Upper-Ocean Processes and Air-Sea Interaction in the Indonesian Seas

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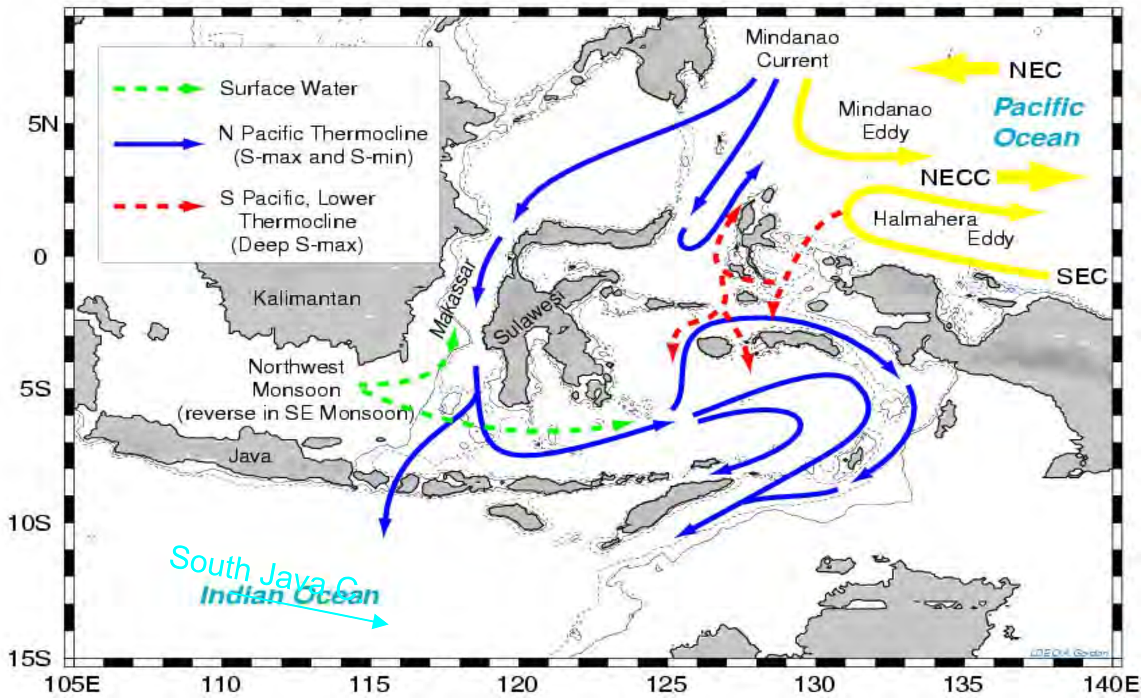
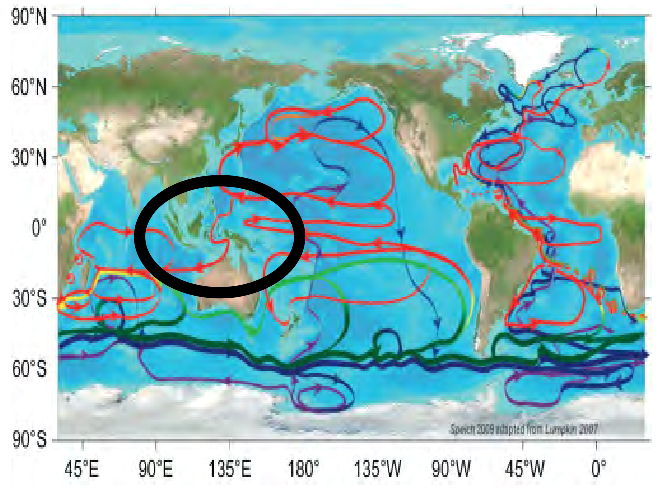
the Indonesian Seas and Throughflow (ITF)

