Diurnal air-sea coupling, air-sea fluxes, and the upper ocean state during the suppressed phase of the Madden-Julian Oscillation (MJO)

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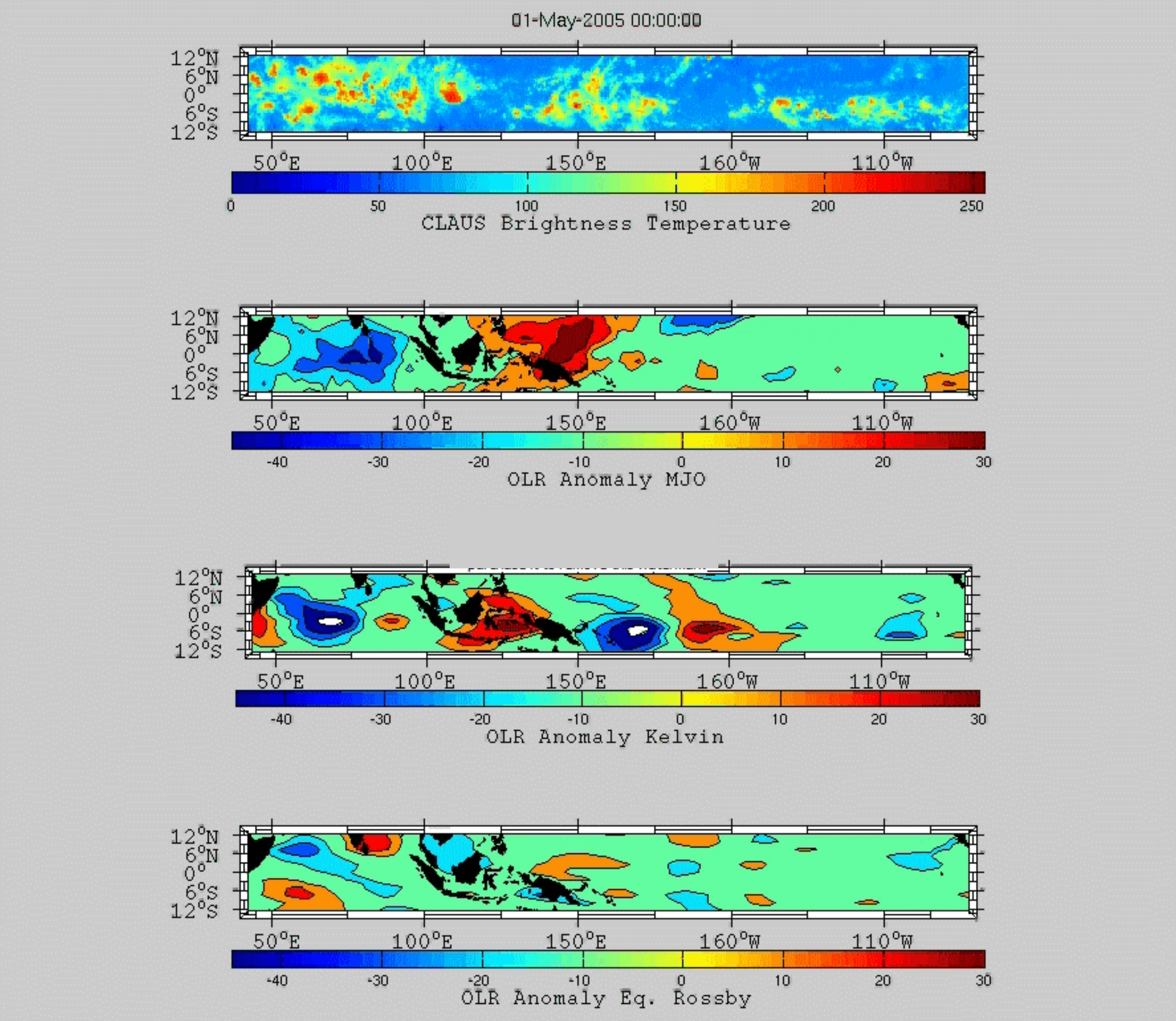
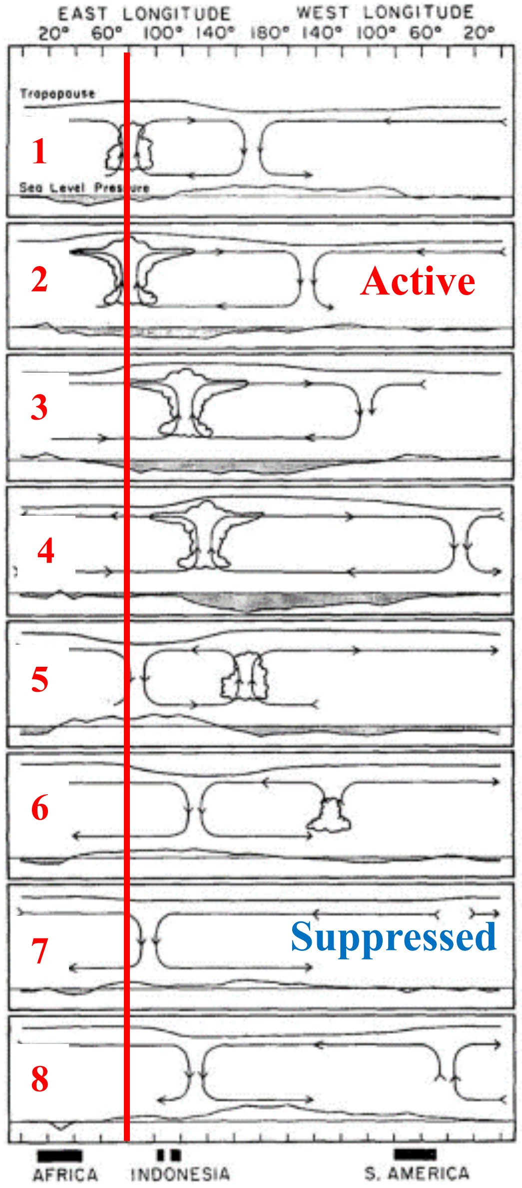
MJO and Intra-Seasonal Oscillations



Adames, A., J. Patoux and R. C. Foster, 2014: The contribution of extratropical waves to the MJO wind field, J. Atmos. Sci., 71, 155-176.

