Evaluating Model Physics in the Unified Forecast System (UFS) Medium-Range Weather Application

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Abstract

To support the development of the Global Forecast System (GFS) physics suite and identify opportunities for improving the model physics in the UFS, the Developmental Testbed Center (DTC) conducted an array of analyses for evaluating the operational GFSv15 forecasts and the experimental forecasts using the GFSv16beta physics suite distributed with the UFS Medium-Range Weather Application v1.0 public release. Five-day GFSv16beta forecasts for one boreal winter season were generated using the operational GFS analyses as initial conditions. The evaluation metrics included tools from Model Evaluation Tools (MET) and in-house process-oriented diagnostics. The evaluations focused on the perpetuating GFS forecast errors pertaining to the planetary boundary layer (PBL), land-surface, cumulus, radiation, and cloud processes. The runs using GFSv16beta outperformed the operational GFSv15 with respect to the root-mean-square errors of large-scale environmental variables and the anomaly correlation coefficient for 500 hPa geopotential height. Nevertheless, larger biases associated with key physical processes were identified in the GFSv16beta forecasts. For example, the global precipitation forecast skill degrades and a dry bias remains in the tropics, suggesting a persistent problem in the cumulus scheme. The near-surface and boundary-layer cold biases are larger over most continents and polar regions, which is partly related to the systematic negative temperature errors in the GFS analysis. The overestimated near-surface wind speed particularly at night in the northeastern U.S. implies that the surface drag may be underrepresented. Excessive short-wave radiation reaching the ground in the high-latitudes of the summer hemisphere appears to be related to low cloud liquid and ice water path. These and other results will be described in this presentation.

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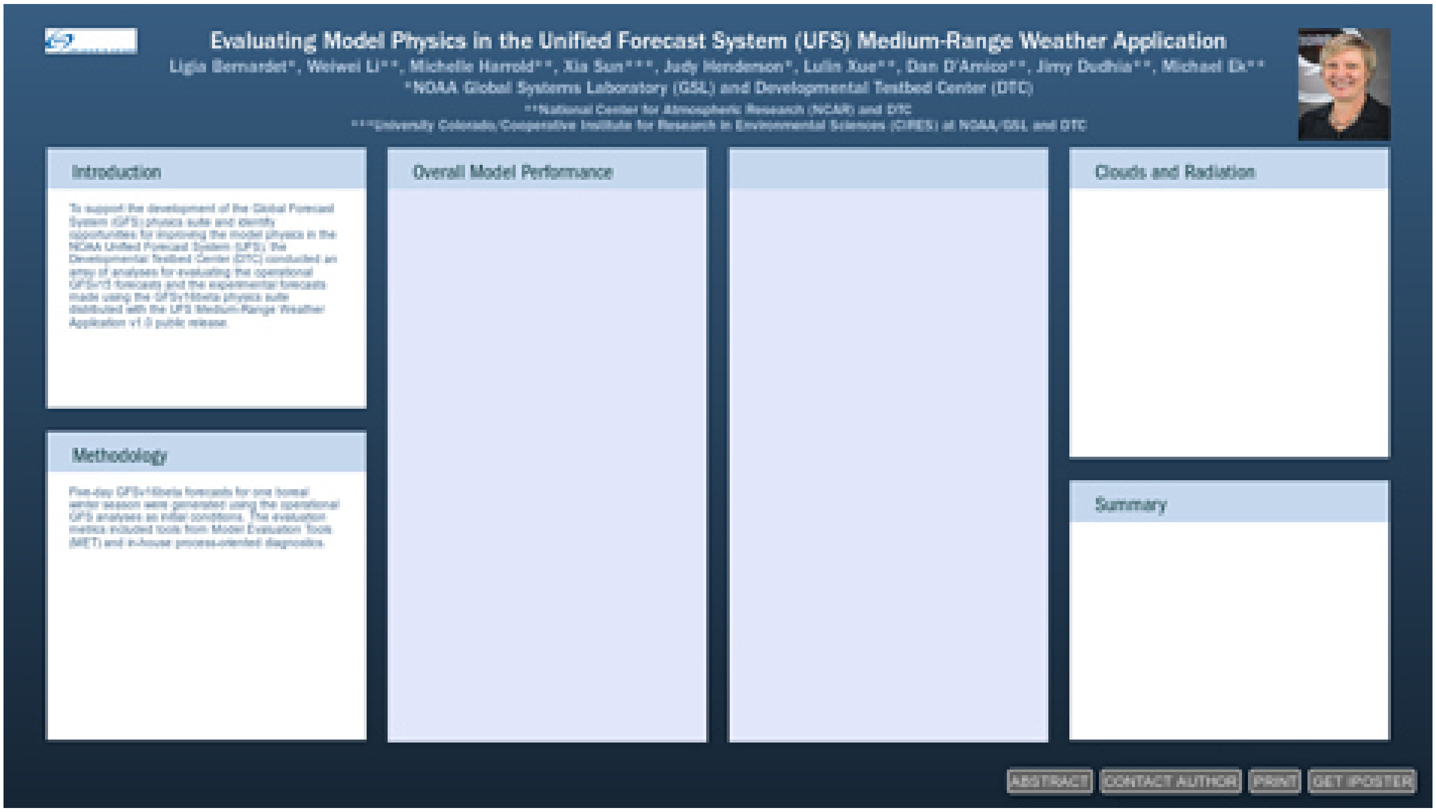

