Evaluation of Unified Forecast System Tropical Cyclone Quantitative Precipitation Forecasts

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Overview

Introduction

- Quantitative precipitation forecast (QPF) verification provides insight on both storm structure and total precipitation, which is useful for understanding model processes
  - Microphysics, PBL, and other parameterizations & interactions between parameterizations
  - Establishing tools for large sample evaluations of QPF enables regular assessments
- Provide assessment of recently operational UFS-based Hurricane Analysis and Forecast System (HAFS) for TC precipitation forecasts
  - Storm focused evaluation using various methods
  - Over land and water
- HAFSv1 went operational 27 June 2023
  - Two configurations replacing operational Hurricane Weather Research and Forecast (HWRF) and Multi-scale Ocean-coupled Non-hydrostatic Model (HMON)

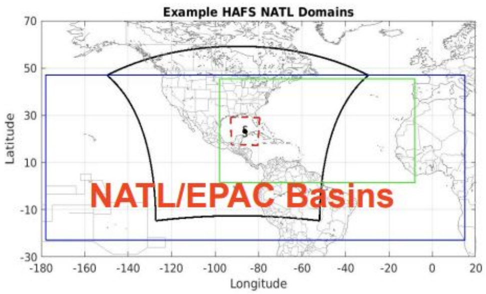

Fig1: HAFSv1 domain for NATL/EPAC basins, Mehra et al. 2023

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Overview

Model configurations

- HAFSv1 (HFSA, HFSB) evaluated for all 2021-2022 N. Atlantic basin storms
  - Evaluation using parent domain (6 km), masking for storm region
  - Operational baseline: HWRF

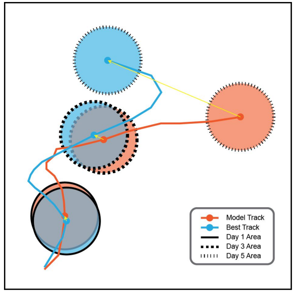
	HFSA	HFSB	HWRF
Land surface	Noah	Noah	Noah
Surface layer	GFS, HWRF TC-specific sea surface roughness	GFS, HWRF TC-specific sea surface roughness	GFDL surface layer (updated)
Boundary layer	SA-TKE-EDMF, TC-related calibration, mixing length tuning	SA-TKE-EDMF, TC-related calibration, tc_pbl=1, mixing length tuning	GFS-EDMF
Microphysics	**GFDL single-moment**	**Thompson double-moment**	**Ferrier-Aligo**
Radiation	RRTMG	RRTMG	modified RRTMG
Convection	Scale-aware SAS calibrated entrainment	Scale-aware SAS	scale-aware SAS

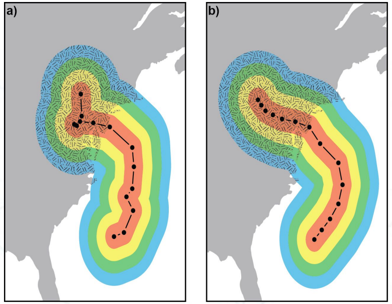
Different microphysics

Overview

Methodology

- Enhanced Model Evaluation Tools (METplus)
  - Tools: gen_vx_mask, regrid_data_plane, PCP-combine, Grid-stat, TC-RMW, MODE
- 6 hour precipitation accumulations, track shifting, land/water and storm based masking
  - 600-km mask around best track for each valid time
- Observations:
  - Integrated Multi-satellitE Retrievals for GPM (IMERG) verification over water
    - 1/10 deg, satellite precipitation product combining active, passive microwave, and geostationary satellite data
  - Climatology-Calibrated Precipitation Analysis (CCPA) verification over land
    - 5-km gauge corrected radar observation product (combines gauge analysis + stage IV)
- All model/observations re-gridded to common grid