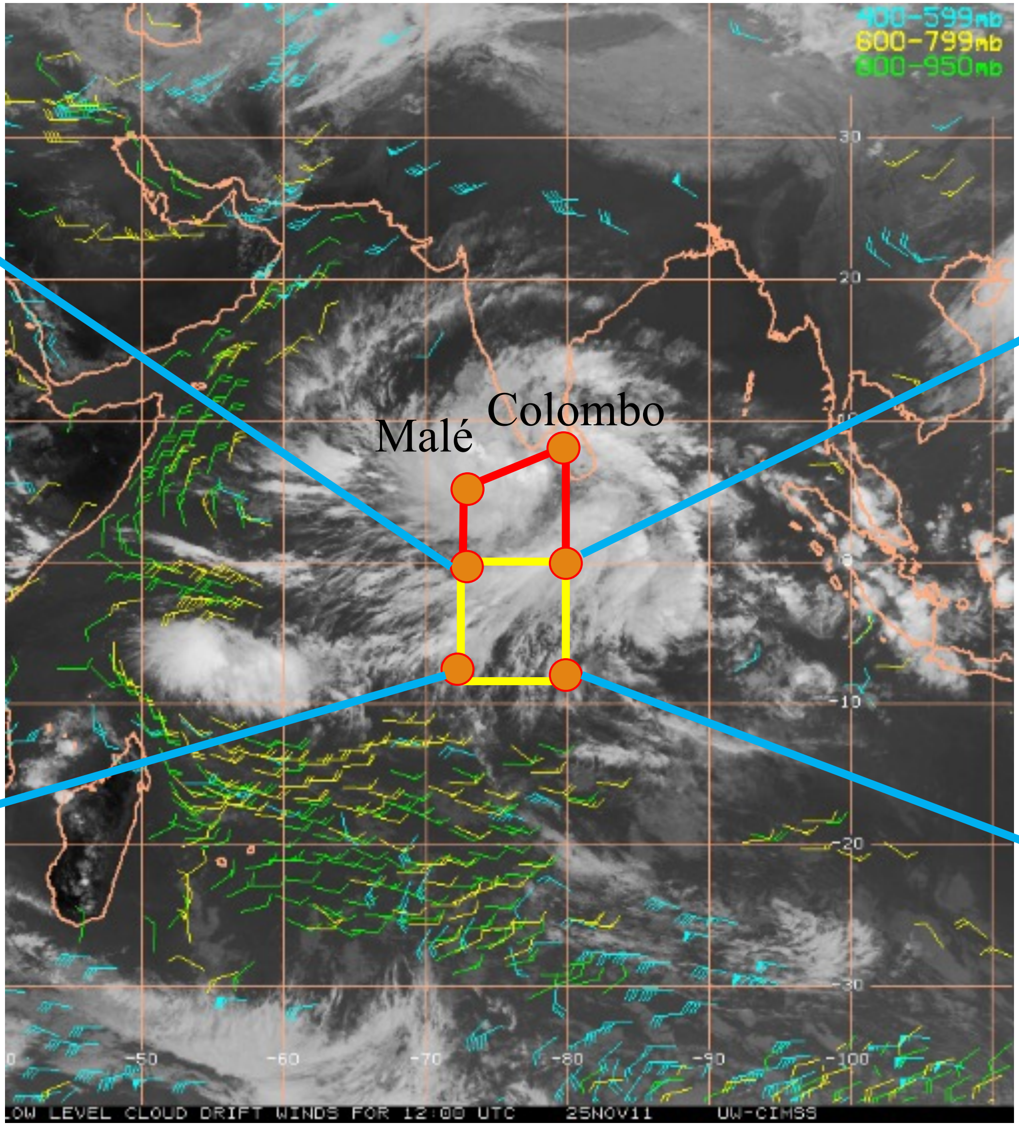


Madden & Julian, 1972

DYNAMO at Sea Assets

Gan
Radar
Soundings
Falcon

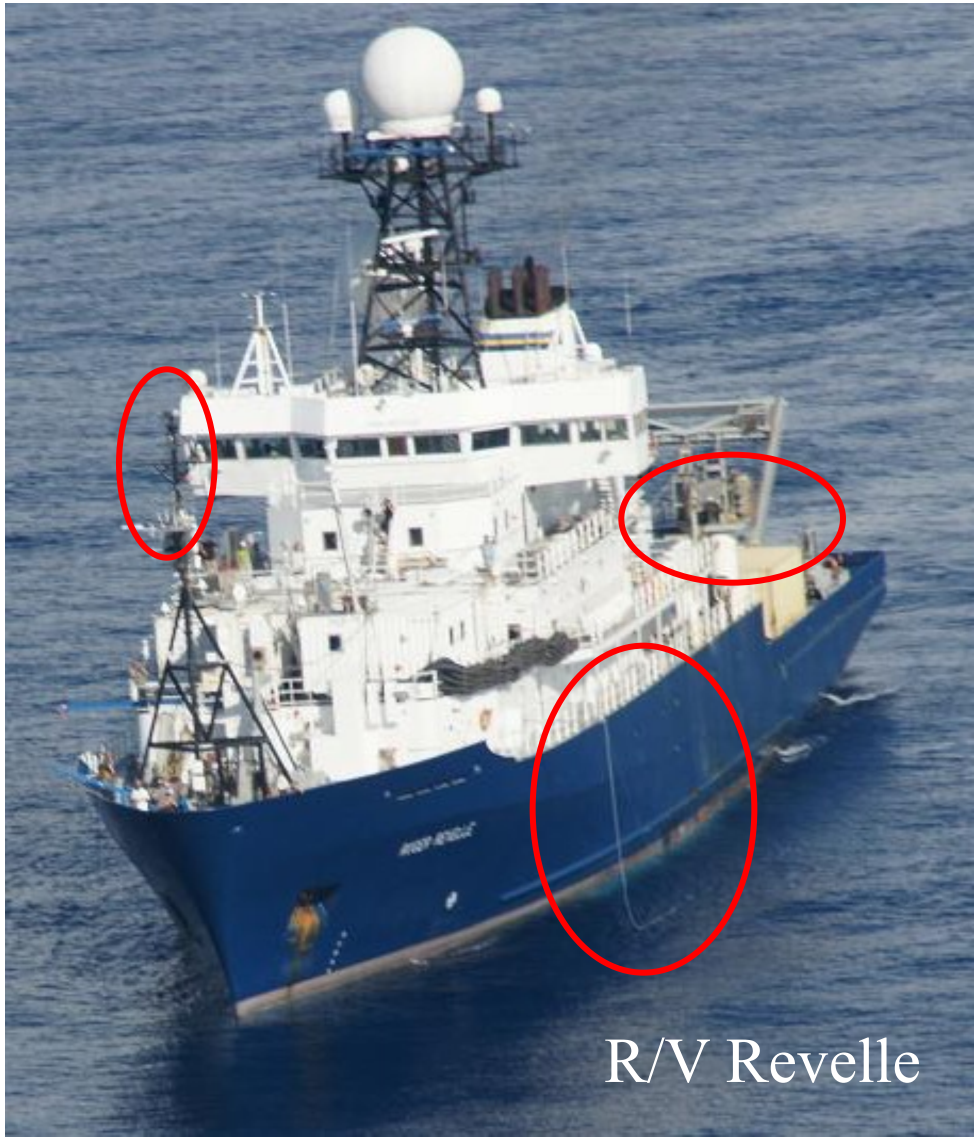
Diego Garcia
ISS
NOAA P-3

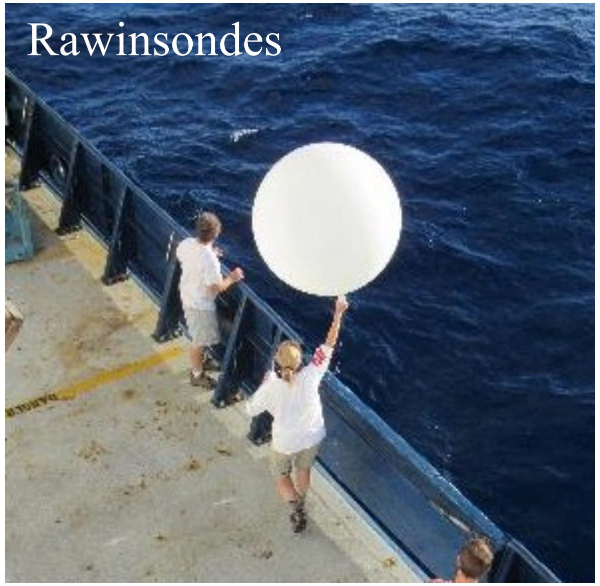


R/V Revelle

R/V Marai

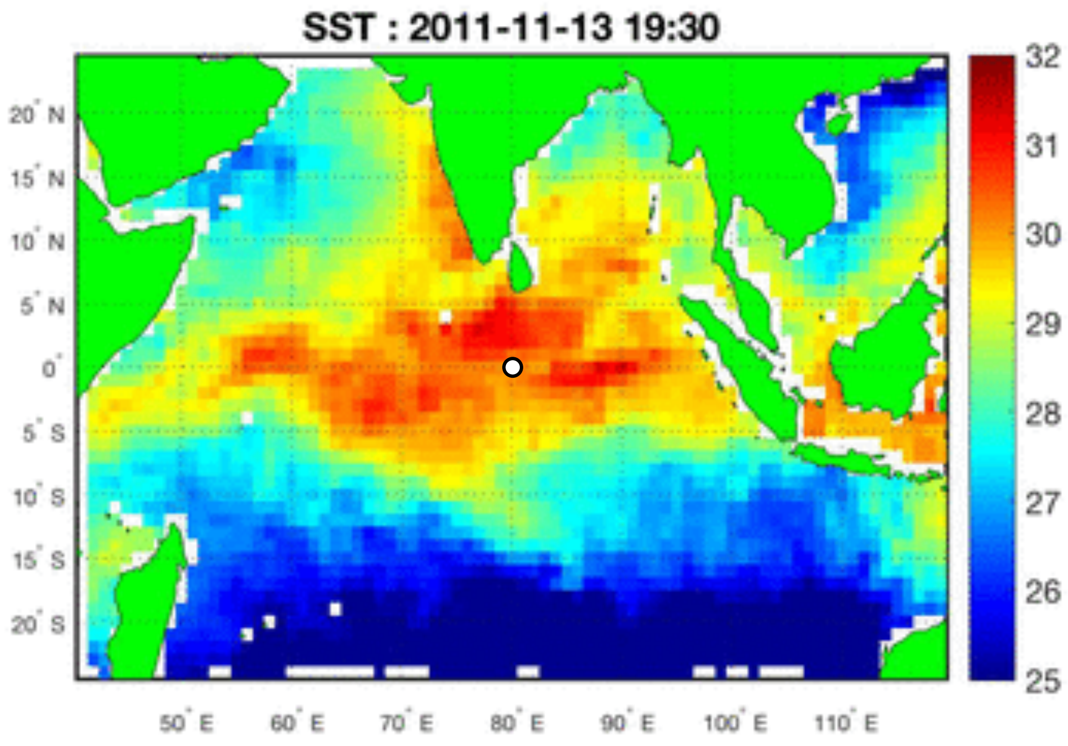
In Situ Measurements





