Analysis and Mitigation of Occasional Precipitation-Type Problems in NCEP Global Forecast System

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1. Introduction

Recent diagnostic analyses by the National Centers for Environmental Prediction (NCEP) Model Evaluation Group (MEG), revealed that the NOAA Global Forecast System (GFS.v15) operational forecasts occasionally presented significant spurious warming in the lower troposphere during cold-season precipitation events. This behavior was detected in several events in the U.S. Midwest and Great Plains, where model-predicted warming led to inaccurate predictions of precipitation type, particularly a significant under-prediction of the areas where precipitation fell as snow. This study summarizes a diagnosis of the mechanisms for the spurious warming through a series of experiments involving the planetary-boundary-layer (PBL) and microphysics (MP) parameterization schemes.

2. Methodology

GFS.v15 has 64 vertical levels and applies the GFDL MP scheme and the hybrid eddy-diffusivity mass-flux (K-EDMF) PBL scheme that includes dissipative heating and modified stable boundary layer mixing (Han et al. 2016). In the series of experiments presented here, alternative parameterizations are used, including the Zhao-Carr and WSM6 MP schemes, along with the TKE-EDMF PBL scheme, which is a 1.5-order closure scheme predicting second-order turbulent kinetic energy of EDMF (Han and Bretherton, 2019) and is slated for implementation in GFS.v16 in early 2021. In addition to the different PBL and MP schemes, sensitivities to both the GFS.v15 and the 127-level GFS.v16 configuration are tested.

3. Forecast experiments

A representative erroneous warming event was evident in the operational GFS.v15 forecast initialized 00 UTC, 22 Jan, 2020. By the 36h forecast time, the GFS.v15 with the operational GFDL MP scheme predicted a temperature profile much warmer than observations between about 800 and 950 hPa and much colder between 600-800 hPa (Fig. 1). When either the Zhao-Carr or WSM6 MP scheme was substituted for the GFDL scheme, similar warm-cold anomalies did not develop (Fig. 1). Similar behavior occurs in the GFS.v16, in spite of its higher vertical resolution, when the same combination of K-EDMF PBL and GFDL MP schemes are used (Fig.2). However, substantial improvement is evident with the TKE-EDMF PBL scheme, regardless of the MP scheme used (Fig.3)

Additional diagnostics, including model temperature tendencies, revealed that the K-EDMF PBL scheme introduced strong vertical mixing across the observed stable layer between about 775 and 850 hPa. Specifically, the PBL scheme diagnosed a high amplitude, stratus-top-driven K profile in and near this layer, leading to strong vertical mixing, with warming below and cooling above the original stable layer. When this mixing mechanism was intentionally scaled back in the K-EDMF PBL scheme, the problem was essentially eliminated (Fig. 4). It remains unclear why, of the three MP schemes tested, only the GFDL MP scheme combines in a certain way with the K-EDMF scheme to trigger this behavior.

4. Summary

A series of sensitivity experiments with GFS.v15 and GFS.v16 were conducted to understand an occasional problem with prediction of precipitation-type in operational GFS.v15 forecasts. It was found that anomalous lower-tropospheric warming was responsible for the erroneous precipitation-type diagnosis and the warming was caused by a combination of the K-EDMF PBL and GFDL MP schemes. It was determined that the overly vigorous mixing can be essentially eliminated by modifying one component of the K-EDMF scheme's K-mixing profile. Nevertheless, additional study needs to be conducted to understand what specific environmental conditions and model-physics interactions lead to this undesirable model behavior.

