How well do CMIP6 models simulate salinity barrier layers in the North Indian Ocean?

Shanshan Pang[1], Xidong Wang[1,2*], Jérôme Vialard[3]

1. Key Laboratory of Marine Hazards Forecasting, Ministry of Natural Resources, Hohai University, Nanjing, China
2. Southern Marine Science and Engineering Guangdong Laboratory (Zhuhai), Zhuhai, China
3. LOCEAN Laboratory, Sorbonne University, Paris, France

shanshan.pang@locean.ipsl.fr

Abstract ID: EGU23-6736

1. Abstract

We investigate how state-of-the-art Coupled Model Intercomparison Project phase 6 (CMIP6) climate models simulate the North Indian Ocean (NIO) barrier layer thickness (BLT). CMIP6 models generally reproduce the BLT seasonal cycle and spatial distribution, but with shallow November-February (NDJF) BLT biases in regions with thick observed BLT (eastern equatorial Indian Ocean [EEIO], Bay of Bengal [BoB], and southeastern Arabian Sea [SEAS]). The CMIP6 equatorial easterly wind bias explains the EEIO shallow isothermal layer depth (ILD) and BLT. Underestimated BoB rainfall leads to overestimated sea surface salinity (SSS), mixed layer depth (MLD), and deep CMIP6-average BLT bias in the BoB. The intensity of equatorial easterly wind bias controls the inter-model spread in the BoB BLT bias, through the propagation of equatorial ILD signals into the NIO coastal waveguide. Finally, the SEAS BLT bias is due to a too-deep MLD, in response to subdued monsoonal currents around India, which do not bring enough BoB low-salinity water. The BL insulating effect does not seem to dominate in CMIP6, and the shallow BLT bias hence does not contribute to the cold SST bias. Rather, salinity-related deep MLD biases diminish the BoB cooling rate in response to winter upward surface heat fluxes, reducing cold sea surface temperature (SST) biases. This suggests that salinity effects alleviate the easterly equatorial winds, cold and dry BoB biases that develop through the positive Bjerknes feedback loop in CMIP6.

2. Background

- Previous studies have hypothesized that climatologically thick salinity-stratified Barrier Layers (BL) in the NIO influence the upper ocean heat budget, SST, and monsoon.
- In CMIP, a equatorial easterly bias in the tropical Indian Ocean is coupled with an unrealistic mean slope of the equatorial thermocline that is tilted toward the eastern Indian Ocean through the Bjerknes positive feedback.

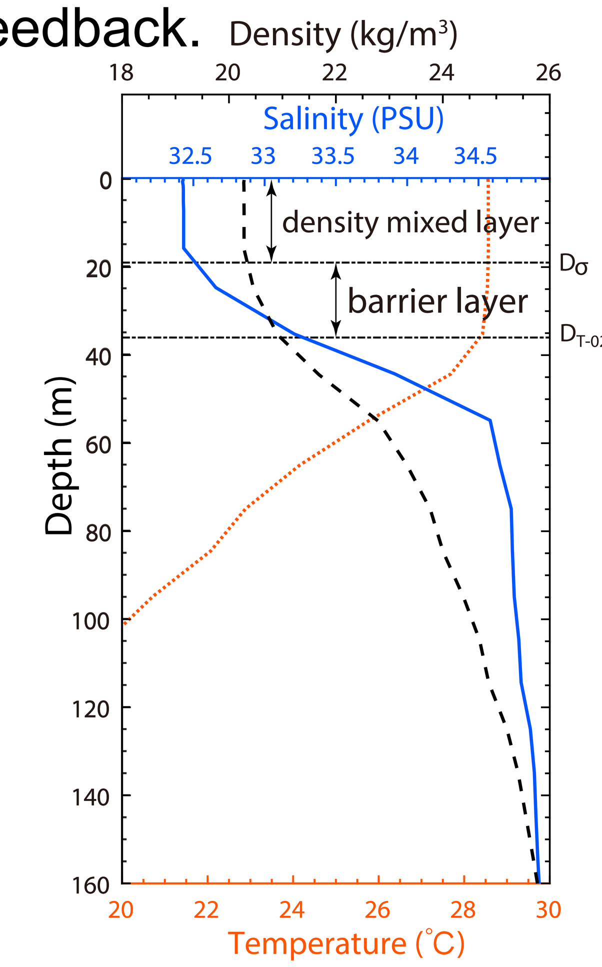

Fig.1 Vertical distribution of temperature, salinity and density, and MLD & BLT.

