Seasonal mixed layer heat balance of the southwestern tropical Indian Ocean

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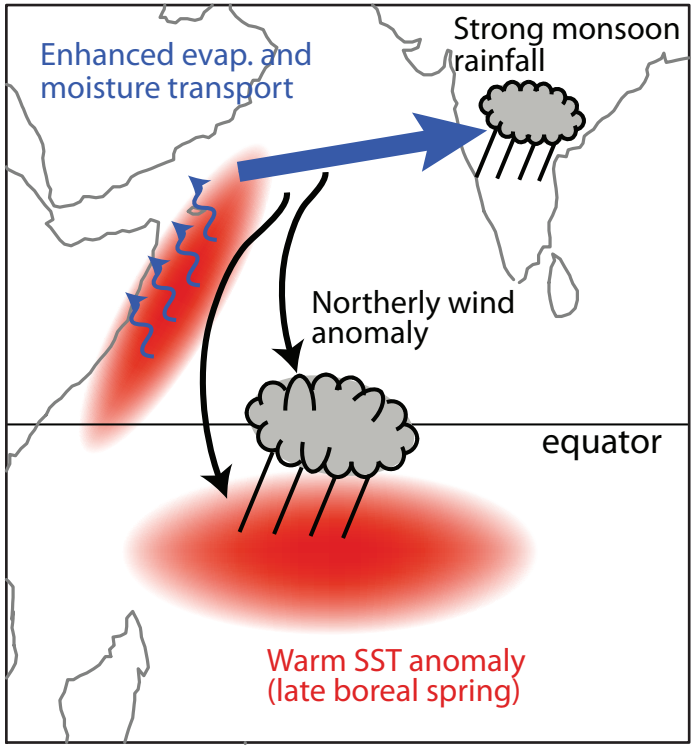
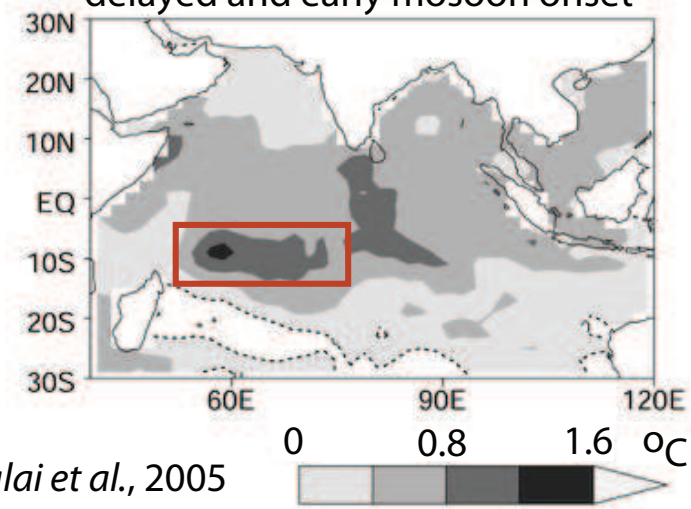
Impacts of southwestern Indian Ocean SST



Izumo et al., 2008

- SST in southwestern tropical Indian Ocean affects timing and strength of Indian summer monsoon.

