The assessment and improvement of the planetary boundary layer schemes in WRF over the central Tibetan Plateau

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Abstract

The planetary boundary layer (PBL) parameterization schemes play a critical role in the weather and climate models. The sensitivity of boundary layer variables to eight PBL parameterization schemes is evaluated over the central Tibetan Plateau with field measurements of the Third Tibetan Plateau atmospheric scientific experiment (TIPEX III). The model underestimates surface temperature and overestimates the sensible and latent heat flux. A sub-grid scale topographic gravity wave drag was conducted using the method of Tsiringakis et al. (2017). It improved performance on the PBL temperature and wind simulations, indicating the necessity of small scale topographic gravity wave drag over complex terrain.

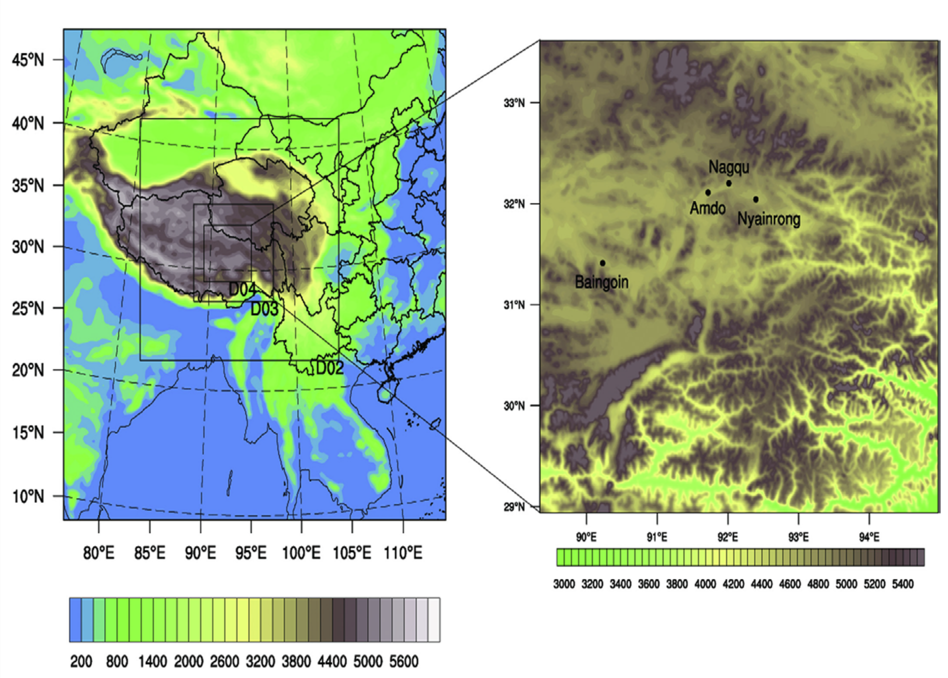

Fig. 1. The WRF model nesting domains (left) and location of the four observational stations in D04 (right) (The shaded area indicates topography, unit: m).