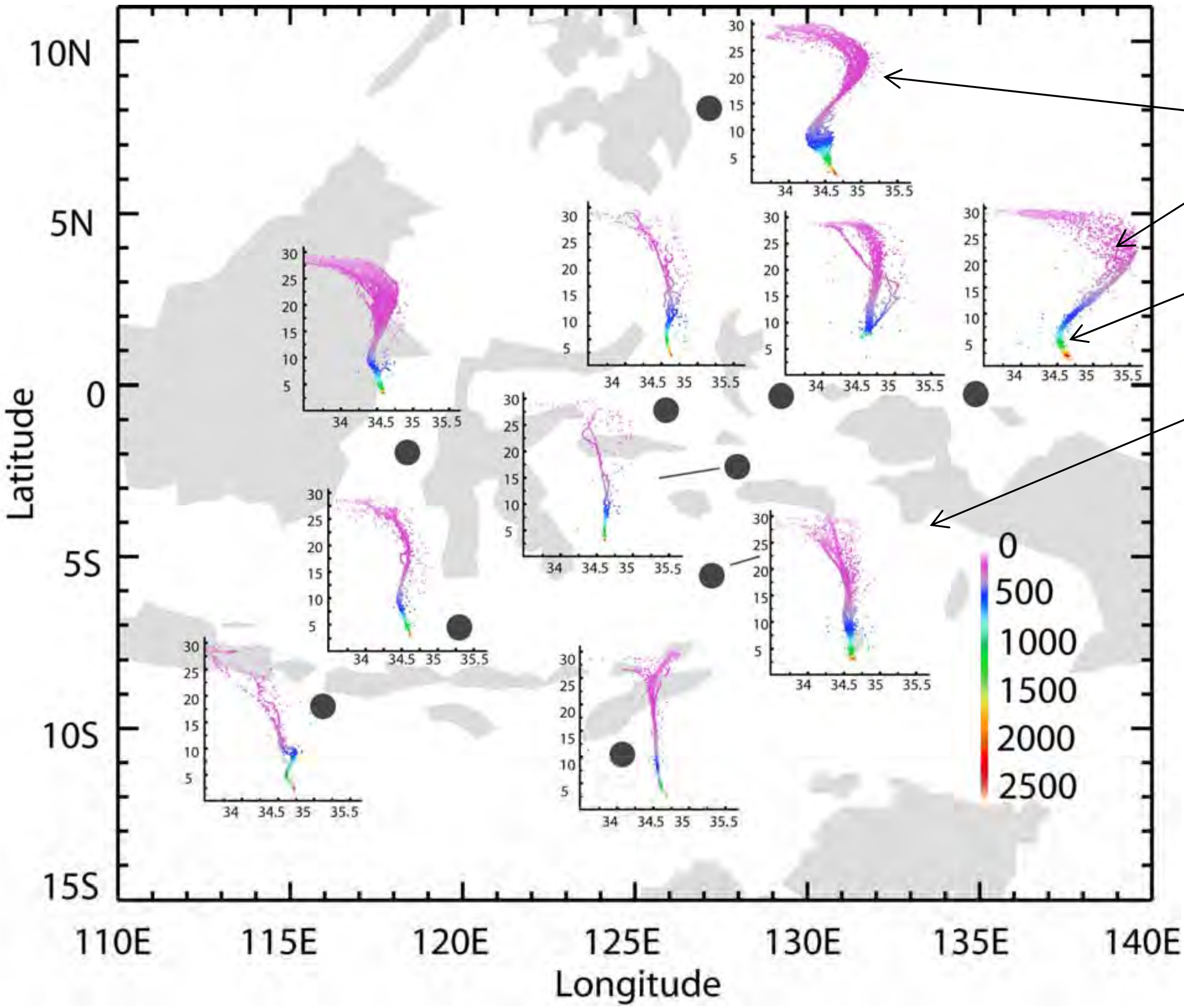




- the only tropical inter-ocean exchange site (~15 Sv)
- transports heat and freshwater from Pacific into Indian Ocean
- pressure gradient between Pacific (high) and Indian Ocean (low) (Wyrtki, 1987)
- ascending branch of Walker Circulation
- closely coupled to the Australasian Monsoon system, MJO, ENSO and IOD
- extends across Indo-Pacific warm pool
- many many islands, deep basins, wide and shallow marginal seas
- mixing from strong tides and enhanced air-sea heat and freshwater fluxes

Strong Mixing

Regional T-S Plots (color coded by depth)

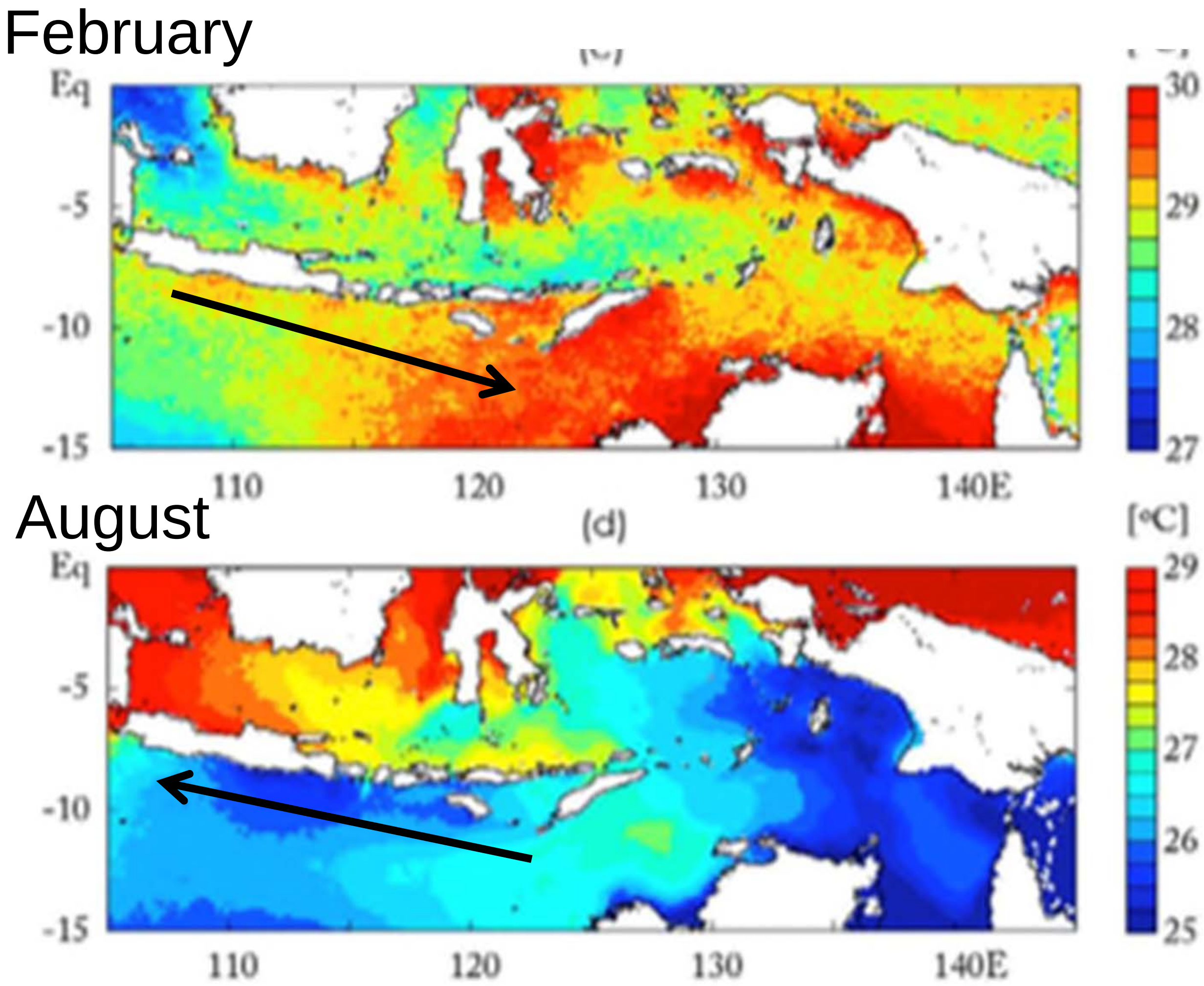


Koch-Larrouy et al. (2007)
Sprintall et al., (2014)

Signatures of the **Smax** in the thermocline and **Smin** in the Intermediate layer **disappear** quickly in the Indonesian seas through vigorous mixing from tides, air-sea interaction and complex bathymetry to form **cool and fresh** Indonesian Seas Water masses

Processes that Drive SST Variability

Annual SST: Monsoon driven upwelling not the whole story!