SST difference between years of delayed and early mosoon onset

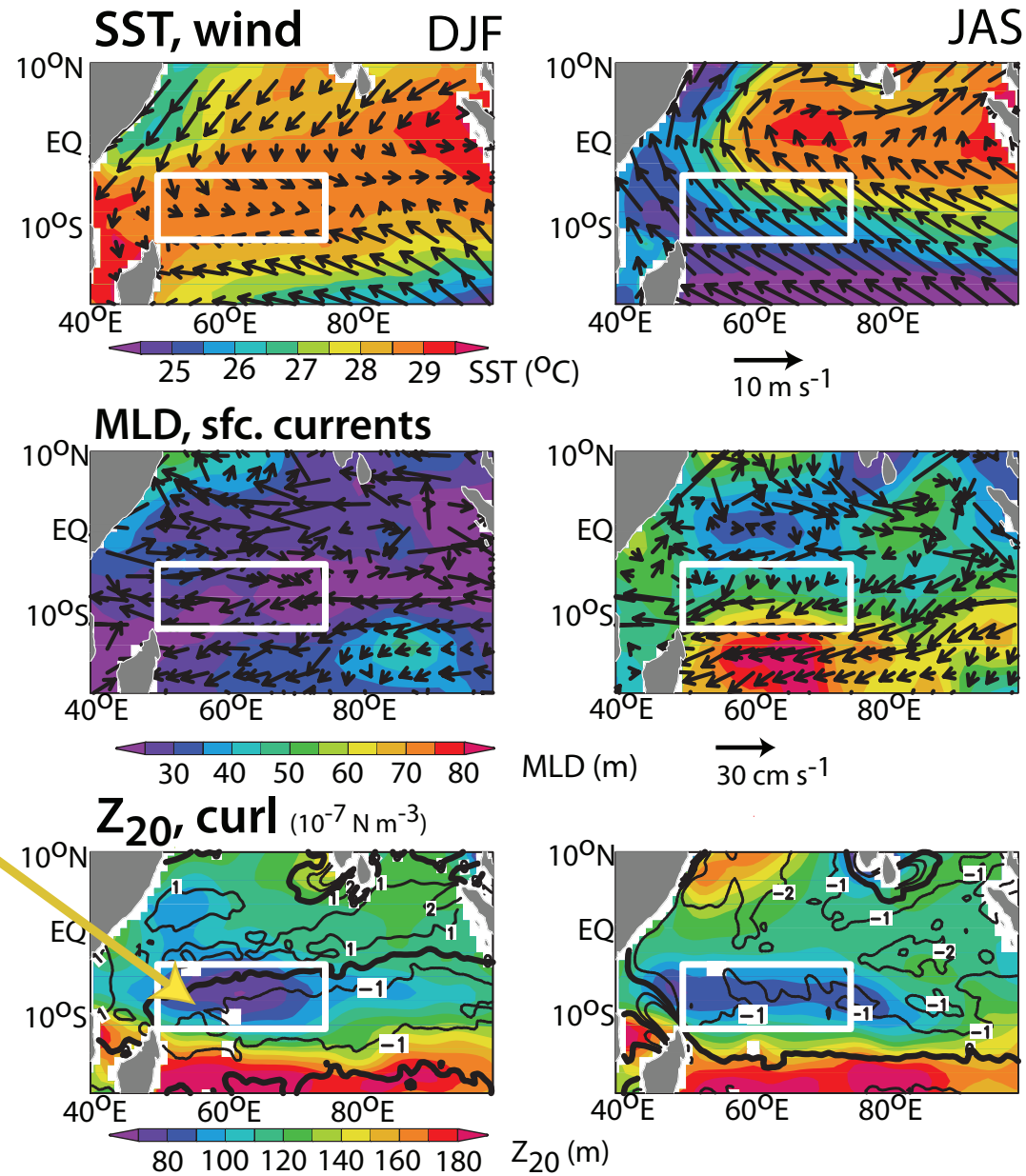


Annamalai et al., 2005

Seasonal cycle

- Strong seasonal cycles of SST, wind, MLD.

Thermocline ridge region



Mixed layer heat equation

Mixed layer heat storage rate

Sfc. heat flux (LHF + Abs. SWR + LWR + SHF)

