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Improving Turbulence Parameterization for an Idealized Supercell at Kilometer-Scale Resolution

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Introduction

The spatial resolution of numerical weather prediction models is approaching kilometer-scale. A significant portion of heat, moisture and other scalar fluxes in deep convective clouds are carried by motions on the scale of several kilometers, hence only partially resolvable on kilometer-scale grids. Therefore subgrid-scale (SGS) turbulence parameterization is essential in modeling deep clouds.

The SGS turbulence flux of a scalar s is :

$$\tau_{ws} = \overline{w's'} = \overline{ws} - \overline{w}\,\overline{s}$$

Conventional eddy-viscosity-based turbulence schemes are expressed like this :

$$\tau_{ws} = -K_h \frac{\partial \overline{s}}{\partial z}$$

They are in **down-gradient forms** so that unable to reproduce locally **counter-gradient** fluxes.

New schemes are introduced based on decomposition and reconstruction from **Taylor series**. (Clark 1977, Chow 2005, Moeng 2010, Moeng 2014, Verrelle 2017)

Modified Clark (MC) model :

$$\tau_{ws} = C_{\Delta x}\left(\frac{\partial \overline{w}}{\partial x}\frac{\partial \overline{s}}{\partial x} + \frac{\partial \overline{w}}{\partial y}\frac{\partial \overline{s}}{\partial y}\right)$$

Mixed model :

$$\tau_{ws} = -K_h \frac{\partial \overline{s}}{\partial z} + C_{\Delta x}\left(\frac{\partial \overline{w}}{\partial x}\frac{\partial \overline{s}}{\partial x} + \frac{\partial \overline{w}}{\partial y}\frac{\partial \overline{s}}{\partial y}\right)$$

Model setting

We implement the new models in the Advanced Regional Prediction System (ARPS). A 50 m high-resolution large-eddy simulation (LES) of an idealized supercell (Roberts 2016) is used as the control run (CNTL). Different regimes and different resolutions were tested.

TAB.1 Model settings.

Domain size (x,y)	(64km,96km) for 50m(CNTL), 500m and 1km runs (96km,128km) for 2km runs
Domain height/vertical levels	16 km, 81 levels
dz	20m ~ 400m
Time steps	Large: 0.1s, small 0.05s
Lateral/top boundary condition	Open/Rayleigh boundary conditions
Bottom boundary condition	Friction with constant coefficient
Horizontal/vertical advection	Fourth-order/second order
Microphysics	Lin
Coriolis	36°N
Turbulent mixing	TKE-1.5 Modified Clark model Mixed model

Results

Offline diagnosis and online simulations were implemented. The offline tests were produced by coarse-graining the CNTL to 500m, 1km and 2km using box-average method horizontally. The SGS fluxes and counter-gradient features were diagnosed. The online simulations were initialized from a thermal bubble as the CNTL.