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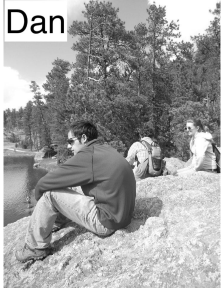
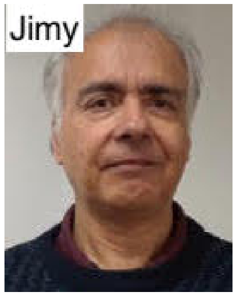
**National Center for Atmospheric Research (NCAR) and DTC
***University Colorado/Cooperative Institute for Research in Environmental Sciences (CIRES) at NOAA/GSL and DTC





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INTRODUCTION

To support the development of the GFS physics suite and identify opportunities for improving the model physics in the NOAA UFS, the DTC conducted an array of analyses for e

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valuating the operational GFSv15 forecasts and the experimental forecasts made using the GFSv16beta physics suite distributed with the UFS Medium-Range Weather Application v1.0 public release.

UFS: The Unified Forecast System (https://ufscommunity.org/) is a community-based, coupled, comprehensive Earth modeling system. The UFS numerical applications span local to global domains and predictive time scales from sub-hourly analyses to seasonal predictions. It is designed to support the Weather Enterprise and to be the source system for NOAA‘s operational numerical weather prediction applications.

UFS Medium-Range Weather Application: (https://ufscommunity.org/science/aboutapps/) a UFS configuration that supports prediction of atmospheric behavior out to about two weeks. It combines a numerical model (the UFS Weather Model), data assimilation, post-processing, workflow, and other elements.

UFS Medium-Range Application public release (http://UFS Medium-Range Application public release): v1.1 was released in October 2020. It is a user-friendly tool for those interested in numerical weather prediction research. The public release contains a subset of the capabilities of the Application, and includes a pre-processor, a forecast model, a post-processor, a workflow, and supporting libraries. Documentation and user support are available. Two physics suites are supported for use with the public release: GFSv15p2 (used in the GFS v15 operational model) and GFSv16beta (an experimental set of phhysics under consideration for use in GFS v16; note that this experimental physics differs from what will ultimately be implemented operationally in GFS v16).

GFS: the Global Forecast System (https://en.wikipedia.org/wiki/Global_Forecast_System) is the operational implementation of the UFS Medium-Range Weather Application. GFS v15 is currently in operations, and GFS v16 is planned for operational implementation in 2021.

DTC: the Developmental Testbed Center (http://dtcenter.org/) is a distributed facility where the NWP community can test and evaluate new models and techniques for use in research and operations.

CONFIGURATION & EVALUATION

Configuration

- **Components:** UFS Weather Model publicly released with the UFS Medium-Range Weather Application v1.0 using the GFSv16beta suite
- **Grid:** C768 (~ 13 km spacing), 64 vertical levels
- **Sample:** one boreal winter season
- **Forecast length:** 5-day forecasts
- **Initialization:** operational GFS analyses

Evaluation

- **Tools:** METplus and process-oriented diagnostics
- Verified against: surface and upper-air observations and analyses (operational GFS, NASA CERES, precipitation)
- **Control:** Operational GFS v15 forecasts

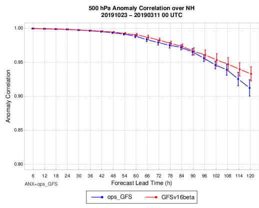
METplus (http://dtcenter.org/community-code/metplus) is a verification framework developed primarily by the Developmental Testbed Center. The core components of the framework include MET, the associated database and display systems called METviewer and METexpress, and a suite of Python wrappers to provide low-level automation and examples, also called use-cases.

