Barrier Layers and Temperature Inversions in the Eastern Pacific Fresh Pool and Their Impact on the Heat and Freshwater Balance

Shota Katsura[1], Janet Sprintall[1], J. Thomas Farrar[2], Dongxiao Zhang[3,4] and Meghan F. Cronin[3]

1: Scripps Institution of Oceanography, University of California, San Diego

2: Department of Physical Oceanography, Woods Hole Oceanographic Institution

3: NOAA Pacific Marine Environmental Laboratory

4: Cooperative Institute for Climate, Ocean, & Ecosystem Studies, University of Washington

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Introduction: Barrier Layer and SPURS-2

○**Barrier Layer (BL):**

- The difference between a shallow mixed layer and a deeper isothermal layer.
- A stable barrier against heat and momentum exchange with the subsurface.

→ BL can significantly affect SST.

○**The Salinity Processes in the Upper-ocean Regional Study 2 (SPURS-2):**

・Three Mooring Observations along 125W:

・WHOI mooring (10N)

・PICOSP01 mooring (11N)

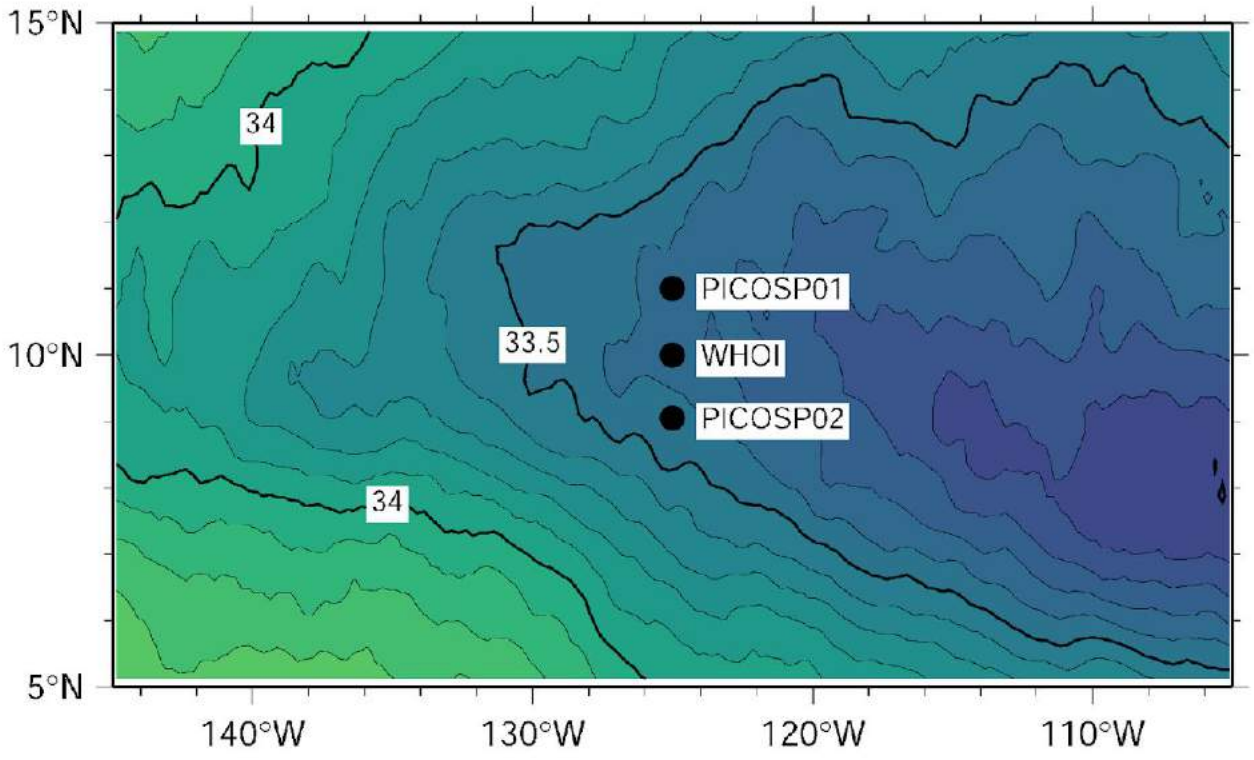
・PICOSP02 mooring (9N)

○Purpose of this study is to investigate:

・The formation of BLs and associated TIs

・Their impact on mixed layer temperature and salinity budget

Mean SSS in 2016-2017



Data and Method

○**SPURS-2 moorings:**

・Temperature and Salinity

PICOSP01 (11N): 25 August 2016 - 3 July 2017

WHOI (10N): 24 August 2016 – 6 November 2017

PICOSP02 (9N): 22 August 2016 – 2 November 2017

・Precipitation, wind, wind stress, and sensible and latent heat flux

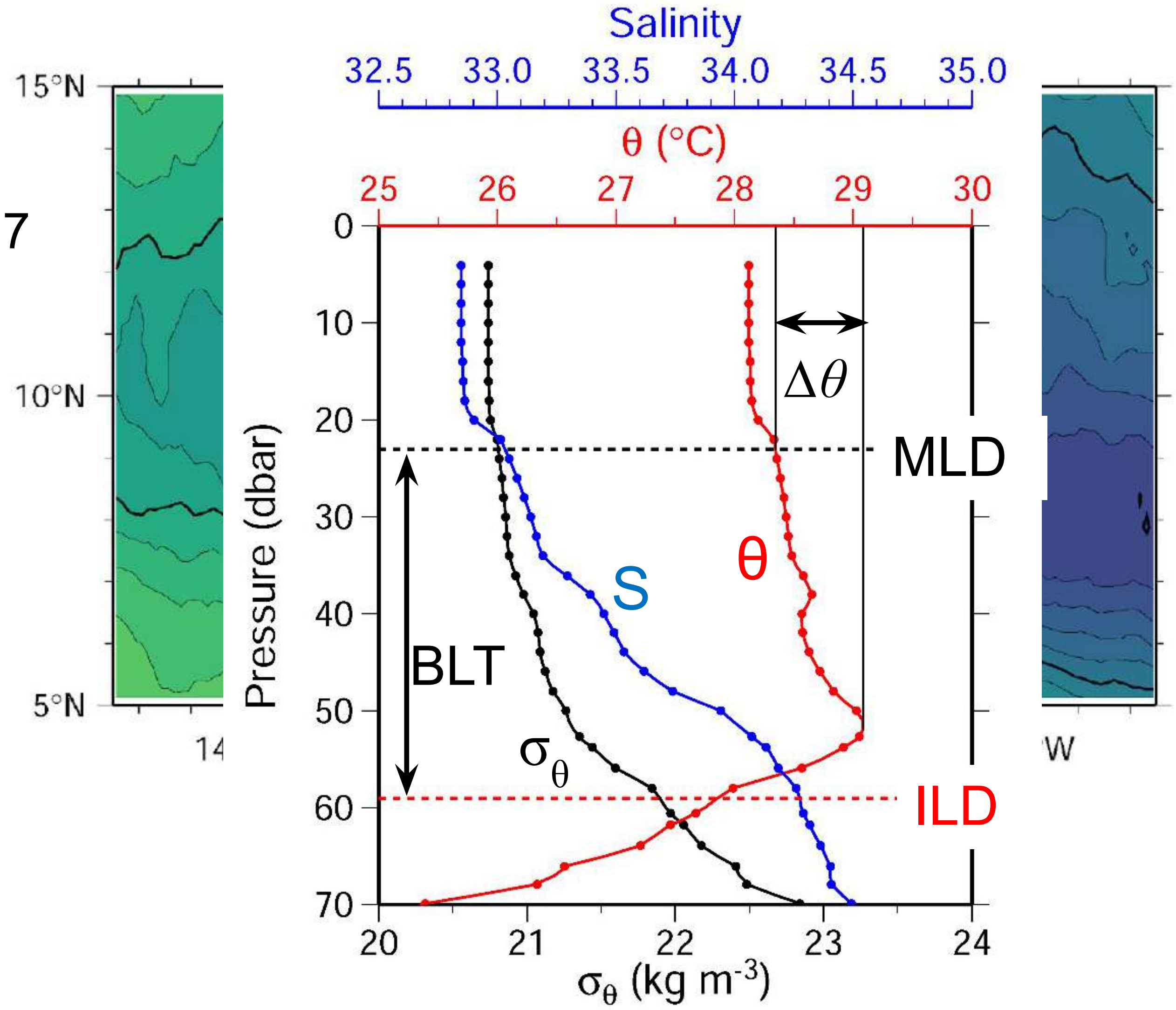
・Current velocity and longwave and shortwave radiation at the WHOI mooring

○**Others:**

・SSS from SMAP ・SST from OISST

○**BL and TI:**

- BL Thickness (BLT):
  BLT = ILD – MLD when ILD > MLD
- Magnitude of temperature inversion (TI):
  $\Delta\theta$ = (vertical temp maximum with BL) – (temp at MLD)



