The role of the ocean mixed layer in tropical air-sea interaction

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Atmospheric Convection and Air-Sea Interactions over the Tropical Oceans

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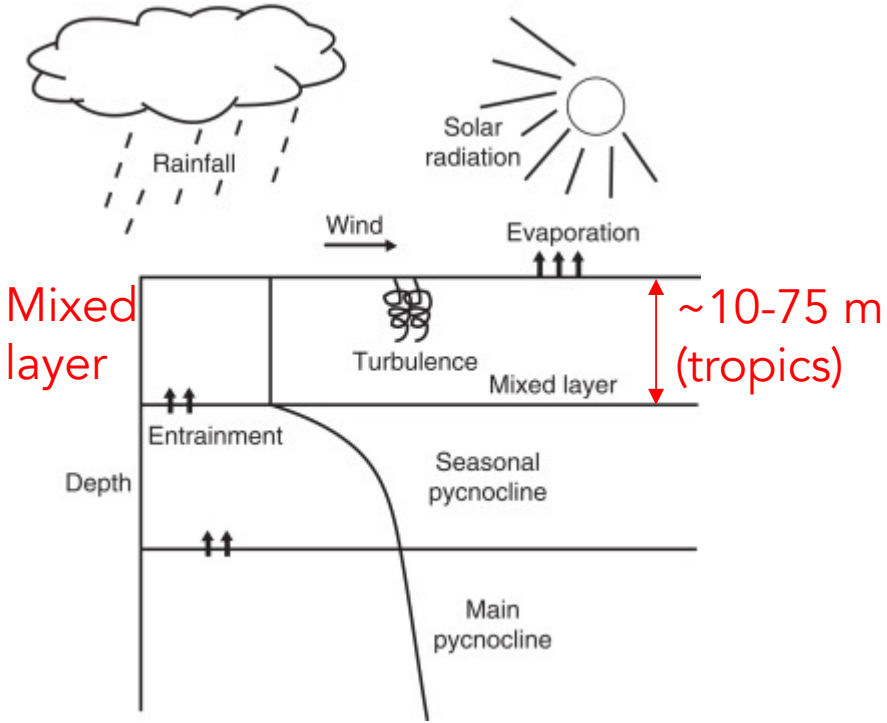
The ocean mixed layer (depth)



Mixed layer:
the well-mixed, homogeneous near-surface layer of the ocean.

Mixed-layer depth:
controls the impact of air-sea fluxes (heat, momentum, material) on the ocean – and hence on feedbacks to the atmosphere

Sprintall & Cronin 2009

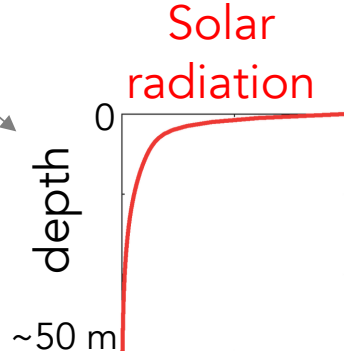
The mixed layer is critical for air-sea interaction

particularly in the tropics, where warm SSTs drive atmospheric convection so small SST anomalies matter

Mixed-layer depth (MLD) affects SST, and hence convection:

- surface heat flux (Q_o) is mixed over the MLD (h)
- solar radiation that penetrates through the base of the ML does not warm SST

$$\frac{\partial T}{\partial t} = \frac{Q_o}{\rho c_p h}$$



Incorrect representation of MLD can lead to biases in model SST and hence in heat fluxes, convection, etc.