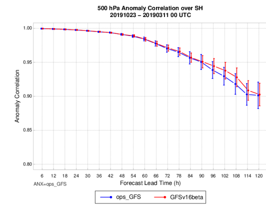
MET
Model Evaluation Tools

OVERALL MODEL PERFORMANCE

Anomaly Correlation

The 500-hPa geopotential anomaly correlation indicates the usual decrease of forecast skill for longer lead times. The GFSv16beta forecasts are better on average than the operational model, especially in the winter (Northern) Hemisphere.





Summary Statistics

Root mean square errors for a number of variables, levels, and domains indicate that the experimental physics performs the same or better than the operational physics.

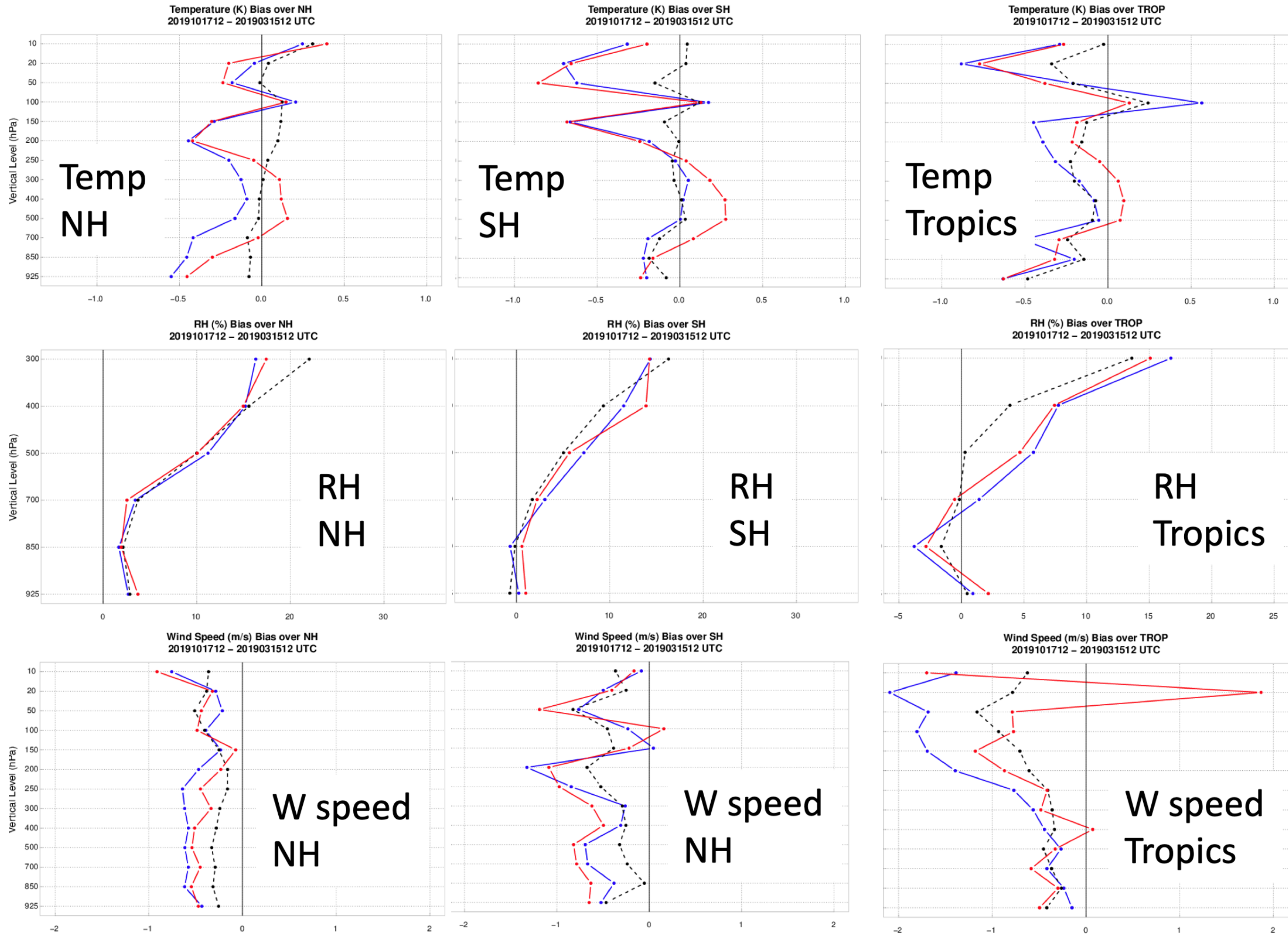
Skill (RMSE)	200-hPa Winds	850-hPa Temp	850-hPa RH	850-hPa Winds	10-m Winds	2-m Temp	2-m Dew point Temp
N. Hem	Improved	Improved	Somewhat Improved	Improved	N/A	N/A	N/A
S. Hem	Neutral	Neutral	Neutral	Neutral	N/A	N/A	N/A
Tropics	Neutral	Neutral	Neutral	Improved	N/A	N/A	N/A
CONUS	Improved	Improved	Somewhat Improved	Somewhat Improved	Improved	Neutral	Somewhat Improved
E. CONUS	Somewhat Improved	Improved	Neutral	Somewhat Improved	Improved	Neutral	Neutral
W. CONUS	Improved	Improved	Somewhat Improved	Somewhat Improved	Improved	Improved	Improved