Offline diagnosis

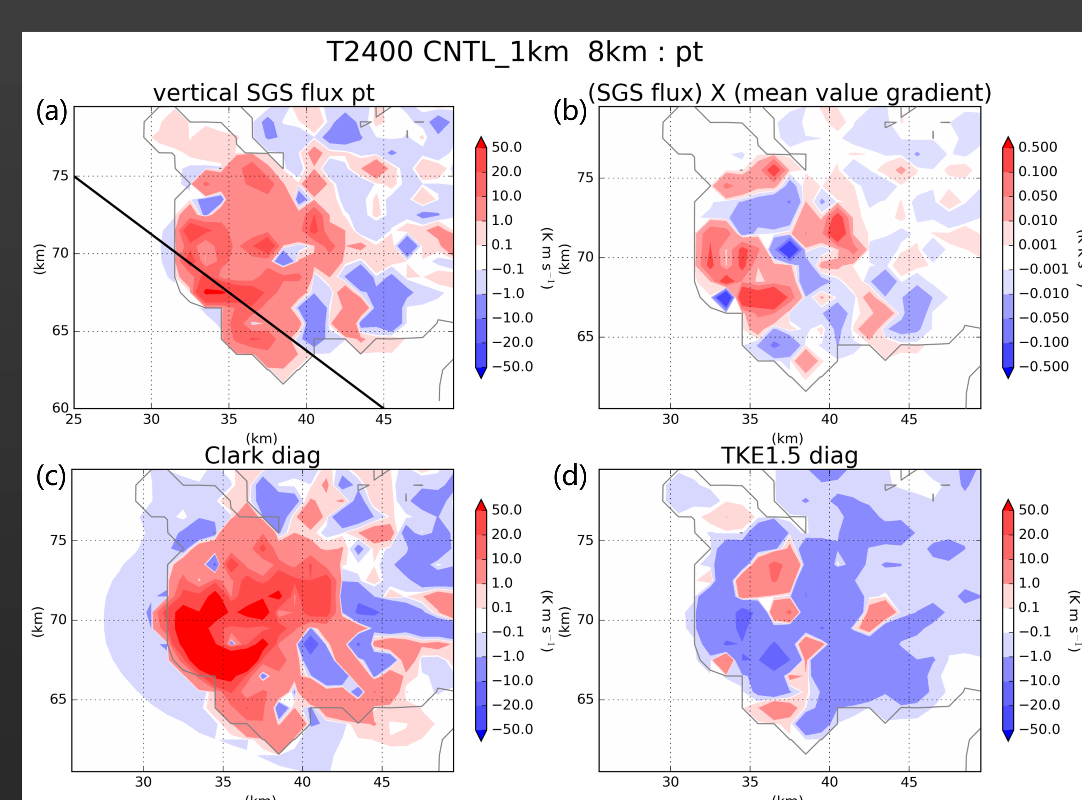

FIG.1 Horizontal cross sections of the 1 km coarse-grained LES (CNTL run) at 8 km AGL. (a) SGS vertical flux of θ obtained from the CNTL by box filtering at 1 km resolution, used as the benchmark. (b) The product of $\overline{w'\theta'}$ and $\partial\overline{\theta}/\partial z$. Red(blue) means counter(down)-gradient SGS transport. Diagnosed $\overline{w'\theta'}$ from the (c) MC and (d) TKE-1.5 closures. The cloud boundaries are marked by the sum of cloud and ice water mixing ratios above 0.001 g kg^{-1} (gray contours).

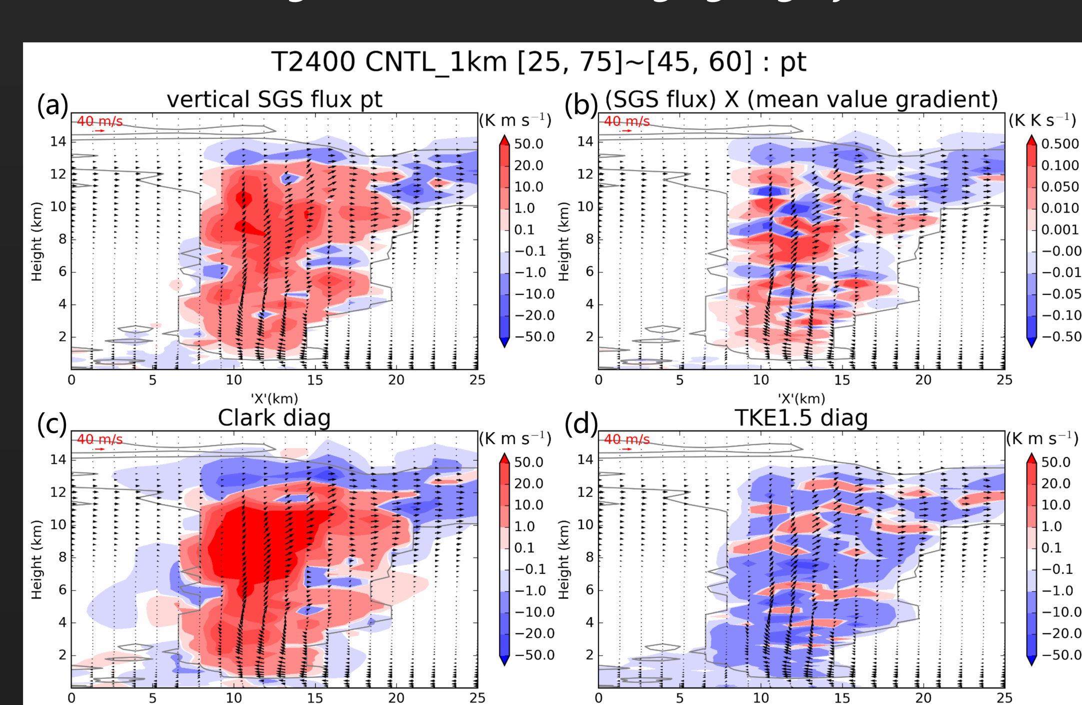

FIG.2 As in FIG.1, but for vertical cross sections along the black line in FIG.1a .

