Estimation of the Barrier Layer Thickness in the Indian Ocean using satellite derived salinity

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Acknowledgements:

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NASA Physical Oceanography Program

Barrier Layer (BL) Dynamics

- BL play an important role in regulating surface heat exchanges.
- BL formation in the Indian Ocean is driven by the monsoon cycle
- BL formation is most rigorous in the post-monsoon season.
- Tracking the low saline waters is difficult.
- Little research has been conducted on the interannual variation of the barrier layer.
- Recently Aquarius and SMOS salinity data are used to track the barrier layer.

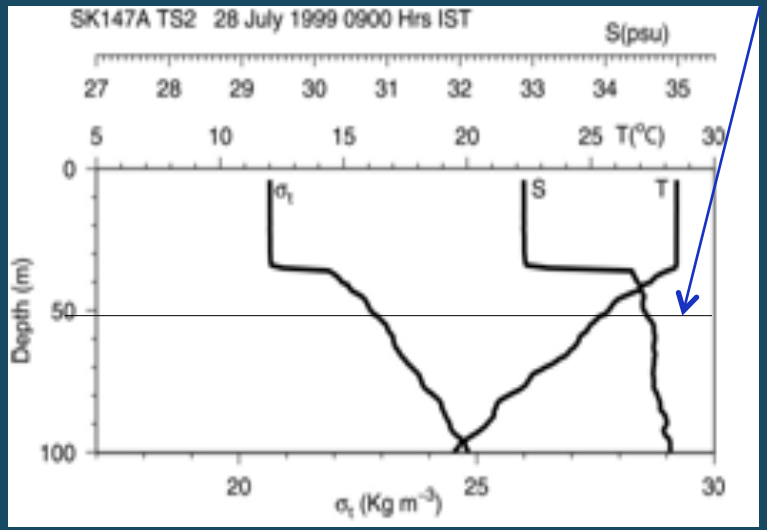
Example profile

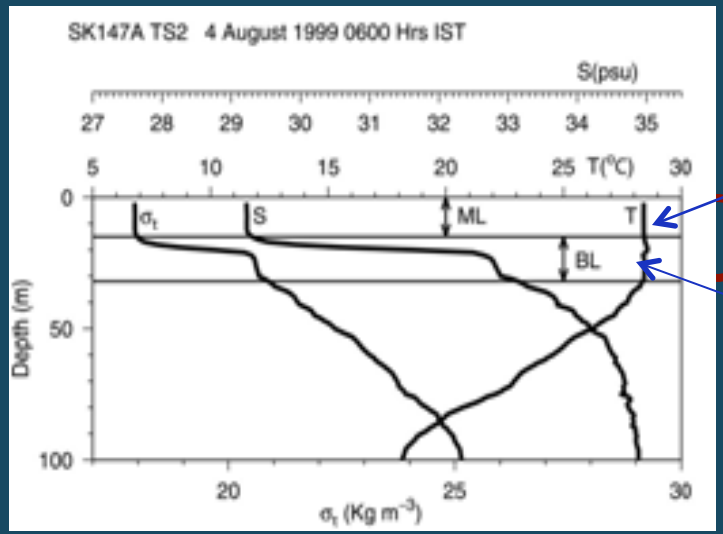
Isothermal layer depth (ILD)-depth where the temperature at depth reaches ±0.5 °C from the surface value. BLT=ILD-MLD

Without salinity stratification

MLD=ILD

With salinity stratification





Mixed Layer

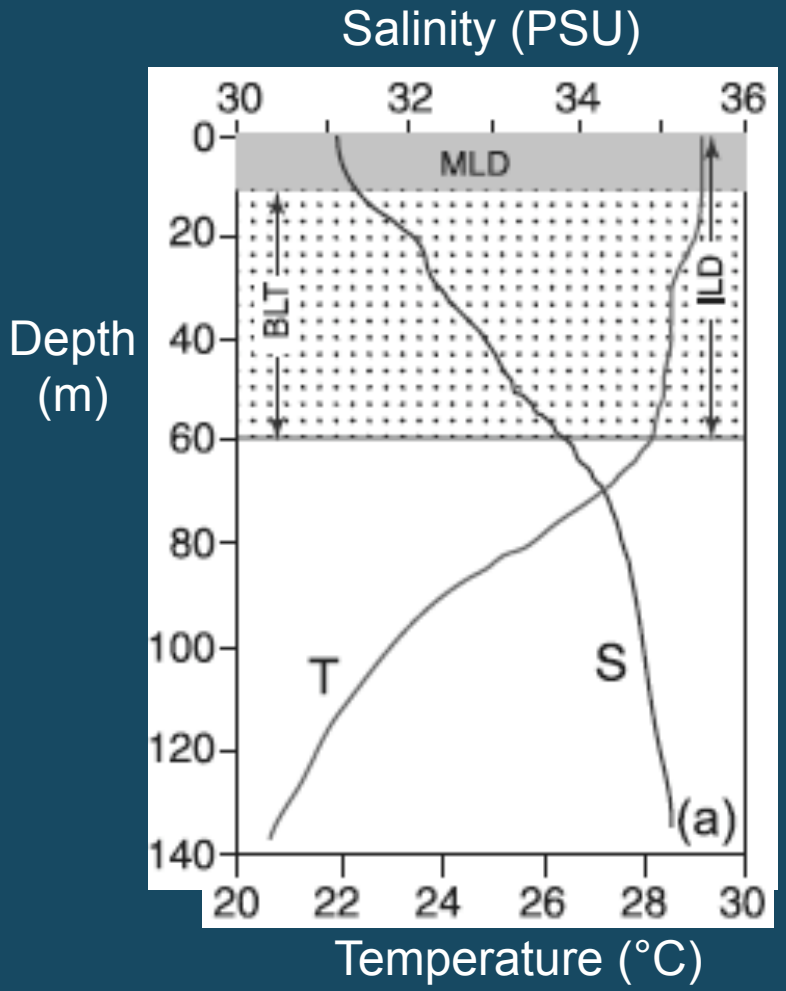
Isothermal Layer

Barrier Layer

Vertical profiles of temperature (T), salinity (S) and density (σ_t) in the upper 100-m in the absence of a low saline water plume (left) and in the presence of a low saline water plume (right) in the Bay of Bengal.

Vinayachandran et al. 2002

Example profile

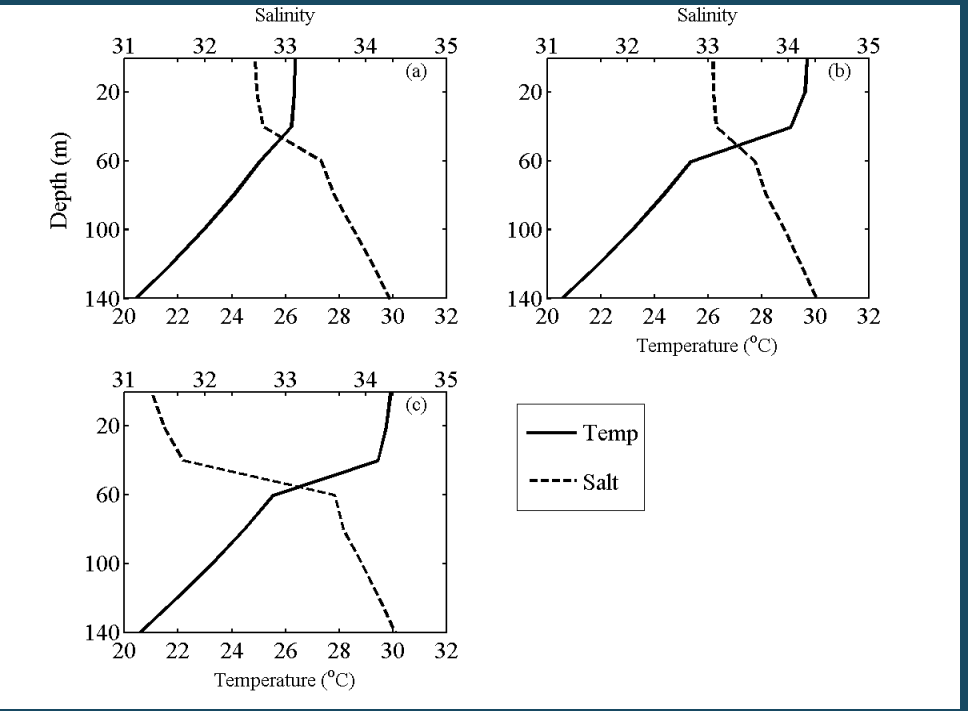


- The barrier layer is defined as the difference between the isothermal layer (ILD) and the mixed layer depths (MLD).