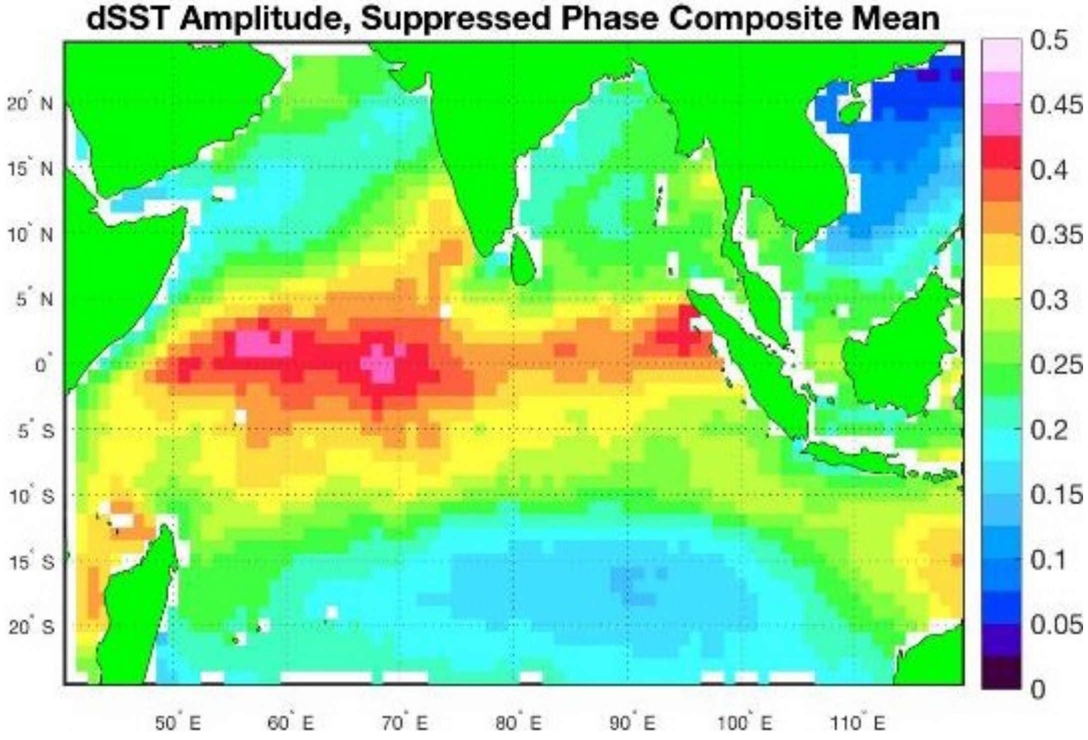
Diurnal Warming Signal

- Diurnal warming is ubiquitous throughout the tropical Indian Ocean (10S-15N, 50E-110E) throughout the suppressed phased of the MJO
- Average values are 0.3°C



Animated loop of 3-hourly sea surface temperatures from the SeaFlux-CDR during the November MJO event during DYNAMO