(Here we focus on convection, but MLD also matters for energy budgets, biogeochemistry, gas flux…)

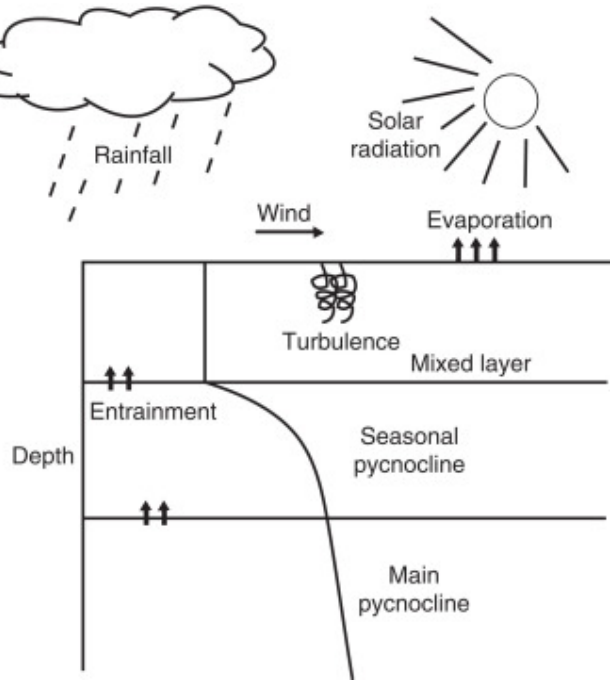
Drivers of mixed-layer depth (MLD) variability I: Surface forcing dominate at diurnal, seasonal, interannual timescales; well predicted by 1-d ocean models

Stabilizing drivers (shoal the ML):

- Solar heating
- River runoff
- Rain

Destabilizing drivers (deepen the ML)

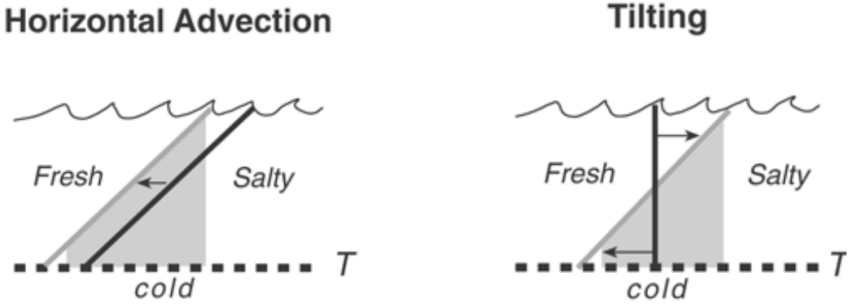
- Surface cooling (sensible & latent heat flux)
- Wind mixing

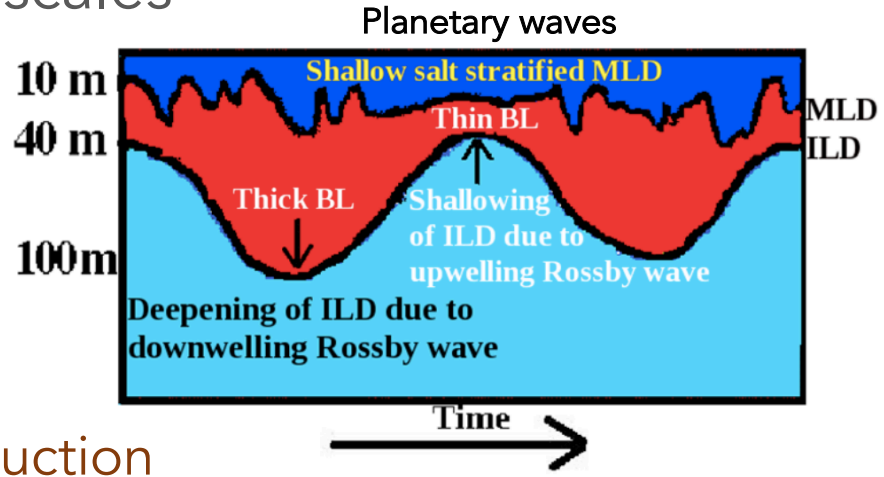


Sprintall & Cronin 2009

Drivers of MLD variability II: Ocean dynamics (3-dimensional)