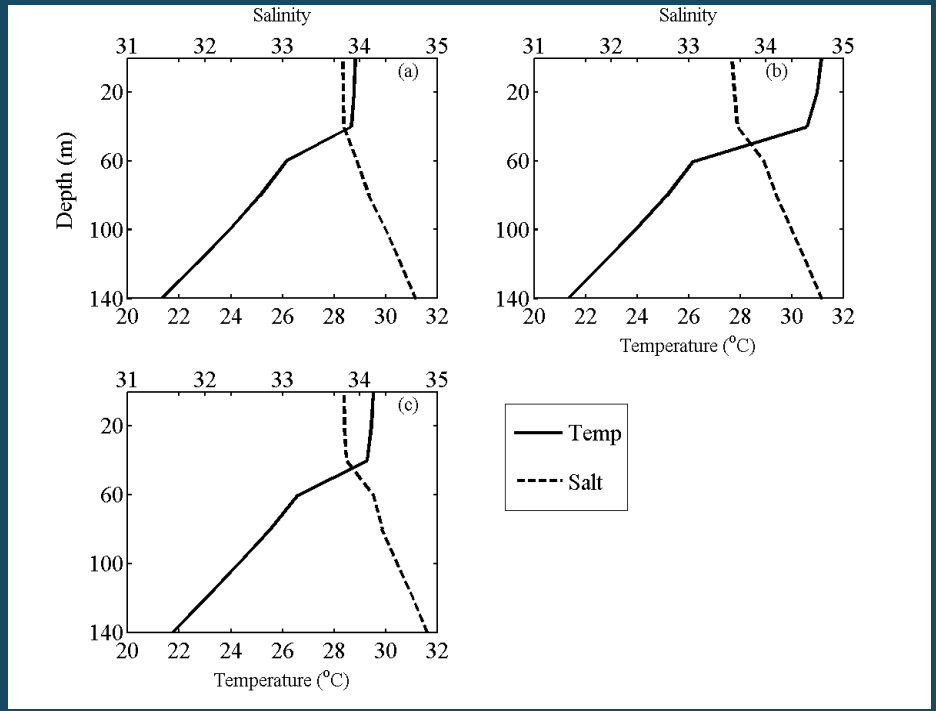
Thadathil et al. 2007

Salinity and Temperature in the BoB

Northern BoB

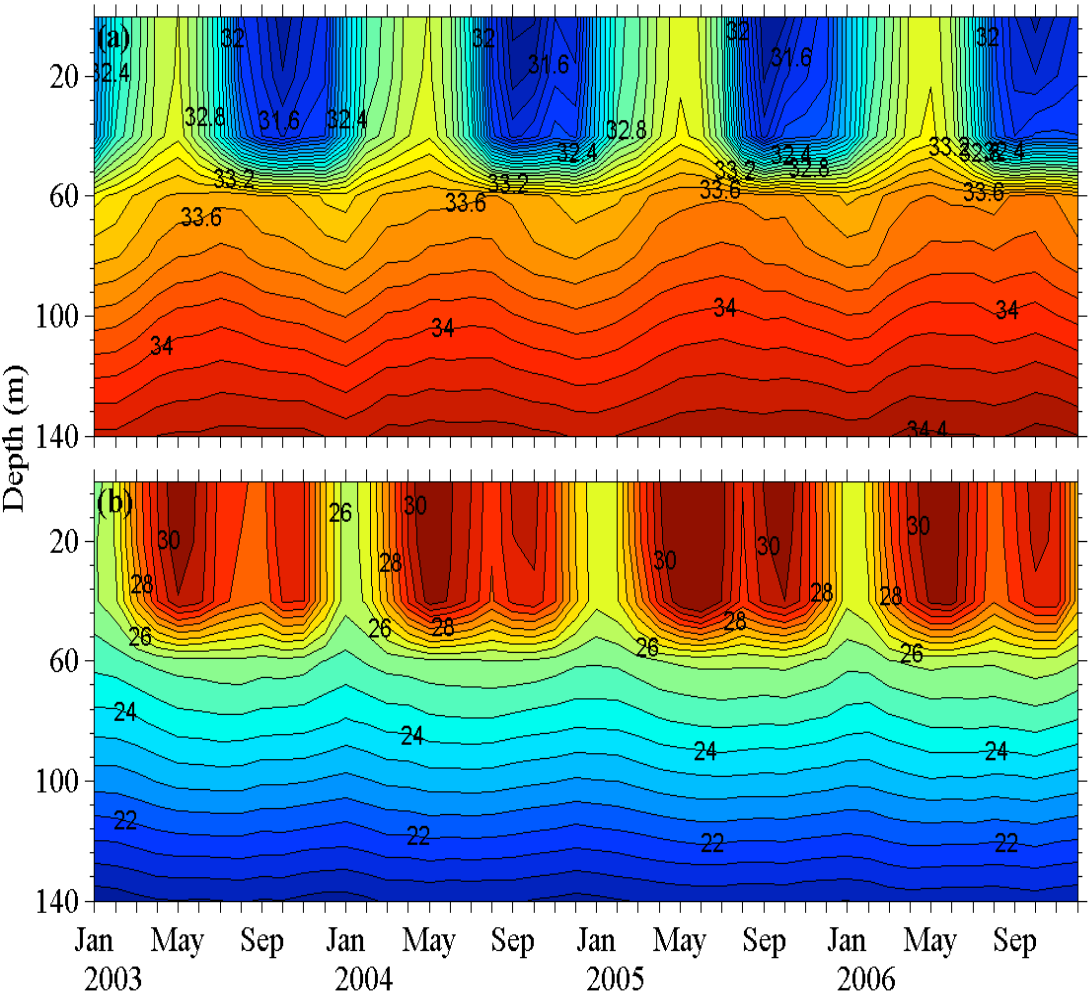


Southern BoB



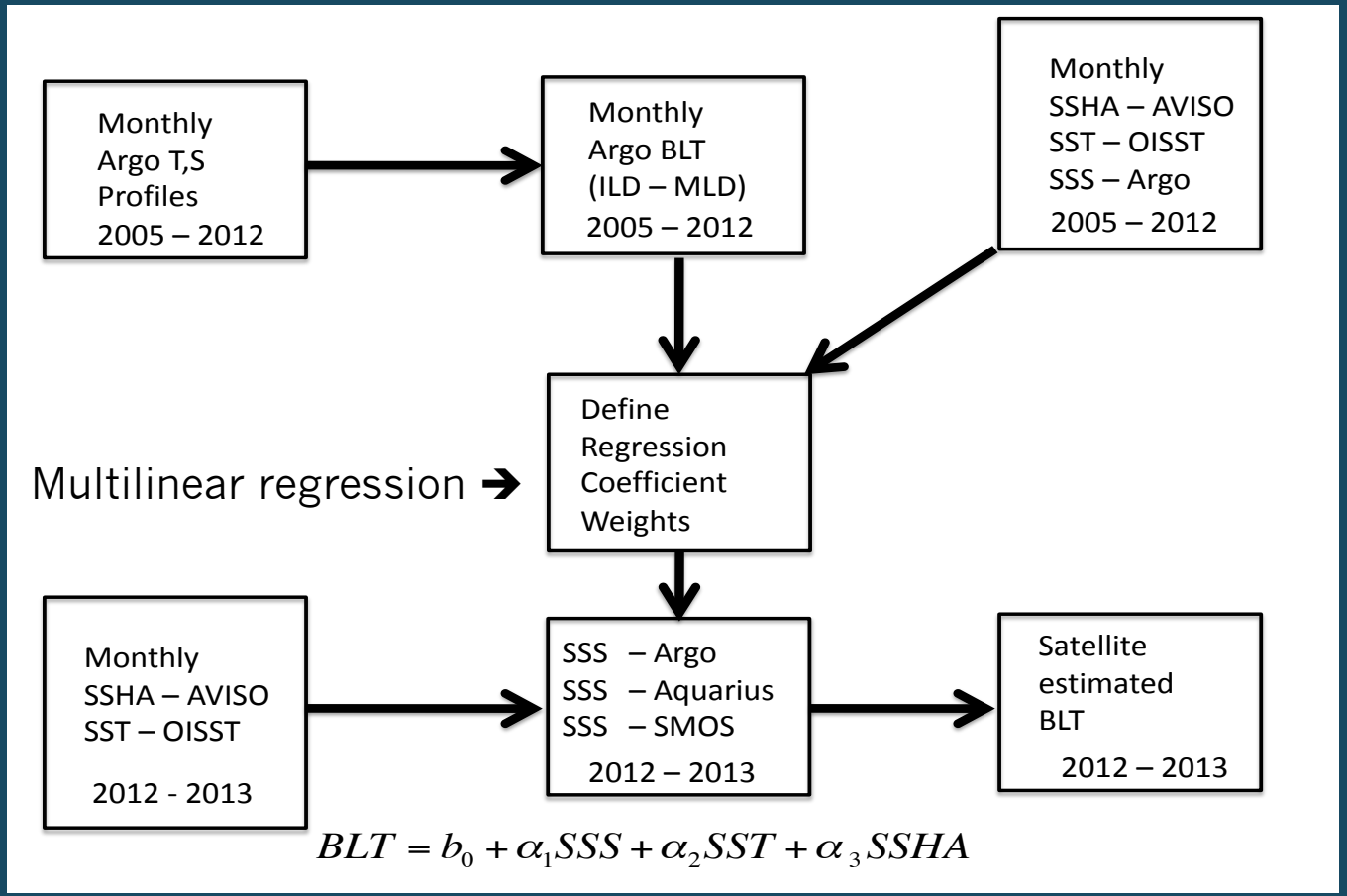
(a) February (Winter), (b) April (Summer), (c) October (post-monsoon)

