Process-Level Differences Between Two PBL Schemes Used in NOAA’s GFS Model

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Introduction

In numerical weather prediction, the planetary boundary layer (PBL) parameterization is responsible for representing vertical mixing processes in a model grid column. This includes small-scale (local) diffusion-driven turbulent mixing as well as the larger-scale, convectively driven (nonlocal) mixing that can take place in an unstable atmosphere and the vertical circulations that can be driven by clouds at the PBL top.

Recent updates to NOAA’s operational Global Forecast System (GFS) have modified both the local and nonlocal components of the PBL scheme. Some key features of the two schemes are listed below. In the work presented here, results from the Single-Column Model (SCM) (Firl et al 2021) with the Common Community Physics Package (CCPP) are used to diagnose and illustrate some of the differences in physical tendencies that result from the changes in the PBL parameterization, to better understand the impact of this update.

PBL Schemes in the v15 and v16 GFS: Essential Physics and Advanced Features

The v15 Hybrid-EDMF scheme (Han et al. 2016)

- K-Profile eddy diffusivity
- A counter-gradient mixing term due to large convective eddies for weakly unstable PBLs
- A dry mass flux scheme to represent the counter-gradient flux for strongly unstable PBLs
- Inclusion of the effect of the updraft-induced pressure gradient force

The v16 TKE-EDMF scheme (Han and Bretherton 2019)

- Prognostic TKE used to specify the eddy diffusivity, with 3-D advection of TKE
- Inclusion of moist processes in both the surface-driven and the stratocumulus-driven mixing
- Interaction of TKE with cumulus convection
- Scale awareness

The LASSO/MSDA Case

The case shown here is one that is provided with the SCM, derived from a large-eddy simulation of shallow convection (Gustafson et al. 2020). The initial time is approximately local sunrise on 18 May 2016.

Control Experiments: GFSv15 and GFSv16

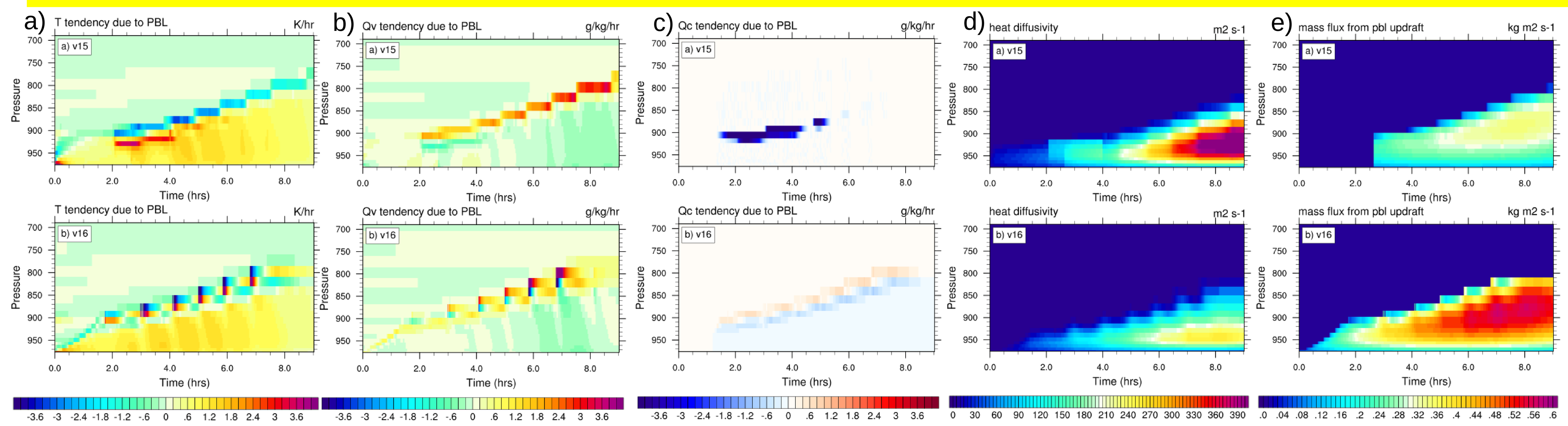

Fig. 1. Time-height sections showing PBL a) temperature tendencies, b) specific humidity tendencies, c) cloud water tendencies, d) eddy diffusivity for heat (Kh), and e) PBL updraft mass flux for SCM runs using the v15 (top) and v16 (bottom) versions of the PBL scheme.