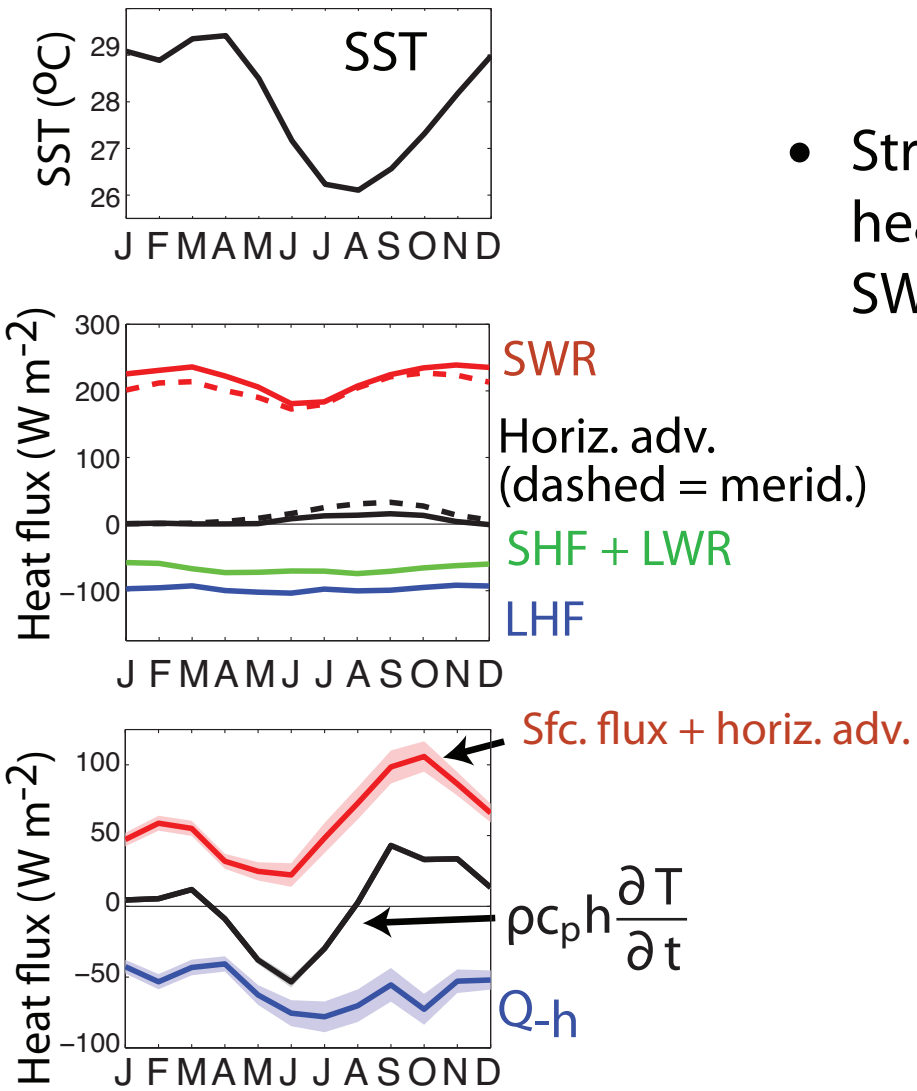
Horiz. advection

$$\rho c_p h \frac{\partial T}{\partial t} = Q_0 - \rho c_p h \vec{\mathbf{v}} \cdot \nabla T + Q_{-h}$$

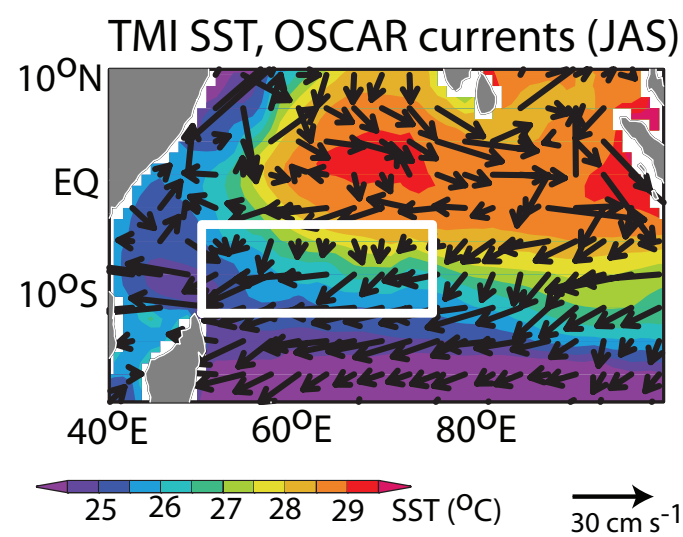
Vert. turb. mixing

- **Heat storage**: In situ T, S
- **Sfc. fluxes, horiz. adv.**: Satellite/reanalysis turb. flux, OLR; OSCAR currents
- **Vert. turbulent mixing**: Residual