3. Data & Methods

- **Data** [monthly, 2002-2014]

CMIP6 historical runs

- ocean temperature/salinity/horizontal currents, wind stress, evaporation and precipitation.

Argo ISAS-15 product

- ocean temperature and salinity.

OAFlux/GPCP/ERA-5 /GLORYS12

- evaporation, precipitation, wind stress, and surface current velocity.

- **Methods**

Linear regression analysis

Salinity budget analysis

$$\frac{\partial S_m}{\partial t} = \frac{S_m(E-P)}{h} - \vec{u}_m \cdot \nabla S_m + residual$$

4. Basin scale climatological BLT biases

- The CMIP6 multi-model mean (MMM) has maxima in the same three regions as observations (the EEIO, BoB and SEAS), but with a clear shallow BLT bias.

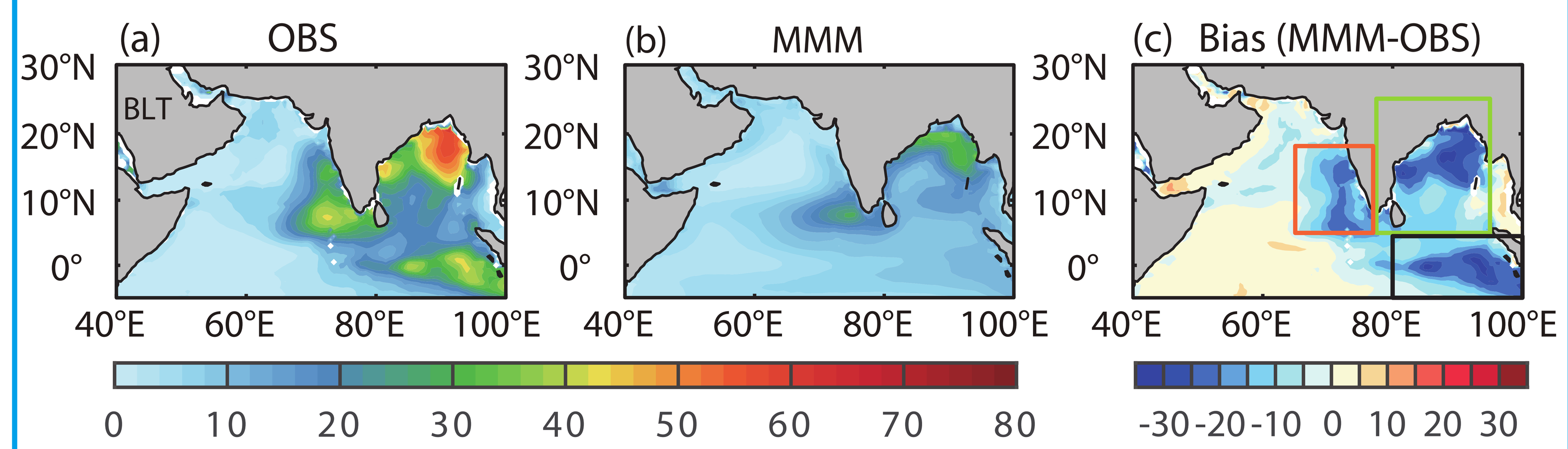

Fig.2 Observed and average CMIP6 NDJF BLT climatology. NDJF BLT (m) in the (a) observation, (b) CMIP6 MMM, and (c) bias (MMM minus observations). The green, red, and black boxes denote the BoB, SEAS and EEIO.