Katsura and Sprintall 2020

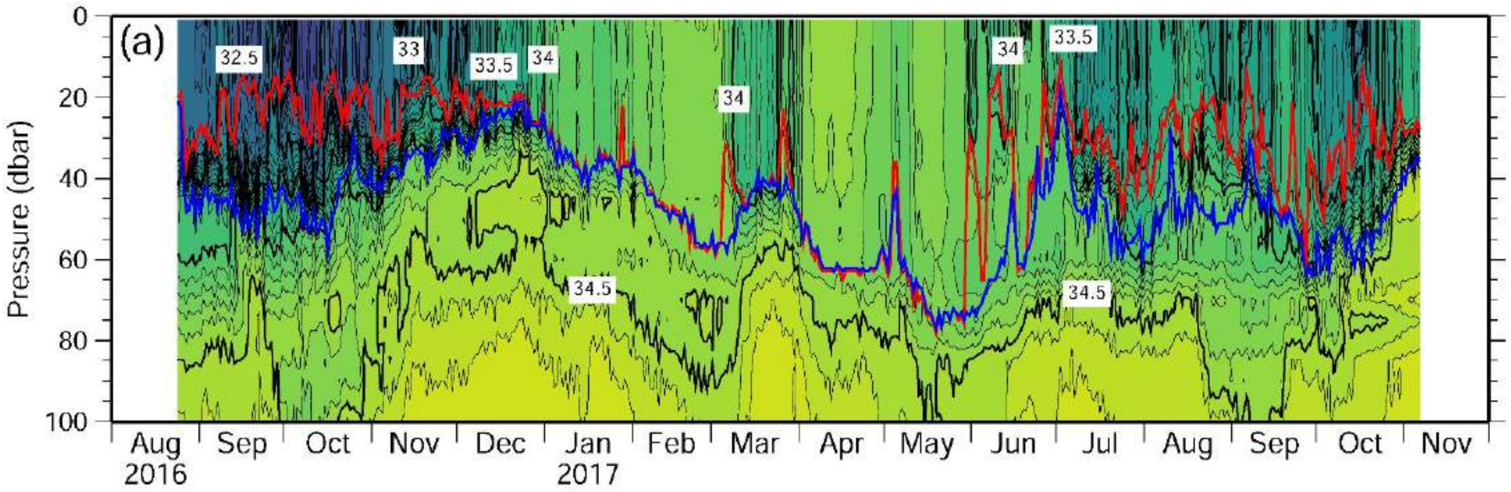
Variability of BLs and TIs

・Surface layer salinity was low in boreal summer and autumn, resulting in shallow mixed layer and BL.

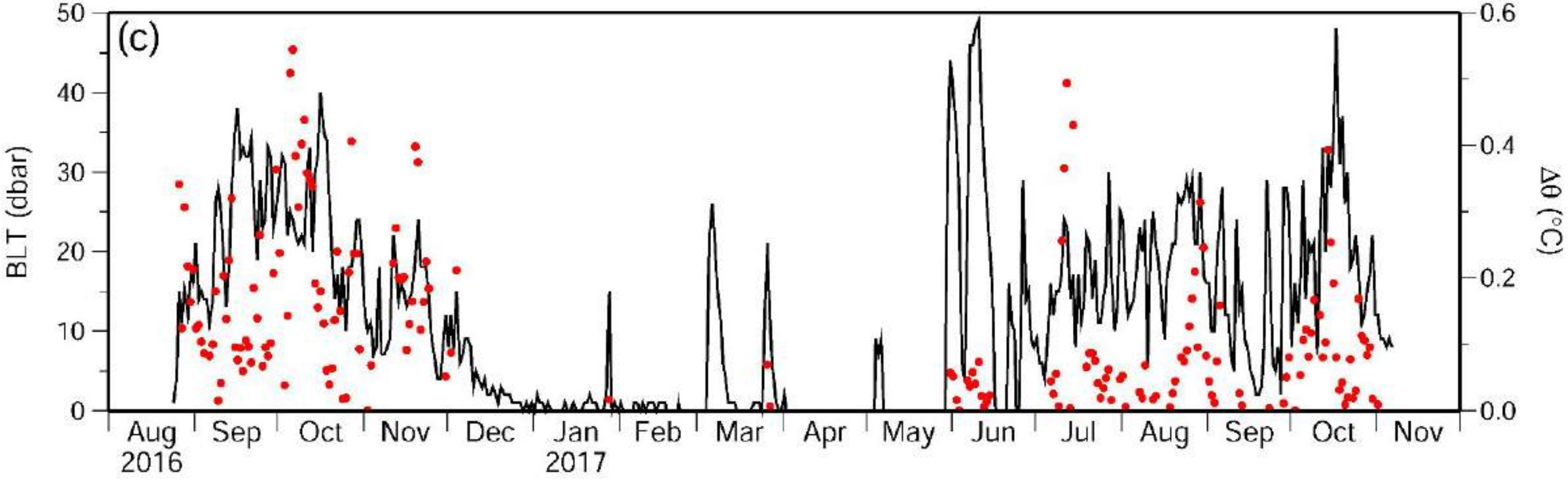
・TIs were also observed during boreal summer and autumn.

