Case Study of Low Convective Available Potential Energy Bias in the United Forecast System

Weizhong Zheng[1], Jongil Han[2], Michael Barlage[2], Fanglin Yang[2], and Helin Wei[1]

[1]Lynker at NOAA/NCEP/EMC, College Park, MD 20740, USA; [2]NOAA/NCEP/EMC, College Park, MD 20740, USA
Email: Weizhong.Zheng@noaa.gov

1. Introduction

As the Global Forecast System (GFS) of the National Centers for Environmental Prediction (NCEP) has been continuously updated, including significant changes being made in model physics parameterizations, its forecast skill has continuously improved. However, it has long been known that GFS Convective Available Potential Energy (CAPE) forecasts in the summer has notable low biases. The CAPE magnitudes in the GFS version 16 (GFSv16) were consistently lower than those in the GFS version 15 (GFSv15). The low CAPE biases are exacerbated in the NOAA Unified Forecast System (UFS) and the next GFS prototype version (GFSv17), which are being developed at NOAA.

CAPE represents the amount of buoyant energy available for atmospheric convection. It is an important parameter for predicting the development and intensification of thunderstorms (Cotton and Anthes, 1989). A low bias of forecast CAPE can result in a model underestimating the intensity of thunderstorms and other convective systems.

This report documents the low CAPE bias in the UFS high resolution version (HR1) as well as its possible causes through the data analysis and model sensitivity tests.

2. Case Study of CAPE

One typical case of strong convective events, which occurred over the Northern and Central Great Plains in the United States on 24-25 July 2020, is selected for investigating the causes of low CAPE biases in the UFS. Five upper air sounding stations, Aberdeen in SD (ABR), Omaha in NE (OAX), North Platte in NE (LBF), Chanhassen in MN (MPX) and Topeka in KS (TOP), were affected by this strong storm case. The UFS (C768L127) without coupling to the ocean and ice is used for this study. Initial conditions for the land and atmosphere at 00Z, 23 July 2020, were obtained from the operational GFS analyses.

Figure 1 presents a comparison of CAPE forecasts in the first 48 hours by the UFS (the CTL run), the operational GFS, and the Rapid Refresh (RAP) numerical weather model analysis (RAPanl) against observations at all five sounding stations. The CAPE in the CTL run is substantially lower than observation and RAPanl, especially during the daytime. GFS shows low CAPE biases. But the UFS has the largest biases. Further analysis indicates that the UFS (CTL run) has drier soil moisture in the initialization condition, lower latent heat flux, and drier humidity near the surface (Fig.2a) compared to observations.

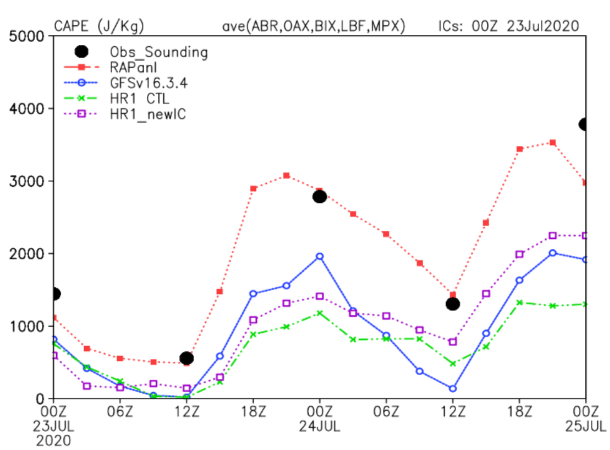

Fig.1. CAPE averaged at five sounding stations. The UFS and GFSv16.3.4 runs are initiated at 00Z, 23 July 2020.

3. CAPE sensitivity to land initial conditions and non-local turbulent mixing in the PBL

As indicated in Cotton and Anthes (1989), CAPE is very sensitive to small differences in moisture and temperature profiles. In this report, three experiments are carried out to explore the sensitivities. In addition to the control (CTL) experiment, sensitivity experiments with spun-up land initial conditions (newIC) and with the removal of non-local turbulence mixing in the PBL scheme (noMassF) were carried.

The UFS uses the Noah-MP land surface model (LSM) (Niu et al., 2011) instead of the Noah LSM (Ek et al., 2003) as in the GFS.v16. The land model was first spun up off-line with GFS.v16 atmospheric analyses to produce balanced land initial conditions. The newIC experiment was performed with the spun-up land initial conditions, as shown in Figure 1 (purple line with HR1_newIC). CAPE in the newIC run is increased by hundreds of Julie/kg unit, reaching closer to the GFSv16 value, but is still much lower than observations. Compared to the CTL, newIC shows a reduction of the dry bias below 900 hPa and only small differences in temperature (Figs. 2a and 2b). Moisture in the middle troposphere is also improved.