$$dSST = T_{max} - T_{predawn}$$

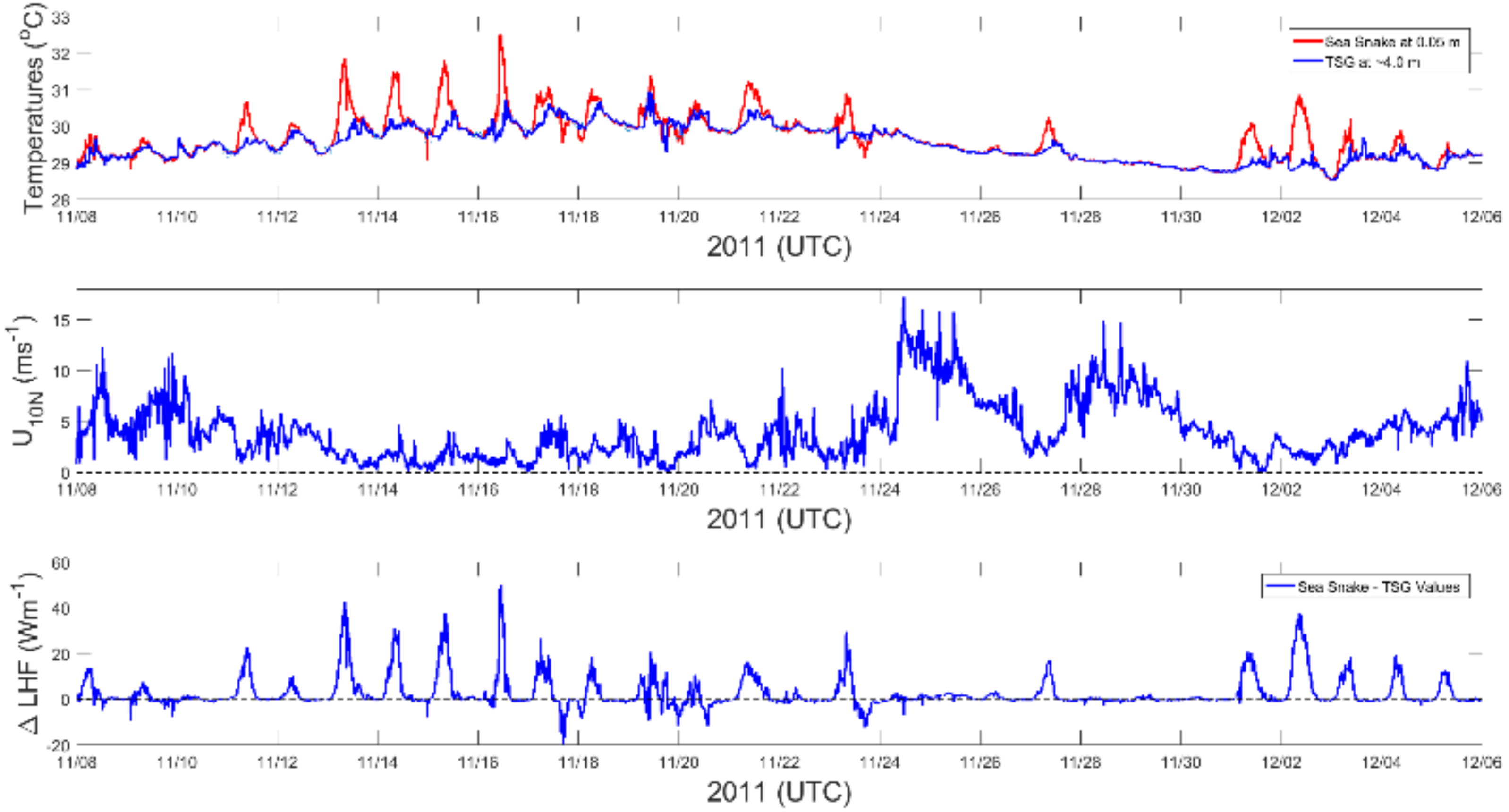


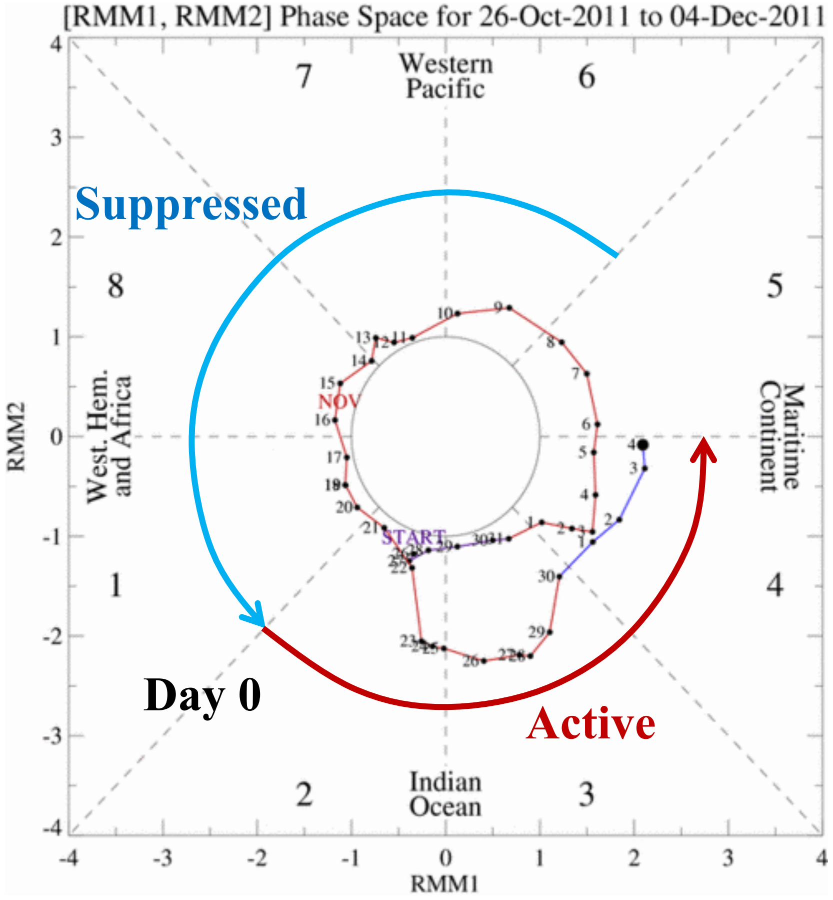
Average diurnal warming amplitude (dSST) over all MJO events during the -8 to 0 days during the suppressed phase.

Diurnal Warming during an MJO Event

6	7	8	1	2	3	4	5

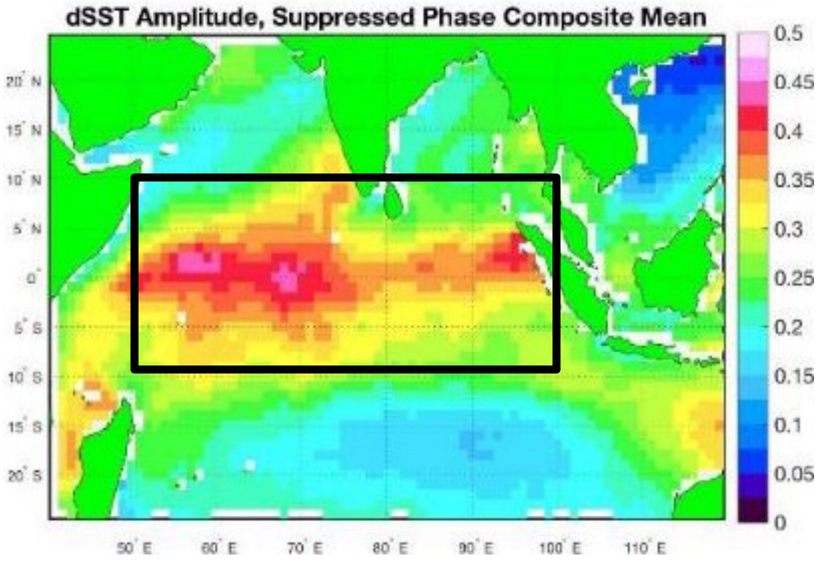
Suppressed Phase **Active Phase**





$dSST$ = 1.35°C +/- 0.66°C

Data Sets & Study Region



Study Period:

- March 2000 through December 2014 (ONDJFM only)