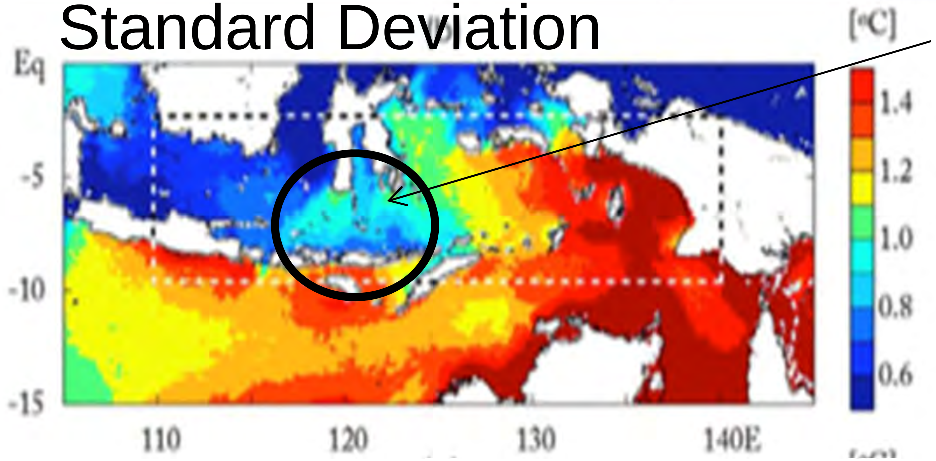
NW Monsoon:
Also large P -> high R/O warms SST by limiting latent heat release & mixing. Freshwater caps trap heat in near surface

SE Monsoon: Wind driven upwelling and Arafura shelf-break cools SST

Kida and Richards, JGR, 2009
Kida and Wijffels, JGR, 2012

Seasonal SST: Role of the ITF in Summer

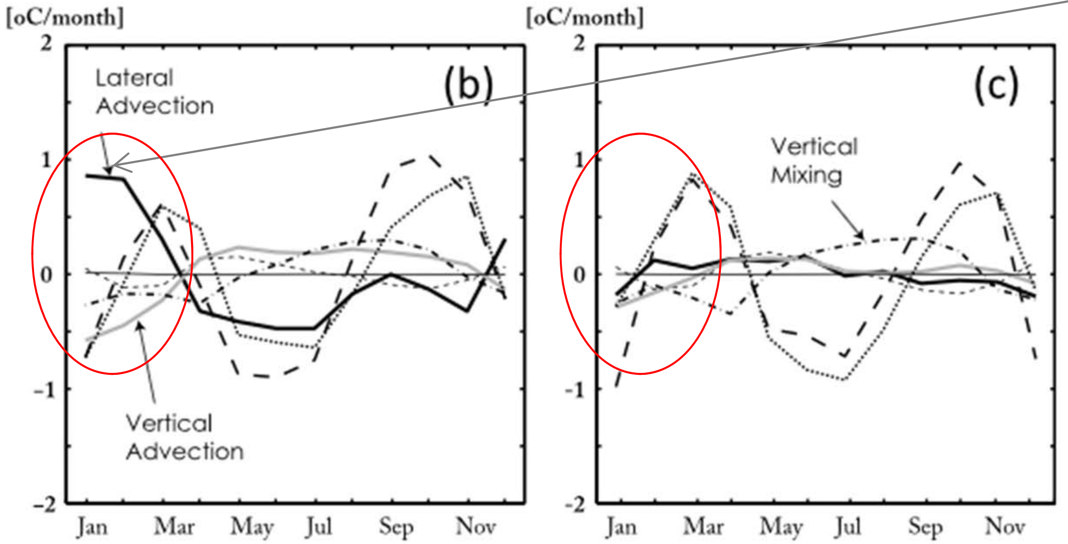
Standard Deviation



Note weak seasonality in Flores Sea. What other processes are important to SST here?

Flores Sea: Control

NO-ITF



Heat balance shows **in austral summer**, lateral advection warms SST while vertical mixing and Q cools SST, i.e the ITF impacts SST by advection of warm water

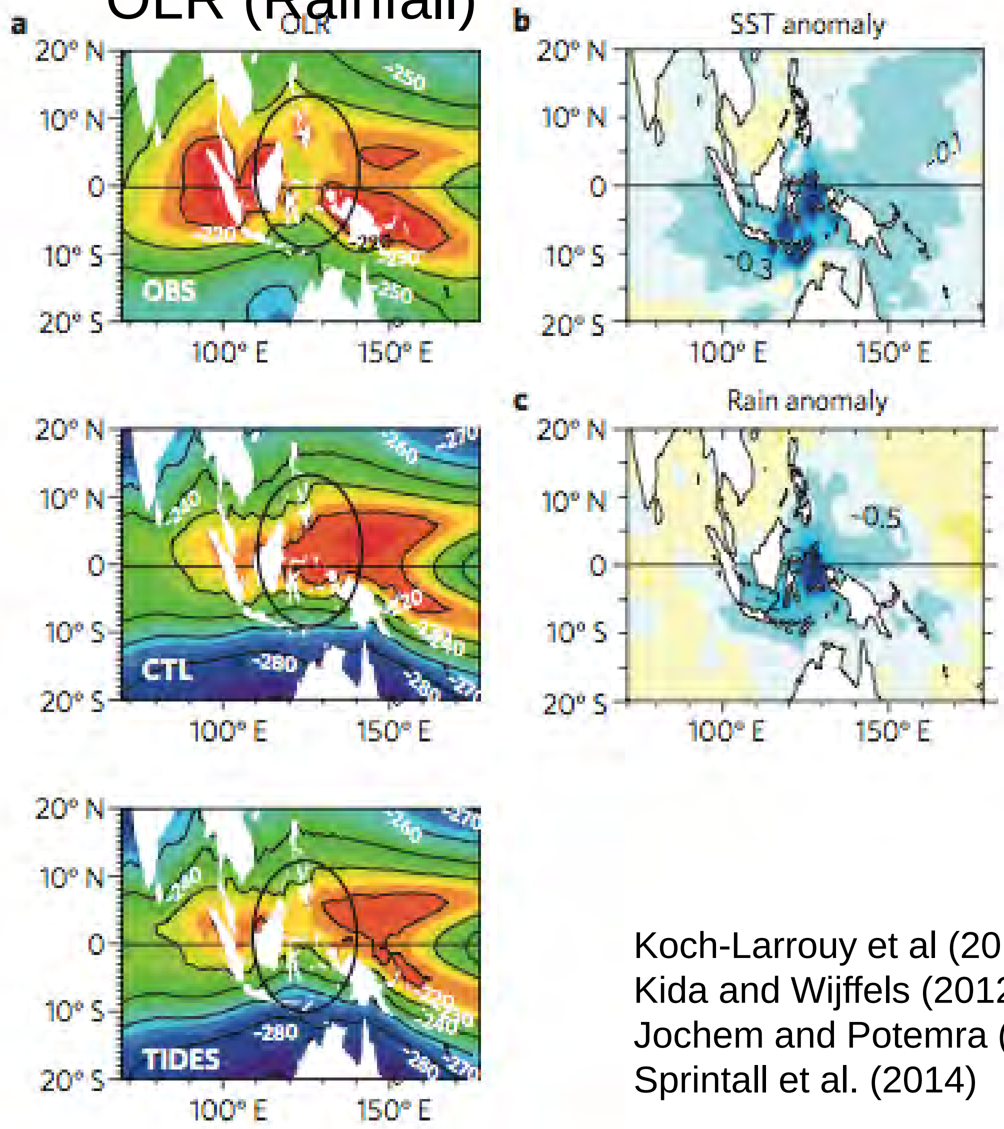
Kida and Wijffels, JGR, 2012

Resolving Mixing is Important

Annual SST and precipitation differences in coupled simulations with/without tides