Salinity and Temperature in the Northern BoB



- Warmer SSTs occur in May, and are associated with the relatively high salinity waters.
- By September-October, there is a secondary warming period in the NBoB and coincides with the occurrence of the freshwater layer in the top 30-50 m.
- This secondary warming is associated with the arrival of the freshwater plumes into the NBoB .

Estimation of Barrier Layer



For Each Month

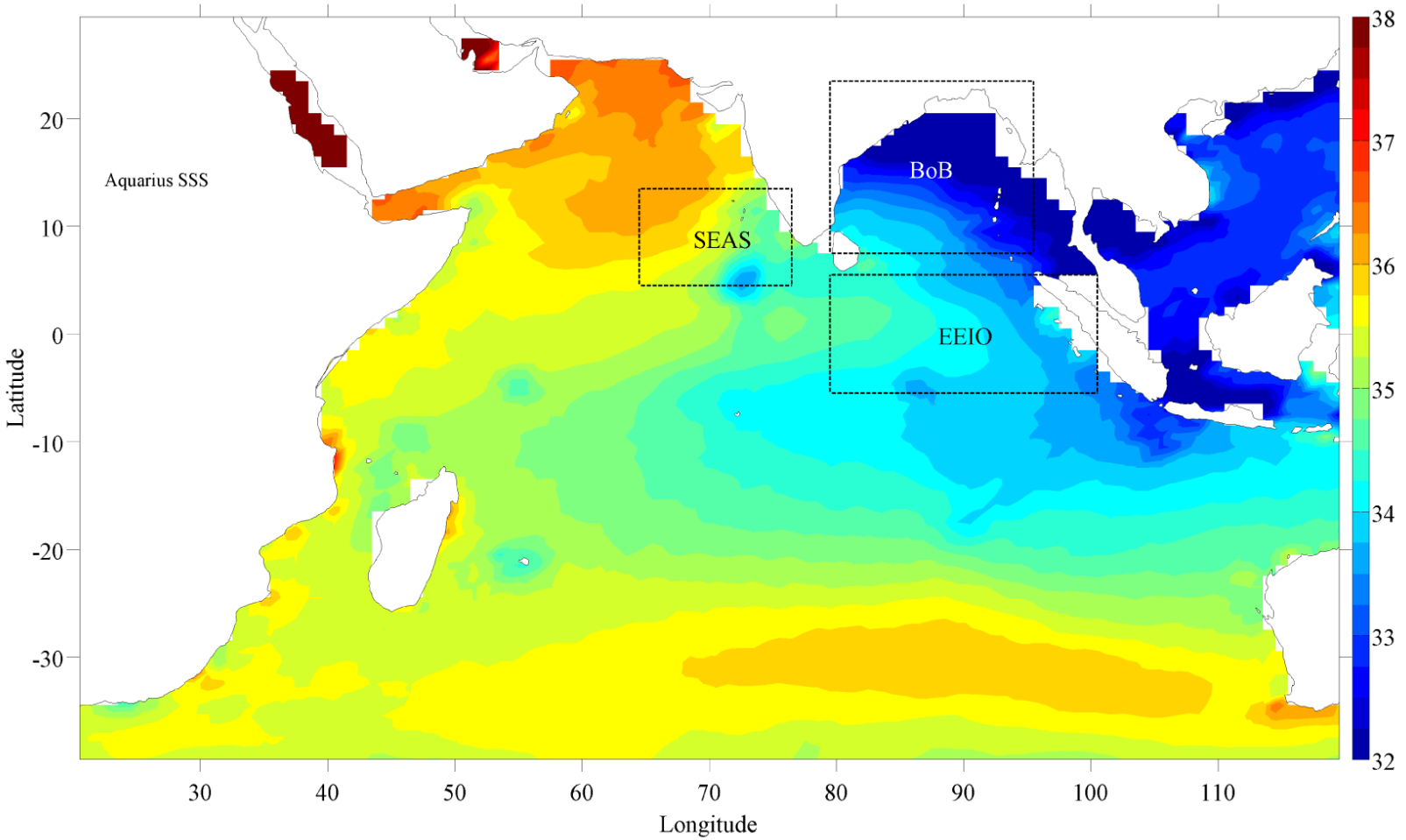
Assumptions:

Argo BLT is the truth comparison

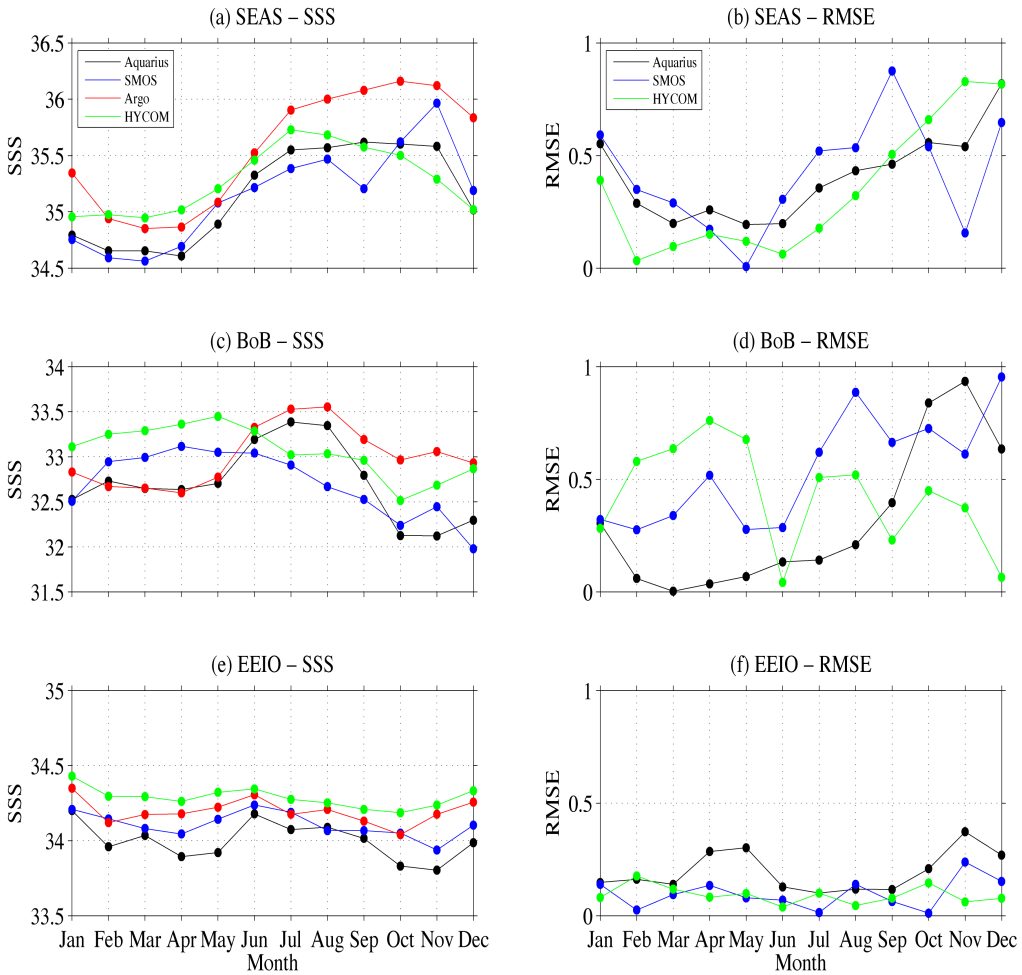
SSS represents salinity in mixed layer

BLT can be represented as a linear combination

Salinity Distribution



Mean Sea Surface Salinity & RMSE

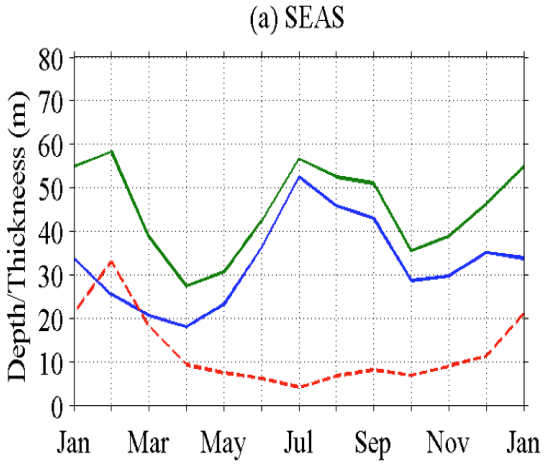


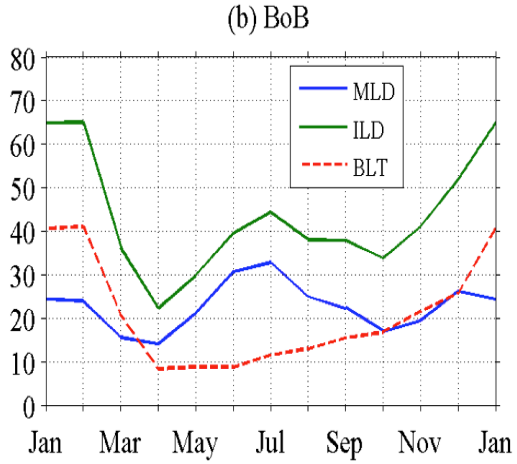
Aquarius is able to capture the seasonal cycle well in each of the three study regions.

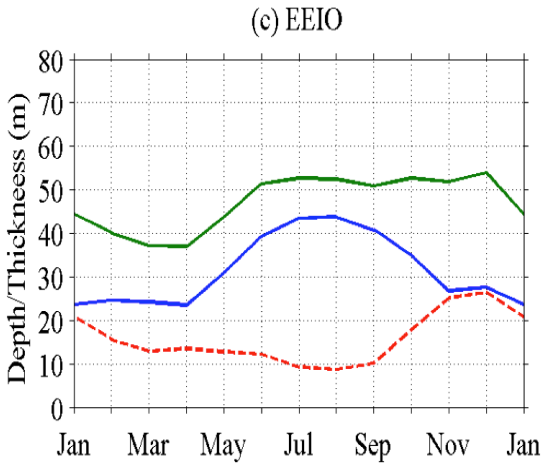
Seasonally large SSS deviations in the SEAS and BoB.

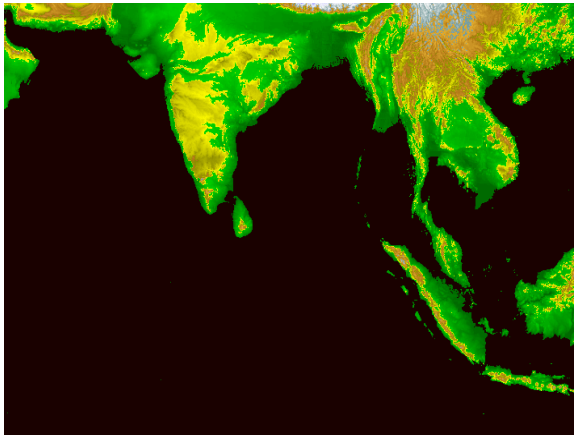
EEIO SSS is stable throughout the year among the three data sets, with low monthly RMSE values (<0.4 PSU).

Argo MLD, ILD, and BLT









SEAS region, the BLT is driven by the seasonal influx of low saline waters from the BoB.

BoB, the BL also peaks during the winter (Dec–March), when the redistribution of low saline waters from precipitation and river runoff throughout the Bay causes strong upper ocean stratification.

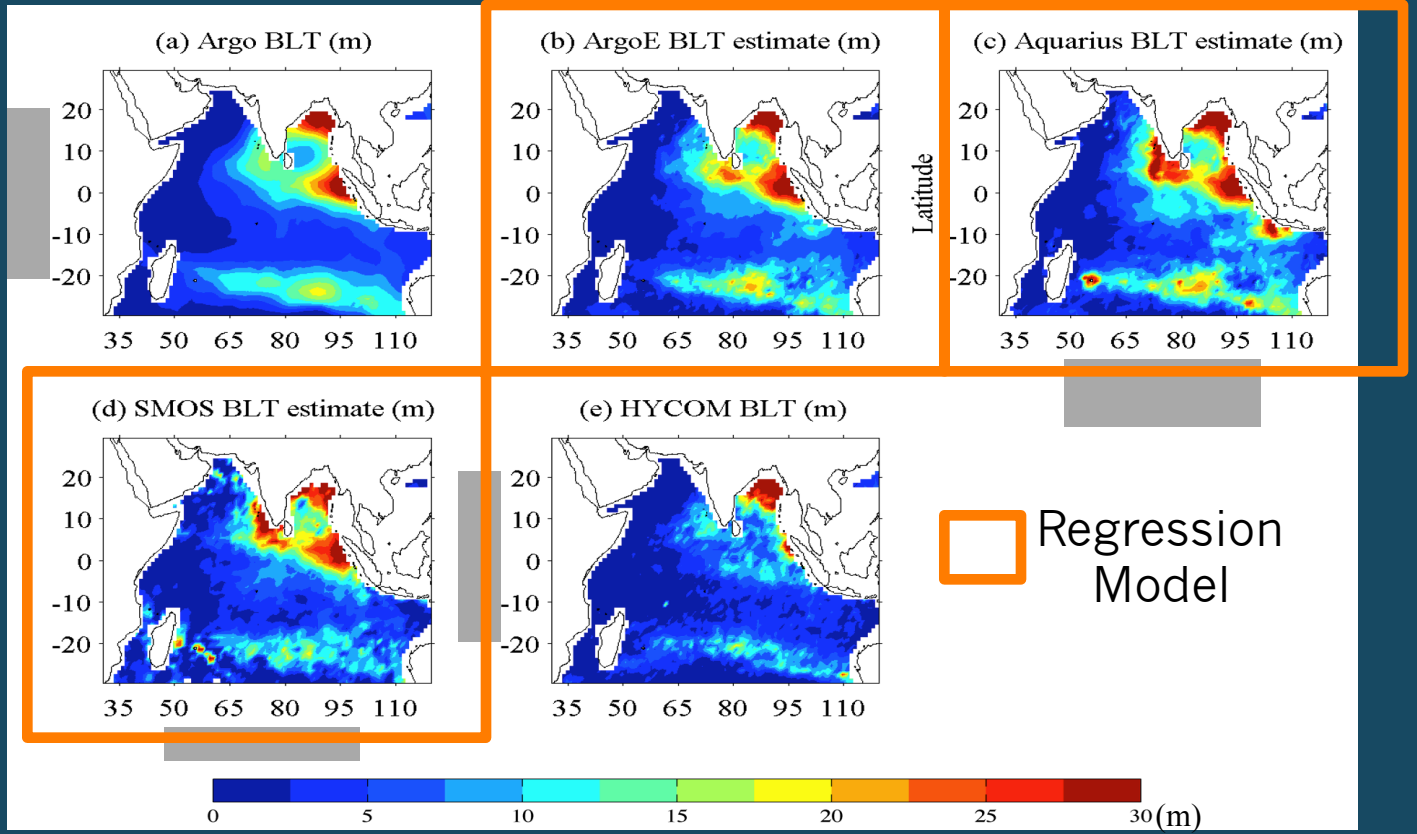
EEIO, the BL peaks from November to January.

