Water-mass transformation in the Indonesian Seas:
the interplay of wind, tides, and air-sea fluxes

Chengyuan Pang[1,2], Maxim Nikurashin[1,2,3], Beatriz Pena-Molino[3,4], Bernadette M. Sloyan[4]

[1]Institute for Marine and Antarctic Studies, [2]ARC Centre of Excellence for Climate Extremes,[3]Australian Antarctic Program Partnership,[4]CSIRO Environment

Introduction

- As the ***only tropical pathway*** between the Pacific and Indian Oceans, **the Indonesian Seas** play a central role in the global climate and ocean circulation [1, 4].
- Strong ***diapycnal mixing*** driven by tides, wind, and air-sea fluxes causes water-mass transformation, leading local (via ***SST***) and global (via ***MOC***) impacts [1, 3, 4].
- Previous studies indicates massive formation of ***thermocline water*** at the expense of surface and deep water [2, 4].
- Using the ***coarse-resolution*** ($1/4^o$) model with ***prescribed mixing***, Koch-Larrouy et al. (2008) suggests thermocline water formation is mainly driven by ***tidal mixing*** and ***wind*** is ***irrelevant*** [4].
- In this study, we use a ***high-resolution*** ($1/50^o$) regional model with ***explicit tides*** to explore the water-mass transformation mechanism.

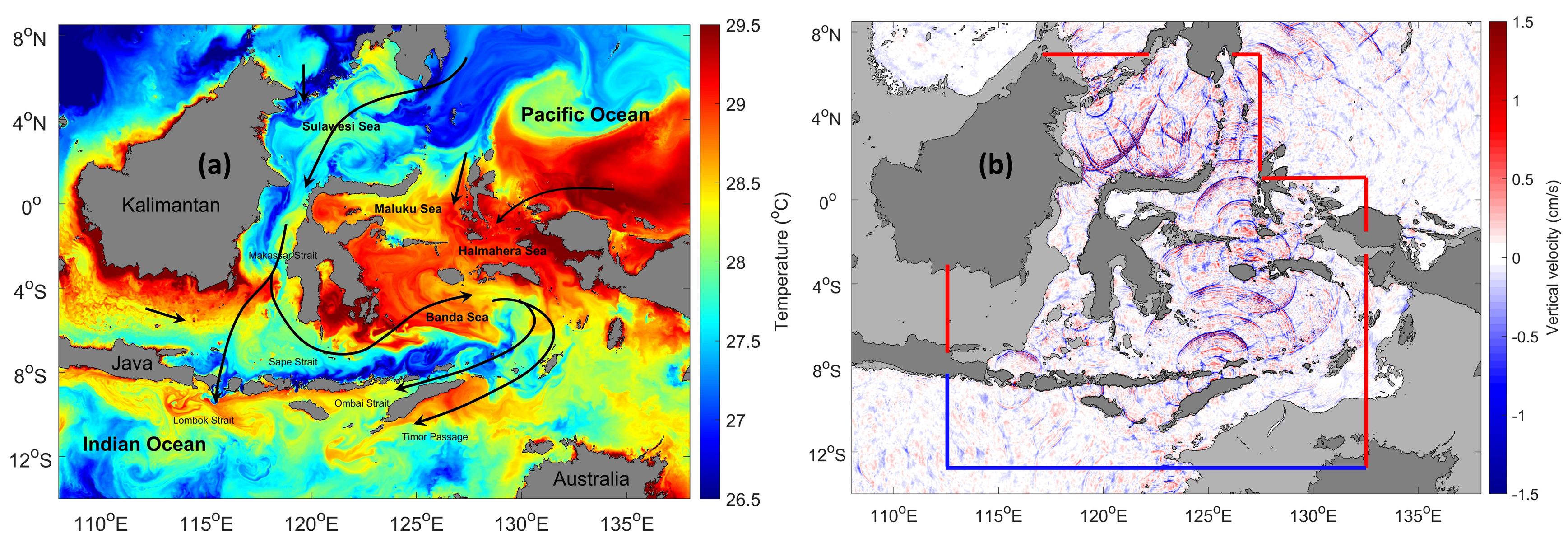

Figure 1: Model snapshots of (a) SST (^{o}C) and (b) vertical velocity (m/s) at 140m.

Model configuration

- ***MITgcm*** at $1/50^o$ (2 km) horizontal resolutions with 100 vertical levels.
- Open boundaries from ***ACCESS-OM2-01 RYF 1990-91***.
- High-resolution bathymetry from ***SRTM30_PLUS***.
- Barotropic tides from ***TPXO9v4*** (12 constituents).
- ***KPP*** mixing parameterization for shear-driven mixing.