→ Consistent with the climatological seasonal study (Katsura and Sprintall 2020)

Time series of Salinity at the WHOI mooring with MLD and ILD



BLT and Δθ at the WHOI mooring



Mixed Layer Salinity and Temperature Budget

〇Mixed layer salinity (MLS) budget:

$$\frac{\partial S_m}{\partial t} = \frac{ES_m}{h_m} - \frac{PS_m}{h_m} - \mathbf{u_g}\nabla S - \mathbf{u_{Ek}}\nabla S - \frac{\kappa_v}{h_m}\left(\frac{\partial S}{\partial z}\right) + S_{ent}$$

Evaporation | Precipitation | Geostrophic advection | Ekman advection | Vertical diffusion | Entrainment/ Detrainment

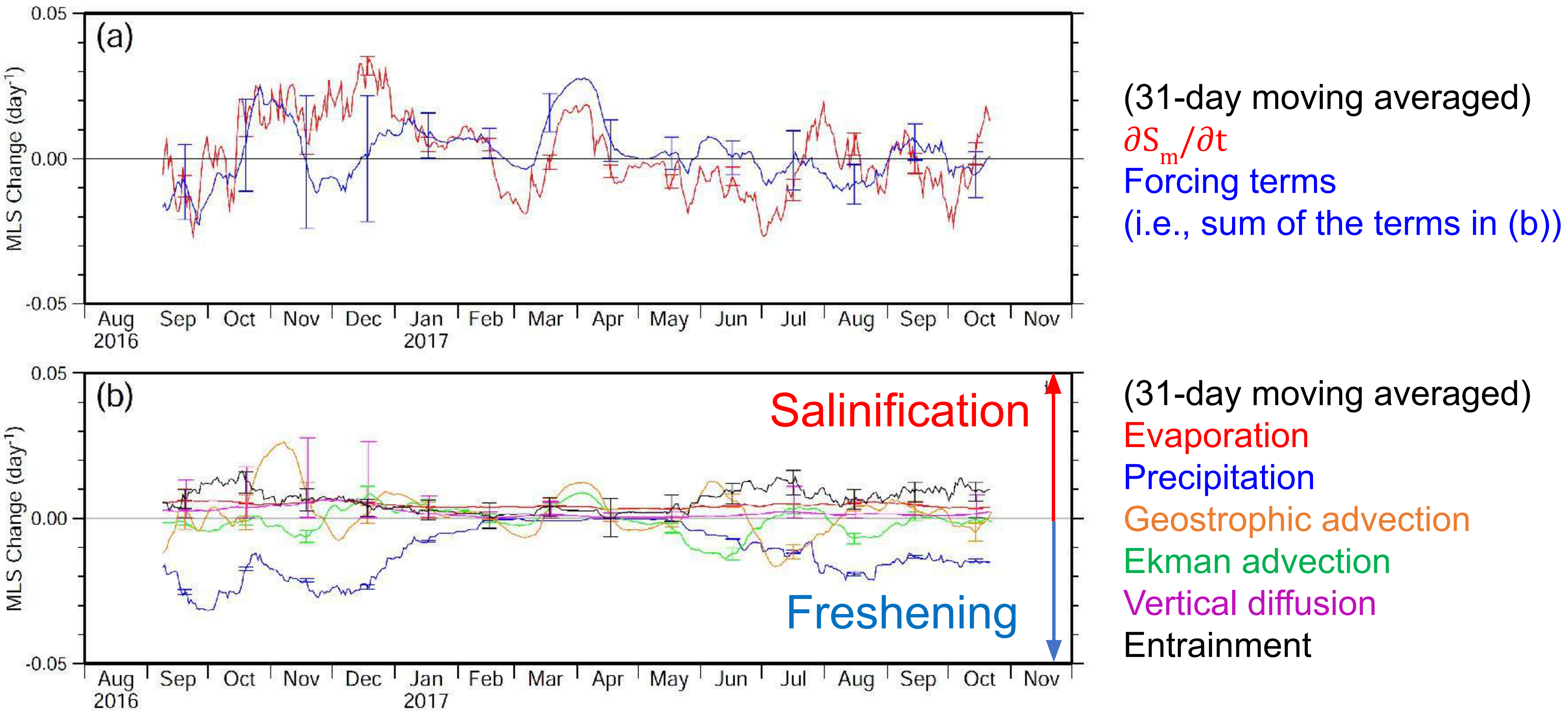
〇Mixed layer temperature (MLT) budget:

$$\frac{\partial T_m}{\partial t} = \frac{Q_{net}}{\rho_0 c_p h_m} - \frac{Q_{pen}}{\rho_0 c_p h_m} - \mathbf{u_g}\nabla T - \mathbf{u_{Ek}}\nabla T - \frac{\kappa_v}{h_m}\left(\frac{\partial T}{\partial z}\right) + T_{ent}$$

Net heat flux | Penetration of shortwave radiation | Geostrophic advection | Ekman advection | Vertical diffusion | Entrainment/ Detrainment

- $\mathbf{u_{Ek}}$ was estimated from wind stress.
- $\mathbf{u_g}$ was estimated as the difference between current velocity and $\mathbf{u_{Ek}}$.
- $\kappa_v = 2 \times 10^{-5}$ m^2/s (Farrar et al. 2019)
- Effect of entrainment/detrainment was explicitly estimated following Kim et al. (2006)
- We focus on BL formation through surface freshening and TI formation through surface cooling.