Newman et al. 2023

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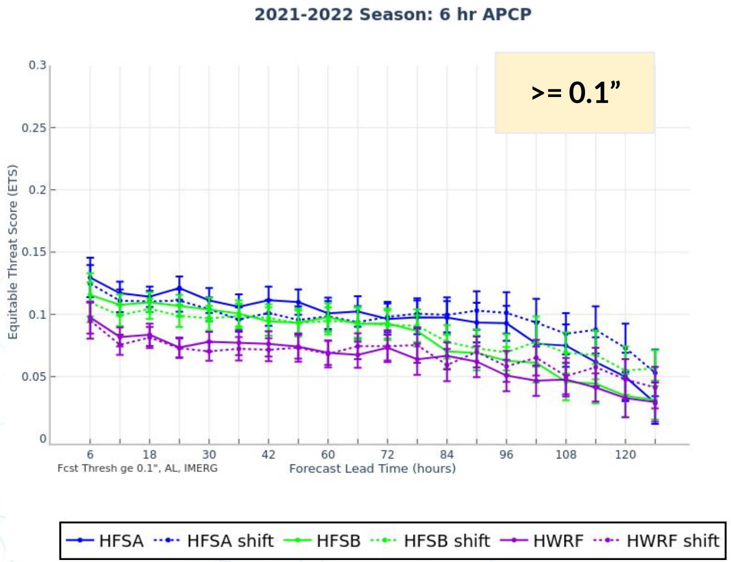
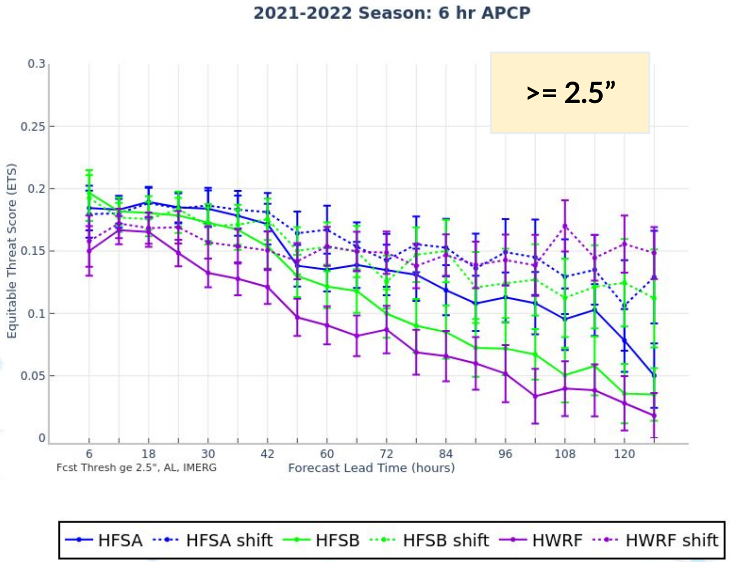
ETS: 0 = no-skill,
1 = perfect forecast

Grid-based QPF

Equitable Threat Score





- Impact from shifting less when there are many grid cells with precipitation (low thresholds)
- Shifting helps stabilize skill scores at longer lead times
- Low skill scores: issues with ETS calculation of random chance adjustment with many rainy grid cells over a small domain (Wang et al. 2014)