Models that include tides can reproduce the rainfall (Δ20%), SST (Δ2°C) and heat flux (Δ20 Wm^{-2}) patterns observed in the Indonesian Seas than those without

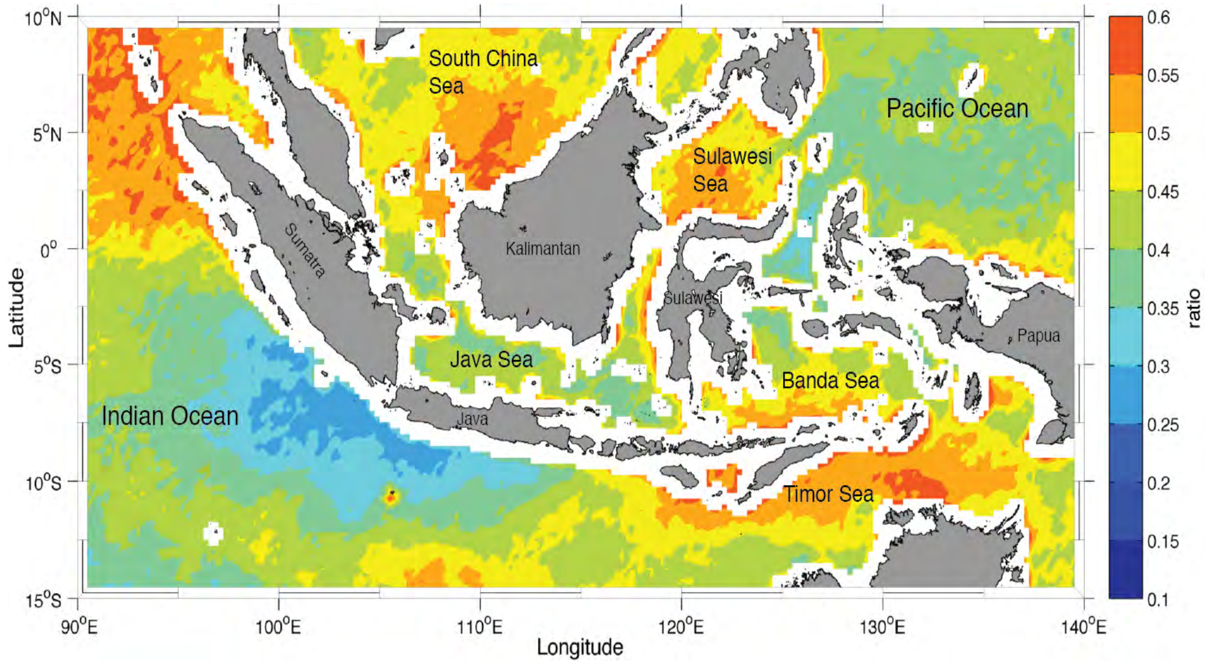
OLR (Rainfall)



Koch-Larrouy et al (2010)
Kida and Wijffels (2012)
Jochem and Potemra (2008)
Sprintall et al. (2014)

Intraseasonal SST

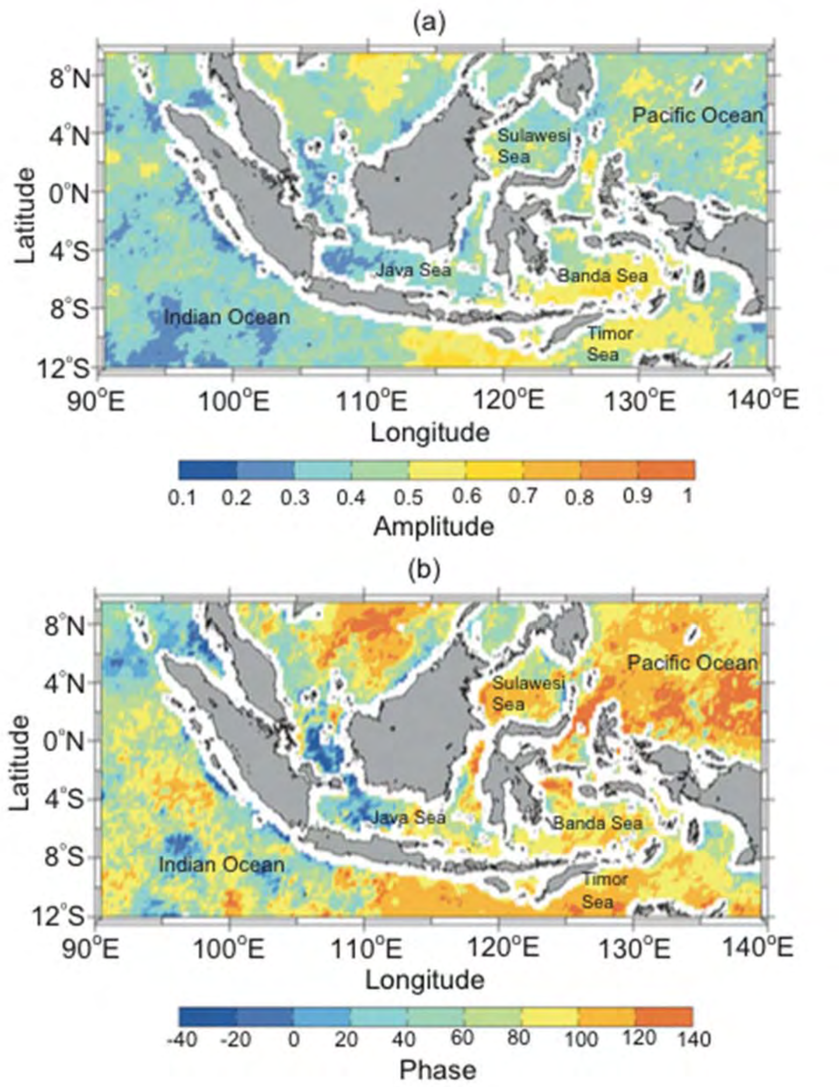
Contribution of intraseasonal variability to total SST variance



Largest intraseasonal SST variance (55-60%) found in Banda Sea, Timor Sea, and in the Sulawesi Sea.

Napitu, Gordon and Pujiana, submitted, 2014

Intraseasonal SST



Coherence of SST and OLR at intraseasonal timescales.