Important on multiple time/space scales



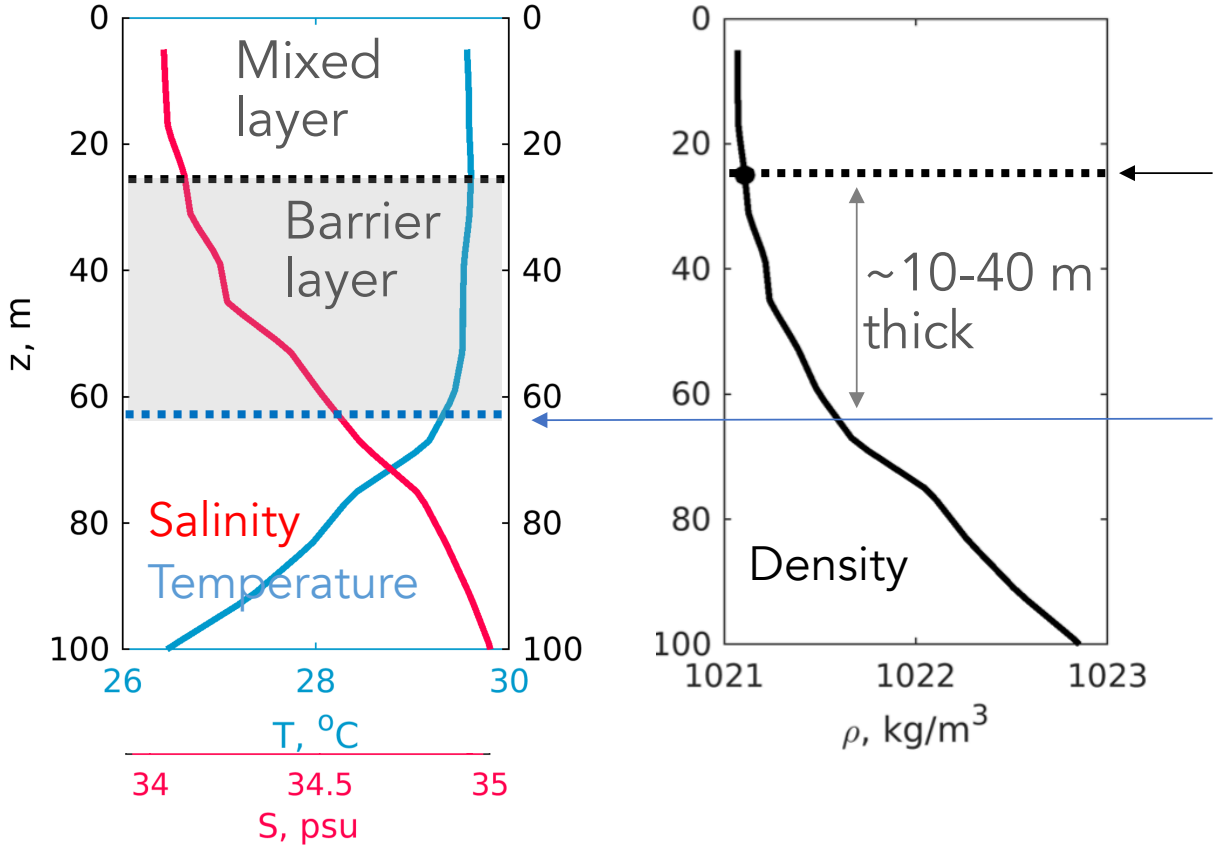


- Frontal advection / tilting / subduction
- Ekman pumping
- Internal / planetary waves
- Small-scale processes, e.g.
  - Submesoscale (1-10km) fronts → instabilities → restratification
  - Langmuir circulation (strong vertical velocities)