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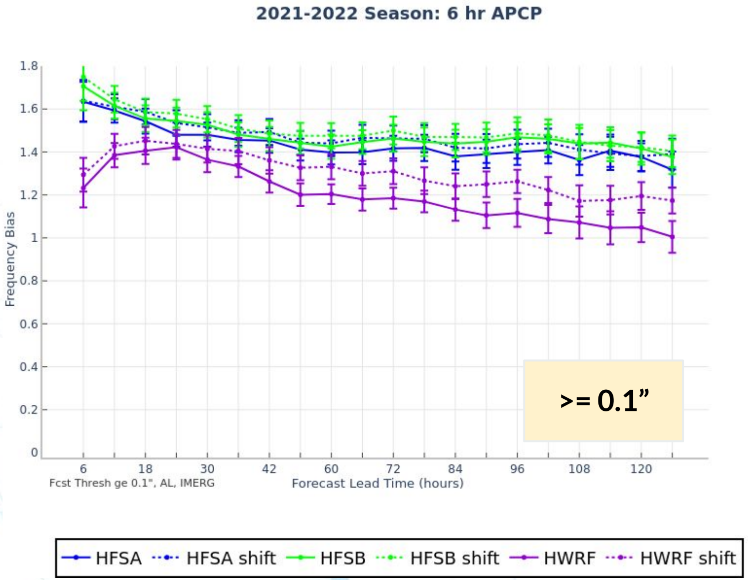
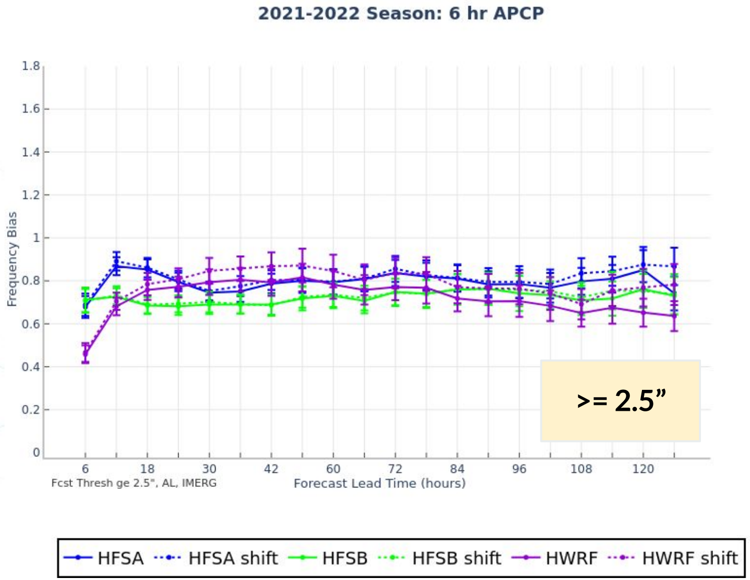
Grid-based QPF

Frequency Bias

FBIAS: “good forecast” = 1,
> 1 is forecasted too frequent,
< 1 is not forecasted frequently enough





- Over forecast precipitation for lower thresholds, under forecast for larger thresholds
- Shifting does not impact results - exception of HWRF at lowest thresholds (potentially large track errors)

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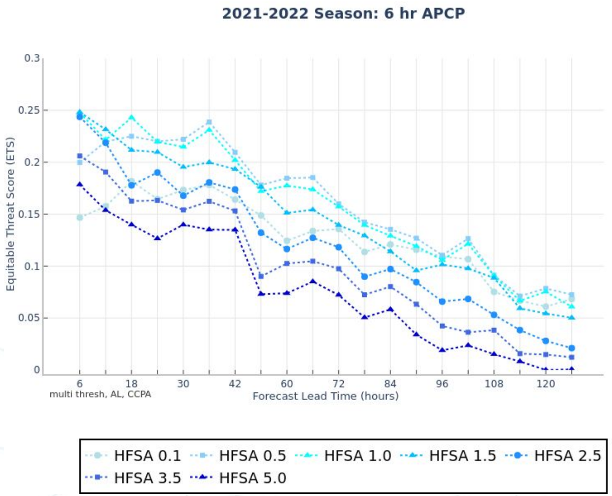
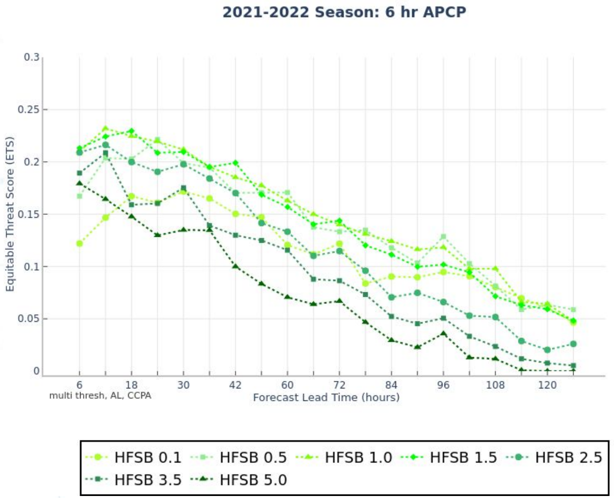
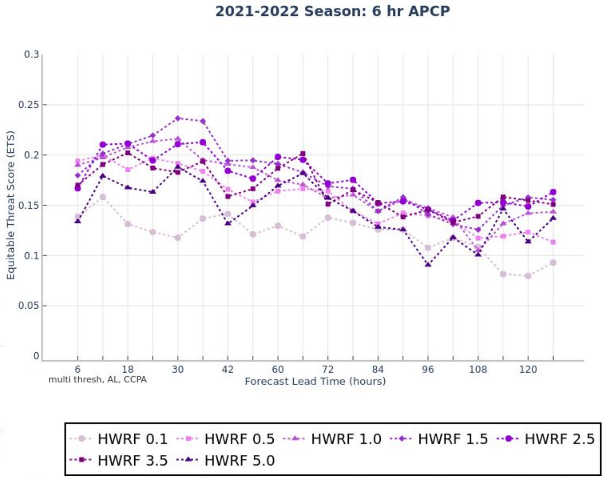
Grid-based QPF

