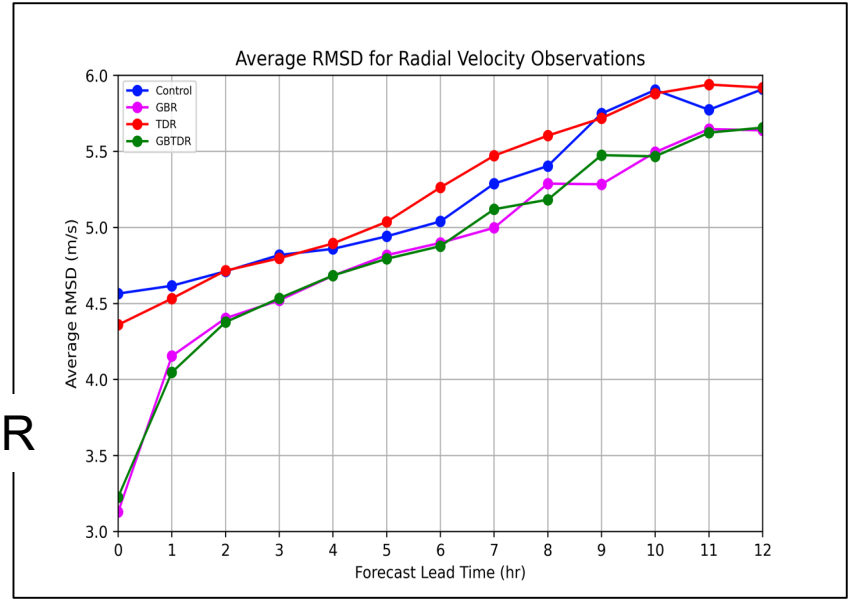
Control

TDR

GBR

GBTDR

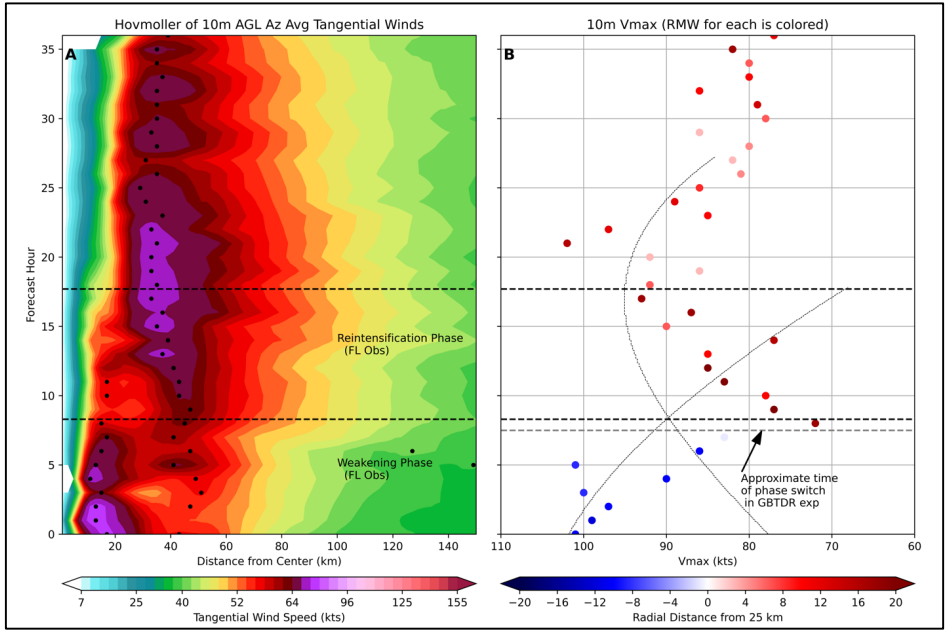




- Control: No ability to capture correct structural forecasts
- TDR: Not able to capture primary eyewall consistently
- GBR and GBTDR: Consistently forecast both primary and secondary eyewalls
- Forecast RMSD against GBR observations shows the most accurate forecast by GBR and GBTDR