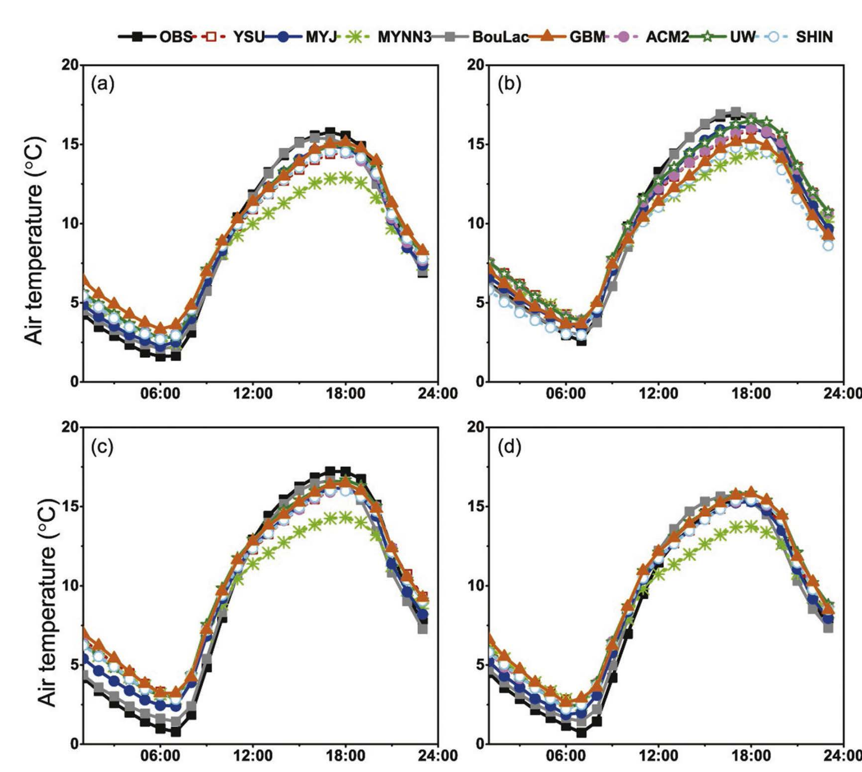

Fig. 2. Diurnal cycle of air temperature (2 m) averaged over the whole simulation period for- different PBL schemes and observations (a) Amdo (b) Baingoin (c) Nagqu (d) Nyainrong (unit: ° C).

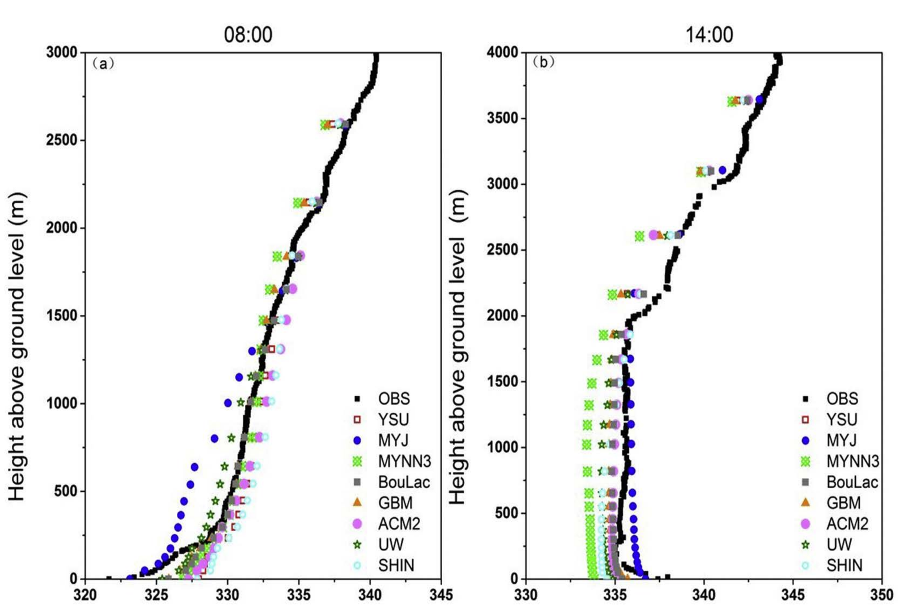

Fig.3 Comparison of potential temperature between observations and the YSU、MYJ、MYNN3、BouLac、GBM、ACM2、UW、SHIN scheme simulations at the Nagqu site at (a) 8:00 (b) 14:00 in 29 July 2015 (unit: K).