However, when considering the systematic errors (bias), the results are mixed, with the experimental physics improving or degrading the results depending on the variable, level, and domain. At 850 hPa, the GFSv16beta forecasts are mostly degraded, suggesting a problem with the planetary boundary layer representation.

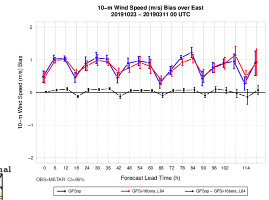
Skill (Bias)	200-hPa Winds	850-hPa Temp	850-hPa RH	850-hPa Winds	10-m Winds	2-m Temp	2-m Dew point Temp
N. Hem	Improved	Improved	Degraded	Degraded	N/A	N/A	N/A
S. Hem	Improved	Degraded	Somewhat Degraded	Neutral	N/A	N/A	N/A
Tropics	Improved	Degraded	Improved	Degraded	N/A	N/A	N/A
CONUS	Somewhat Improved	Neutral	Degraded	Neutral	Improved	Neutral	Somewhat Improved
E. CONUS	Somewhat Improved	Neutral	Degraded	Neutral	Improved	Somewhat Degraded	Improved
W. CONUS	Somewhat Improved	Improved	Degraded	Degraded	Improved	Improved	Improved

Biases against radiosondes

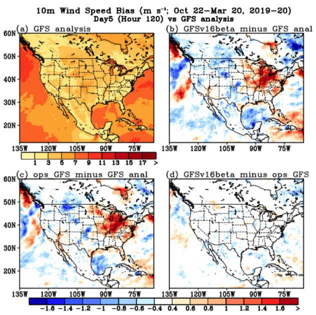
Biases for the operational GFS (blue) and the experimental physics (red) mimic those of GFS analyses (black). Low levels are too cold, have high relative humidity, and slow winds.

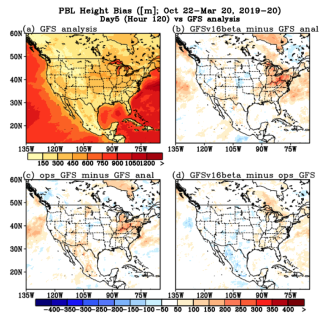

Temperature (K) Bias over NH
2019101712 – 2019031512 UTC
Temp
NH
Temperature (K) Bias over SH
2019101712 – 2019031512 UTC
Temp
SH
Temperature (K) Bias over TROP
2019101712 – 2019031512 UTC
Temp
Tropics
RH (%) Bias over NH
2019101712 – 2019031512 UTC
RH
NH
RH (%) Bias over SH
2019101712 – 2019031512 UTC
RH
SH
RH (%) Bias over TROP
2019101712 – 2019031512 UTC
RH
Tropics
Wind Speed (m/s) Bias over NH
2019101712 – 2019031512 UTC
W speed
NH
Wind Speed (m/s) Bias over SH
2019101712 – 2019031512 UTC
W speed
NH
Wind Speed (m/s) Bias over TROP
2019101712 – 2019031512 UTC
W speed
Tropics
Vertical Level (hPa)

DRILLING DOWN: SURFACE WIND SPEED HIGH BIAS IN GREAT LAKES REGION



Both the GFSv16beta and the operational GFS have excessive 10-m wind speeds in the East CONUS (Contiguous US). This high wind bias is most pronounced over the Great Lakes and coincides with a positive bias in planetary boundary layer depth.

