Evaluation of PBL simulation in the GFDL AGCM

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Introduction

Diurnal cycles (DCs) in the planetary boundary layer (PBL)

- The DCs in the PBL impact on life cycles of weather and climate systems by altering surface fluxes, cloud processes, air quality, and etc.
- Correctly simulating the DCs remains challenging for state-of-the-art weather and climate models.
- The DCs of the PBL parameters have received less attention in GCM studies, compared to the variations at monthly, seasonal and annual time scales.

This presentation contains:

- **evaluation of the performance of the GFDL AGCM in simulating the annual-mean and DC climatologies of PBL parameters**: T2 (2-m temperature), U10 (10-m wind speed), and PBLH (PBL height)
- **comparison of two PBL schemes** in simulating the PBL parameters and the DCs

Model Setup

- 10-year climatology runs driven by prescribed SST and sea ice were conducted using the GFDL AGCM with two PBL parameterization schemes.
- Horizontal resolution: about 100 km / Vertical resolution: 33 interface levels (32 grid-center levels) with the lowest model level height at around 33 m
- Two PBL parameterization schemes in the GFDL AGCM compute:

Vertical transport (mostly) in the PBL $\frac{\partial \bar{c}}{\partial t} = -\frac{\partial \overline{w'c'}}{\partial z}, \quad \overline{w'c'} = -K_c \frac{\partial \bar{c}}{\partial z}.$ by unresolved turbulent vertical flux

(1) 1st order K-profile scheme based on Lock et al. (2000): **KPP**

For surface-driven and/or radiatively-driven mixed layers

$$K_c = \underbrace{K_{c,prof}^{sfc} + K_{c,prof}^{rad}}_{\text{prescribed K-profile in the mixed layer}} + \underbrace{K_{c,ent}^{sfc} + K_{c,ent}^{rad}}_{\text{entrainment parameterization at the mixed-layer top}}$$

Otherwise

$$K_c = \underbrace{l_c^2 f_c \left|\partial U / \partial z\right|}_{\text{based on local Ri, from the SFC to the model top}}$$

✓ This is the standard option in the GFDL AGCM.

(2) TKE scheme based on Mellor and Yamada (1974, 1982): **TKE**

$K_c = q l_c^{TKE} S_c$ where $q = \sqrt{2TKE}$, S_c : Stability functions (Galperin et al. 1988)

$$l_c^{TKE} = \frac{\kappa z}{1 + \kappa z / l_0}, \quad l_0 = \alpha \int_0^{z_{top}} z q \, dz \Big/ \int_0^{z_{top}} q \, dz.$$

✓ Recently implemented into the GFDL model (J.-C. Golaz, H. Guo, B. Xiang, M. Zhao).
✓ It showed promise of improved simulations in stratocumulus regions, while degradations were introduced elsewhere.

Reference data

- **T2, U10, and PBLH: a reanalysis ensemble (ANL)** was generated by combining four reanalysis sets (ERA-20C, ERA-Interim, NCEP CFSR and NASA MERRA) and used as a reference.

✓ The ensemble spread could provide information on the uncertainty of the parameters.
✓ The ensemble shows better statistical scores than the individual reanalysis sets, when they are evaluated against the CRU T2 observations.

- **Surface turbulent fluxes and Vertical profiles: ERA-20C** is used.

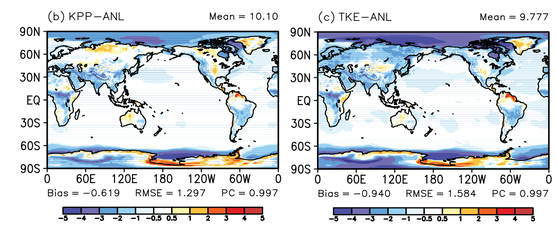
✓ The diurnal cycles of temperature and wind profiles in ERA-20C resemble those observed best among the four reanalysis sets, at the highest vertical and temporal resolutions.