Equitable threat score by threshold (over land)

Shifted tracks verified against CCPA







- Large thresholds & lowest (>= 0.1”) have lowest skill
- Intermediate (>= 0.5-1.5”) perform better for HAFS configurations
- HWRF skill more stable by lead time

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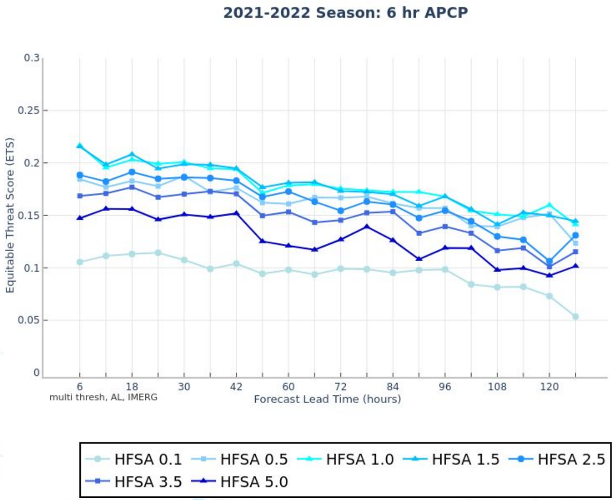
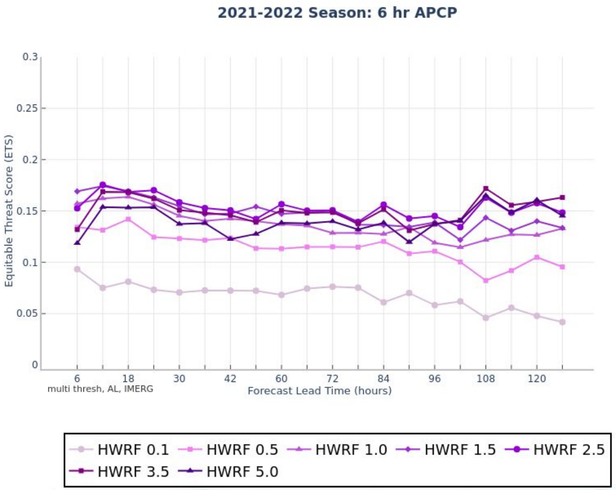
Grid-based QPF

Equitable threat score by threshold (over water)

Shifted tracks verified against IMERG





- >= 0.1" thresholds: lowest skill (ETS calculation)
- Track shifting results in fairly constant skill throughout forecast