Cronin & McPhaden 2002

Girishkumar et al. 2011

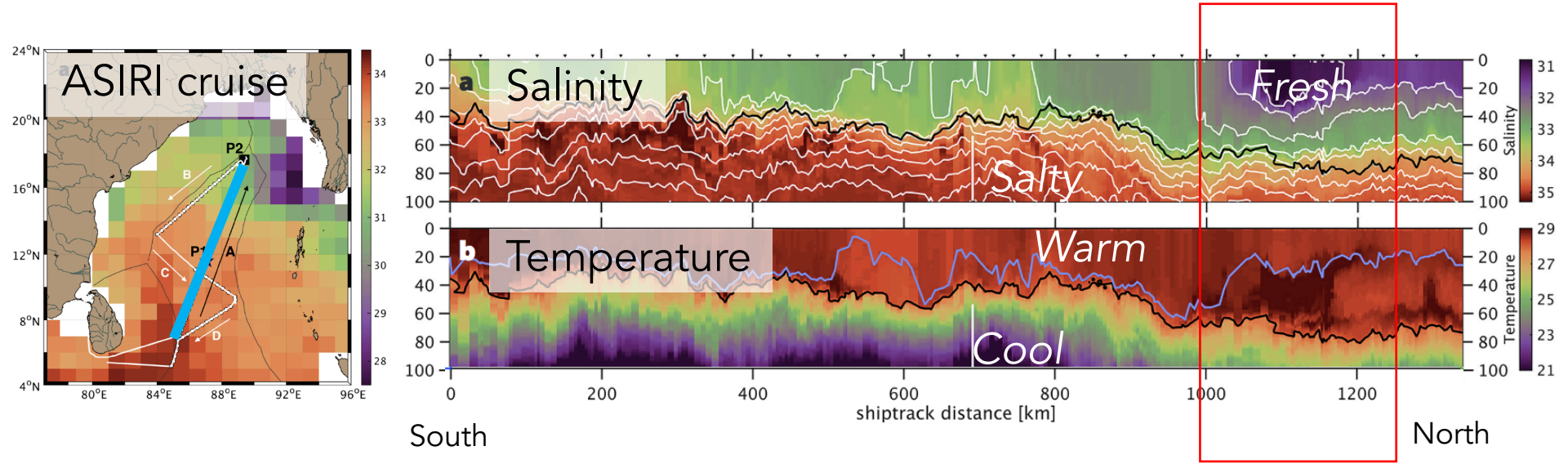
Salinity stratification can cause a shallower mixed layer – and a "barrier layer" beneath the ML