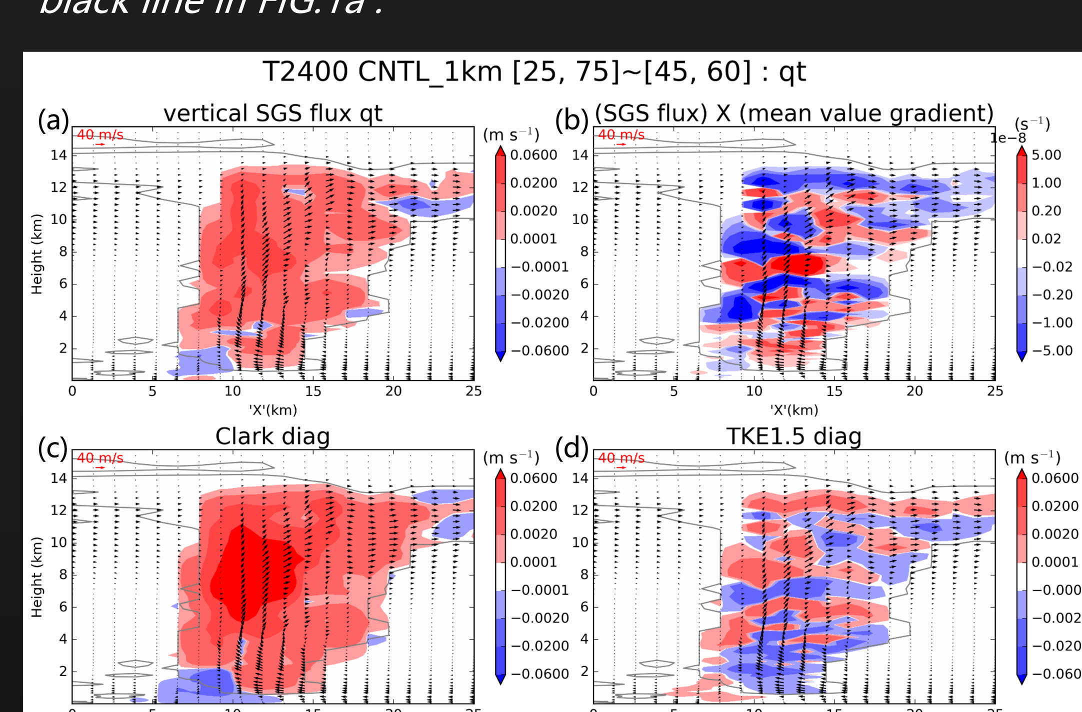

FIG.3 As in FIG.2, but for mixing ratio of total liquid water.

Significant **counter-gradient SGS transports** of potential temperature and total liquid water were observed.

Compared to the LES results, the MC closure could produce better SGS fluxes than the TKE-1.5 closure for potential temperature and total liquid water.