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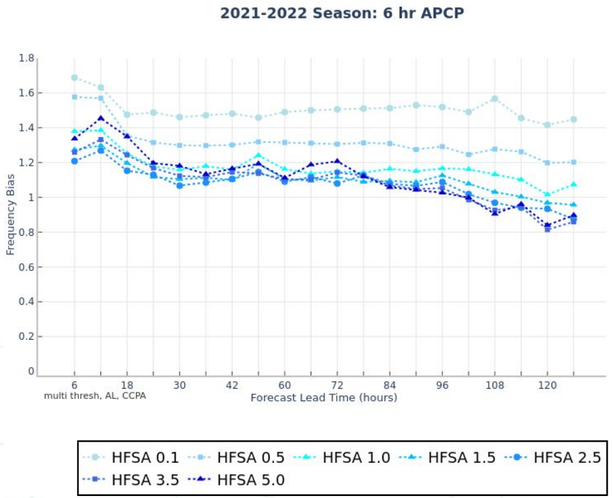
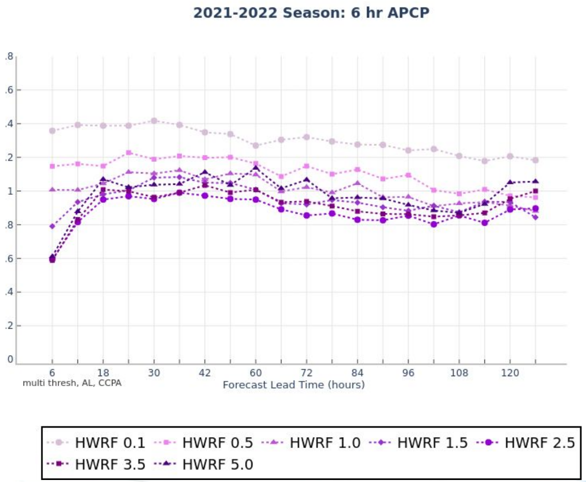
Grid-based QPF

Frequency Bias by threshold (over land)

Shifted tracks verified against CCPA





- Largest thresholds perform well, near 1.0
- Smaller thresholds tend to over forecast precipitation for all models/configurations

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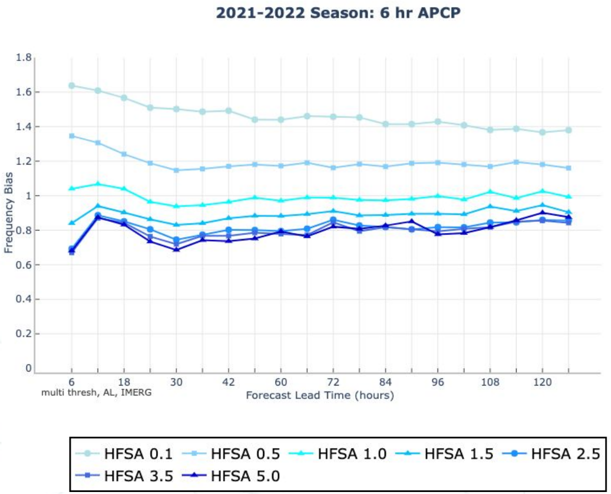
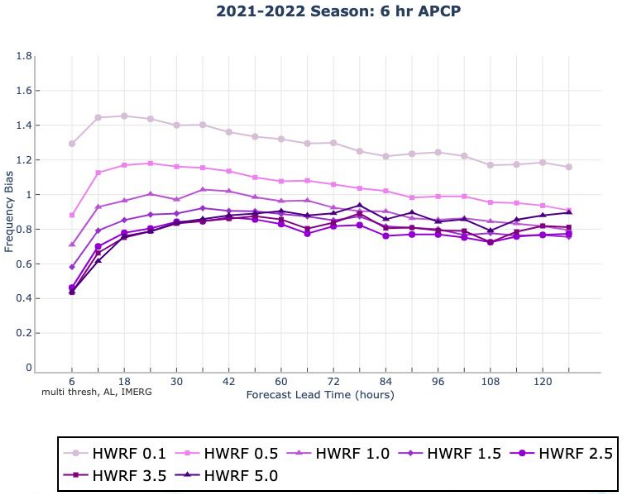
Grid-based QPF

Frequency Bias by threshold (over water)

