Sensitivity of Boundary Layer Parameterization to the Critical Bulk Richardson Number in a Climate Model over India and its Adjoining Regions

Prabhakar Namdev (prabhakarnmdv@iitd.ac.in), Maithili Sharan, and Saroj K. Mishra
Centre for Atmospheric Sciences, Indian Institute of Technology Delhi, New Delhi, India-110016

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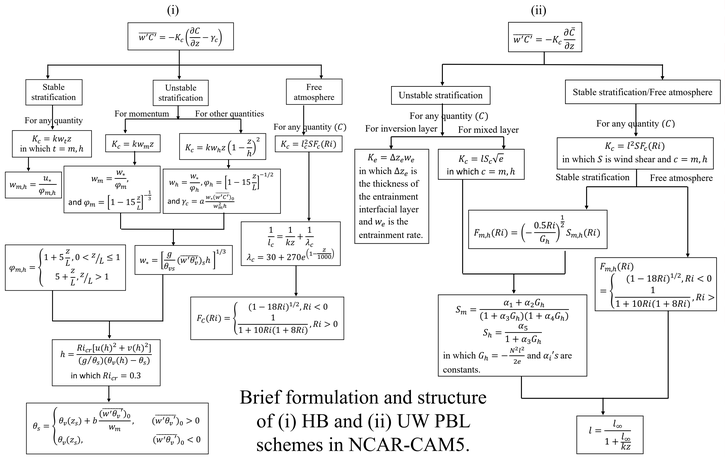
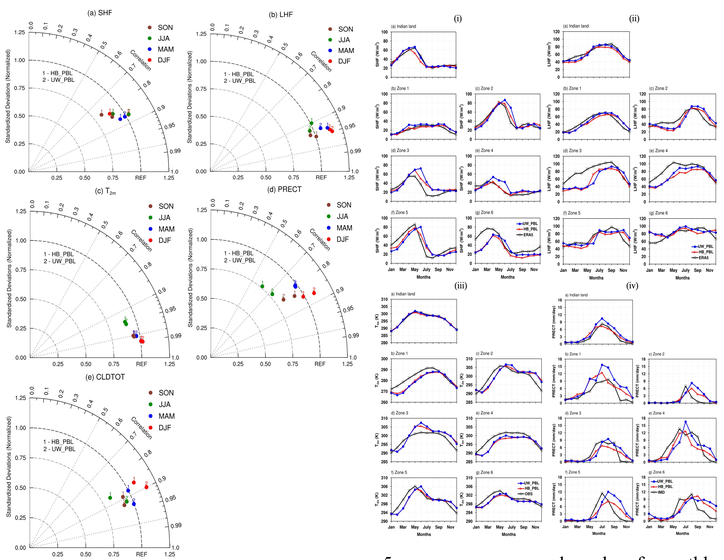
Background

The PBL schemes proposed by Holtslag and Boville (1993) (HB PBL) and Bretherton and Park (2009) (University of Washington Moist Turbulence scheme; UW PBL) are available in NCAR-CAM5 model.



Brief formulation and structure of (i) HB and (ii) UW PBL schemes in NCAR-CAM5.



Statistics of the simulated variables by HB PBL and UW PBL schemes with respect to reference data for different seasons over south Asian domain (20S-40N, 40E-140E).

5-year average annual cycle of monthly means of (i) SHF, (ii) LHF, (iii) T2m, and (iv) PRECT by reference data (black line), UW_PBL (blue line), HB_PBL (red line) over Indian land as well as six different climatic zones exist with in Indian land.

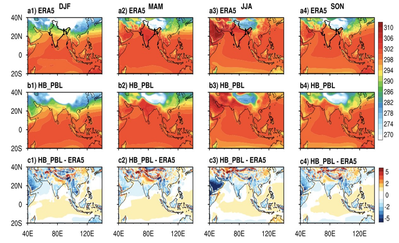
Objective

In order to improve the performance of HB PBL scheme, this study focused on to analyze the impact of different values of critical bulk Richardson number in HB PBL of NCAR-CAM5 on the simulation of certain near surface atmospheric variables as well as precipitation over India and its adjoining regions.

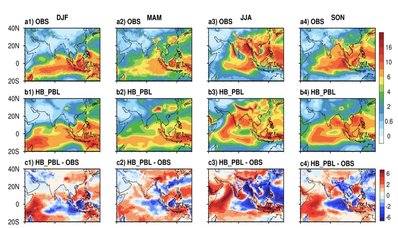
Methodology

- Five sets of simulations have been conducted using different values of critical bulk Richardson number (Ri_{cr}) in HB PBL with NCAR-CAM5 model for 6 years each at a horizontal resolution of 0.9^o latitude × 1.25^o longitude.
- Different experiments are as follows:
  1. L0 ($Ri_{cr} = 0.19$)
  2. L1. ($Ri_{cr} = 0.25$)
  3. CTRL ($Ri_{cr} = 0.30$; default value)
  4. H0 ($Ri_{cr} = 0.35$)
  5. H1 ($Ri_{cr} = 0.50$)
- First, the CTRL simulation has been validated against ERA5 and other observational (IMD and TRMM precipitation) dataset over south Asian domain (SAD; 20S-40N, 40E-140E) as well as Indian land for different seasons (DJF, MAM, JJA and SON).
- Then certain considered variables from different experiments (L0, L1, H0 and H1) have been compared with respect to CTRL simulation for evaluating the impact of different values of Ri_{cr} over whole SAD and only land and ocean within SAD.