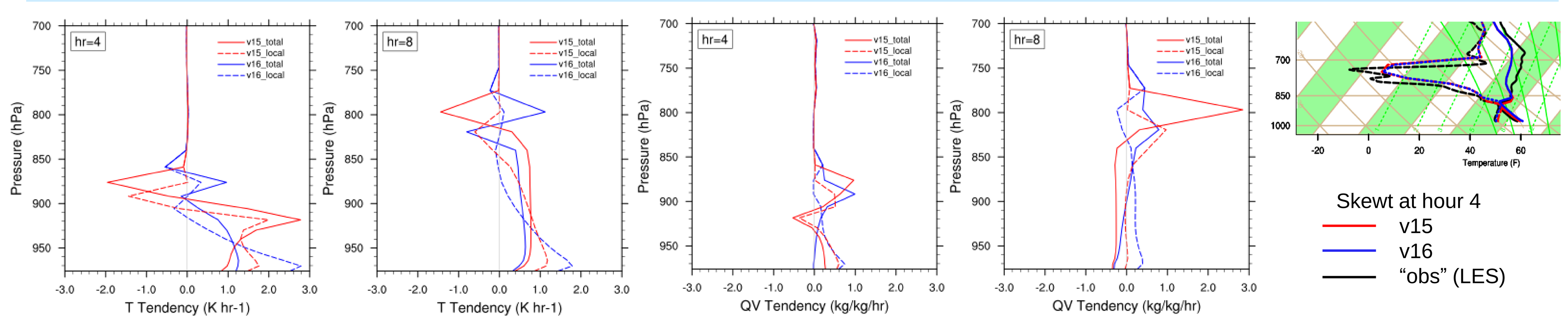

Fig. 2. Vertical profiles of the local (dashed) and total (solid) tendencies of temperature and specific humidity mixing ratio from the PBL at hours 4 and 8, when using the v15 Hybrid-EDMF scheme (red) and the v16 TKE-EDMF scheme (blue).

Figs. 1 and 2 indicate that, for this case, the v16 parameterization has a smaller eddy diffusion coefficient, and larger mass flux than in v15. The local component in the v16 scheme heats more near the surface than the v15 scheme. The PBL top is higher when using the v16 scheme, and the v16 PBL temperature tendencies have a zigzag structure near the PBL top. Some sensitivity tests were performed to further quantify these differences.

Sensitivity tests: Local mixing only, and swapping MF schemes

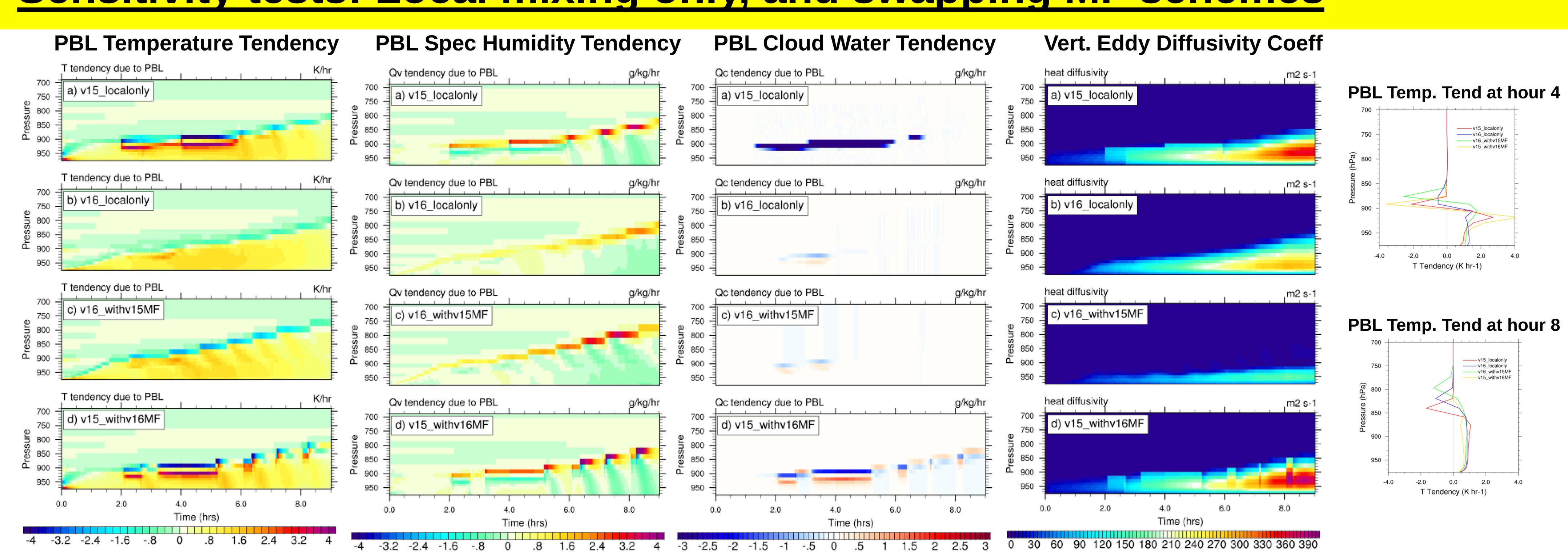

Fig. 3. The top row is an experiment using v15 with local mixing only, 2nd row is v16 with local mixing only, 3rd row is v16 but the mass flux computed as in v15, and the bottom row is v15 but the mass flux computed with the v16 method. Vertical profiles of temperature tendencies are shown at hours 4 and 8.