Shifted tracks verified against IMERG



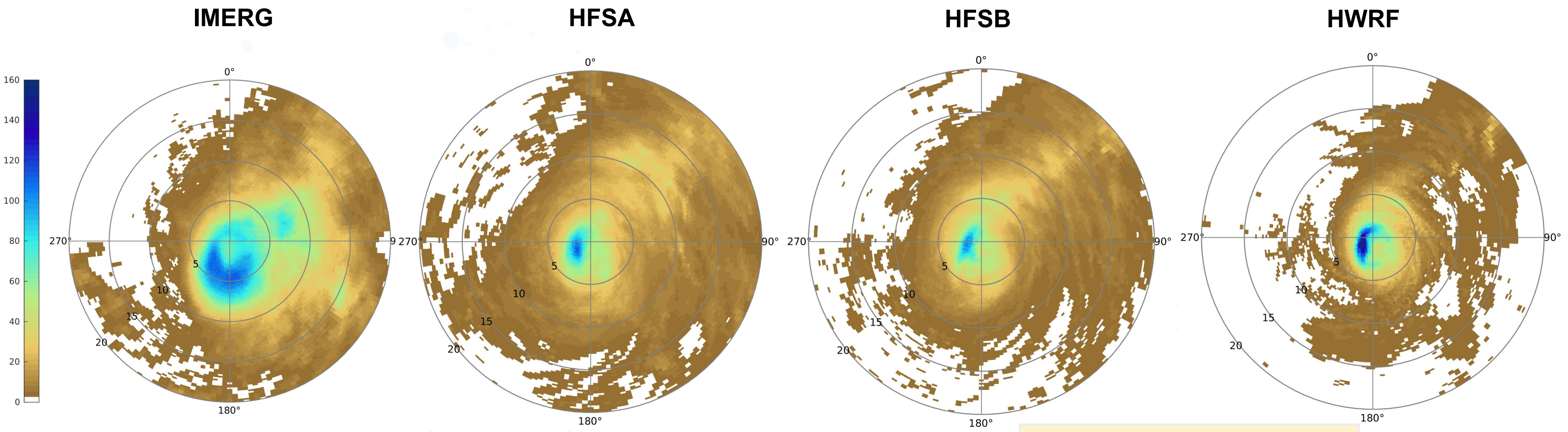


- Largest thresholds tend to under forecast precipitation for all models/configurations
- Smaller thresholds tend to over forecast precipitation for all models/configurations

Hurricane Ian

12-hr forecasts: Storm relative, normalized by RMW

Shading: precipitation accumulation (mm/6 hours)



Composites from 2022092500-2022092818

- IMERG shows larger storm and more precipitation in the eastern semicircle
- HAFS configurations similar
- HWRF more compact and more intense closer to center
- Less precipitation in the eastern semicircle for HWRF
- Persistent outer band in the upper right quadrant around 5-10 RMW (better placement in HAFS configurations)

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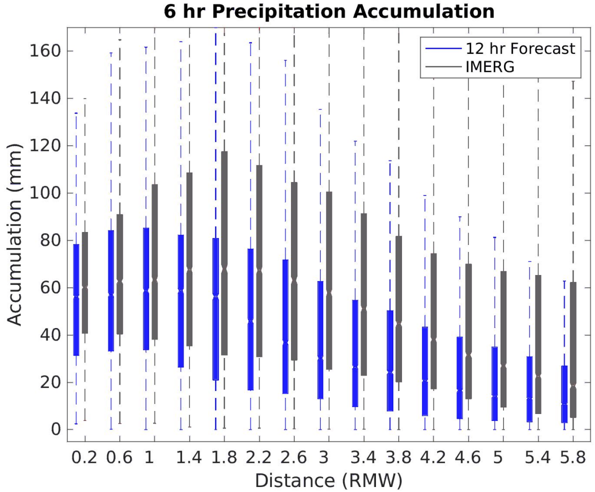
Hurricane Ian