Validation

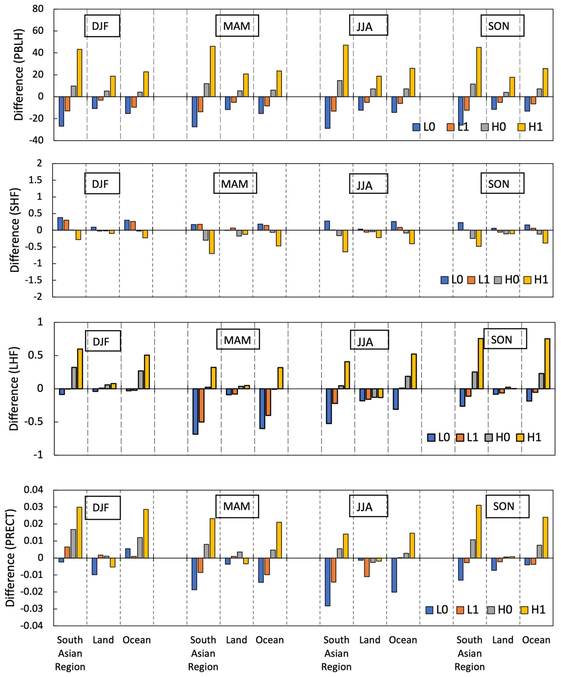


Spatial distribution of 5-year average monthly means of 2-m temperature by ERA5, HB PBL and their differences with respect to ERA5 for different seasons.

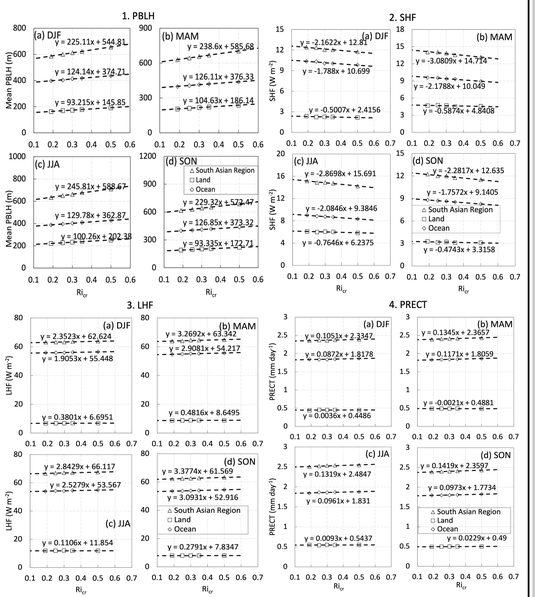


Spatial distribution of 5-year average monthly means of total precipitation from observations, HB PBL and their differences with respect to ERA5 for different seasons.

Results



Mean differences between simulated variables between CTRL simulation and different experiments (L0, L1, H0, H1).



Simulated variables as a function of Ri_{cr} during different seasons.

Conclusions

- The study suggests that the mean planetary boundary layer height (PBLH) increases linearly with increasing Ri_{cr} during all four seasons.
- The surface sensible (latent) heat flux decreases (increases) as Ri_{cr} increases during all four seasons.
- The 2-m temperature, wind and specific humidity changes are marginal and insignificant during all seasons.
- Total precipitation averaged over the whole domain also shows increasing behaviour as Ri_{cr} increases.

References:

- Holtslag, A. A. M., & Boville, B. A. (1993). Local Versus Nonlocal Boundary-Layer Diffusion in a Global Climate Model. *Journal of Climate*, 6, 1825–1842.
- Bretherton, C. S., and S. Park, 2009: A New Moist Turbulence Parameterization in the Community Atmosphere Model. *J. Climate*, **22**, 3422–3448,
- Zhang, Y., Gao, Z., Li, D., Li, Y., Zhang, N., Zhao, X., and Chen, J.: On the computation of planetary boundary-layer height using the bulk Richardson number method, *Geosci. Model Dev.*, 7, 2599–2611.

Future directions

- To incorporate atmospheric stability varying Ri_{cr} based on the work by Zhang et al. (2014) in HB PBL scheme and analyzed the results with scheme with constant Ri_{cr} .
- Incorporation of similarity functions in HB PBL same as that of in surface layer parameterization of NCAR-CAM5 to make it consistent with the surface layer scheme.

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