The experiments in Figs. 1-3 show an unrealistic structure at the PBL top with the v16 PBL, including small amounts of negative cloud water below the PBL top (not shown). The flipflop of signs in the heat and moisture tendencies is not seen when only local diffusion is permitted (see Fig. 3). Additional experiments linked this issue to the way that moist processes were included in the v16 nonlocal scheme. We then investigated 3 potential solutions:

a) Omit these moist processes

b) Apply a positive-definite Total Variation Diminishing (TVD) scheme

c) Do not allow the addition of cloud water immediately; instead, save it to be added just prior to the calculation of microphysics (as is done with the convection-produced cloud water).

Tests of Potential Solutions

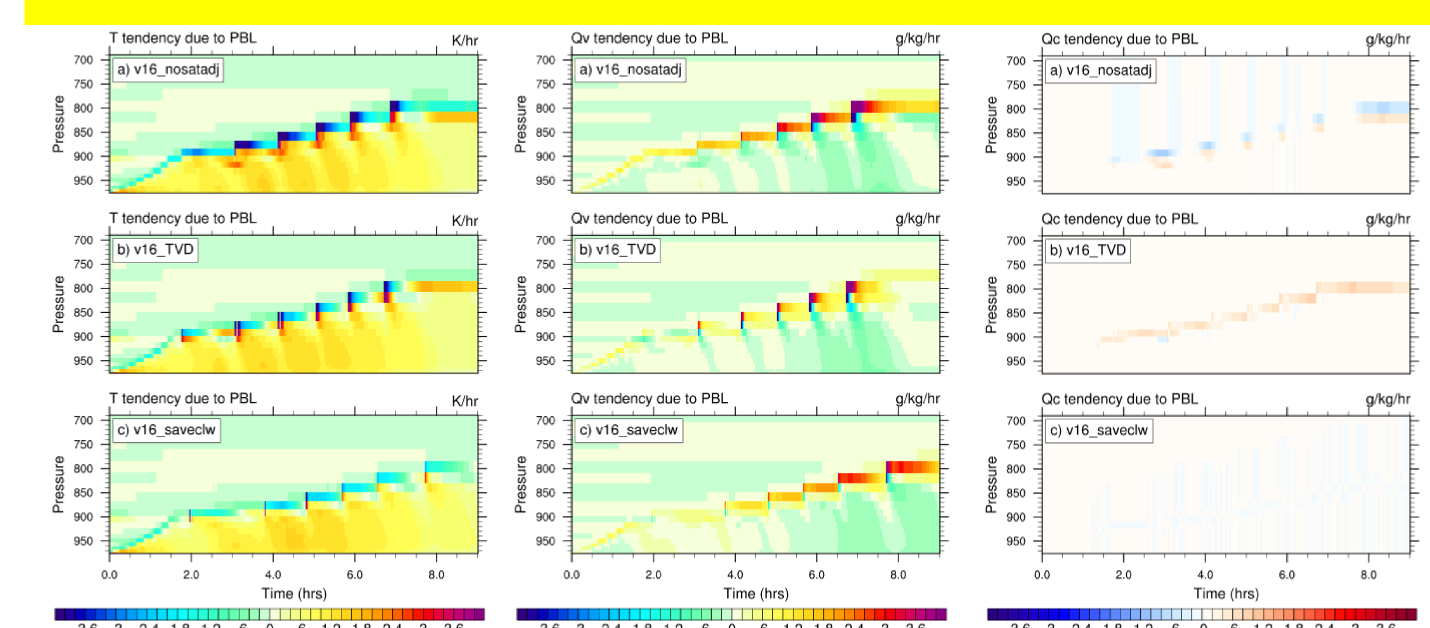

Fig. 4. Temperature, specific humidity and cloud water PBL tendencies, when using solutions a, b, c as described above.

Discussion

The v16 TKE-EDMF scheme mixes more strongly than the v15 Hybrid-EDMF scheme for this weakly convective case because the mass-flux mixing in the former is much more dominant than that in the latter. The moist processes associated with the mass flux mixing are the root cause for the physically undesirable structure of the thermal state tendencies and the artifact of negative cloud water near the PBL top simulated by the TKE-EDMF scheme. Several possible solutions for the problem are explored in the single-column model.

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