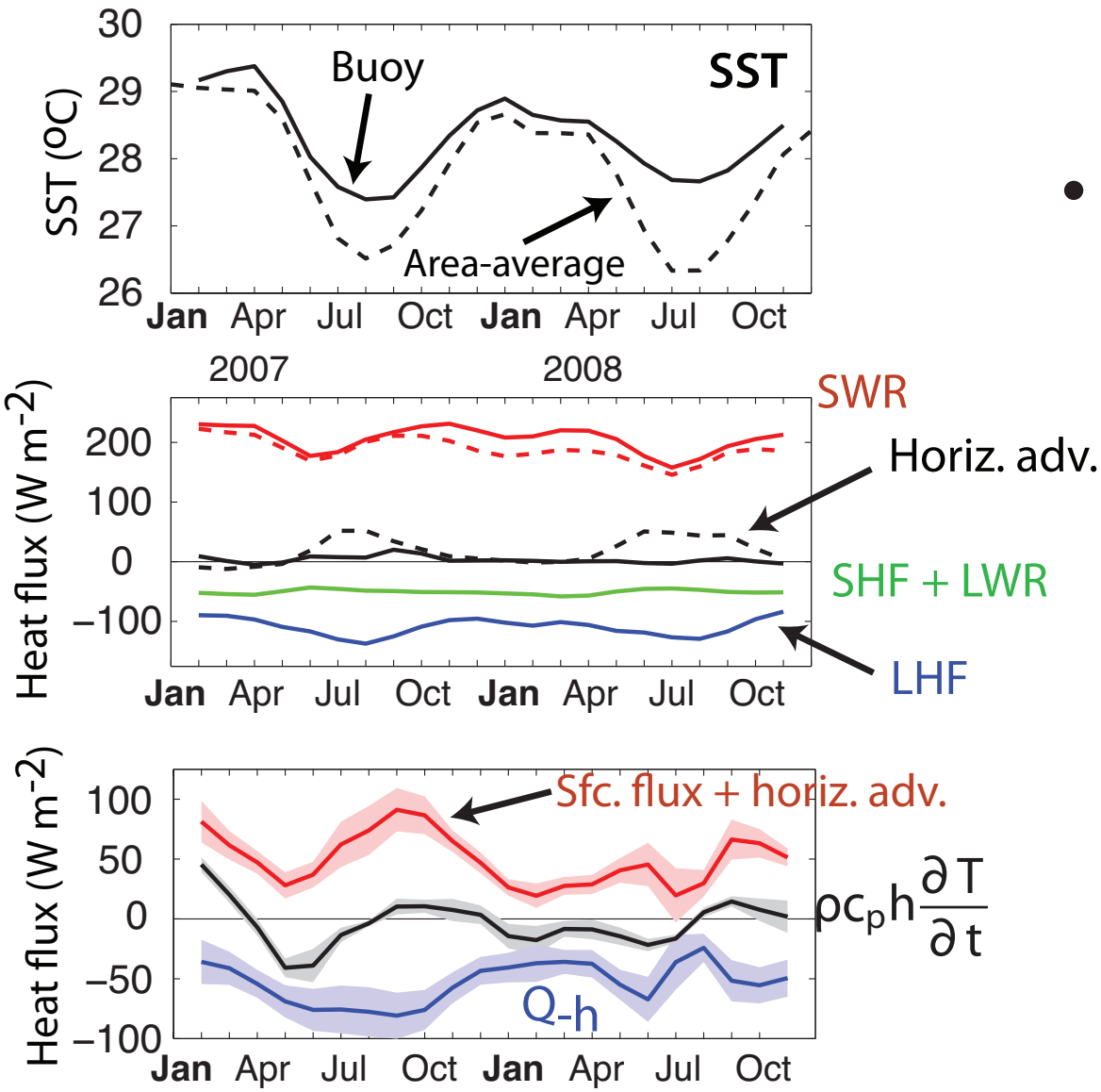
Area-averaged heat balance



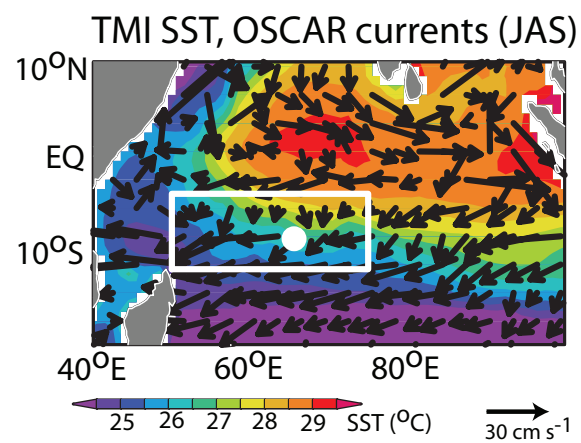
- Strong seasonal cycle of mixed layer heat storage is driven by sum of SWR, horiz. adv., and Q_{-h}