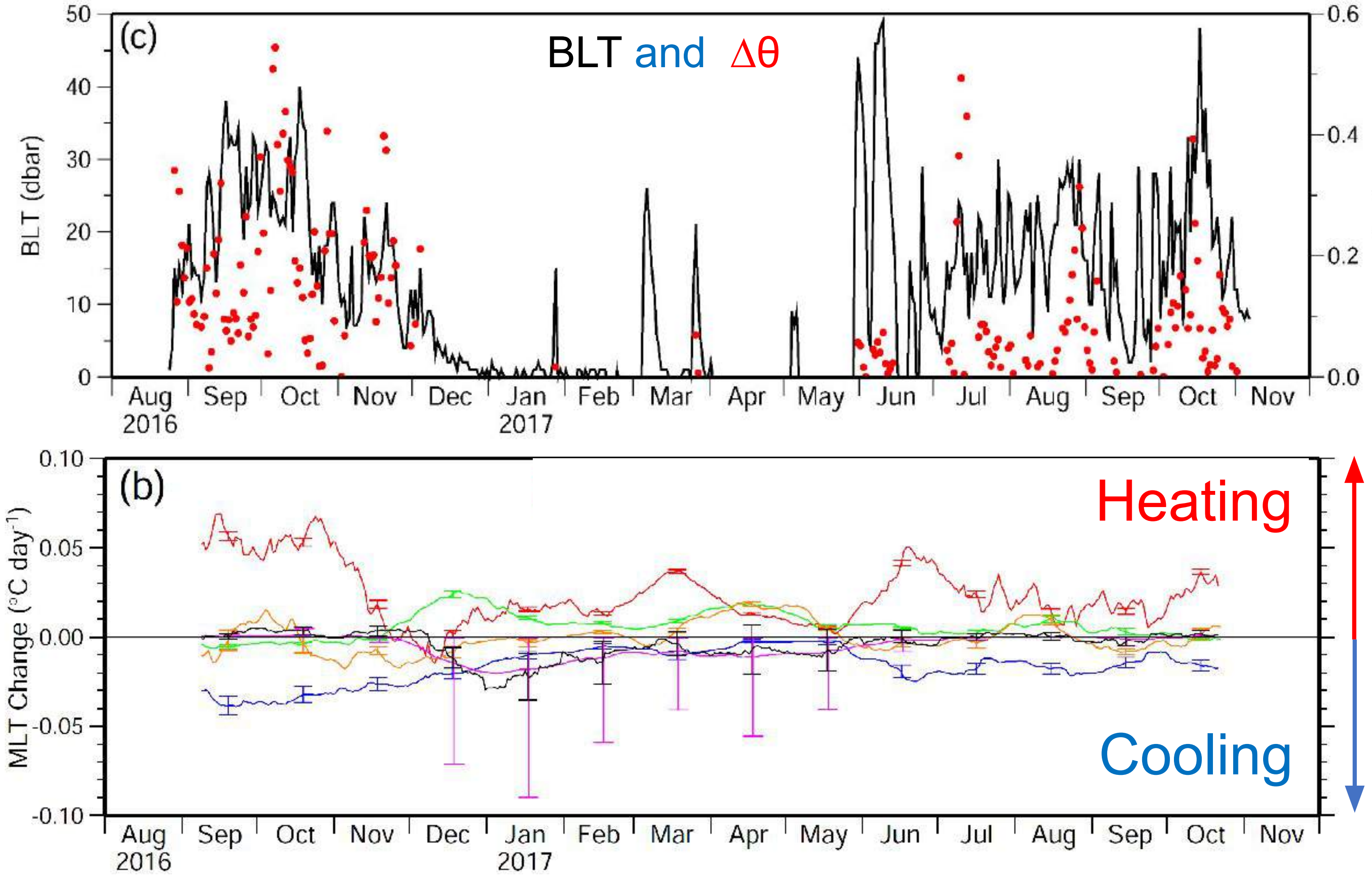
Mixed Layer Salinity Budget: Formation of BLs



- Precipitation was a prime contributor to BL formation in summer and autumn.
- Horizontal advection contributed to BL formation in June-July 2017.

→ BLs were initially formed in response to horizontal advection of freshwater and then primarily maintained by precipitation.