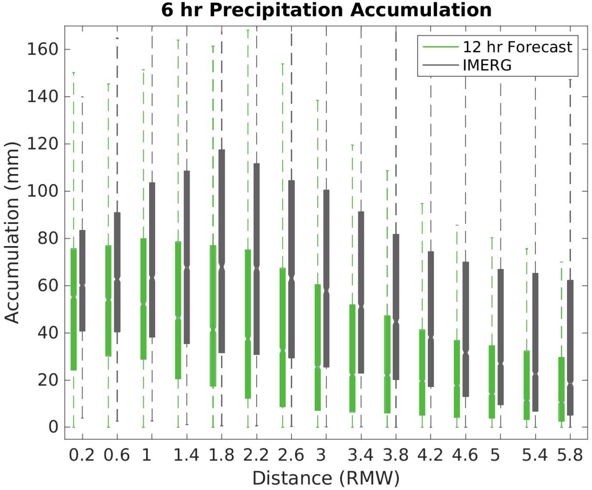
12-hr forecasts: Histograms by RMW

bins of 0.4 RMW

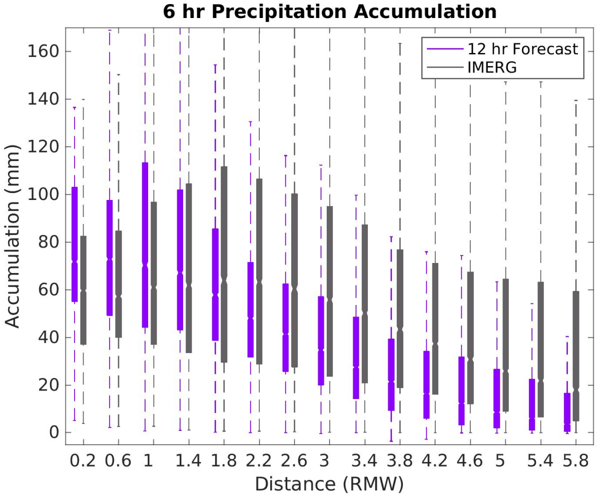
HFSA



HFSB



HWRF



- HAFS gradient - moving from center - better match IMERG
- HWRF has higher intensities closer to the RMW with a steep drop after about 2-3 RMW

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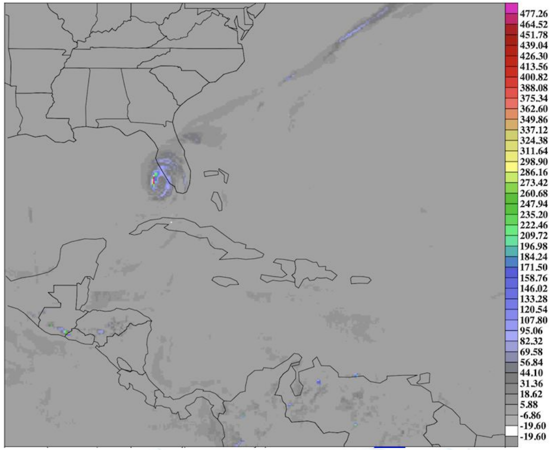
Hurricane Ian

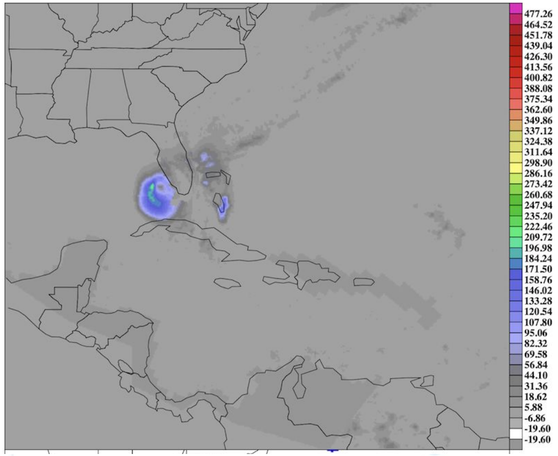
Method for Object Based Evaluation (MODE)

MODE object identification algorithm mimics subjective matching of observed and forecasted objects using a multistep process and fuzzy logic engine

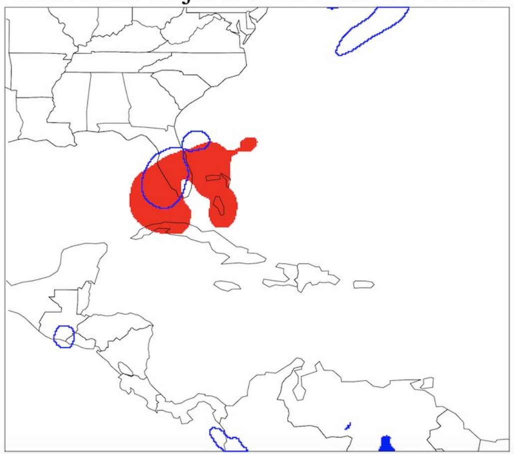
MODE: APCP at A6 vs APCP at A6
Forecast



MODE: APCP at A6 vs APCP at A6
Observation



Observation Objects with Forecast Outlines



- Example output from MODE algorithm: forecast and observed 6-hr acc precipitation
- Objects identified by the MODE algorithm: red observations, blue output model