Results: Water-mass transformation in the 3 models

Table 1: The annual mean water-mass (divided by neutral density ranges) transformation rates in the control (reference) model and 2 perturbation simulations.

Density Range	Layers	Control	No Tide	No Wind
$\gamma^n < 22$	Surface	-2.1	+0.1	+1.7
$22 < \gamma^n < 26$	Thermocline	+3.3	+0.4	-0.7
$\gamma^n > 26$	Intermediate & Deep	-1.2	-0.5	-1.0

- ***Strong*** thermocline water is formed (>3 Sv) in the ***control*** model.
- ***Negligible*** thermocline water is formed (<1 Sv) in the 2 ***perturbation*** simulations.
- ***Both*** tide and wind are ***necessary*** for thermocline water formation.

Reference

[1] Sprintall, J., Gordon, A. L., & Koch-Larrouy, A. The Indonesian Seas and their impact on the Coupled Ocean Climate System. *Nature Geosci.* **7**, 487–492 (2014).
[2] Gordon, A. L., Sprintall, J., Van Aken, H. M., Susanto, D., Wijffels, S., Molcard, R., Ffield, A., Pranowo, M., & Wirasantosa, S. The Indonesian throughflow during 20042006 as observed by the INSTANT program. *Dynam. Atmos. Oceans.* **50**, 115–128 (2010).
[3] Nagai, T. & Hibiya, T. Internal tides and associated vertical mixing in the Indonesian Archipelago. *J. Geophys. Res.* **120**, 3373–3390 (2015).
[4] Koch-Larrouy, A., Madec, G., & Iudicone, D. Physical processes contributing to the water mass transformation of the Indonesian Throughflow. *Ocean Dynamics* **58**, 275–288 (2008).

Results: Diapycnal mixing in the 3 models

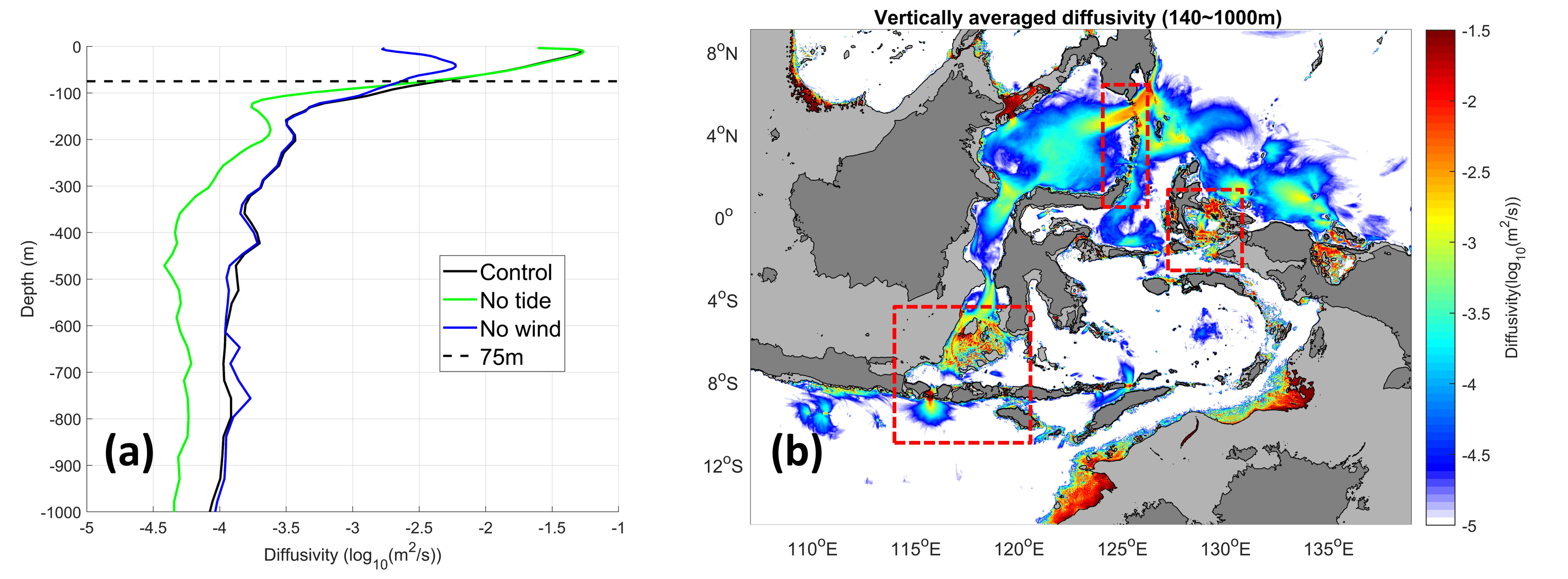

Figure 2: (a) Vertical profiles of horizontally-averaged diffusivity of the model domain. (b) Map of vertically averaged (140-1000m) diffusivity of the control model.