Heat balance at mooring location

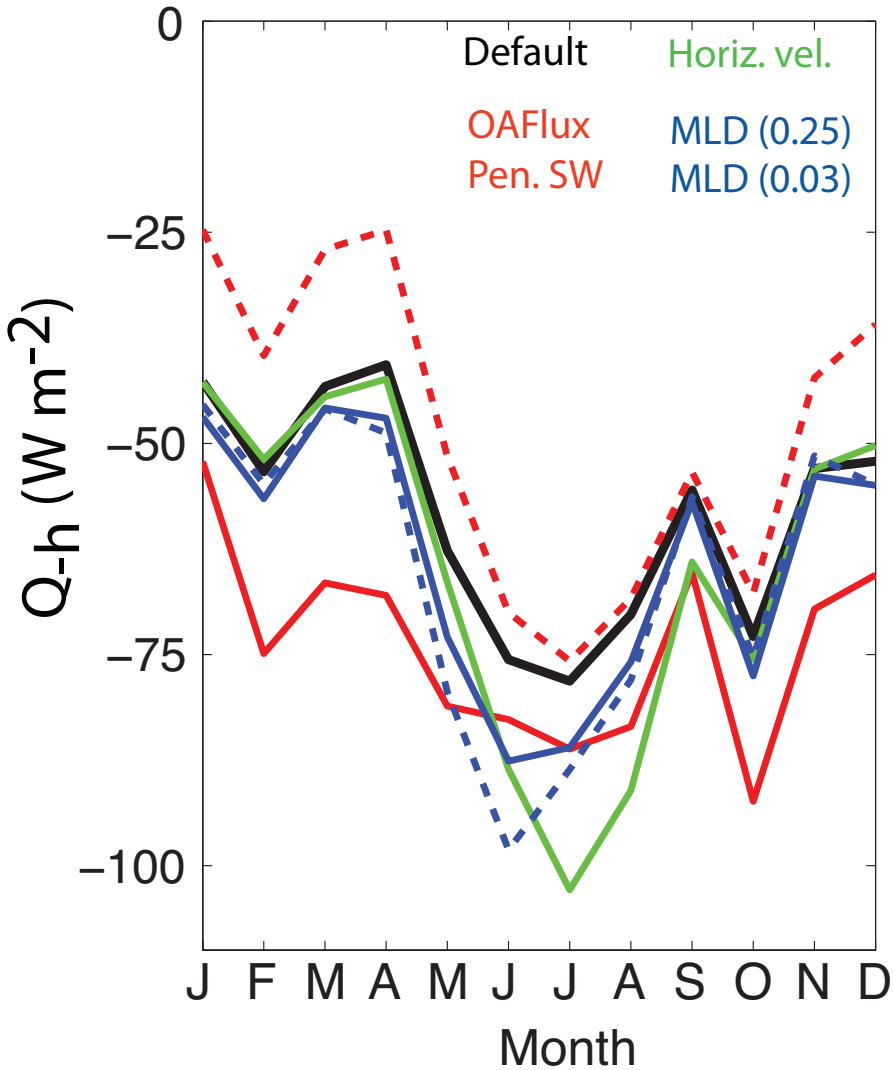


- Similar to area-averaged heat balance



Heat balance residual

- Similar seasonal cycle of Q_{-h} for different sfc. flux, currents, MLD.