Domain

- 10°S to10°N, 50°E-100°E

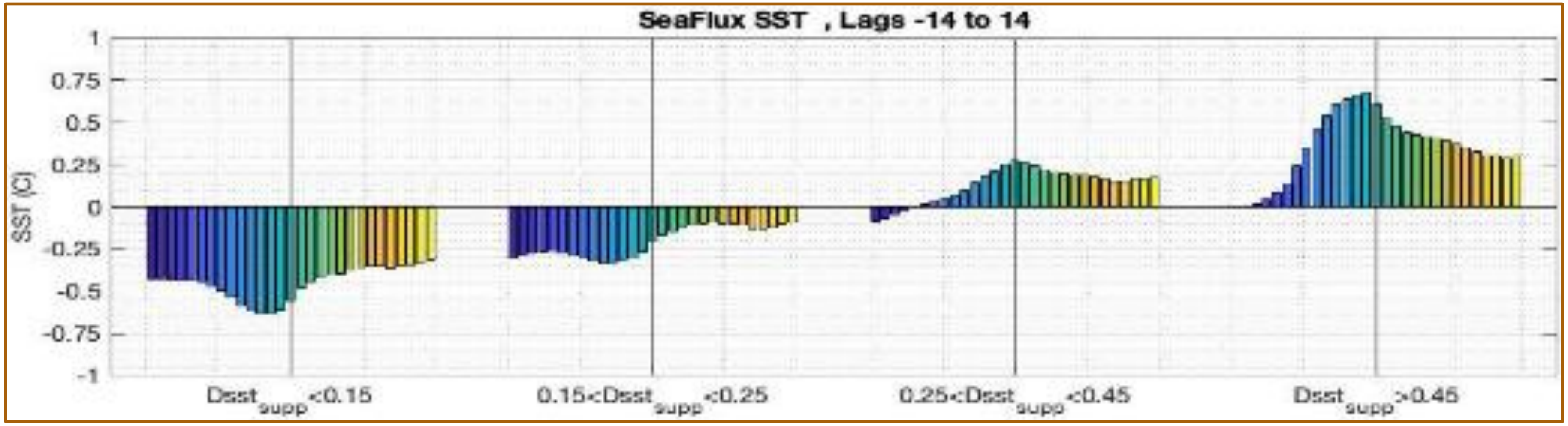
Data Sets:

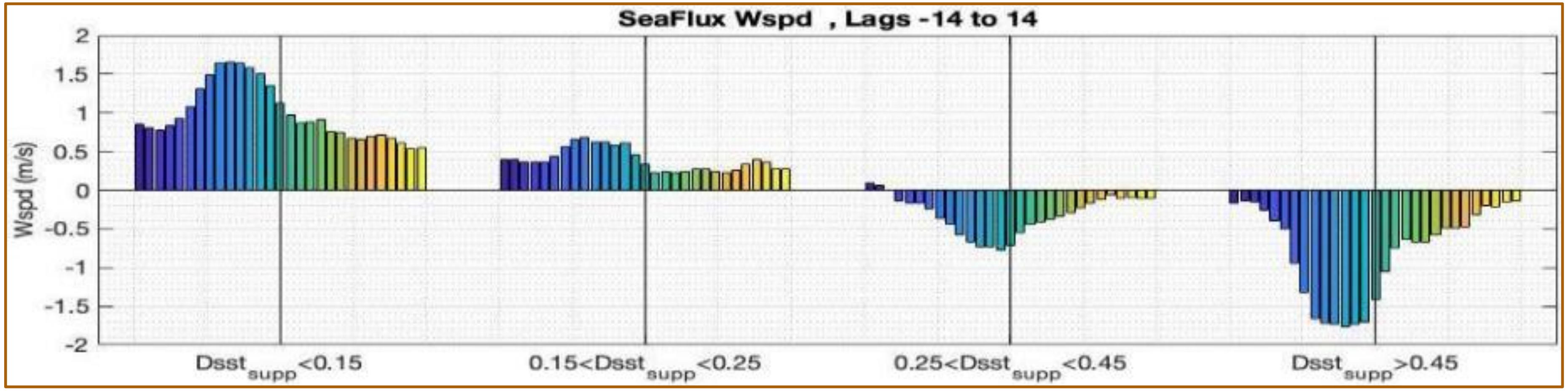
- CERES Edition 3 Radiative fluxes (3-hour, 1° resolution)
- SeaFlux-CDR Turbulent Fluxes (3-hour, 1° resolution)
  - Includes diurnally varying SST parameterized with Wind speed and SWR
- GODAS Ocean Heat Content (0 to 60m) and Mixed Layer Depth (based on density threshold)
  - Pentad -> Resampled to daily with linear interpolation and 1deg resolution
- TRMM 3B42 Rainfall (3-hour, resampled to 1x1 degree)
- MERRA2: Precipitable Water, Vertically-integrated moisture convergence (3-hour, resampled to 1x1 degree)

Methodology

- MJO events were identified using the OLR index given by Matthew (2008) 20-200 day band-passed OLR index
- Maps of mean dSST were computed using the 3-hourly data during the suppressed phase for each of 29 events.
- The compositing was done by averaging the data over those locations of dSST = ~0->0.15, 0.15-0.25, 0.25-0.45, and >0.45.
- For a single event, those locations falling into each dSST bin were then composited as a function of lag over the +/- 15 day window

