Reduction of 2-m Temperature Forecasting Errors in the NCEP Global Forecast System

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1. Introduction

Accurate forecast of the near surface fields in numerical models is regarded as the key for improving numerical weather and climate prediction, although it has proven to be challenging. Different types of biases and systematic errors are found in near-surface forecasts. They can be attributed to various factors such as the land surface model, planetary boundary scheme, other physics processes, and coupling between the surface and atmosphere (Mahrt 2014; Steeneveld 2014; Zheng et al. 2017, Haiden et al. 2018). It has long been known that the NOAA National Centers for Environmental Prediction (NCEP) Global Forecast System suffers from large biases in near surface forecasts over land. This study addresses the wintertime 2-m temperature warm bias in the first version of the Finite Volume Cubed Sphere (FV3) dynamic core based GFS (GFSv15). The background diffusivity in the planetary boundary scheme is revealed to strongly modulate the 2-m temperature forecast. Optimization of this parameter shows significant positive impact for cases where large wintertime warm biases exist.

2. Methodology

The FV3GFS uses the hybrid eddy-diffusivity mass-flux (EDMF) planetary boundary layer scheme. It includes dissipative heating and modified stable boundary layer mixing (Han et al. 2016). The background diffusivity K_0 for momentum, heat and moisture used in the GFS exponentially decreases with height,

$$K_0 = d_k e^{[-10(1-P/P_s)^2]}, \qquad (1)$$

where P is atmospheric pressure, Ps is surface pressure, and d_k is a constant, set to 1.0 in this model.

To investigate how the background diffusivity affects the PBL structure and near-surface parameters, various d_k or K_0 values are tested. The background diffusivity is further modified based on the stability as follows:

$$d_k' = d_k, \text{for } R_{ib} \le 0$$
$$d_k' = d_k \times (1-\frac{R_{ib}}{R_{ibc}})^2 + d_{kmin} \times [1-\left(1-\frac{R_{ib}}{R_{ibc}}\right)^2], \qquad \text{for } 0 < R_{ib} < R_{ibc} \qquad (2)$$
$$d_k' = d_{kmin}, \qquad \text{for } R_{ib} \ge R_{ibc}$$

where R_{ib} is the surface bulk Richardson number, R_{ibc} equals to 0.25 and d_{kmin} equals 0.1. Two values of d_k ,1.0 and 2.0, are tested in this report.

3. Forecast experiments

A case study covering the period December 18 to 23, 2017 was selected. The FV3GFS was integrated forward for 7 days. One control run and three sensitivity experiments were carried out. The control run (CTL) uses the model default value of d_k=1. d_k is further set to 0.0, 0.1 and 0.5 in the sensitivity runs KK00, KK1 and KK2. Both KK1 and KK2 use the modified background diffusivity with the stability, while d_k is set to 1.0 and 2.0, respectively. Figure 1 shows the 2-m temperature change for the 3-h period ending at 0000 UTC December 23, 2017. The control run has a large warm bias, up to 7 °C in the evening, indicating the surface layer is overly mixed. Reduction of the background diffusivity results in cooler 2-m temperatures. In the KK00 run with no background diffusivity, the model 2-m temperature is even lower than the observation at night. Daytime 2-m temperature also decreased, resulting in a large daytime cold bias. The modification of K_0 based on the stability substantially reduced the night-time warm bias, bringing the forecast closer to the observations. The KK2 run also exhibits a weaker daytime cold bias than does the KK1 run.

To gain more insight into the impact of the proposed change on forecast skill, a set of daily 7-day forecasts were conducted for a one-month winter period. Figure 2 presents the changes in 2-m temperature diurnal cycle over the CONUS west between the CTL and KK2 experiments. The CTL run has night-time temperatures warmer than the observed, up to 1.6 degrees. KK2 reduced this warm bias, with reductions up to 0.5 °C.

Figure 3 shows the 500-hPa geopotential height anomaly correlation coefficient. A positive impact from the proposed change is evident for the first 120 hours of the forecast. The improvement is statistically significant at the 95% confidence level.

4. Summary

Background diffusivity has a significant impact on 2-m temperature. Results from a set of medium-range forecasts showed that the proposed modification to the background diffusivity reduced the systematic 2-meter temperature warm bias in the FV3GFS. In addition, the 500-hPa height anomaly correlation was improved as well.

References

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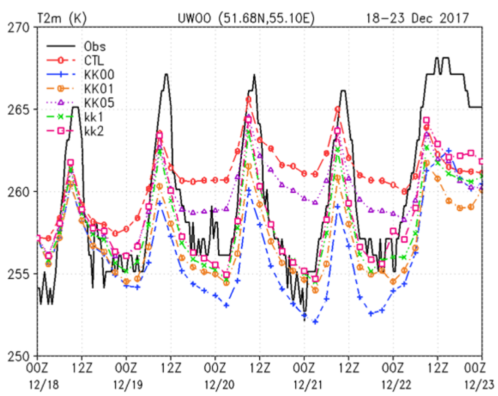

Fig.1. 3-hourly 2-m temperature (K) (a) and 10-m wind speed (m/s) (b) at the UWOO station for different d_k values for December 18 to 22, 2017.

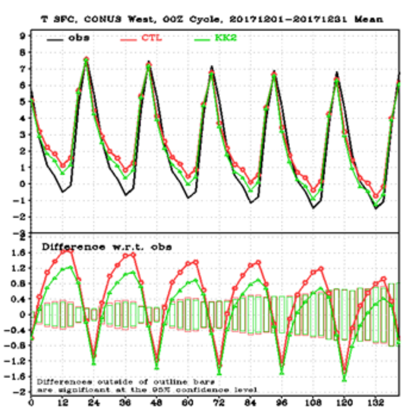

Fig. 2. The top panel depicts 2-m temperature diurnal cycle averaged over the CONUS West and for the period of 1–31 December 2017 for observation (black), the CTL run (red) and the KK2 (green), respectively. The bottom panel shows the differences of the experiments compared to the observation. Differences outside of the hollow bars are statistically significant at the 95% confidence level for a Student's t test.

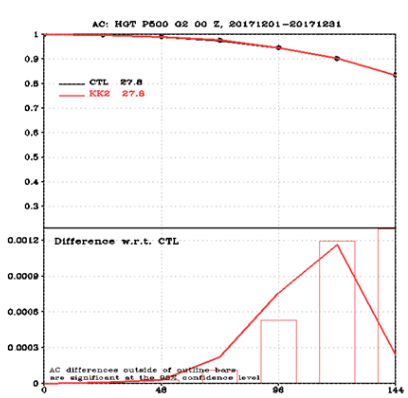

Fig. 3. Global mean anomaly correlation coefficient of 500-hPa geopotential heights as a function of forecast length (top panel), and the differences between the KK2 and CTL runs. Differences outside of the hollow bars are statistically significant at the 95% confidence level for a Student's t test.