5. Mechanisms of the CMIP6 biases

Region: EEIO

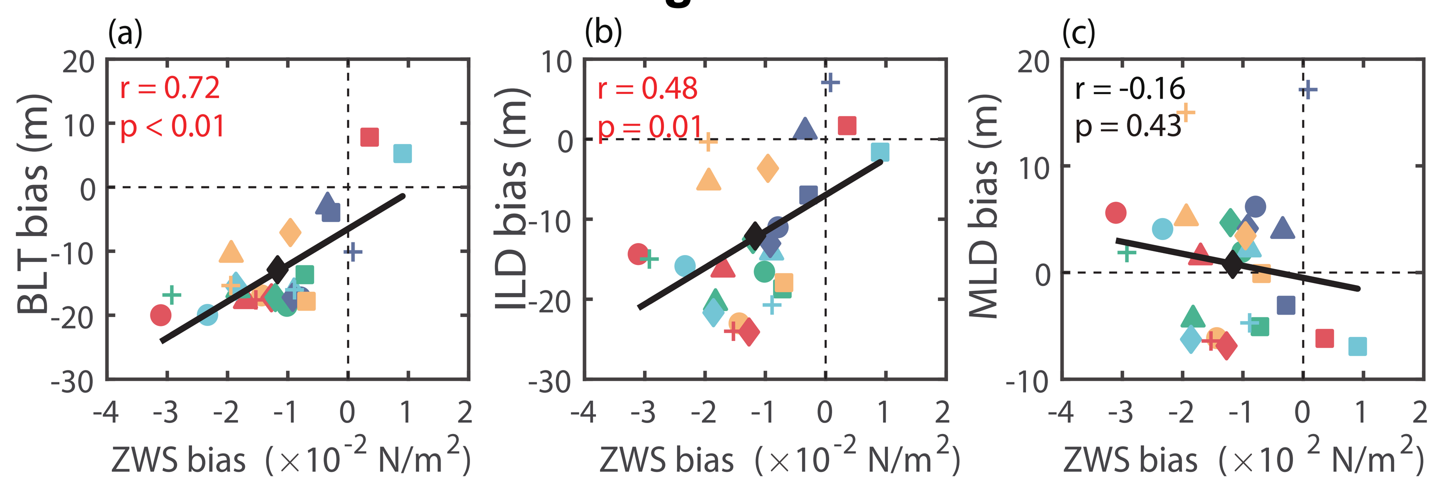

Fig. 3 Scatterplots of the October-December zonal surface wind stress (N/m²) bias over the central Indian Ocean with the (a) NDJF BLT (m), (b) ILD (m) and (c) MLD (m) biases in the EEIO.