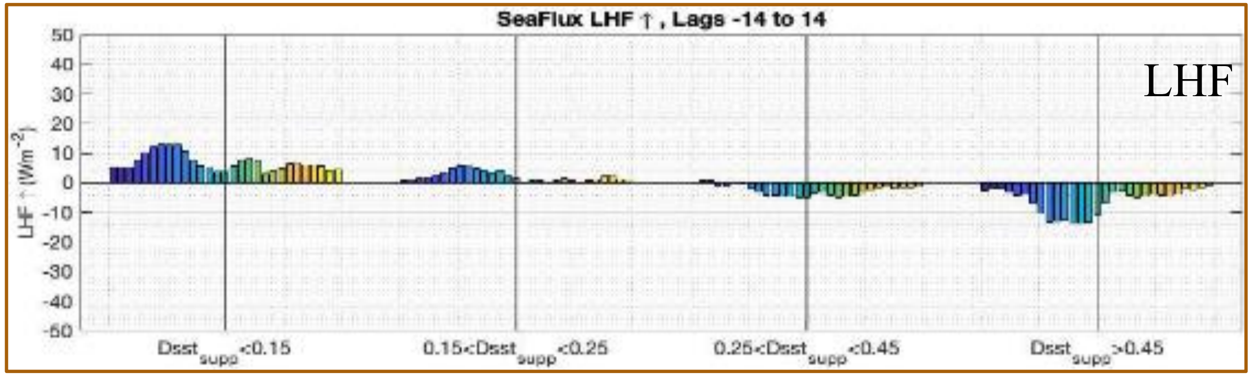
Results: Sea Surface Temperature

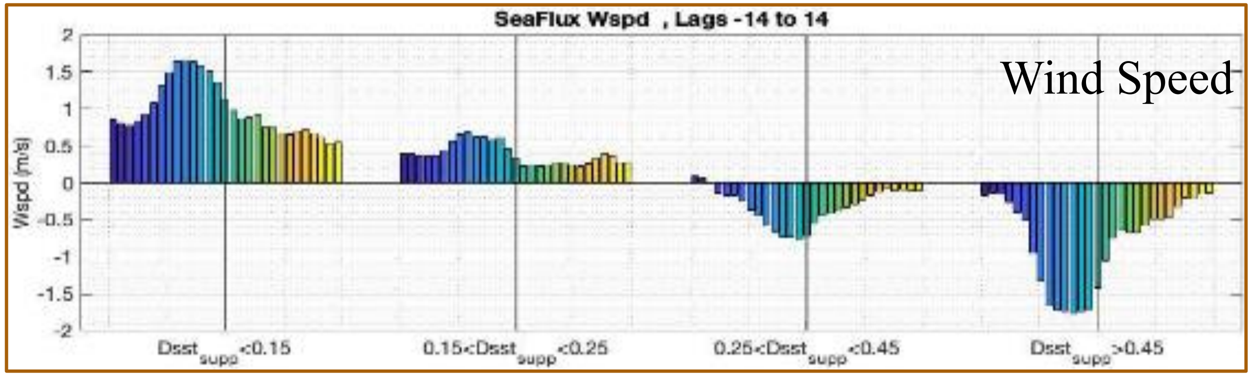


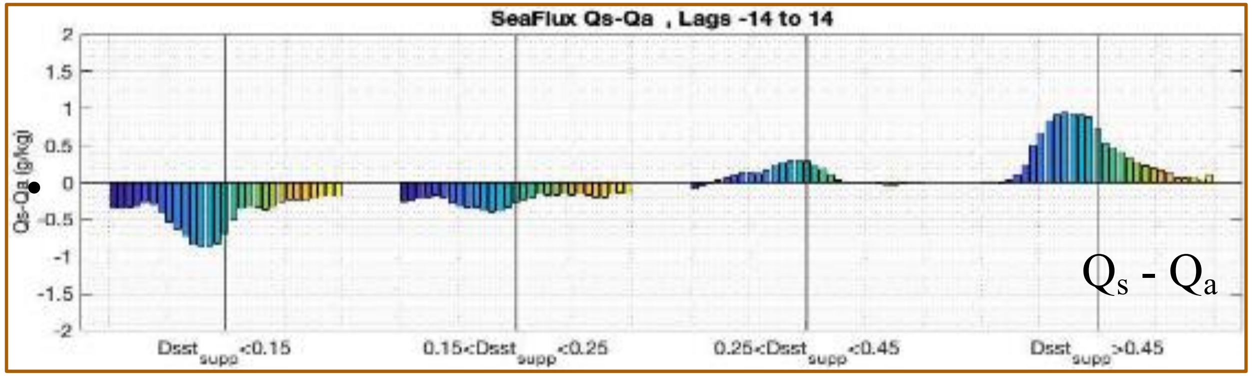


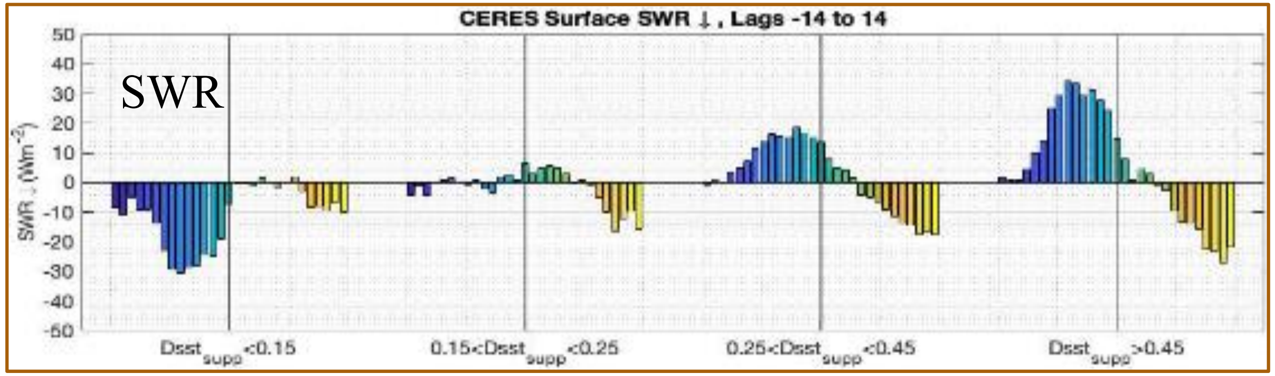
- The regions with the highest dSST not only strong ramp up but maintain higher SST (i.e., strong anomalous warming) over the active period.