Entrainment heat flux

Energy balance:
(*Niiler and Kraus*, 1977)

$$\mathbf{w_e} = \frac{\text{Wind} - \text{Sfc. Bouy.} - \text{Pen. SW}}{\text{Stratification} - \text{Current shear}}$$

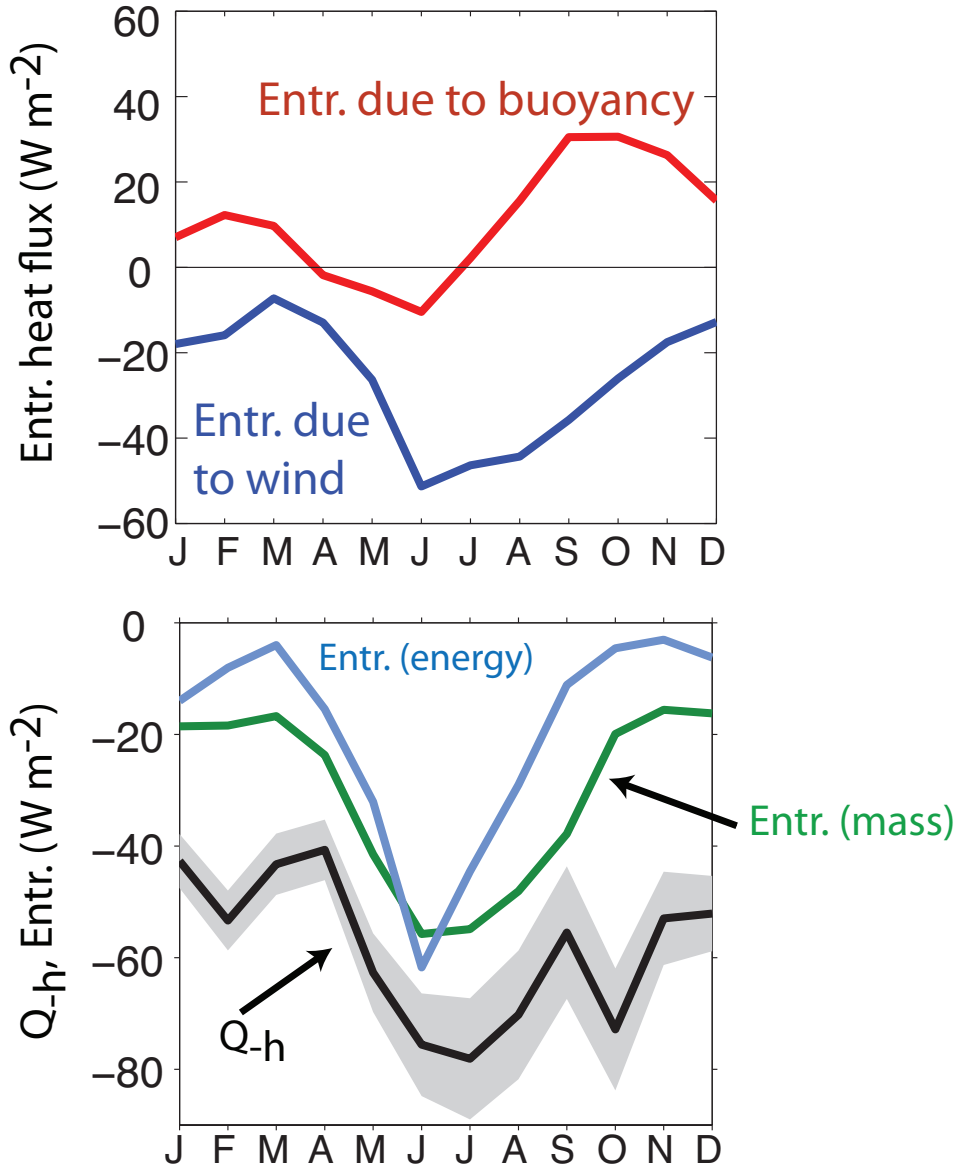
Mass balance:

$$\mathbf{w_e} = \frac{\partial h}{\partial t} + \nabla \cdot h\vec{v}$$

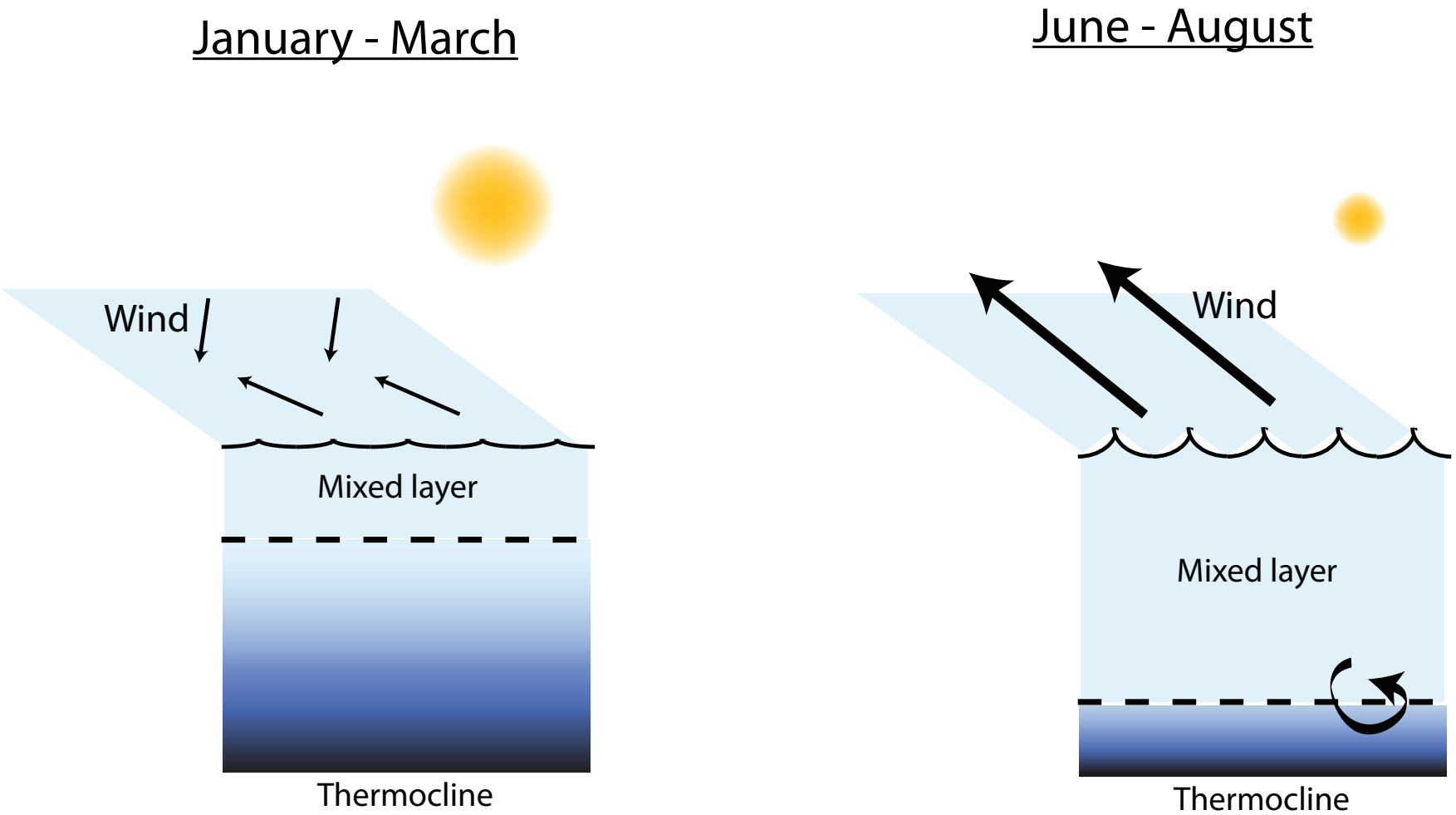
$$Q_{entr} = \rho c_p \, \Delta T \, \mathbf{w_e} \qquad \Delta T = T_{h+10} - T$$

Entrainment

- Strongest entrainment cooling occurs in austral winter, in phase with Q_{-h}



Seasonal cycle of entrainment



Summary

- Strong seasonal cycle of mixed layer heat storage in the southwestern tropical Indian Ocean is driven by the combination of shortwave radiation, horiz. advection, and entrainment.

- Entrainment is strongest in austral winter/spring, when winds are strongest, the surface buoyancy flux is weakest, and the base of the mixed layer is closest to the thermocline.

Foltz, G.R., J. Vialard, P.B. Kumar, and M.J. McPhaden (2010), Seasonal mixed layer heat balance of the southwestern tropical Indian Ocean, *J. Climate*, *23*, 947-965.