Online simulations

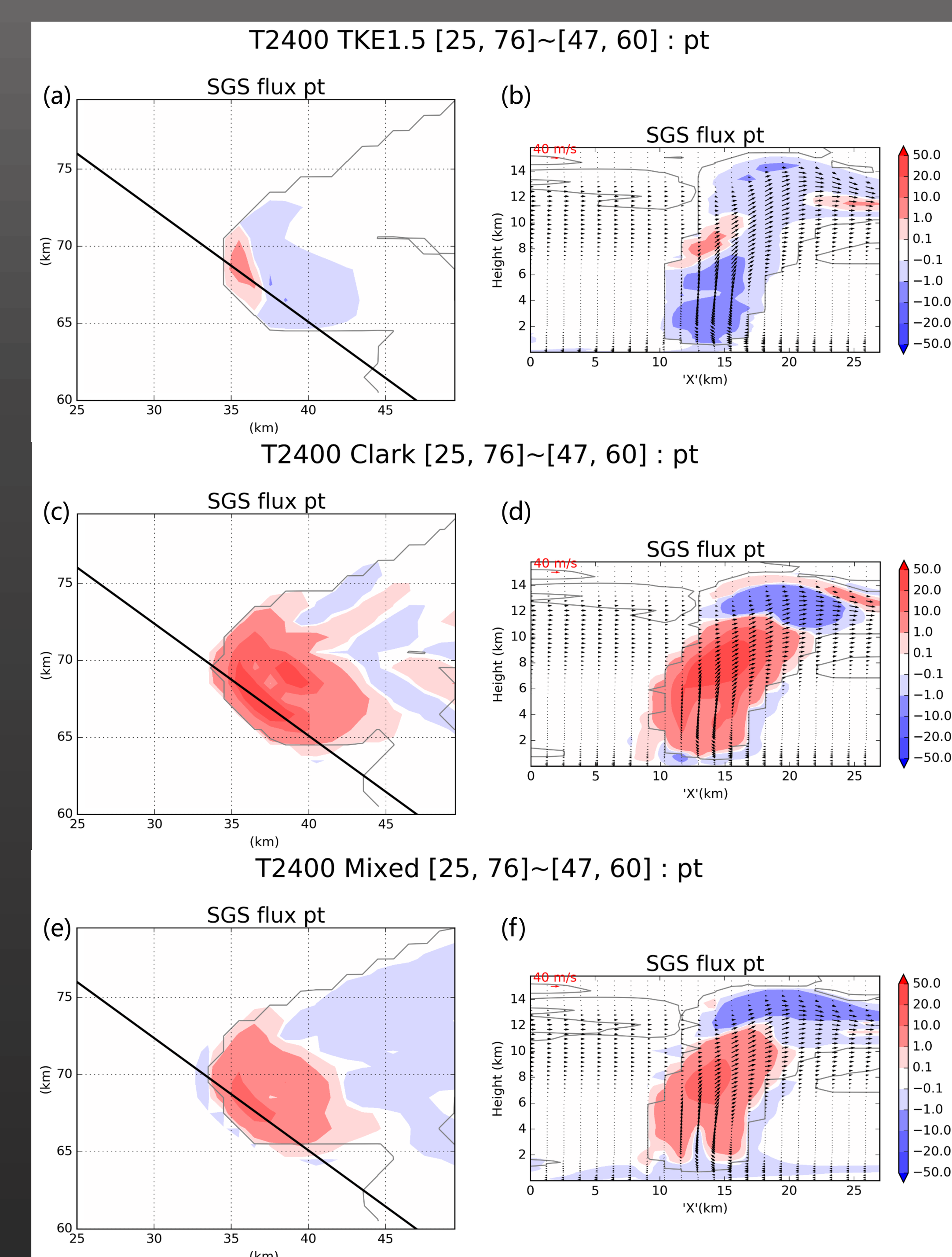

FIG.4 Similar to FIG.1a and FIG.2a, $\overline{w'\theta'}$ of the 1 km-resolution simulations with the (a)(b) TKE-1.5, (c)(d) MC, and (e)(f) mixed turbulent mixing closures.

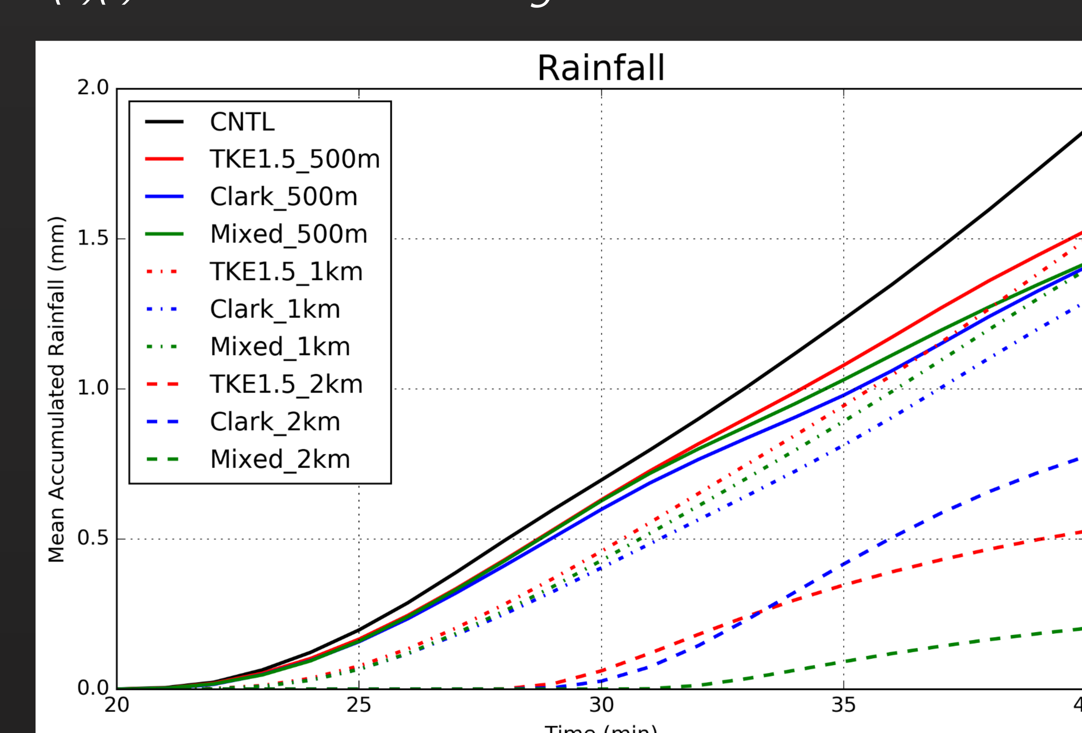

FIG.5 Time series of domain-averaged accumulated rainfall.

Online simulations supported the prior results from LES diagnosis. The MC and the mixed scheme produced better θ SGS fluxes.

But few improvements were observed in precipitation. Further studies are needed.

Future work

We want to introduce the new schemes to the horizontal directions and to the SGS momentum mixing.

Acknowledgments

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