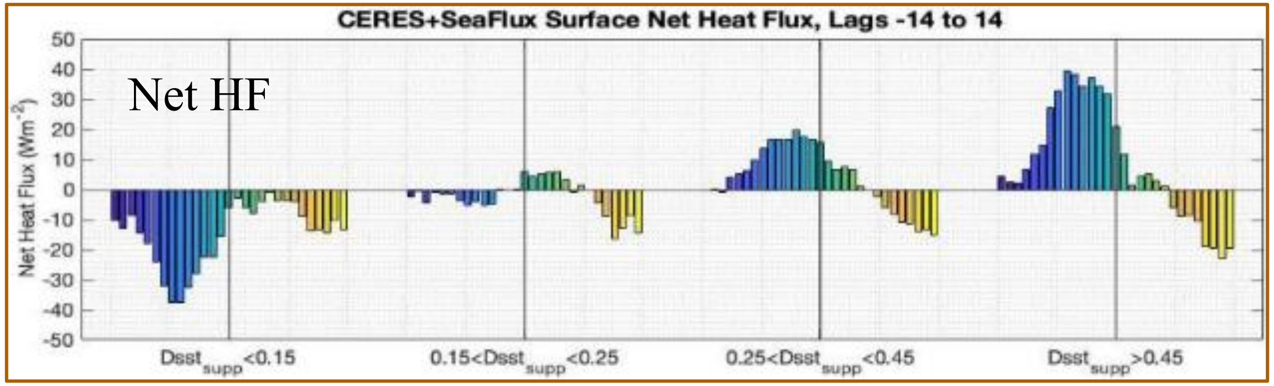
Results: Surface Fluxes





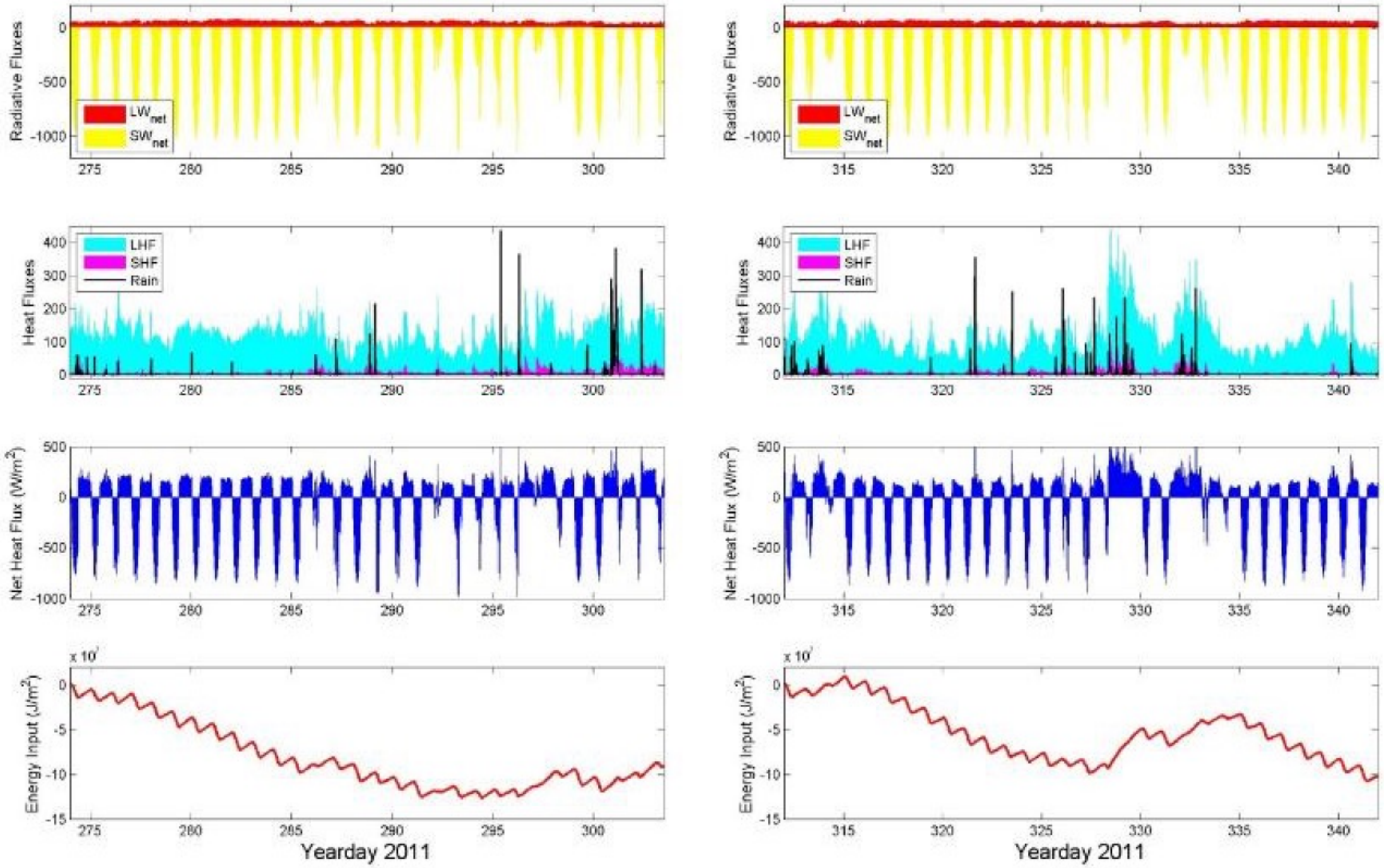


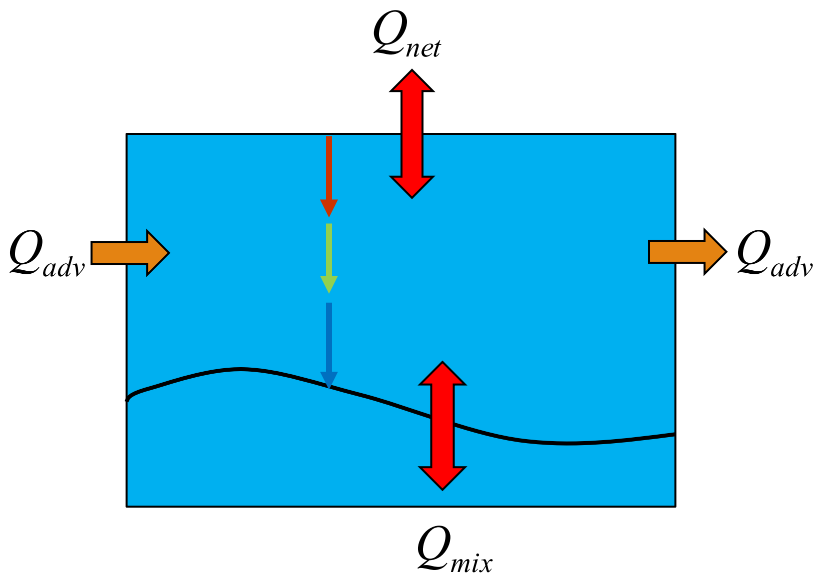




- Surface SWR is really driving things across all the regimes.
- It's the dominant term in the Net Heat Flux
- LHF is weaker than anticipated, but is likely a result of low winds at higher dSST bins, which overwhelms the increase in $Q_s - Q_a$