Concluding remarks

- This study is the first attempt at documenting the performance of the GFDL AGCMs in the representation of the diurnal cycle climatologies of the PBL parameters. Several systematic biases were found compared to the reanalysis ensemble, and the problems in the PBL parameterization schemes and in the current vertical resolution were identified.
- Based on the findings of this study, we plan to implement a non-local transport term in the PBL schemes for increasing the vertical mixing in the convective PBLs and refine the vertical resolution in the surface layer for better resolving the stable PBLs.

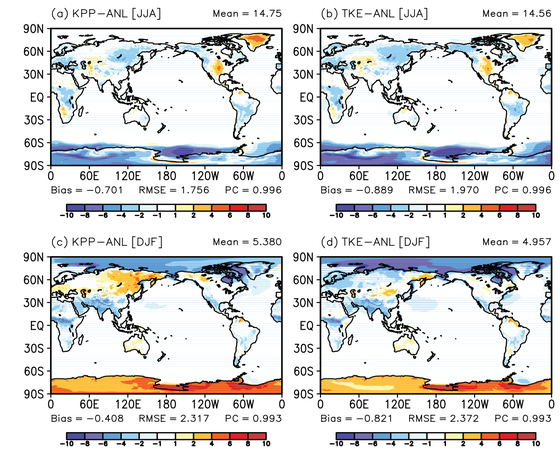
Results – Temperature

• Annual means

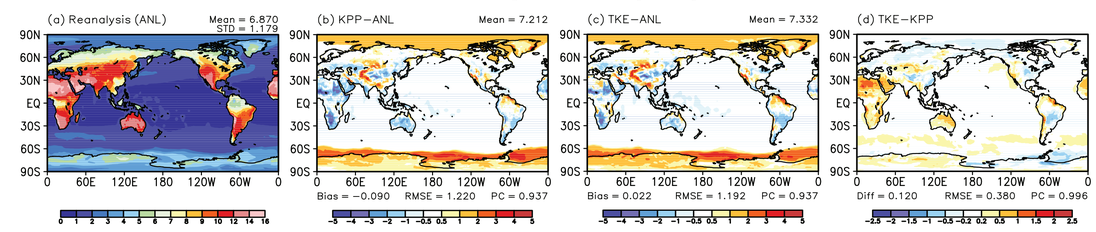


✓ **(ANN)** KPP and TKE exhibit wide-spread cold biases, which are larger in TKE.
✓ **(JJA, DJF)** In the polar regions, the cold biases are more severe in local winter.
✓ **(DJF)** The warm biases are prominent, and TKE performs better.

• Seasonal means

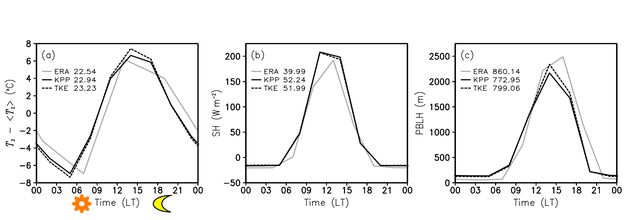


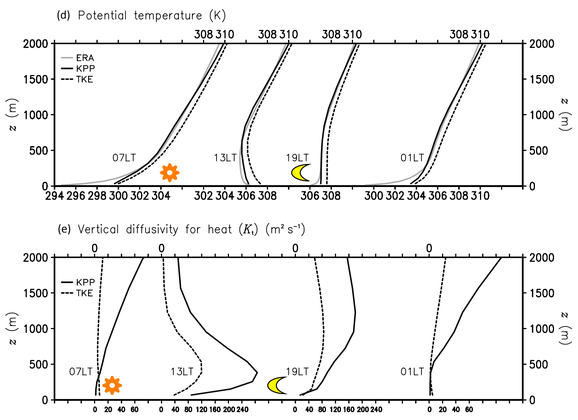
• Diurnal amplitude (DA) of T2



✓ The models underestimate DAs of T2 in the arid and semi-arid regions.
✓ TKE simulates larger DAs in the dry regions.