Observation and Model comparisons

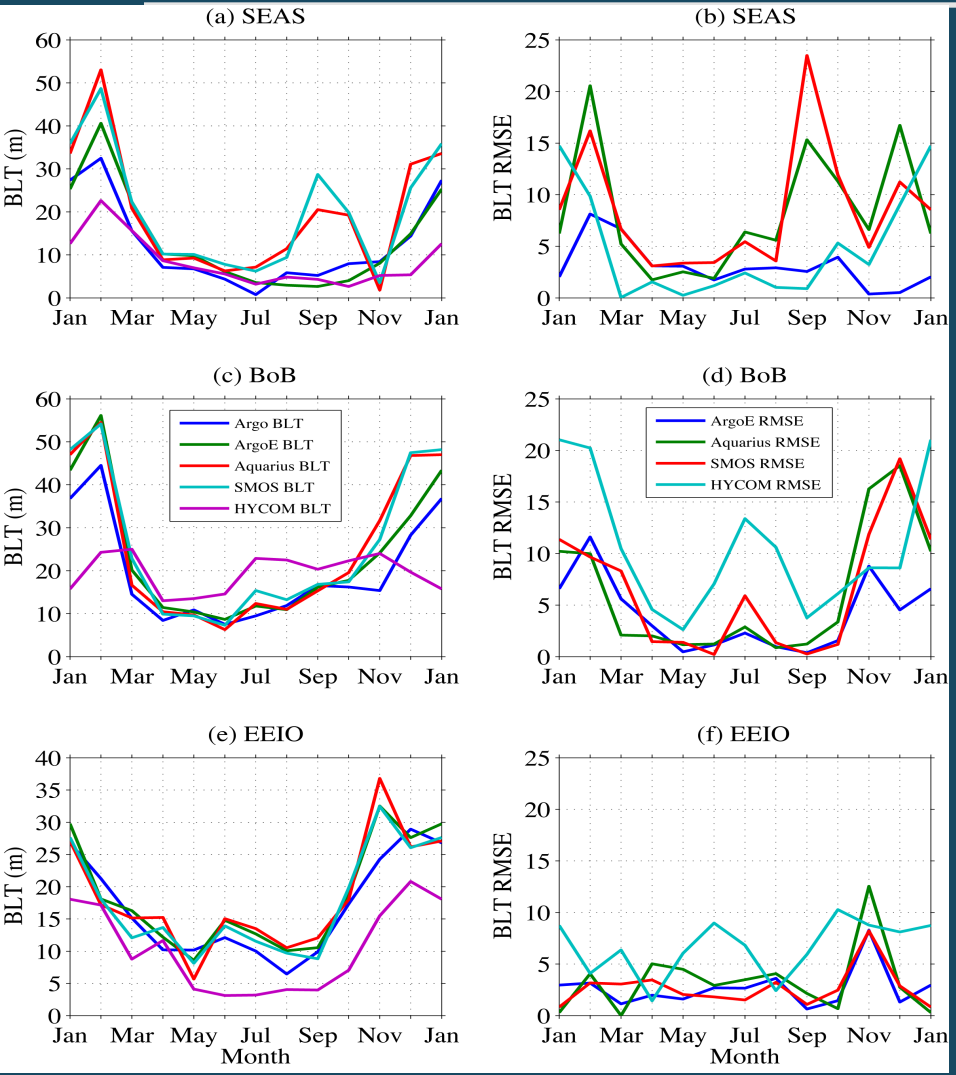
Thick barrier layer is resolved well by the MRM

Overestimates are highest in the SEAS region

HYCOM is unable to reproduce the structure along the Sumatran coastline



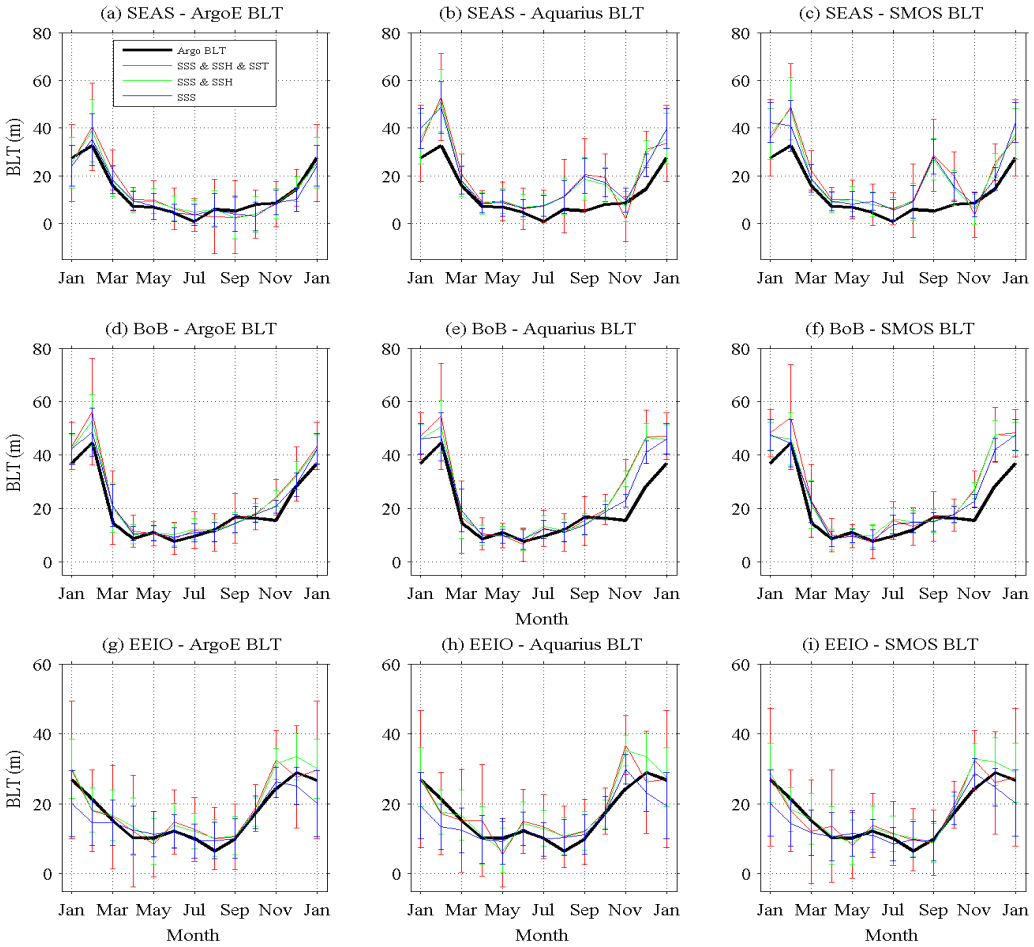
Box averaged BLT



(left) Seasonal cycle of box averaged BLT and (right- relative to Argo BLT).

RMSE from Argo, MRM estimations, and HYCOM in the (a and b) Southeast Arabian Sea, (c and d) Bay of Bengal, and (e and f) Eastern Equatorial Indian Ocean for 2012. January is shown twice to complete the seasonal cycle.