Highest amplitude in Banda Sea and Timor Sea

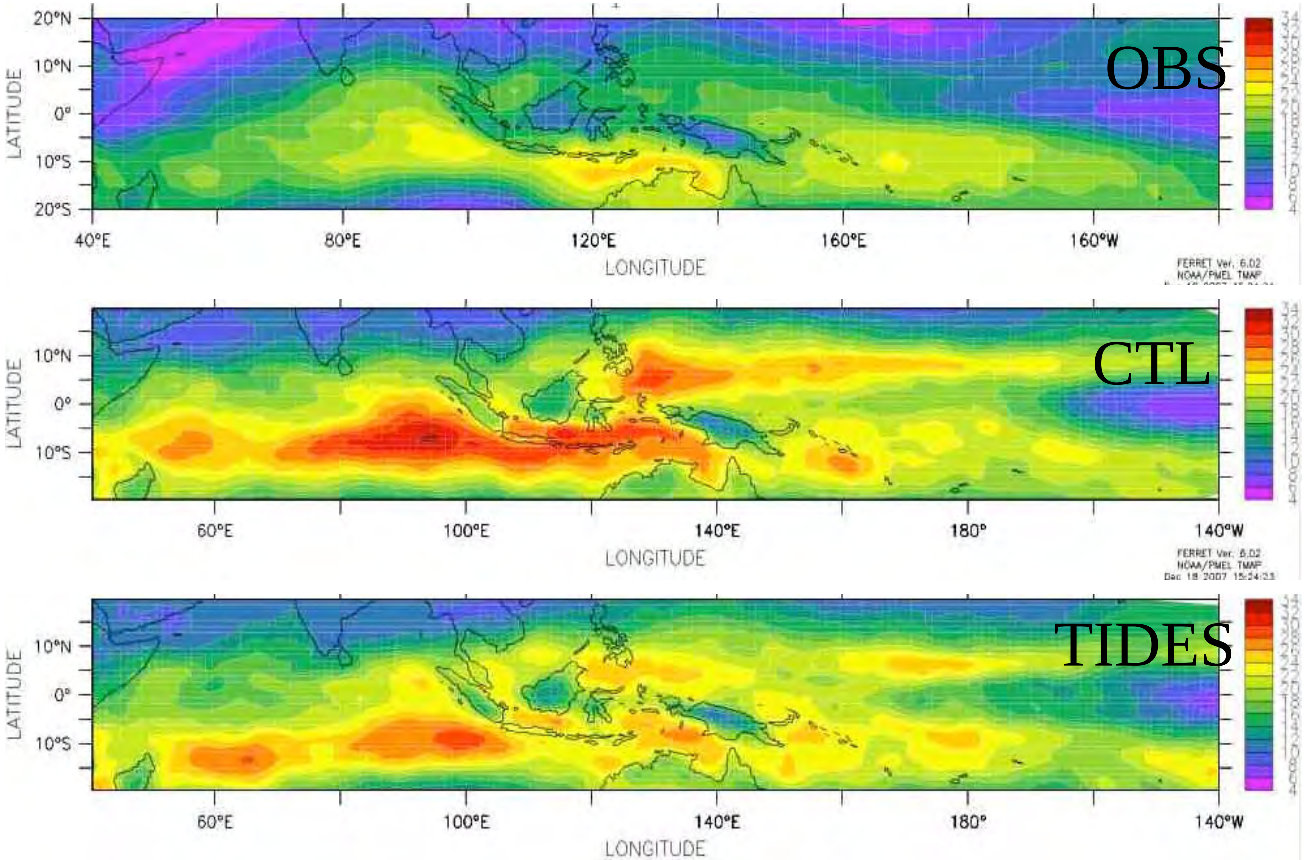
OLR leads SST by 1-2 weeks

Napitu, Gordon and Pujiana, submitted, 2014

Mixing Impact on Intraseasonal OLR

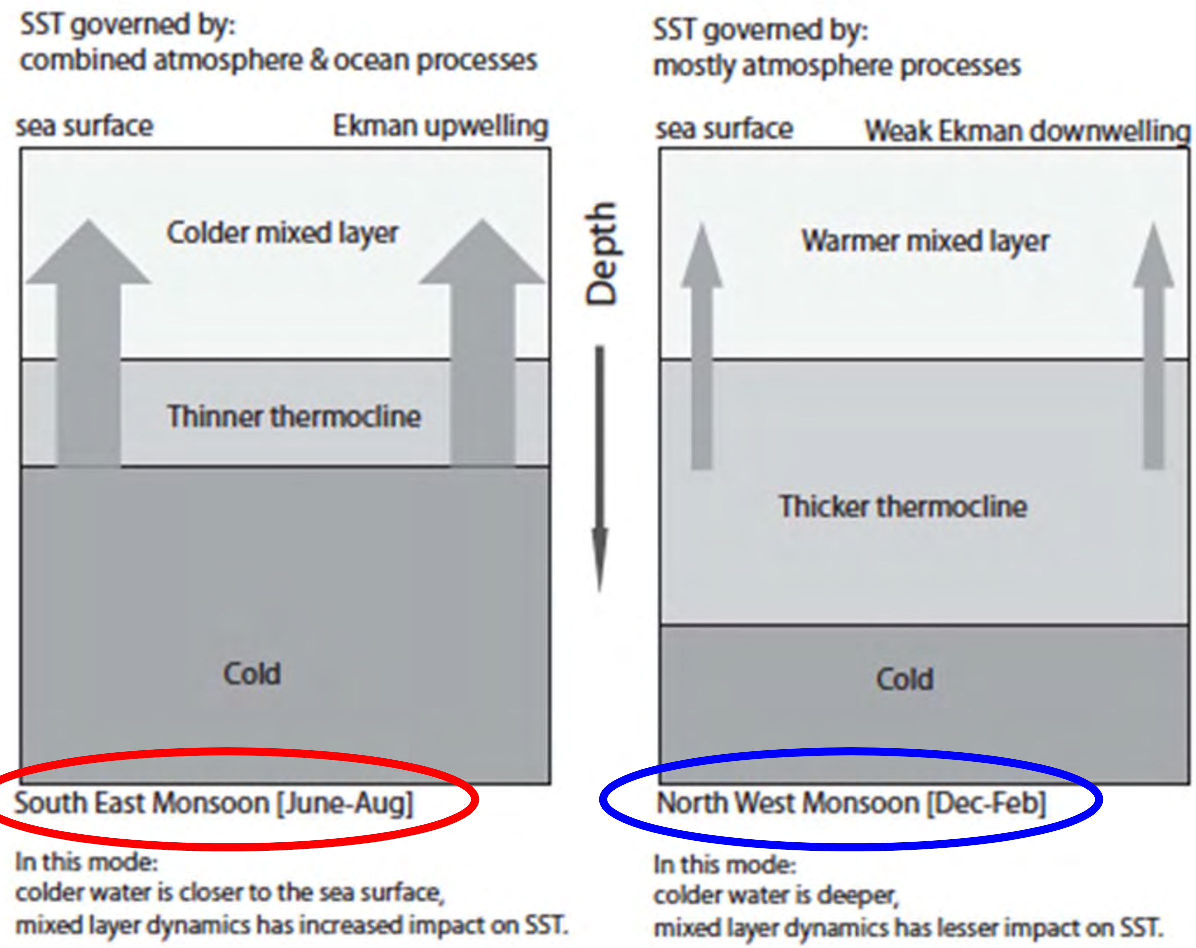
Coupled model with tidal parameterization ⇒ reduced intraseasonal variability in good agreement with observations