Method

The model underestimates near surface temperature, and overestimates surface turbulence mixing, leading to a colder and wetter PBL over the central Tibetan Plateau. Previous researches have pointed out that the sub-grid scale orography drag has important effect on the PBL processes (Shin and Hong, 2015; Lorente-Plazas et al., 2016). Steeneveld et al. (2008) hypothesized that sub-grid scale orographic gravity wave drag can express the missing drag. Tsiringakis et al. (2017) followed his study and parameterized the effects of the small scale orographic gravity wave drag as following:

$$\boldsymbol{\tau} = \begin{cases} \dfrac{\rho_0 k_s H^2 N U}{2} & \dfrac{N}{U} \geq k_s \\ 0 & \dfrac{N}{U} \geq k_s \end{cases}$$

Where ρ_0 is the air density (kg m^{-3}), U is the wind speed at the PBL top (m s^{-1}), H is the orographic amplitude of the sub-grid scale orography, N is the Brunt–Vaisala frequency and k_s is the orographic wave number.

Results

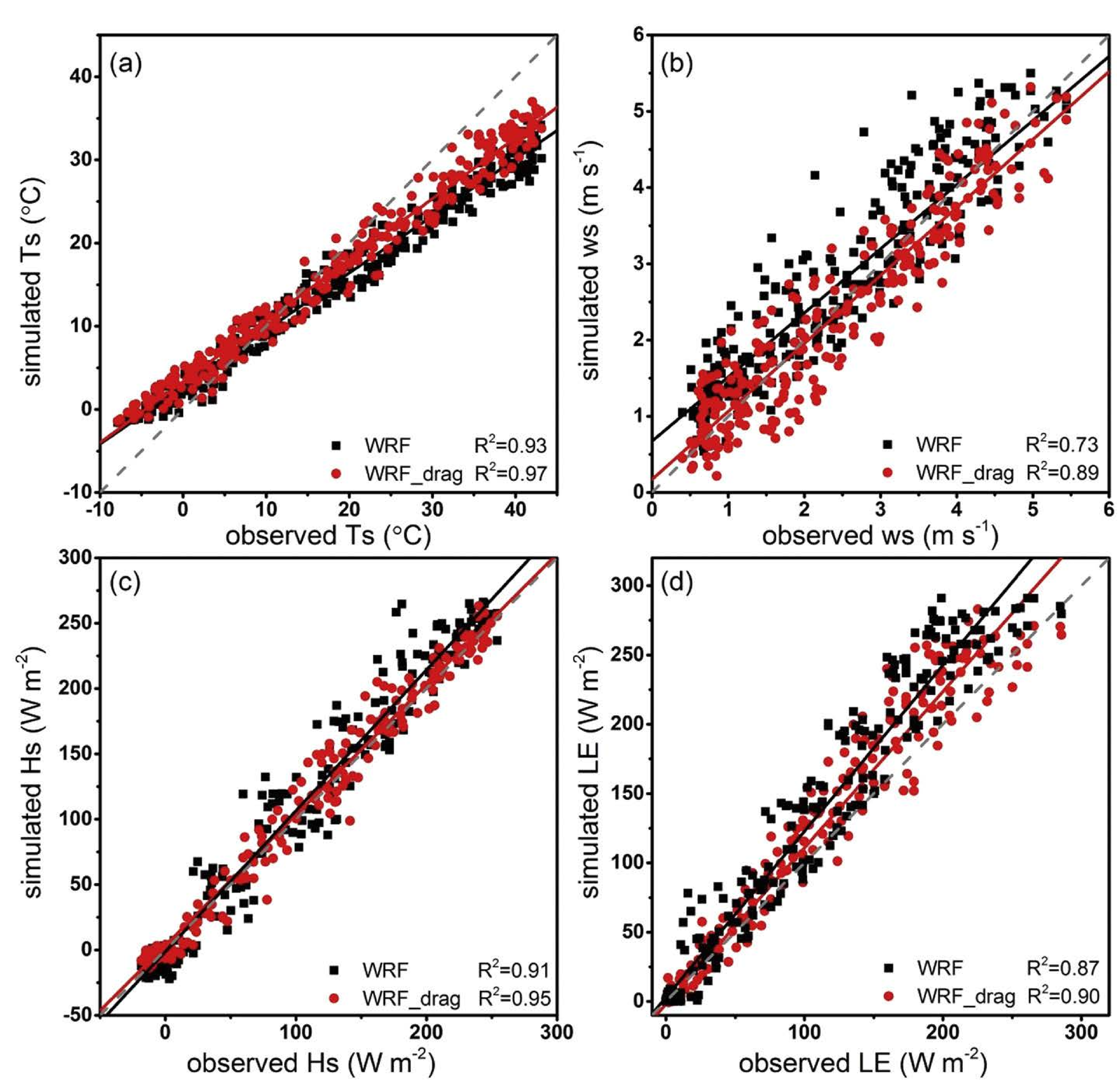

Fig.4 Model predicted surface fluxes versus observations during simulation period at the Nagqu site (a) surface temperature (unit: ° C) (b) wind speed (unit: m s^{-1}) (c) sensible heat flux (unit: W·m^{-2}) (d) latent heat flux (unit: W·m^{-2}). The black (red) rectangles are WRF without (with) sub-grid scale orography gravity wave drag. The gray dotted line is the 1:1 line.