- **Within** the mixed layer (above 75m), strong mixing is dominated by **wind-driven mixing** and is insensitive to tides.
- **Below** the mixed layer, mixing is dominated by **tidal mixing** and insensitive to the wind.
- **Tides are necessary**, but not because of the tidal mixing!!!

Results: Mechanism of water-mass transformation

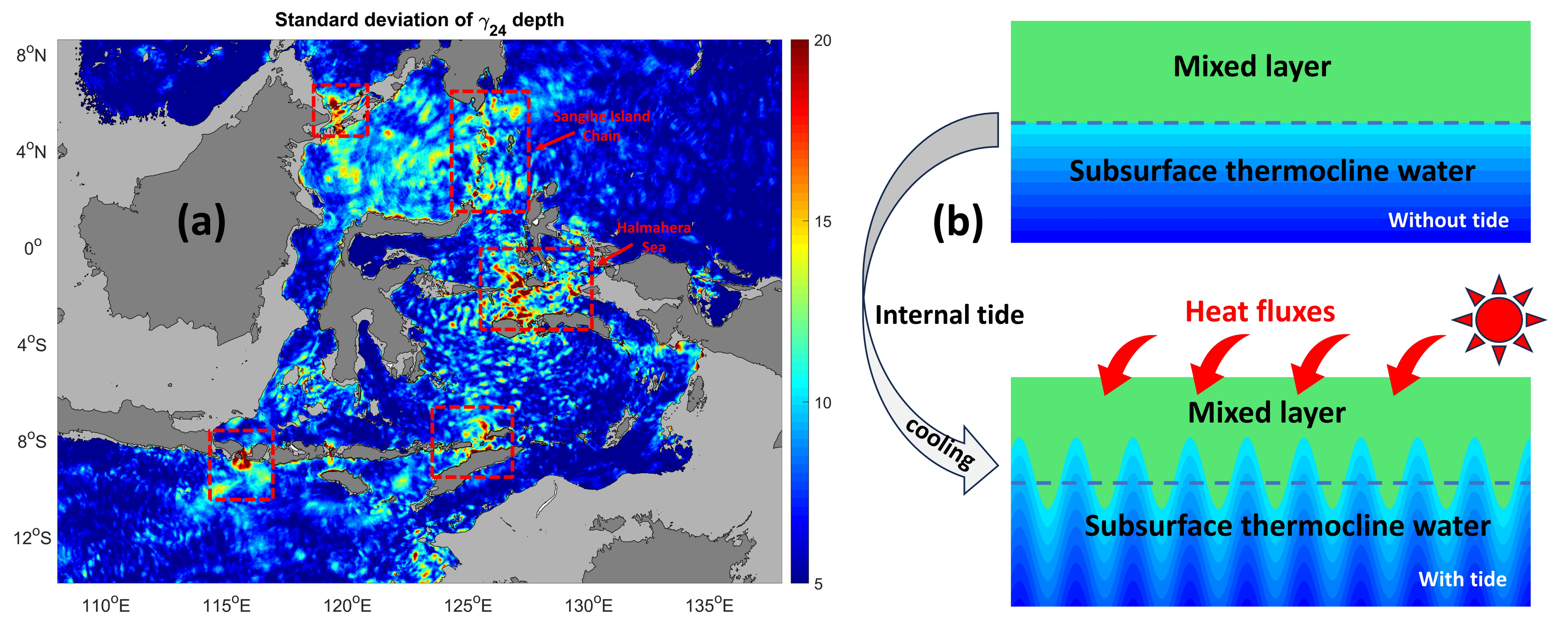

Figure 3: (a) The standard deviation of 3 hourly $\gamma 24$ (neutral density 24 kg/m^3) depth in 10 days. (b) Schematic figure of transformation mechanism.