MLD based on density

isothermal layer depth: "MLD" based on temperature

The presence of a barrier layer affects air-sea interaction



Barrier layer: temperature inversions possible

– warm water below the ML can later be released to the atmosphere

Mixed layer deepening doesn't cause entrainment cooling

Deeper ocean isolated from the atmosphere

Mahadevan et al. 2016: ASIRI data

Key questions

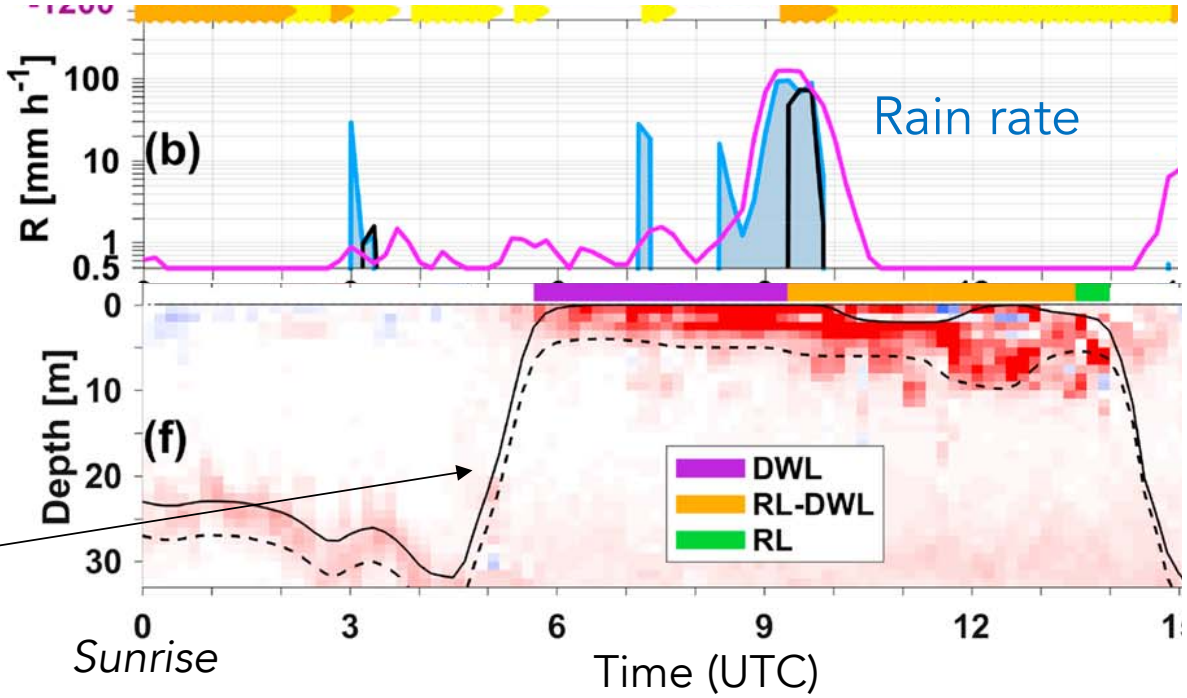
How much does MLD variability affect SST and atmospheric convection?

What time & space (horizontal and vertical) scales need to be resolved in observations and models to capture relevant MLD variations?

Where/when is MLD variability 1-dimensional? When are 3-d ocean dynamics important?

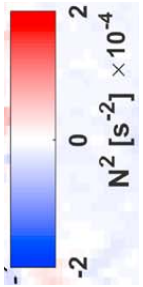
Short timescales:
diurnal warming and/or rain cause stable near-surface layers

These are thin (1-10m), mixed away within ~hours
Their importance has not been well quantified



"stable layer depth"