Std dev OLR bandpass filtered (30-1d)



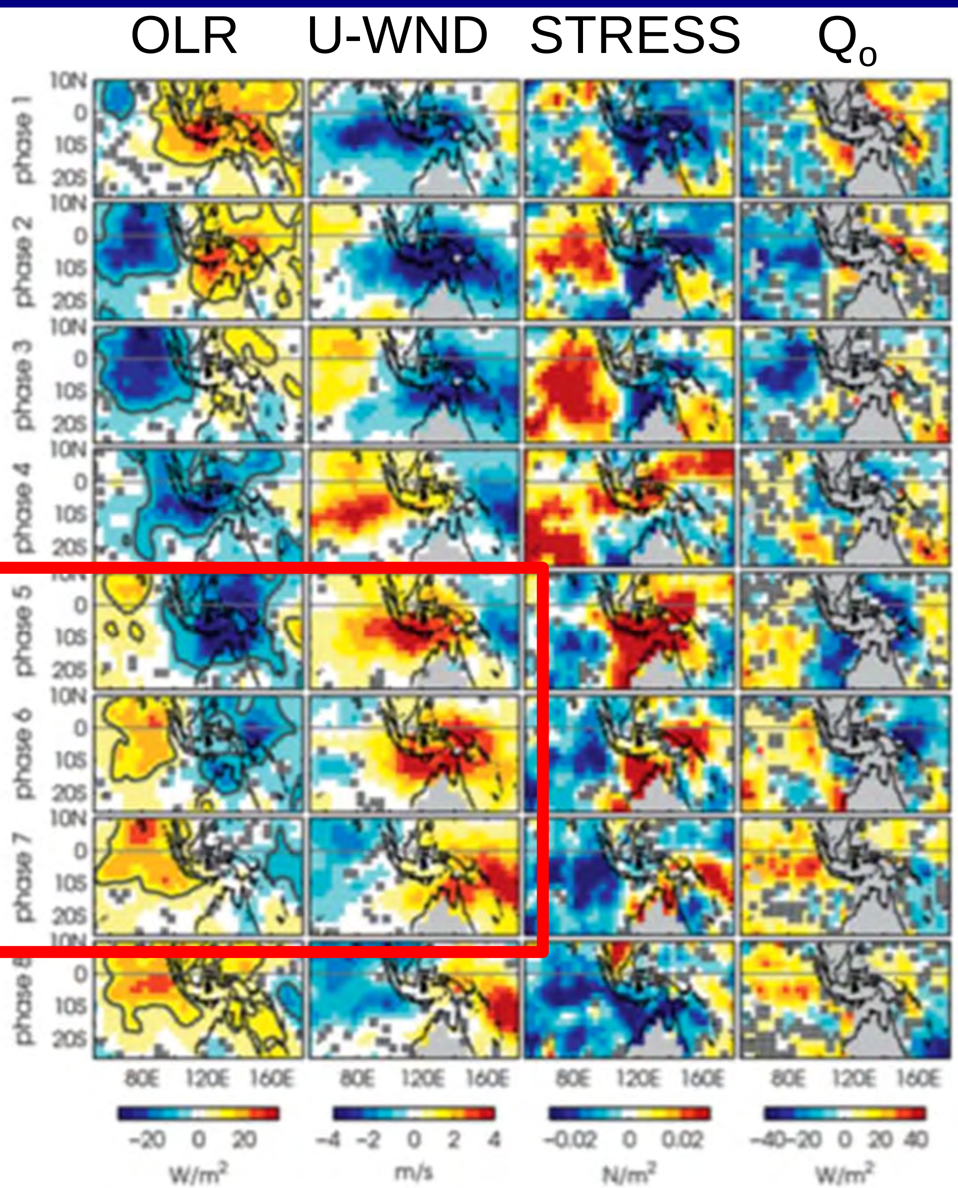
Koch-Larrouy et al (in prep)

Oceanic Processes Influence SST Too!



Napitu, Gordon and Pujiana, submitted, 2014

Indo-Pacific MJO Surface Forcing



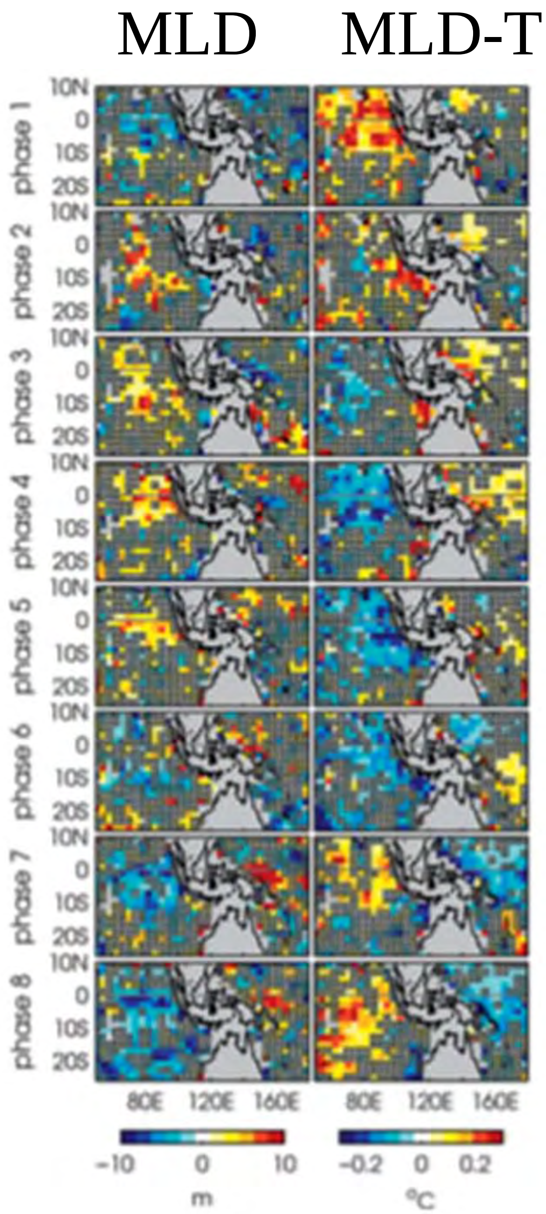
Drushka, Sprintall, Gille and Wijffels, J. Climate, 2012

MJO Composites (Nov-Apr) based on Wheeler and Hendon (2004) Index

Active MJO phase convective cells (OLR<0) lead strong westerly wind anomalies in Indian Ocean (esp. IAB in phases 5-7) but are more aligned in Pacific, and so have different impacts on the SST and mixed layer.