Mixed Layer Temperature Budget: Formation of TIs



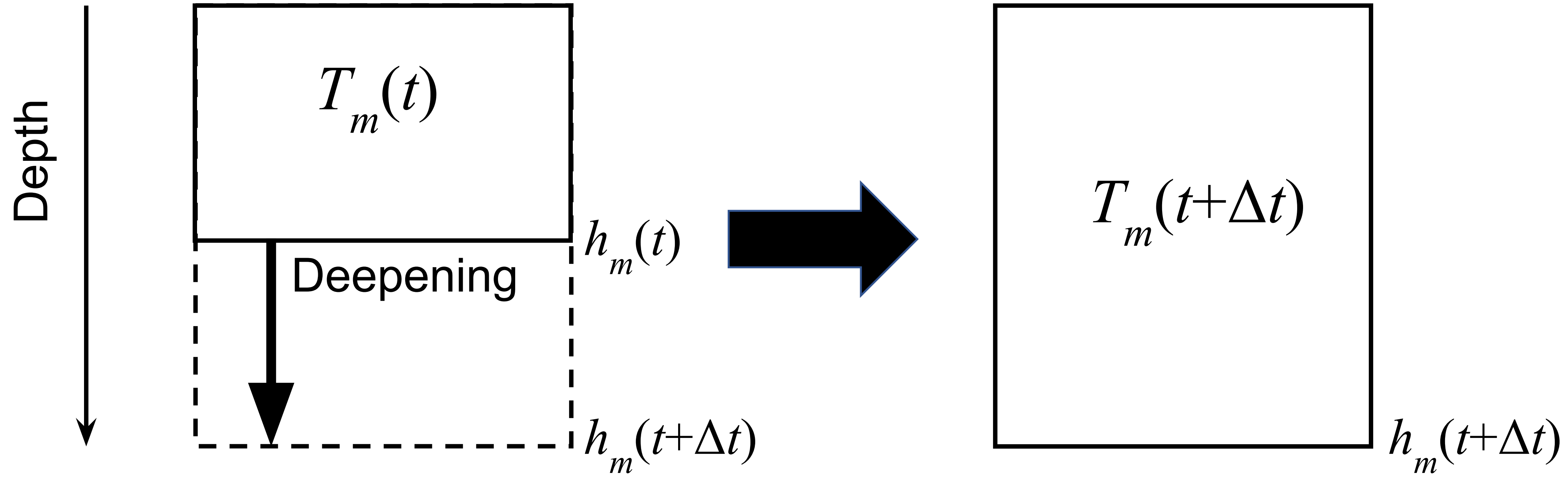
1 day moving averaged)
m/∂t
rcing terms
e., sum of the terms in (b))

(31 day moving averaged)
Net heat flux
Penetrative shortwave
Geostrophic advection
Ekman advection
Vertical diffusion
Entrainment

- Penetrative shortwave radiation was a prime contributor to TI formation in summer and autumn.
- Entrainment cooling was reduced in summer and autumn when BLs were present.

Impacts of BLs and TIs: Entrainment and Detrainment

Effect of Entrainment on Mixed Layer Temperature (Deepening of MLD)