Wind speed:
2-4 m/s
4-6 m/s

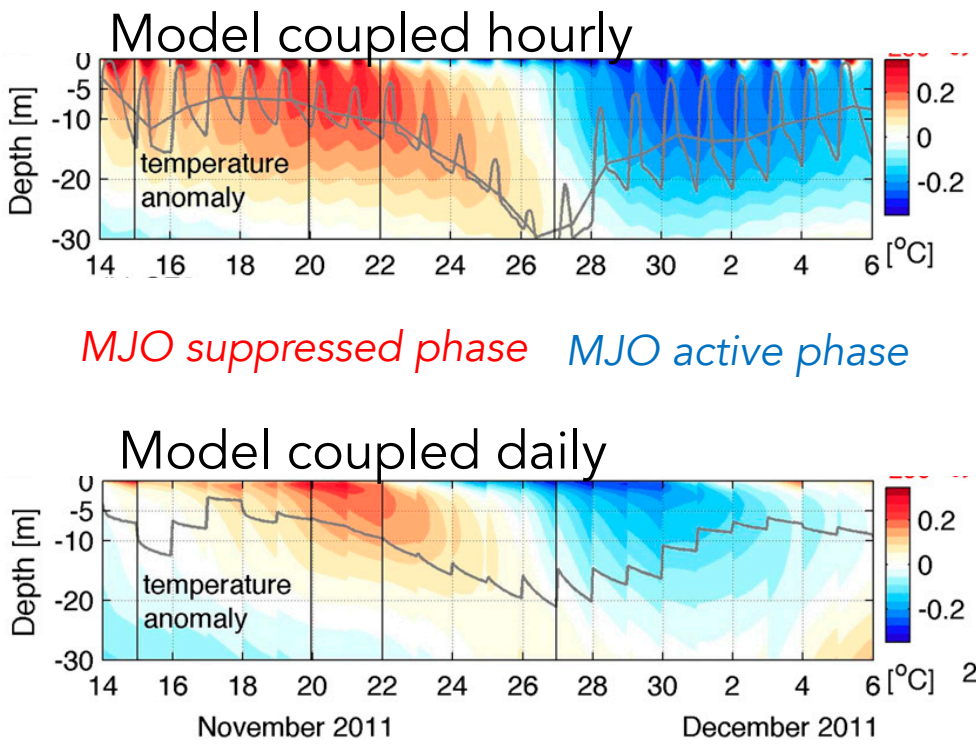


N^2

Thompson et al. 2019: DYNAMO data

Rectification of the diurnal cycle onto longer timescales

Diurnal variability improves MJO representation



Cumulative impacts of diurnal warm layers (DWLs) amplify the MJO SST anomalies

Models including a diurnal cycle:

- Larger, better diurnal heat fluxes
- Better diurnal convection
- Better MJO forecast skill

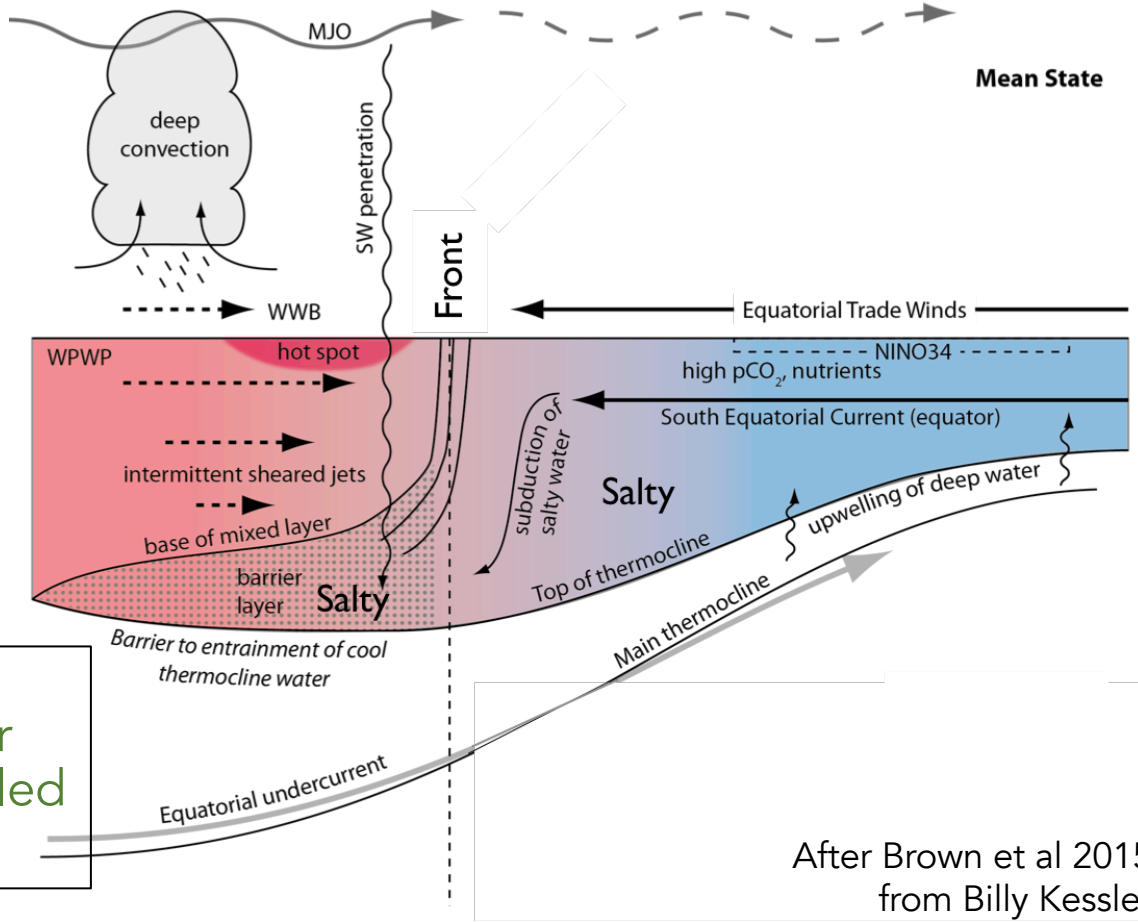
Similarly, models with diurnal coupling better simulate ENSO