• Role of vertical mixing in dry PBLs: the Sahara region (8°–18°E, 18°–28°N)





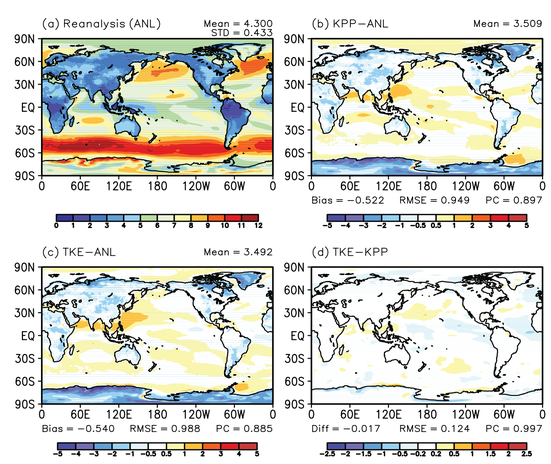
(a) The maximum (minimum) temperature is 0.8 °C warmer (0.4 °C colder) in TKE than in KPP, consistent with the warmer T2 and large DA in TKE (the global maps above).

(b, c) Given the similar SH but the different PBLH between KPP and TKE, the different mixing in the PBL may contribute to the different DA.

13LT (d) TKE is warmer than KPP, (e) due to the less efficient heat transport in TKE.
01LT/07LT (d) The PBL cools more quickly in TKE, (e) due to the weaker mixing.

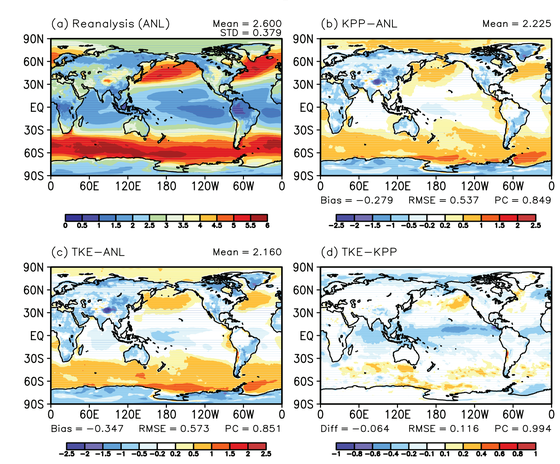
Results – Winds

• Annual-mean U10



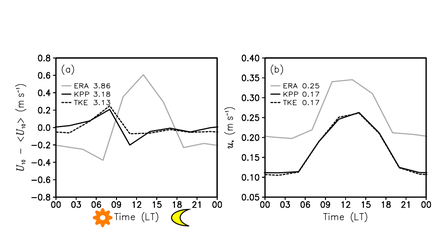
✓ Both KPP and TKE exhibit systematic negative biases over land.
✓ They differ by less than 0.5 m s^{-1}.

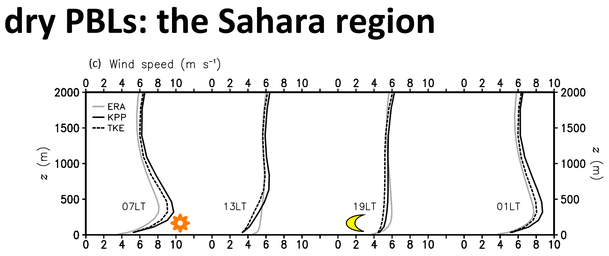
• Diurnal amplitude of U10



✓ The DAs are underestimated over land.
✓ There is no much difference between KPP and TKE.

• Role of vertical mixing in dry PBLs: the Sahara region





(a) The increase in U10 during the morning transition is not capture by KPP and TKE, consistent with the systematic underestimation U10 and the DA (the global maps above).

ERA **07LT** nocturnal Low-Level Jet downward momentum transport from the LLJ → **13LT** well-mixed PBL and diurnal peak in U10
KPP/TKE insufficient momentum transport → minimum U10 around noon