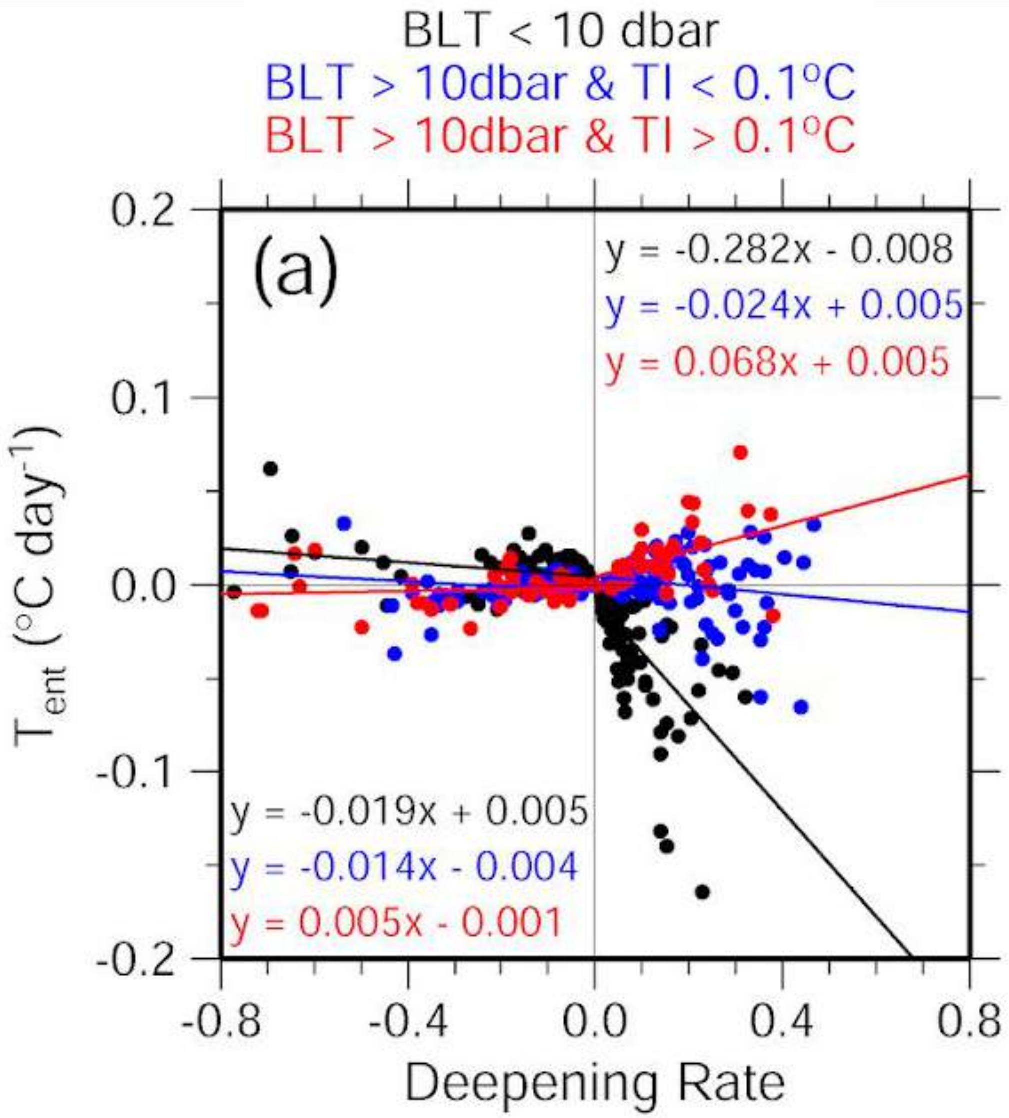


$$T_m(t)\cdot h_m(t) + \int_{-h_m(t+\Delta t)}^{-h_m(t)} \theta(z)dz = T_m(t+\Delta t)\cdot h_m(t+\Delta t)$$

$$\Rightarrow \underbrace{T_m(t+\Delta t) - T_m(t)}_{T_{ent}} = \frac{1}{h_m(t+\Delta t)}\int_{-h_m(t+\Delta t)}^{-h_m(t)} \theta(z)dz - \underbrace{\left(\frac{h_m(t+\Delta t) - h_m(t)}{h_m(t+\Delta t)}\right)}_{\text{Deepening Rate}} T_m(t)$$

Impacts of BLs and TIs: Entrainment and Detrainment

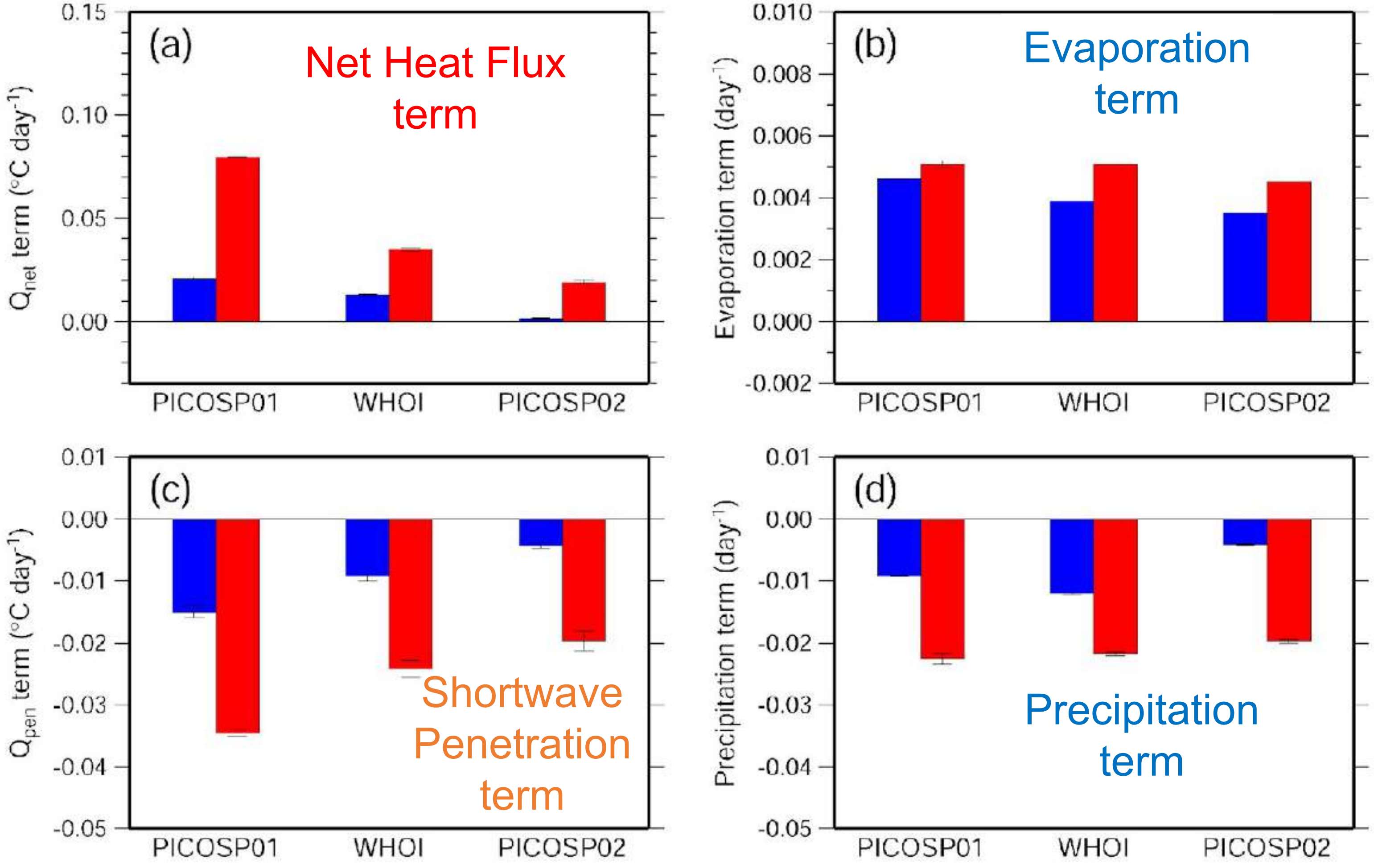
Scatter diagram of T_{ent} respect to Deepening Rate at the WHOI mooring based on **daily** time series



