Evaluation of Unified Forecast System Tropical Cyclone Quantitative Precipitation Forecasts

Kathryn Newman¹,², B. Nelson¹,², L. Pan²,³,⁴, M. Biswas¹,², E. Grell²,⁴,⁵, W. Li¹,²

¹ National Center for Atmospheric Research
² Developmental Testbed Center
³ NOAA/Global Systems Laboratory
⁴ NOAA/Physical Sciences Laboratory
⁵ CU Cooperative Institute for Research in Environmental Sciences
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)
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

<table>
<thead>
<tr>
<th></th>
<th>HFSA</th>
<th>HFSB</th>
<th>HWRF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land surface</td>
<td>Noah</td>
<td>Noah</td>
<td>Noah</td>
</tr>
<tr>
<td>Surface layer</td>
<td>GFS, HWRF TC-specific sea surface roughness</td>
<td>GFS, HWRF TC-specific sea surface roughness</td>
<td>GFDL surface layer (updated)</td>
</tr>
<tr>
<td>Boundary layer</td>
<td>SA-TKE-EDMF, TC-related calibration, mixing length tuning</td>
<td>SA-TKE-EDMF, TC-related calibration, tc_pbl=1, mixing length tuning</td>
<td>GFS-EDMF</td>
</tr>
<tr>
<td>Microphysics</td>
<td>GFDL single-moment</td>
<td>Thompson double-moment</td>
<td>Ferrier-Aligo</td>
</tr>
<tr>
<td>Radiation</td>
<td>RRTMG</td>
<td>RRTMG</td>
<td>modified RRTMG</td>
</tr>
<tr>
<td>Convection</td>
<td>Scale-aware SAS calibrated entrainment</td>
<td>Scale-aware SAS</td>
<td>scale-aware SAS</td>
</tr>
</tbody>
</table>
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
Grid-based QPF

Equitable Threat Score

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

- 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)
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)
Grid-based QPF
Equitable threat score by threshold (over land)

- 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

Shifted tracks verified against CCPA
Grid-based QPF
Equitable threat score by threshold (over water)

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

Shifted tracks verified against IMERG
Grid-based QPF
Frequency Bias by threshold (over land)

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

Shifted tracks verified against CCPA
Grid-based QPF
Frequency Bias by threshold (over water)

- 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

- 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)

Composites from 2022092500-2022092818
Hurricane Ian
12-hr forecasts: Histograms by RMW

- 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
Hurricane Ian
Method for Object Based Evaluation (MODE)

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

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

- 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)
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 overforecast precipitation for smaller thresholds and underforecast 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.

Kathryn Newman
National Center for Atmospheric Research
knewman@ucar.edu
DTC Visitor Program

https://dtcenter.org/visitor-program

Propose a project to work on with us!

Two types of visitor projects:

PI - Up to 2 months salary, travel and per diem - can be split into multiple visits

Graduate Student - Up to 1 year of temporary living per diem and travel expenses for graduate student, plus support for advisor visits

See Announcement of Opportunity on DTC website for more information on how to apply and guidance on topics of interest