The UFS uses the turbulent kinetic energy (TKE)-based moist eddy-diffusivity mass-flux (EDMF) vertical turbulence mixing scheme (EDMF-TKE (Han and Bretherton, 2019). The vertical turbulent flux of a field, either temperature or humidity, is given by a sum of local turbulence mixing and non-local turbulence mixing. The non-local mixing, used with an eddy-diffusivity mass-flux (EDMF) approach, takes into account non-local transport by strong updrafts in the daytime convective boundary layer. It includes the surface driven turbulence mixing and the stratocumulus-top-driven turbulence mixing.

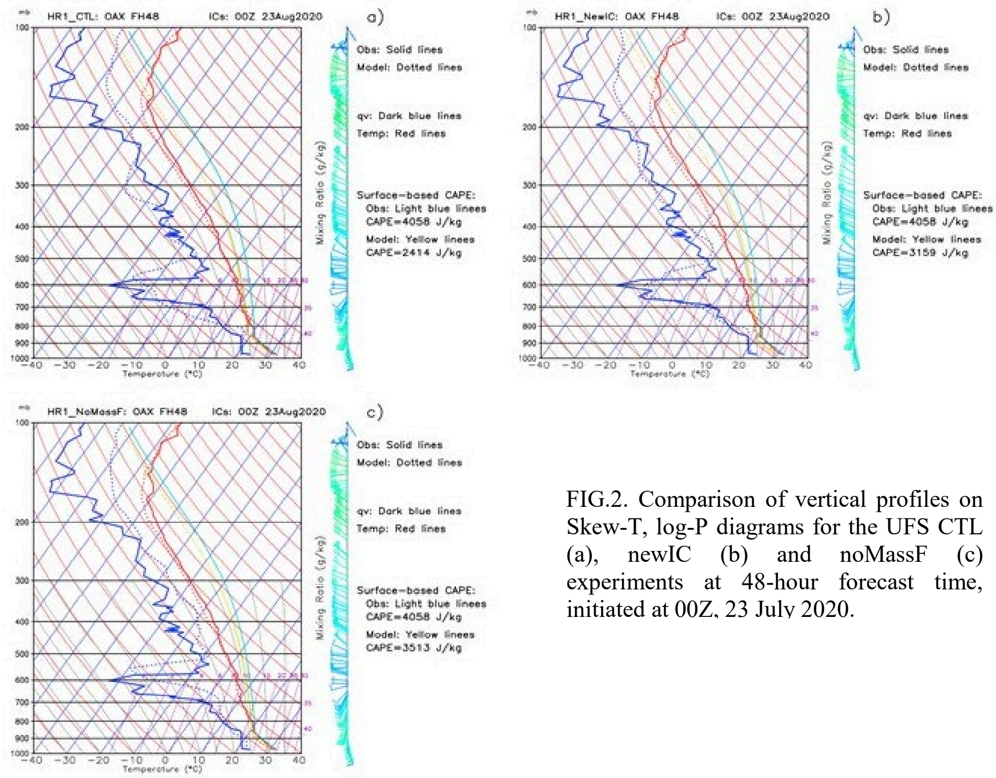

FIG.2. Comparison of vertical profiles on Skew-T, log-P diagrams for the UFS CTL (a), newIC (b) and noMassF (c) experiments at 48-hour forecast time, initiated at 00Z, 23 July 2020.

Sensitivity test with the TKE-EDMF PBL in the UFS indicates that both the surface driven turbulence mixing and the stratocumulus-top-driven turbulence mixing have large impacts on vertical moisture and temperature profiles, and subsequently on CAPE forecasts. Fig.2c presents the sensitivity test with the removal of non-local turbulence mixing. In this case, less moisture from the surface evaporation is transported into high levels within the PBL. More moisture is kept in the low levels. The wet bias near the top of PBL is also reduced. ,Consequently, an increase in CAPE forecast is observed. On the other hand, without non-local turbulence mixing the TKE-EDMF scheme produced wet bias in the low PBL and colder temperature in the entire PBL (Fig.2c). In the low levels, increased moisture leads to increased CAPE but colder temperature reduces CAPE because of reduced atmosphere instability. Nevertheless, the sensitivity test shows that the non-local mixing term has larger impacts on moisture than on temperature.

4. **Summary and ongoing research**

The sensitivity experiments made in this study demonstrated that low CAPE biases in the UFS were closely related to the dry land surface initial conditions and strong non-local turbulence mixing in the TKE-EDMF PBL scheme. Using land initial conditions taken from an off-line land spin-up run led to improved CAPE forecasts. The large increase in CAPE with the non-local turbulence mixing being turned off in the TEK-EDMF PBL scheme suggested that the PBL scheme needs further refinement to reduce surface driven turbulence mixing. Further testing and evaluation are expected that with reduced non-local turbulent mixing both the CAPE and the vertical humidity and temperature profiles can be improved in the UFS.

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