- Entrainment cooling was reduced when BLs were present (blue line).
- Entrainment worked to warm the mixed layer when BLs were associated with TI (red line).
- Detrainment warming was reduced when BLs were present (negative deepening rate).

Impacts of BLs and TIs: Surface Flux Terms

Mean value of **daily** surface heat and freshwater flux terms averaged for BLT < 10 dbar (blue) and BLT > 10 dbar (red)



- Mixed layer was more sensitive to surface heat and freshwater flux when BLs were present due to the shallow MLD.
- BL presence enhanced the formation of TIs increasing the subsurface warming via shortwave penetration.

Summary

○In the eastern tropical Pacific, BLs were initially formed in summer in response to horizontal advection of freshwater and then primarily maintained by precipitation through autumn.

○Penetration of shortwave radiation through the mixed layer base was the dominant contributor to TI formation through subsurface warming.

○BL presence reduced entrainment cooling and detrainment warming, and entrainment worked to warm mixed layer when TIs were present.

○BLs made the mixed layer more sensitive to surface heat and freshwater flux.

Introduction: Barrier Layer

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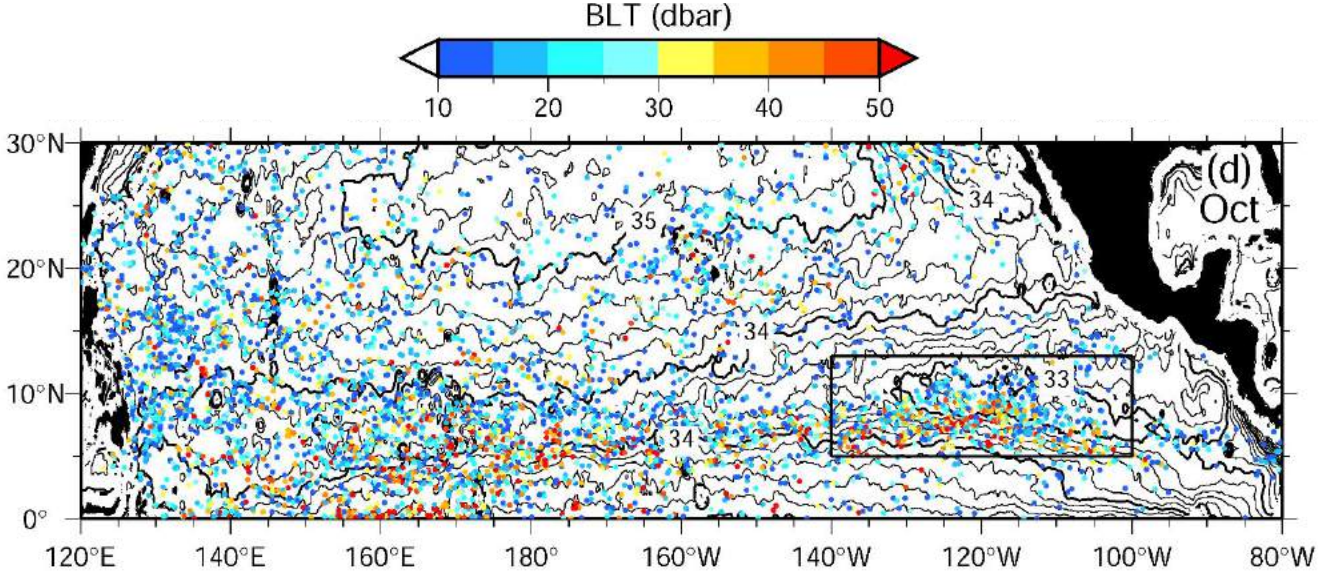
→ BL can significantly affect SST.

- Argo Climatology in the eastern tropical Pacific shows thick BLs occur in boreal summer and autumn along the SSS front. (Katsura and Sprintall 2020)

BL Thickness (color) and mean SSS (contour) in October 2003-2018



Katsura and Sprintall 2020

Vertical profiles in the eastern tropical Pacific observed on 26 Oct 2017.