Region: BoB

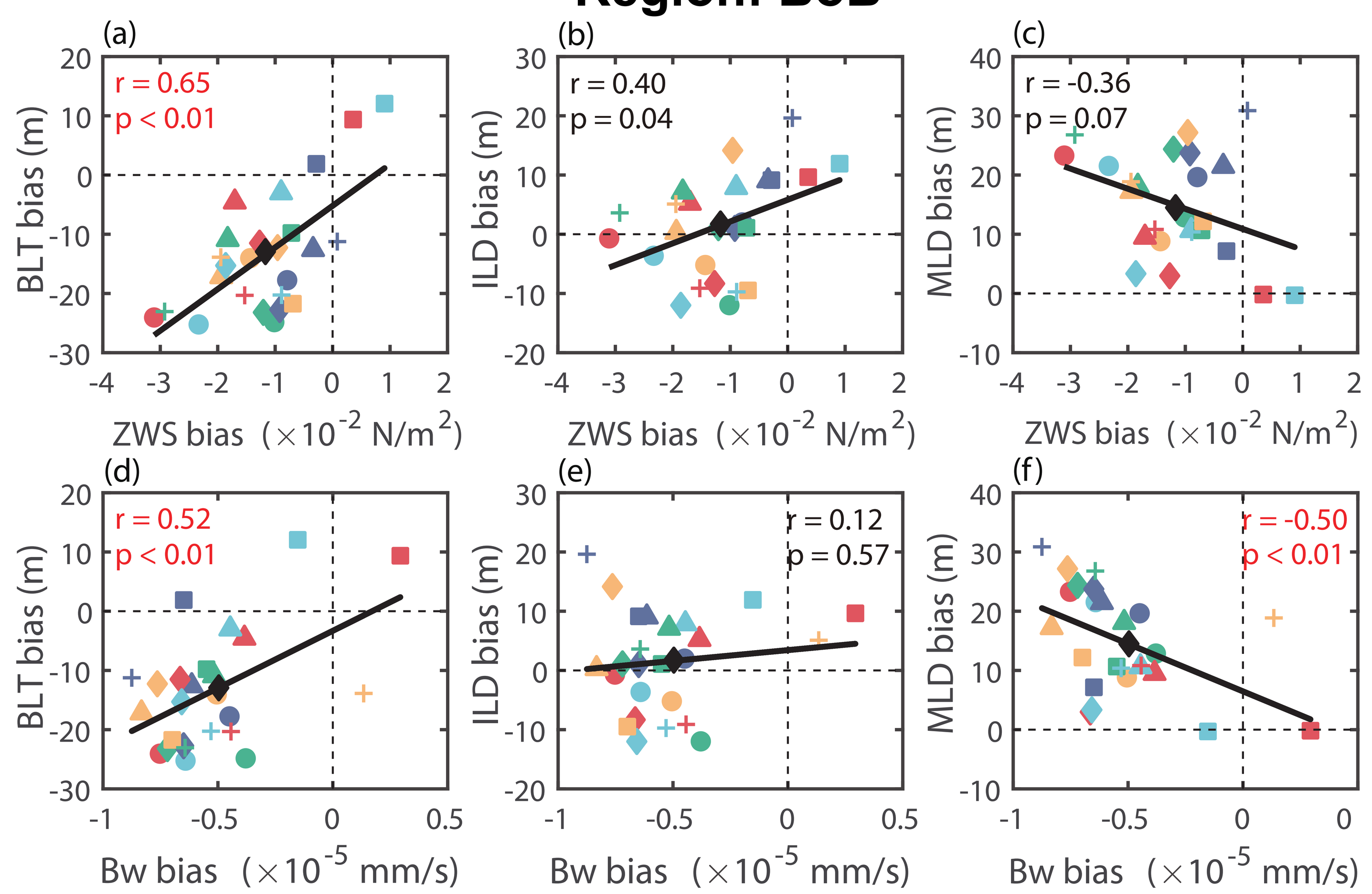

Fig. 4 (a-c) Same as Fig. 3, but for the BoB. Scatterplots of the NDJF buoyancy flux due to fresh water (mm/s) bias with the NDJF (d) BLT, (e) ILD, and (f) MLD biases in the BoB.

Region: SEAS

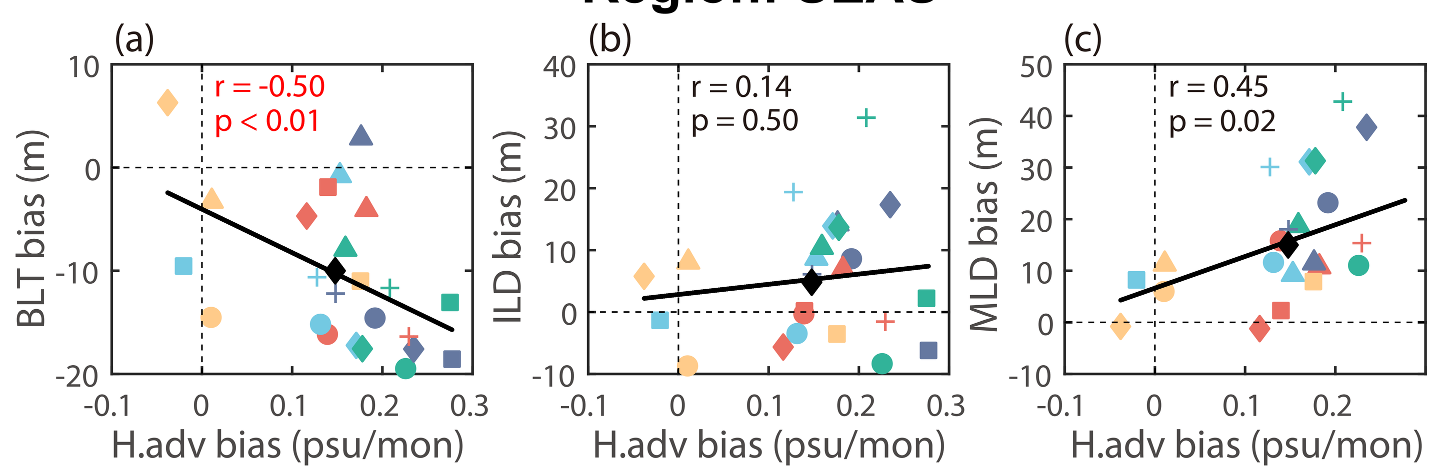

Fig. 5 Scatterplots of the NDJF horizontal salt advection bias (psu/mon) with the NDJF (a) BLT (m), (b) ILD (m), and (c) MLD (m) biases in the SEAS.

6. Impact of SST

- In the CMIP6 models, the shallow BLT bias influence on entrainment cooling does not dominate. Rather, it seems that the associated deep MLD bias in the BoB and SEAS alleviastes the cold SST bias in those regions, through "diluting" the winter surface cooling over a thicker layer.