Seasonal Cycle of BLT in 2012



Seasonal cycle of BLT in the year 2012 as derived: gridded Argo profiles (black),

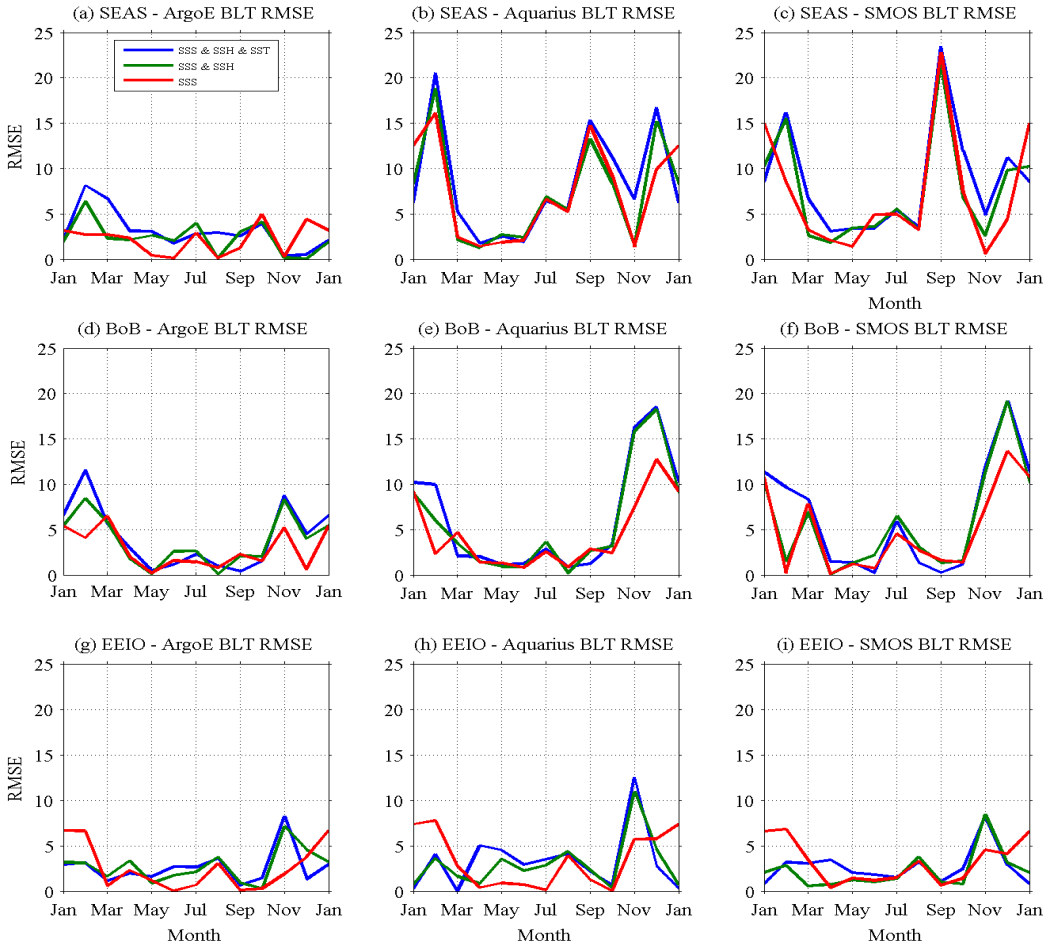
MRM model with SSS, SSHA, SST (red),

MRM model with SSS, SSHA (green),

MRM model with SSS only (blue).

Error bars have been included for each MRM BLT estimate based upon the coefficient(s) error(s) (alpha-0.995).

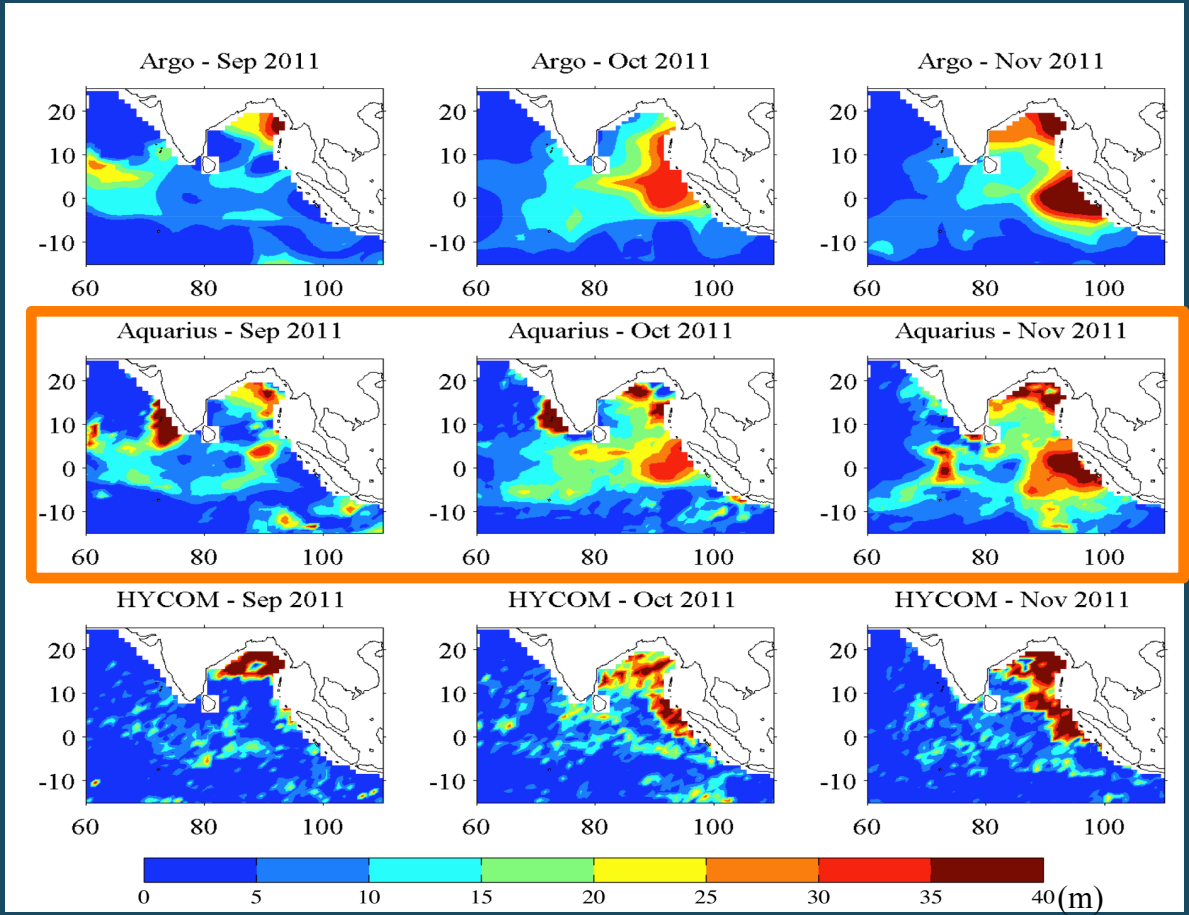
Seasonal Cycle of RMSE in 2012



Seasonal cycle of RMSE (with respect to Argo gridded profile derived BLT) BLT in the year 2012 for MRM model with SSS, SSHA, SST (red), MRM model with SSS, SSHA (green), and MRM model with SSS only (blue). January is repeated to complete the seasonal cycle.

2011 Positive IOD Event

Barrier Layer Thickness



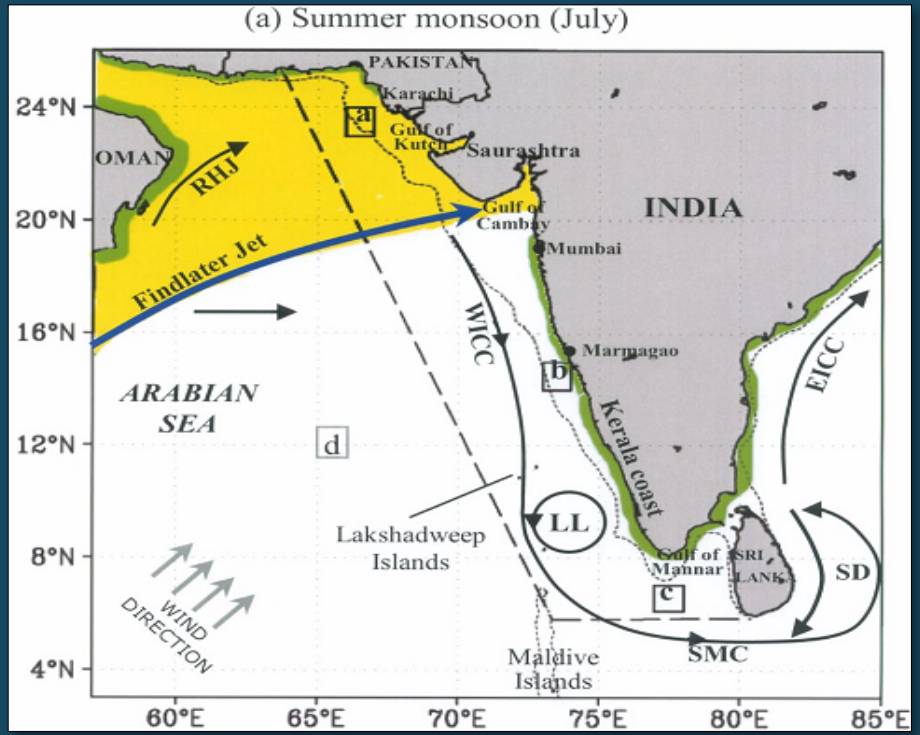
Kelvin waves arrive force thermocline to deepen (ILD)