References

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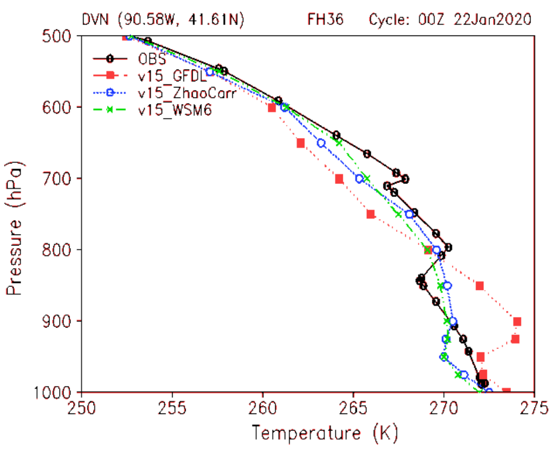

Fig.1. Atmospheric temperature profiles (K) against the sounding observations (black) at Davenport, IL, at 36-h forecast initiated at 00 UTC, 22 Jan, 2020. Three microphysics schemes utilized in GFS.v15 include GFDL (red), Zhao_Carr (blue) and WSM6 (green).

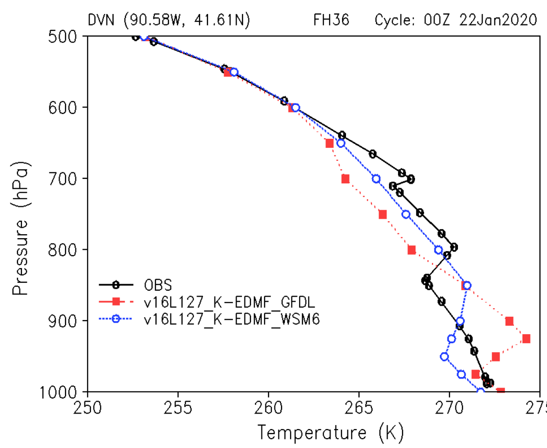

Fig. 2. The same as Fig.1, but for GFDL (red) and WSM6 microphysics schemes (blue) used in GFS.v16.

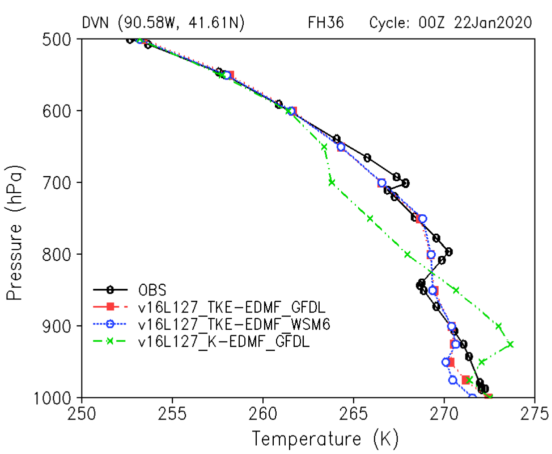

Fig. 3. The same as Fig.1, but for combination of TKE-EDMF PBL scheme with GFDL (red) or WSM6 (blue) microphysics schemes used in GFS.v16, compared to configuration of K-EDMF PBL scheme with GFDL microphysics scheme (green).

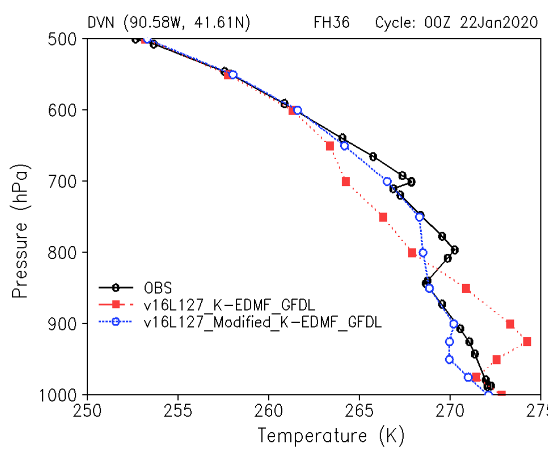

Fig. 4. The same as Fig.1, but for comparison between modified K-EDMF PBL scheme (red) and original K-EDMF PBL scheme (blue) combined with GFDL microphysics schemes used in GFS.v16.