Results

Intensity and Structural Changes for GBTDR forecast initialized @ 1900 UTC



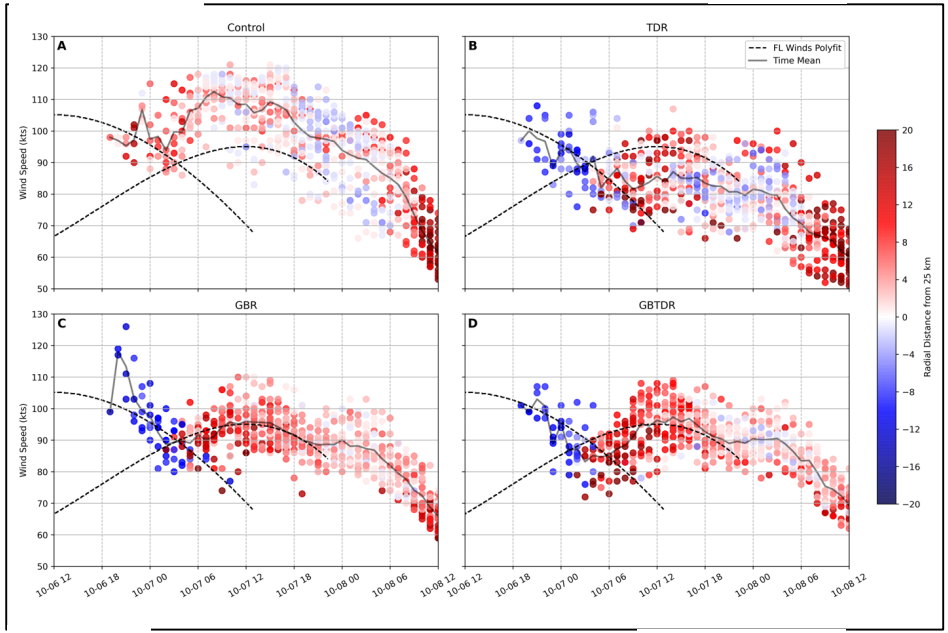
- During weakening phase, primary eyewall is dominant, wind max coming from primary eyewall
- As secondary eyewall contracts and strengthens, it overtakes the primary in intensity, entering the reintensification phase
- This example demonstrates that structural and intensity forecasts are consistent with expected evolution of the ERC

Results

Intensity and Structural Changes: All Forecasts initialized after 1800 UTC

Control

TDR



GBR

GBTDR

- GBR and GBTDR show much clearer switch from blue (primary eyewall) to red (secondary eyewall) when the dip in intensity happens, compared to TDR.
- Intensity trends previously discussed are physically consistent with structural forecasts
- Some evidence of a blue/red shift in TDR compared to Control

Plans

- Publish work as peer reviewed papers
- Develop, test and document ground based radar (GBR) reflectivity data assimilation

NWS/OSTI 2018 FFO PI Presentation
Project title
Project Status as of Oct, 2021

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Project Information and Highlights

Leads:
Xuguang Wang, University of Oklahoma, Multiscale data Assimilation and Predictability (MAP) lab

Scope:
Develop the capability of and evaluate the impact of ground based radar data assimilation in HWRF and collaborate with NOAA to transition the new capability into HWRF operation

Expected Benefits:
- The ending project Readiness Level is expected to be 7-8
- The ground based radar data assimilation capability is expected to improve operational tropical cyclone prediction in HWRF
- Several presentations were given in conferences and 2-3 papers are expected to be published in peer reviewed journals

Implementation Date:
- The new ground based radar radial velocity data assimilation capability is already implemented in operational HWRF beginning 2020
- Additional capabilities to enhance the assimilation is planned to be implemented operationally

Challenges/Problems:

Obtaining access to Jet was delayed for US student. International student has no access to Jet. Efforts have been made to reduce the impact. The project is under no cost extension.

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Deliverables

Milestones	Completion Quarter	Status
Develop and implement ground based radar (GBR) radial velocity assimilation in HWRF	2	Completed
Perform initial test of the GBR Vr assimilation with selected case(s)	3	Completed
Perform systematic cycled GBR Vr assimilation experiments with selected case(s)	7	Completed
Conduct comprehensive evaluation to optimize the configuration and to diagnose the impacts	10-11	Completed
Deliver GBR Vr assimilation capability and operationally implement GBR Vr assimilation in HWRF	7	Completed
Prepare GBR Vr assimilation results for peer reviewed publications	12-13	Near completion
Address reviewer comments and get papers accepted for publication	13-15	Ongoing
Develop, test and document ground based radar reflectivity assimilation	16	ongoing

R Program Attention Required	Y Potential Program Attention Needed	G On Target