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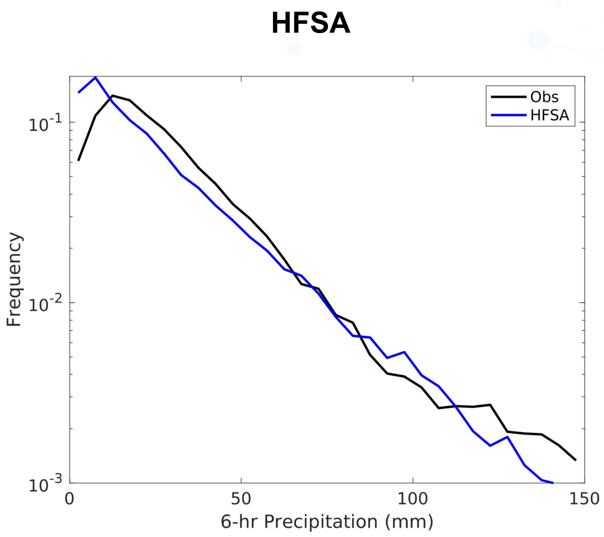
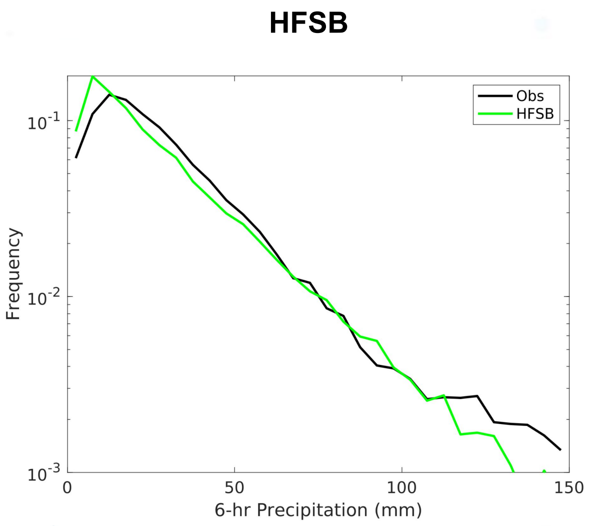
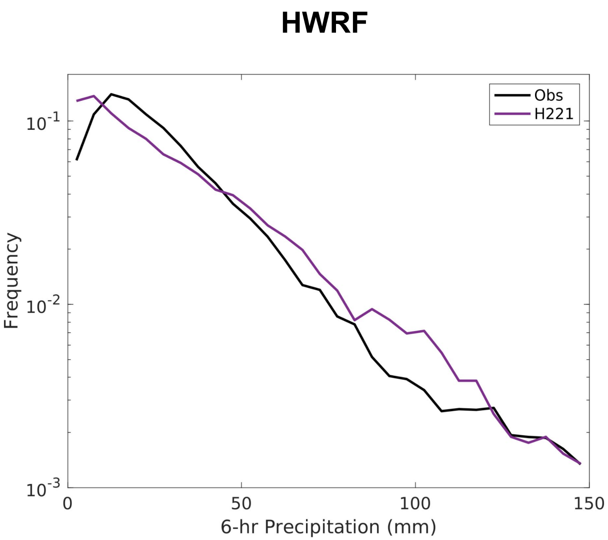
Hurricane Ian

MODE: 6-hr precipitation accumulation PDF (log frequency)

Includes all grid points with precipitation within object







- HAFS (HFSA, HFSB): more light precipitation, lower through most of the distribution
- HWRF: less light precipitation, more heavy precipitation (likely due to over forecast near the core)

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Conclusions

- The more complex microphysics in the HAFS configurations better represent the tropical cyclone (TC) precipitation and the features of the TC
- HAFSv1 configurations tend to over forecast precipitation for smaller thresholds and under forecast precipitation for larger thresholds
- Considerations are needed for assessing skill for lowest thresholds for smaller verification domain with high number of precipitating grid cells

HFSA and HFSB retrospective runs were conducted by NOAA EMC and HRD hurricane teams

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