Variations in Q (Q_{LH}) more closely follow wind stress magnitude

MLD Response to MJO Forcing



- Argo data MLD amplitudes ~ 10 m
- Largest signal in IAB ~0.6C
- No profiles available in Indonesian seas

- Spatial patterns resemble τ and Q
- Active MJO: diabatic cooling & wind stirring cause MLD deepening and cooling
- Suppressed MJO: Surface warming and light winds lead to MLD shoaling and warming
- MLD-T lags Q by one phase, i.e., consistent with model that Q drives MLD-T

Drushka, Sprintall, Gille and Wijffels, J. Climate, 2012

Barrier Layer (BL) Influence on MJO

THIN BL THICK

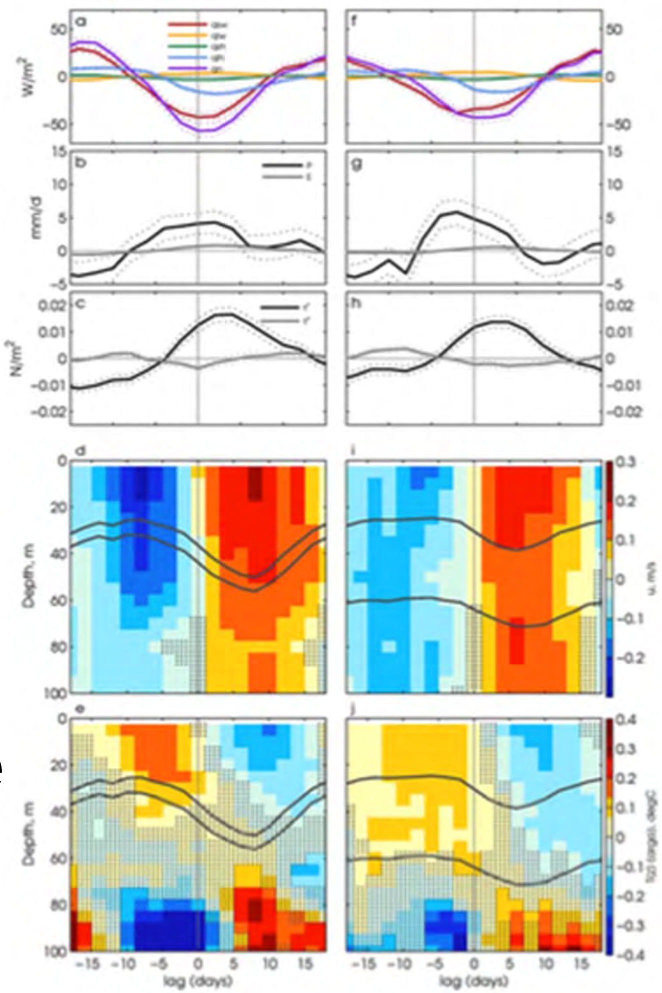
Heat Flux

Precip

Wind Stress

Zonal V

Temperature



- Thin BL:- 15% stronger heat flux and wind stress; 10% stronger P; higher MLD-T; deeper isothermal layer

- Thick BL:- entrainment cooling during MJO reduced so MJO drives weaker SST anomaly

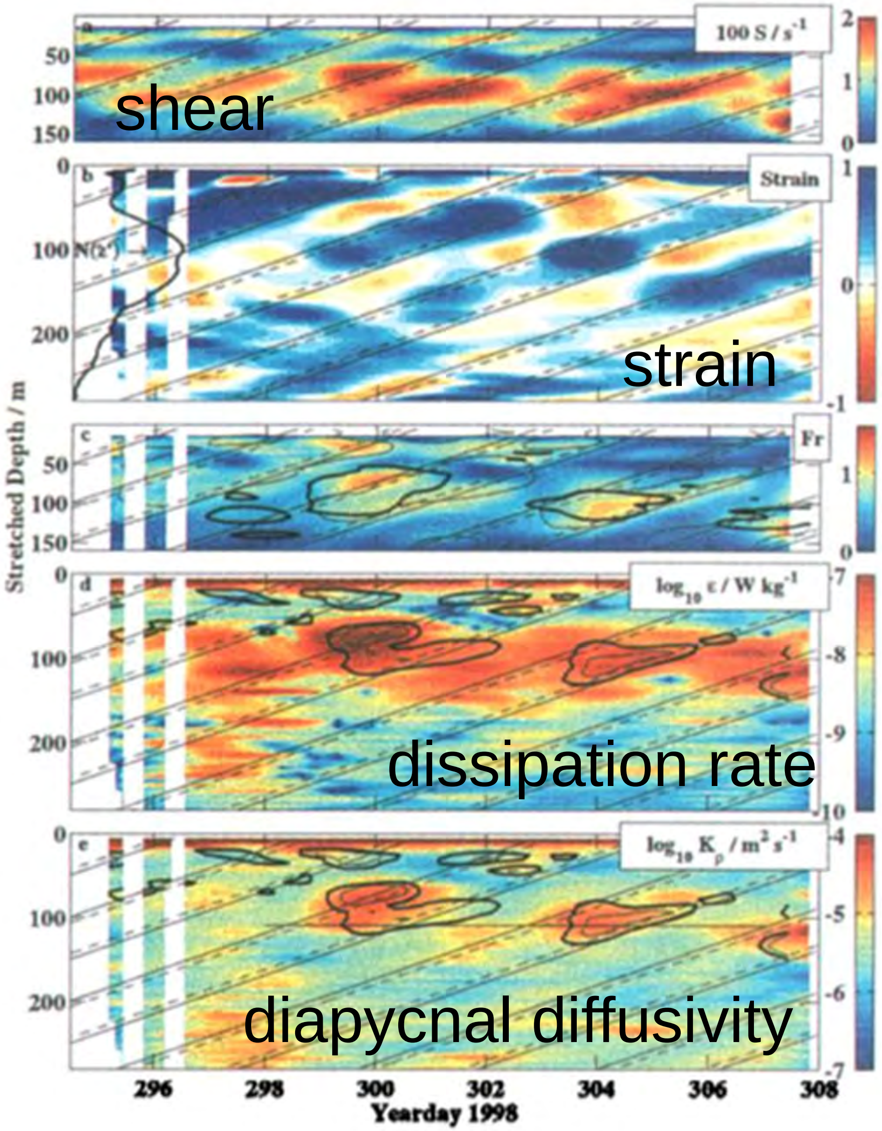
- Modulation of SST by BL thickness can have significant consequences for response of ocean to MJO and in turn, the feedbacks of ocean to atmosphere on MJO time scales

Drushka, Sprintall and Gille, JGR, 2014

Summary

- SST and upper ocean characteristics in the Indonesian Seas are the product of several competing processes (both atmospheric and oceanic driven) over many time scales
- Response may be to local (winds, tides, inertial waves, air-sea interaction) and remote (Kelvin waves) forcing
- Mixing is important! The efficiency of mixing processes depends on stratification, bathymetry and the background oceanic and atmospheric large-scale conditions that vary across the Indonesian seas.