Seo et al. 2014

Barrier layer at the edge of the western Pacific warm pool:
Intraseasonal to interannual variations matter for ENSO

BL inhibits entrainment cooling, traps heat & momentum, responds quickly to westerly wind bursts

Thick BL associated with El Niño onset (Maes et al 2002)



Correctly modeling the location/thickness of the barrier layer is critical for getting coupled air-sea processes right

After Brown et al 2015
from Billy Kessler

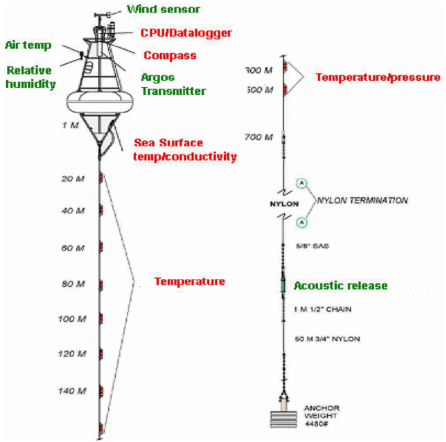
Current state of MLD measurements in the observing system

Argo floats: great vertical resolution to capture MLD

- Time/space sampling: good for >seasonal timescales
- inadequate temporal sampling on faster/smaller timescales (intraseasonal, diurnal, episodic, submesoscale)

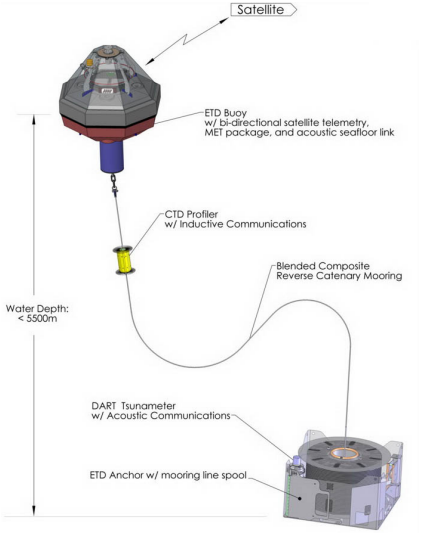
Moorings: good time resolution

(but large horizontal scales only)



Tropical Mooring Array barely captures MLD (poor vertical resolution)

Highly instrumented flux moorings (e.g., ASIRI, SPURS-2) capture MLD well but are $$$ (good for process studies)



Prawler moorings: high resolution, lower cost, higher risk

Some ways forward

Improving observations

- Capture diurnal, intraseasonal, S2S MLD variability in key regions

Improving understanding of where/when/why MLD variability matters

- E.g. with model sensitivity studies, observational process studies
- Emerging: importance of the submesoscale; 3-d ocean dynamics; episodic/small-scale features
- Will allow us to focus future efforts, and where existing MLDs are adequate

Improving observing technology

- Profilers on autonomous vehicles (Wave gliders or Saildrones with winches?)
- Exploiting acoustics to capture MLD

Improving parameterizations of MLD & representation of MLD in data assimilating models

- Small/fast scales still tricky