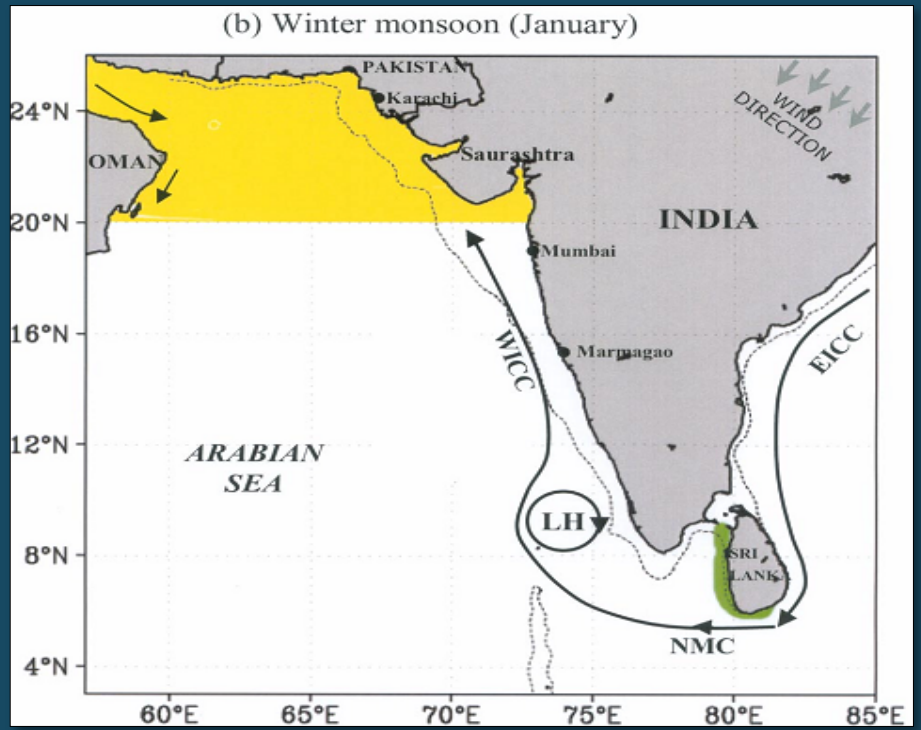
Aquarius MRM captures the BLT structure well

HYCOM is unable to resolve features along the equator

Regression Model

Arabian Sea mini warm pool

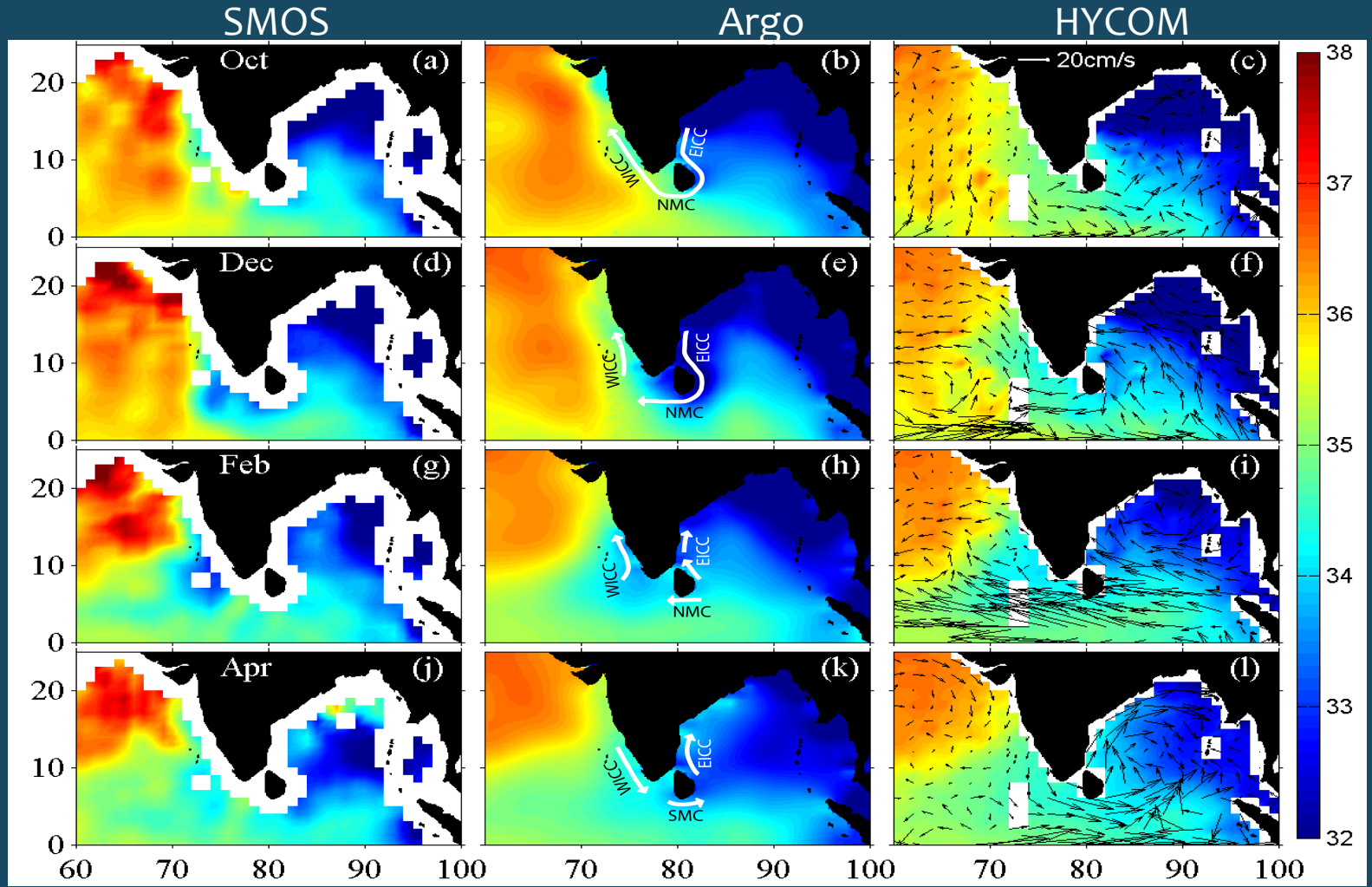




(Source: Luis and Kawamura, 2004)