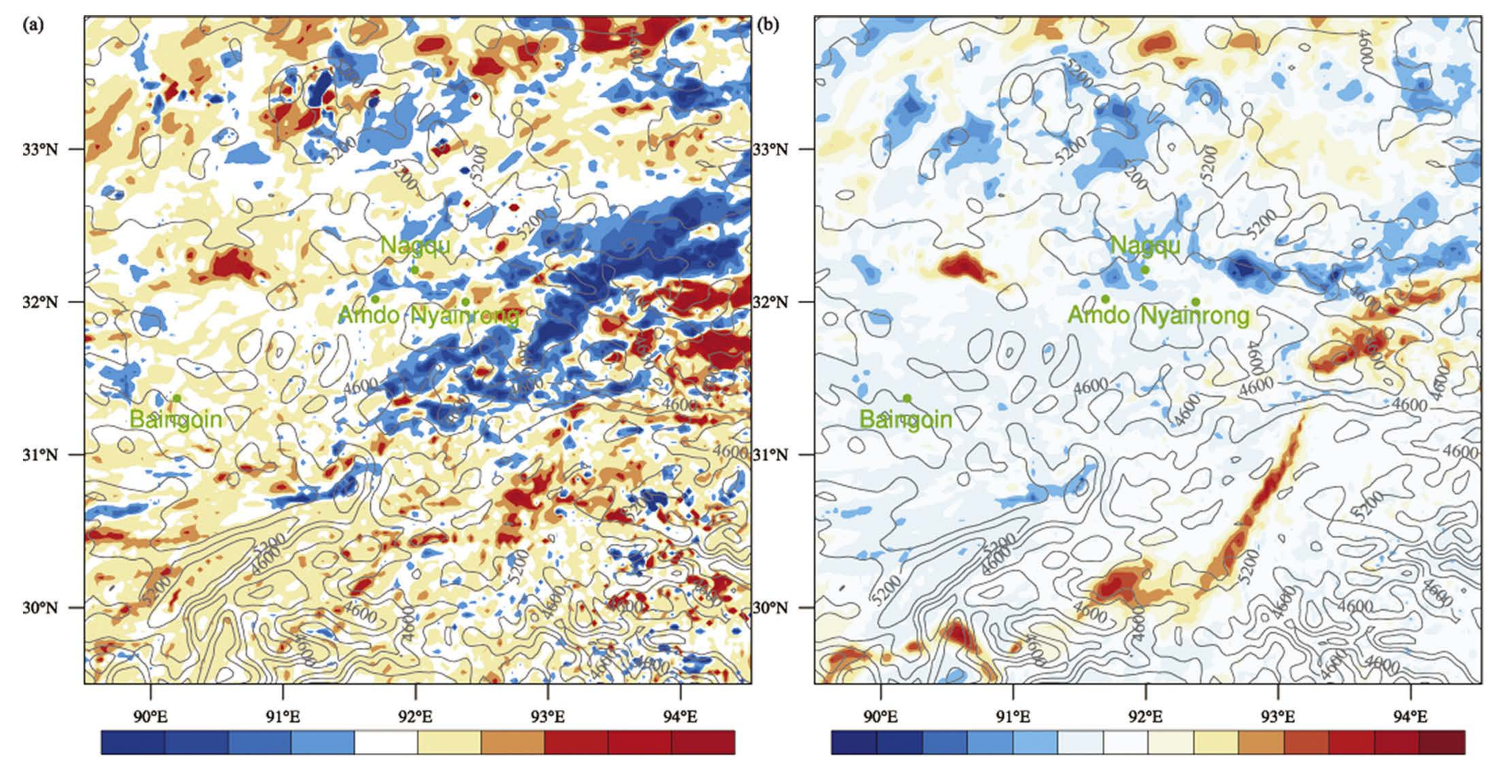

Fig.5 Composite analysis of (a) air temperature (2 m) (° C), (b) relative humidity (units: %) in the innermost domain (simulation with sub-grid scale orography gravity wave drag minus simulation without sub-grid scale orography gravity wave drag). The black solid line indicated the terrain height (unit: m).

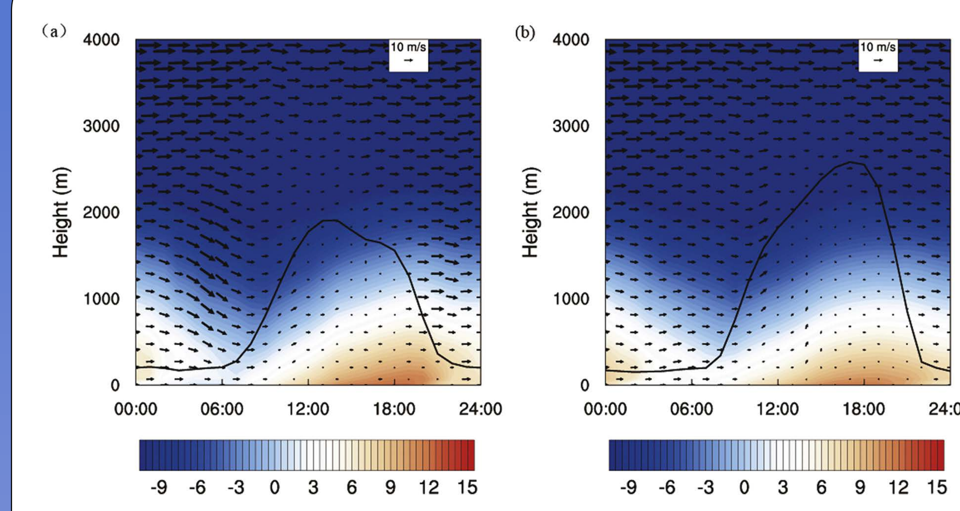

Fig.6 Diurnal cycle of the PBL horizontal wind (unit: m·s^{-1}), PBL height (m) and temperature (unit: ° C) at the Nagqu site (a) WRF without sub-grid scale orographic gravity wave drag (b) WRF with sub-grid scale orographic gravity wave drag.

Conclusions

1. All PBL schemes underestimated the surface temperature over the central Tibetan Plateau. The BouLac scheme showed the minimum cold bias of the surface temperature.

2. The sensible heat flux and the downward longwave radiation were the main factors causing the lower surface temperature.

3. The sub-grid scale gravity wave drag was added to reduce biases result from unresolved topography over the central Tibetan Plateau. It led to smaller cold bias, causing warmer lower-tropospheric temperature, smaller water vapor content and higher PBL height. The modified model results show more close to the observation.

References

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