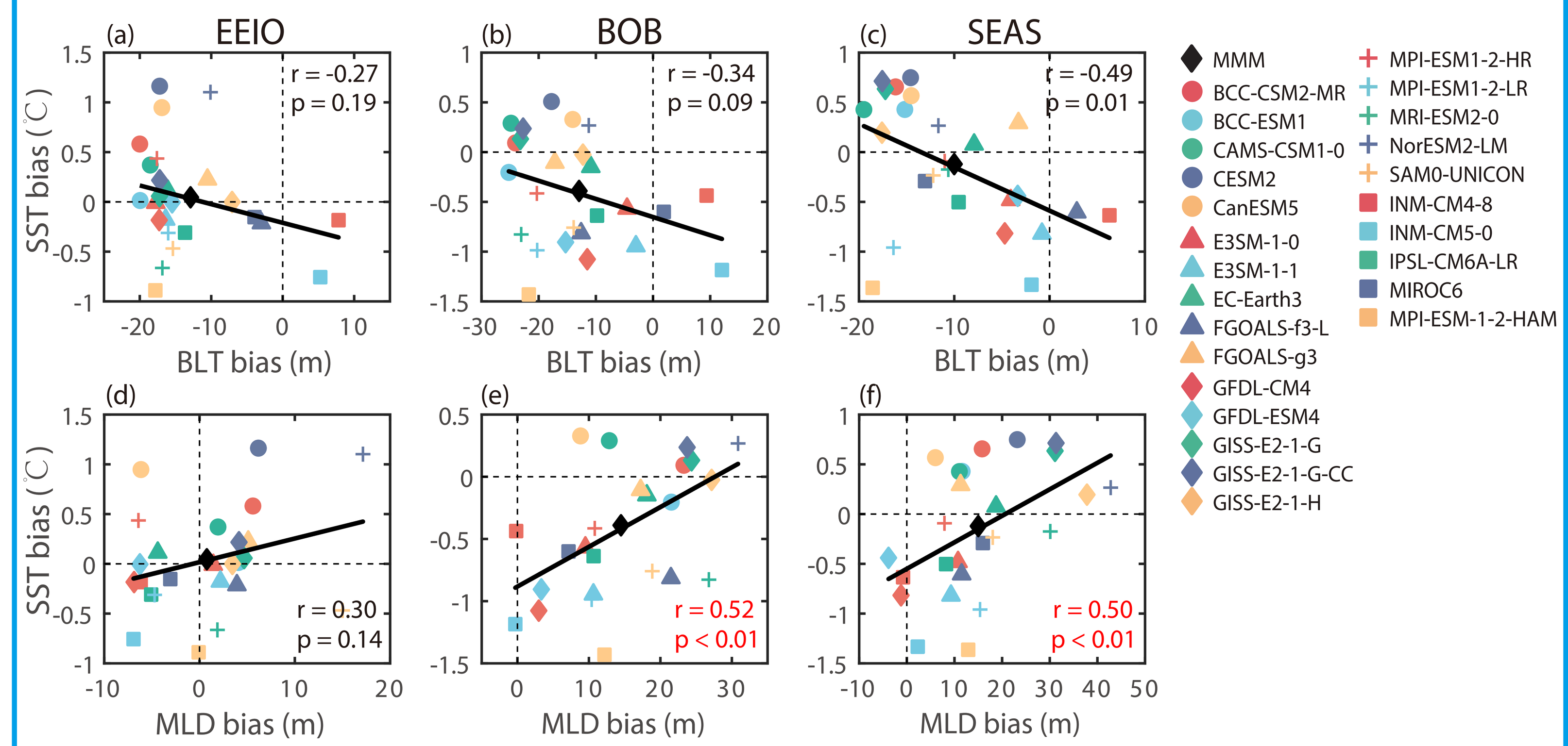

Fig. 6 Scatterplots of the NDJF SST bias (℃) in the EEIO (left), BoB (middle), and SEAS (right) with the (a–c) BLT (m) and (d–f) MLD (m) biases.

7. Conclusions

- Most CMIP6 models reproduce the seasonal cycle and spatial pattern of BLT in the NIO, but with a common shallow bias during NDJF season in the regions (EEIO, BoB and SEAS) where there is a thick observed climatological BLT.
- We investigate the mechanism that controls the MMM BLT biases and its diversity in the three regions:

-EEIO: *the equatorial easterly wind bias controls the shallow ILD and BLT through the Sverdrup dynamics.*

-BoB: *the less rainfall associated with the equatorial easterly wind bias leads to a too-deep MLD and hence shallow BLT bias through the Bjerknes feedback. The intensity of easterly equatorial wind bias also regulates the ILD bias through the coastal waveguide, resulting in the diversity of BLT bias.*

-SEAS: *the weak input of BoB low salinity water into the SEAS explains the MMM shallow BLT biases and its diversity.*

- Salinity effects in the BoB tends to dampen the linked biases developing through the positive Bjerknes feedback loop.