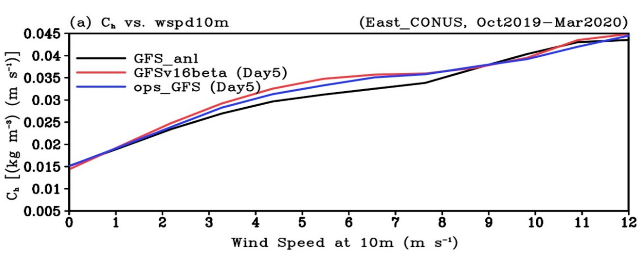




Hypotheses for high wind bias

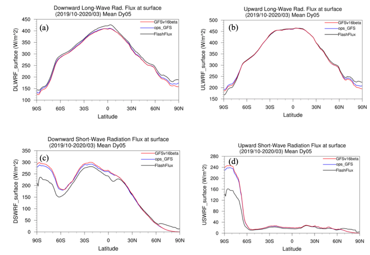
1. Underrepresented surface drag in PBL scheme (nearly stable wintertime PBL strongly depends on surface roughness length)
2. Underrepresented orography variability esp. over snow or ice covered areas e.g., Great lakes
3. Destabilization of the stable or nearly neutral PBL - problem in the stability function in the surface scheme

Land-atmosphere exchanges



In the East CONUS, land-atmospheric exchanges are stronger for a given amount of wspd10m. Because *Ch* depends on friction velocity and the stability function, it suggests a possible deficiency in the calculation of Ch and/or stability function in the surface layer parameterization.

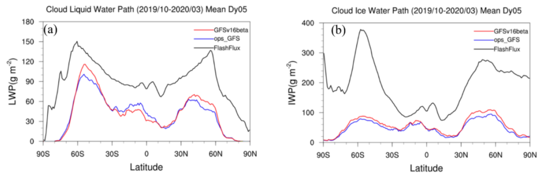
CLOUDS AND RADIATION



Longwave radiation reaching and leaving the surface is reasonable.

There is excessive **shortwave radiation** and leaving the surface in the summer (Southern) Hemisphere.

Cloud liquid and ice water paths have a negative bias, suggesting underestimated cloud thickness, which can help explain the shortwave radiation bias.



Radiation analysis suggests deficiencies in the representation of explicit clouds, which is tied to the microphysics parameterization.

To create this diagnostic, NASA Clouds and the Earth's Radiant Energy System (CERES) project Fast Longwave and Shortwave Flux (FLASHFlux) analyses were compared against model output.

SUMMARY

The GFSv16beta physics suite outperformed the operational GFS with respect to RMSEs of large-scale environmental variables and anomaly correlation for 500-hPa geopotential.

However, larger biases associated with key physical processes were identified in the GFSv16beta forecasts, including that,

- The near-surface and boundary-layer cold biases are partly related to the systematic negative temperature errors in the GFS analysis.
- The overestimated near-surface wind speed particularly at night in the northeastern U.S. implies that the surface drag may be underrepresented and stability function may play a role.
- Radiation analysis may suggest deficiencies in radiation and microphysics (MP) schemes.

Work will continue to identify and correct these problems to improve future operational implementations of the UFS.

ABSTRACT

To support the development of the Global Forecast System (GFS) physics suite and identify opportunities for improving the model physics in the UFS, the Developmental Testbed Center (DTC) conducted an array of analyses for evaluating the operational GFSv15 forecasts and the experimental forecasts using the GFSv16beta physics suite distributed with the UFS Medium-Range Weather Application v1.0 public release. Five-day GFSv16beta forecasts for one boreal winter season were generated using the operational GFS analyses as initial conditions. The evaluation metrics included tools from Model Evaluation Tools (MET) and in-house process-oriented diagnostics. The evaluations focused on the perpetuating GFS forecast errors pertaining to the planetary boundary layer (PBL), land-surface, cumulus, radiation, and cloud processes. The runs using GFSv16beta outperformed the operational GFSv15 with respect to the root-mean-square errors of large-scale environmental variables and the anomaly correlation coefficient for 500 hPa geopotential height. Nevertheless, larger biases associated with key physical processes were identified in the GFSv16beta forecasts. For example, the global precipitation forecast skill degrades and a dry bias remains in the tropics, suggesting a persistent problem in the cumulus scheme. The near-surface and boundary-layer cold biases are larger over most continents and polar regions, which is partly related to the systematic negative temperature errors in the GFS analysis. The overestimated near-surface wind speed particularly at night in the northeastern U.S. implies that the surface drag may be underrepresented. Excessive short-wave radiation reaching the ground in the high-latitudes of the summer hemisphere appears to be related to low cloud liquid and ice water path. These and other results will be described in this presentation.