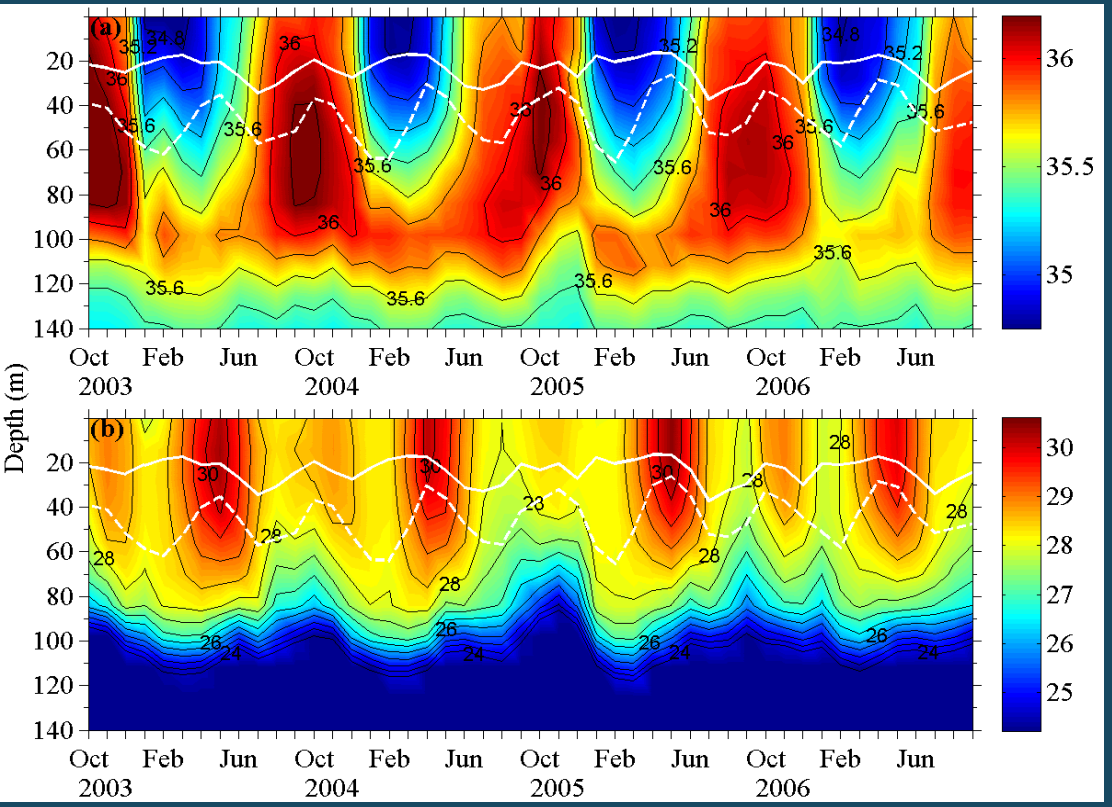
- SW monsoon: strong SW winds, surface cooling, heat loss, Lakshadweep Low
- NE monsoon: weak NE winds, Lakshadweep High

Sea Surface Salinity variations



Nyadjro et al., 2012

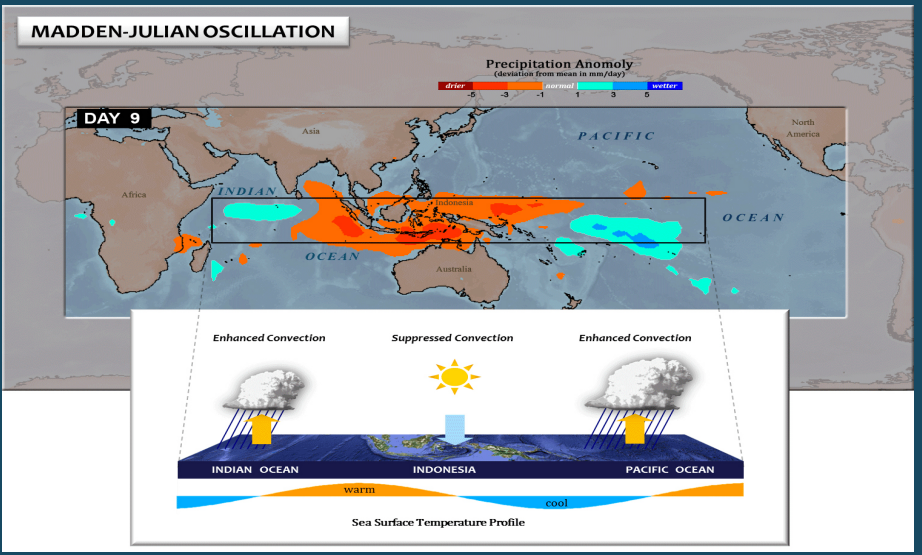
Arabian Sea mini warm pool



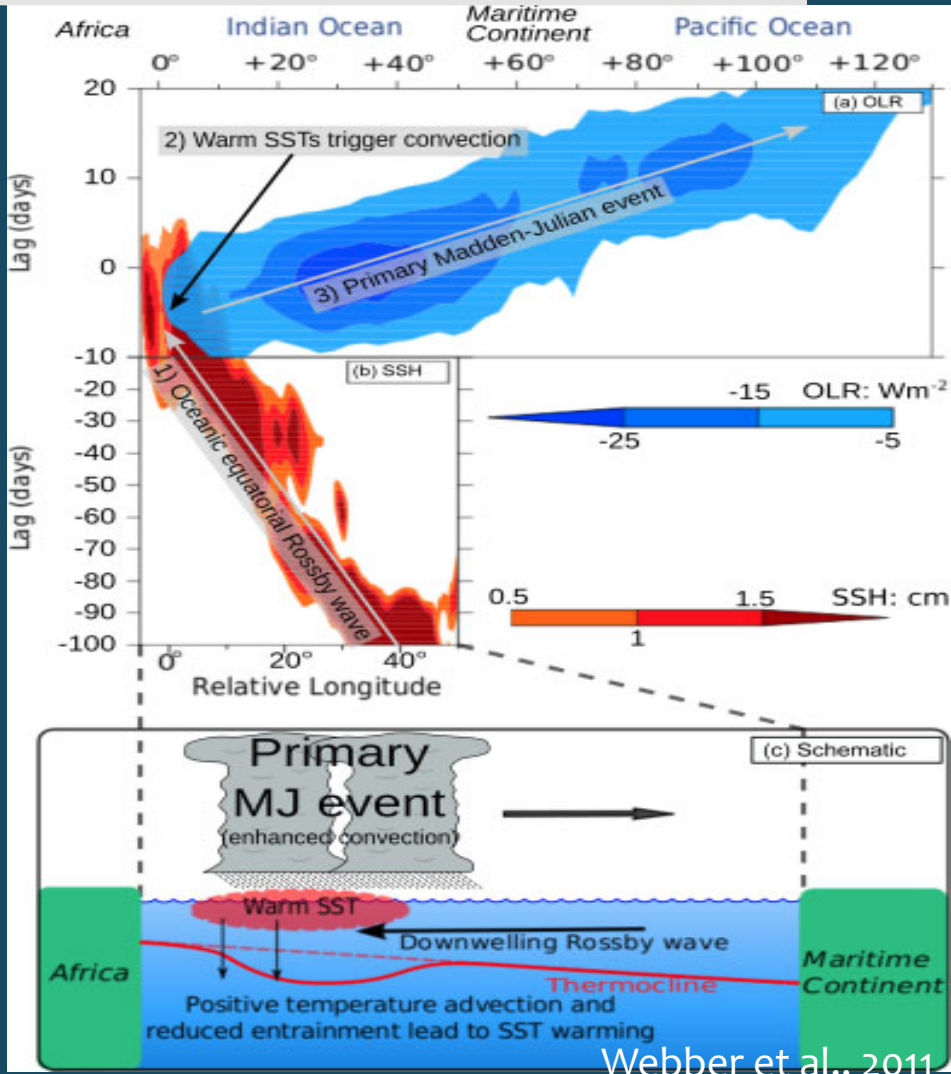
Depth-time section of Argo
(a)salinity and (b) temperature
MLD- solid white lines, Isothermal layer-dashed white line

- average depth of warm pool is 40 m.
- two temperature warm cores; April-May, October-December
- low saline (<34) water in top 60 m between December-June
- Higher salinity (~36) occur below 70 m between July-November.

MJO Dynamics



- Equatorial downwelling Rossby waves create favorable conditions in the western Indian Ocean for the development of MJO related convection.
- The deepening of the warmer mixed layer provides an adequate resource for ocean surface heat flux into the atmosphere.
- However, as MJO related convection propagates across the Indian Ocean, anomalous wind conditions produce reflecting downwelling Kelvin and Rossby waves along the Indonesian Coast.



Webber et al., 2011

Summary

- Aquarius and SMOS salinity measurements can be used to estimate the barrier layer thickness in the North Indian Ocean.
- Sensitivity tests show that SSS is the primary driver of the BLT within the MRM.
- Performance is poor in the Southeast Arabian Sea due to the complexity of processes in this region.
- HYCOM tends to underestimate the barrier layer thickness throughout the Indian Ocean.
- Assimilating remotely sensed SSS into global ocean models will likely improve barrier layer representation.
- BL estimates are important for MJO, IOD and warm pool studies

Felton, C. S., B. Subrahmanyam, V.S.N. Murty, and J. F. Shriver: Estimation of the Barrier Layer Thickness in the Indian Ocean using Aquarius Salinity and HYCOM. *J. Geophys. Res.*, 119, doi:10.1022013JC009759.