Few Direct Observations of Mixing in Indonesian Seas

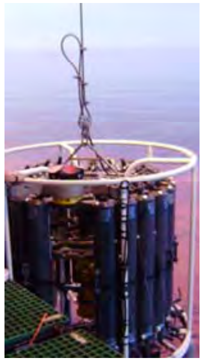


- Near-inertial phase lines evident in shear and strain, leading to pulses of mixing every 4.4 days, the wave period
- Turbulence mixing occurs when low $Ri=N^2/S^2$ (base of MLD)
- At time of observations, local winds were light -> down-ward propagating internal wave likely generated 3 weeks prior and ~200 km away.

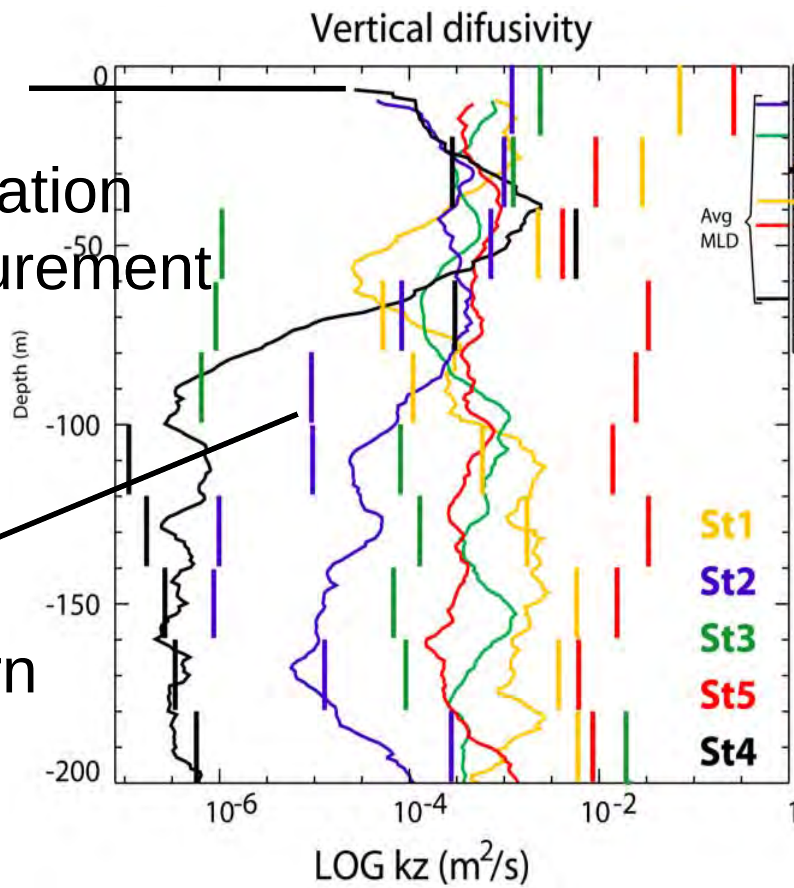
Alford and Gregg, JGR, 2001

Direct measure of vertical mixing : INDOMIX

VMP
direct
Dissipation
Measurement



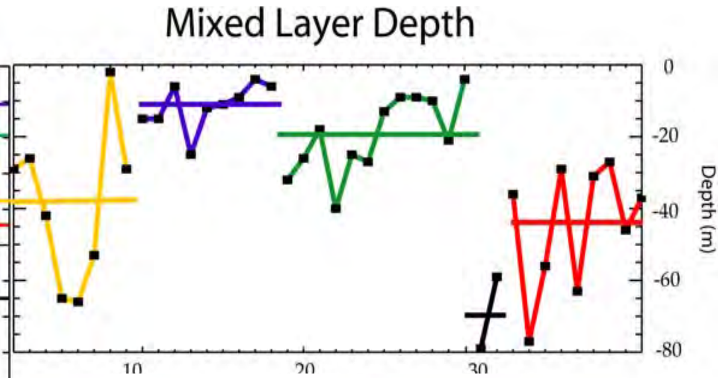
CTD
Indirect
Overturn
Thorpe
method

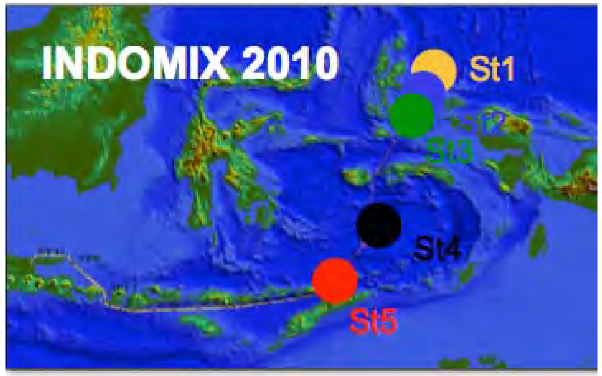


Banda Sea
Far field

Near
field

Above
Straits





Koch-Larrouy, Atmadipoera, van Beek, Madec, Aucan, Lyard, Grelet, and Souhart, submitted DSR, 2015

Discussion Issues

- Mixing Processes:
  - Where does mixing occur? At what depths? Seasonal preference?
- Impact of the ITF advection stream on SST and air-sea interaction
  - if ITF absent or significantly reduced, may enhance the zonal SST gradient
- Shallow versus Deep Basins?
- Precipitation and presence of barrier layer?
  - Large P -> high R/O warms SST by limiting latent heat release & mixing. Also freshwater caps can trap heat in near surface
  - Presence of a barrier layer may significantly affect SST anomalies.
- SST gradients in response to MJO forcing
  - zonal SST gradient in response to seasonal migration across Indonesia and its atmospheric convective activity (convective limit at SST ~27.5C)
- Diurnal variability in SST and surface layer?
- Strong vs. Weak Wind scenarios?
- Regional variability within Indonesian Seas? EEZ Issues? Use of ROV?
- What is the impact on biology? Ecosystem/fisheries interest and also might feedback via solar absorption to SST
- Need *in situ* SST and MLD observations within Indonesian Seas to validate remotely sensed data and model output