- The internal tides move isopycnals **up**/down by **20-30m**, especially close to the narrow straits (Fig.3a).
- Strong thermocline water formation happens in the Sangihe Island Chain (Jan-Mar) and the Halmahera Seas (Jul-Sep) (Fig.4a, 4b).
- Thermocline water is mainly produced during the period **when the thermocline water is exposed to the mixed layer** (Fig.4).
- Mechanism: **internal tide exposes** the thermocline to the mixed layer, then **wind mixes** surface water with thermocline water and transforms surface water to thermocline water (Fig.3b).

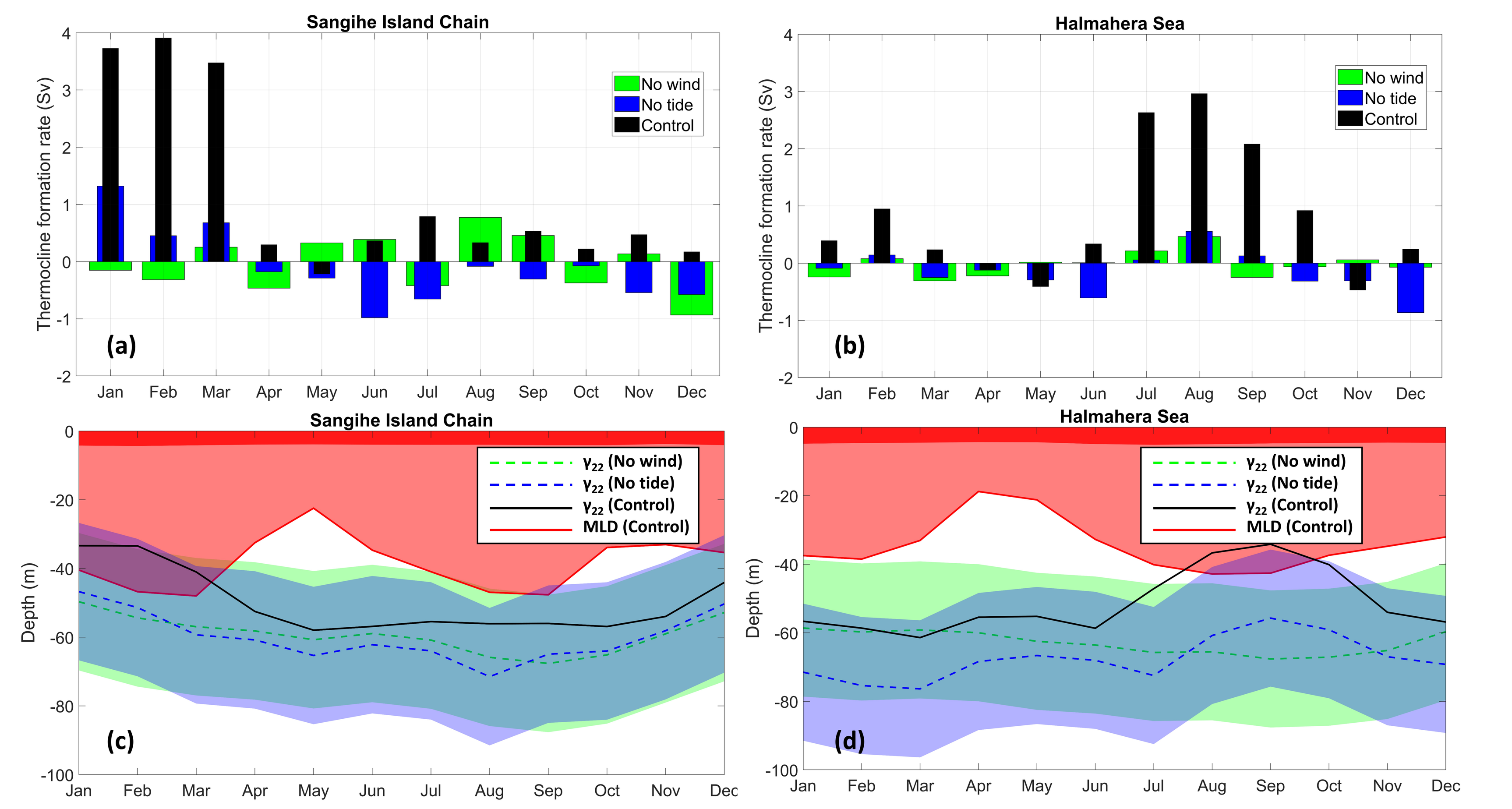

Figure 4: (a) (b) The monthly thermocline water formation rate of 3 models. (c) (d) The monthly depth of the mixed layer and $\gamma 22$ (upper boundary of thermocline).

Contact: chengyuan.pang@utas.edu.au