Heat Budget $Q_{net} = K_{net} + I_{net} + Q_{sens} + Q_{lat} + Q_{rain}$

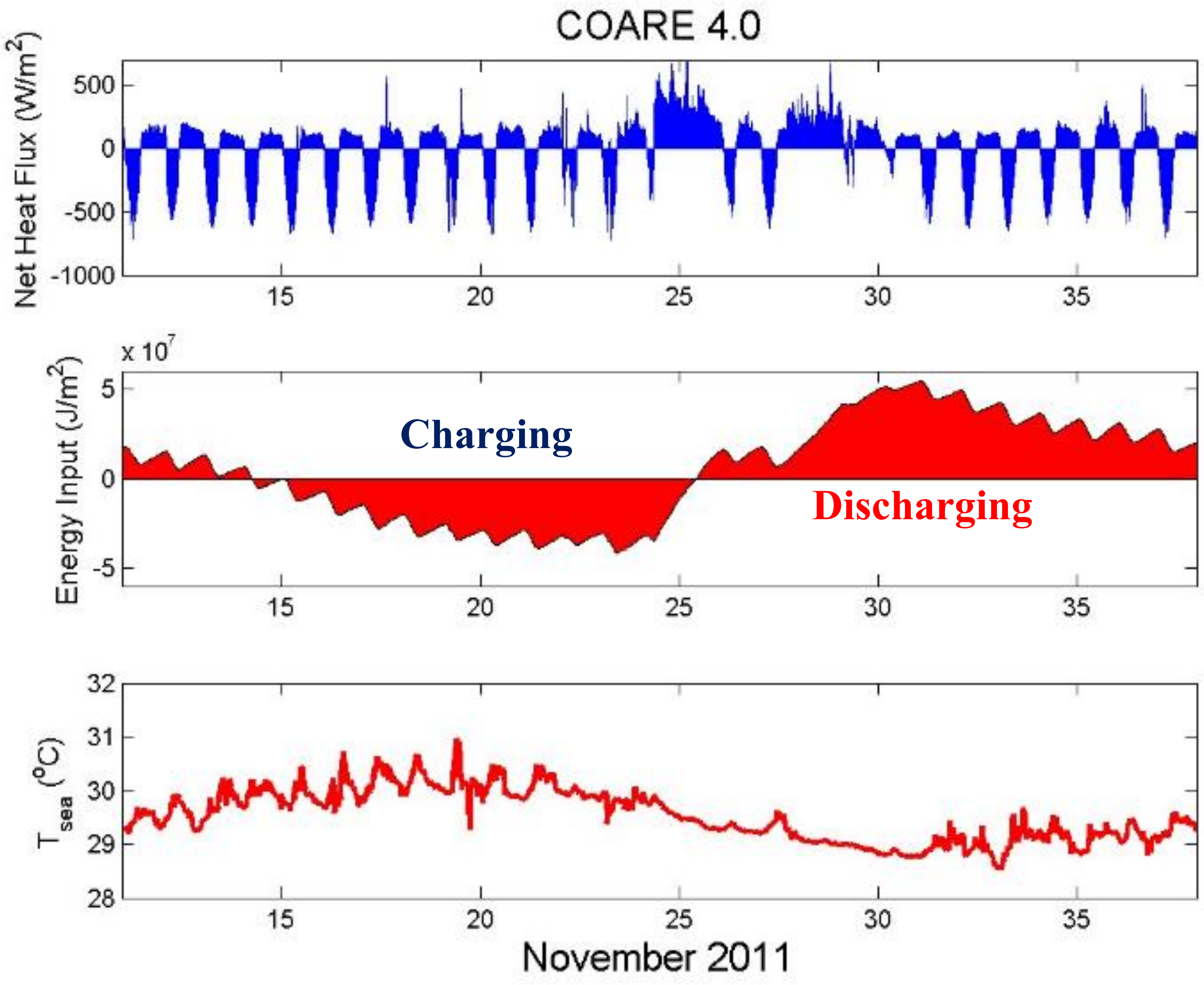




Ocean Mixed Layer

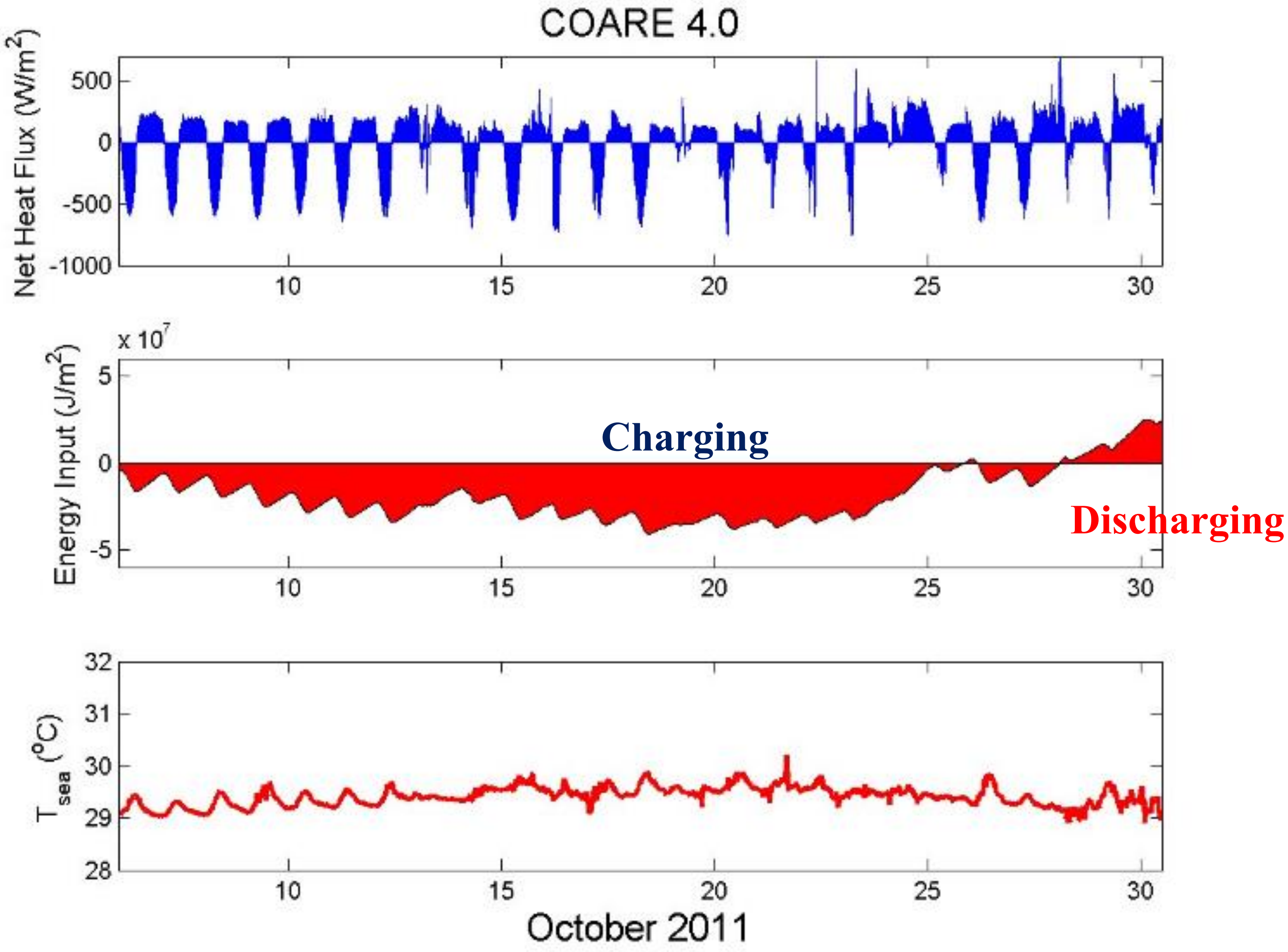
Leg 2 Leg 3

Indian Ocean as MJO Capacitor

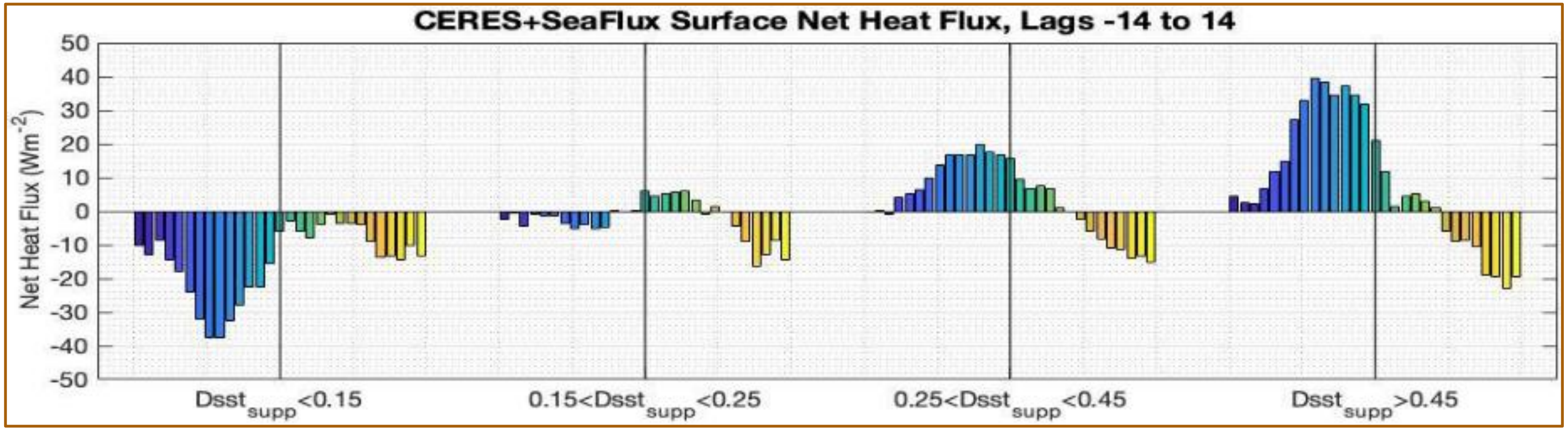


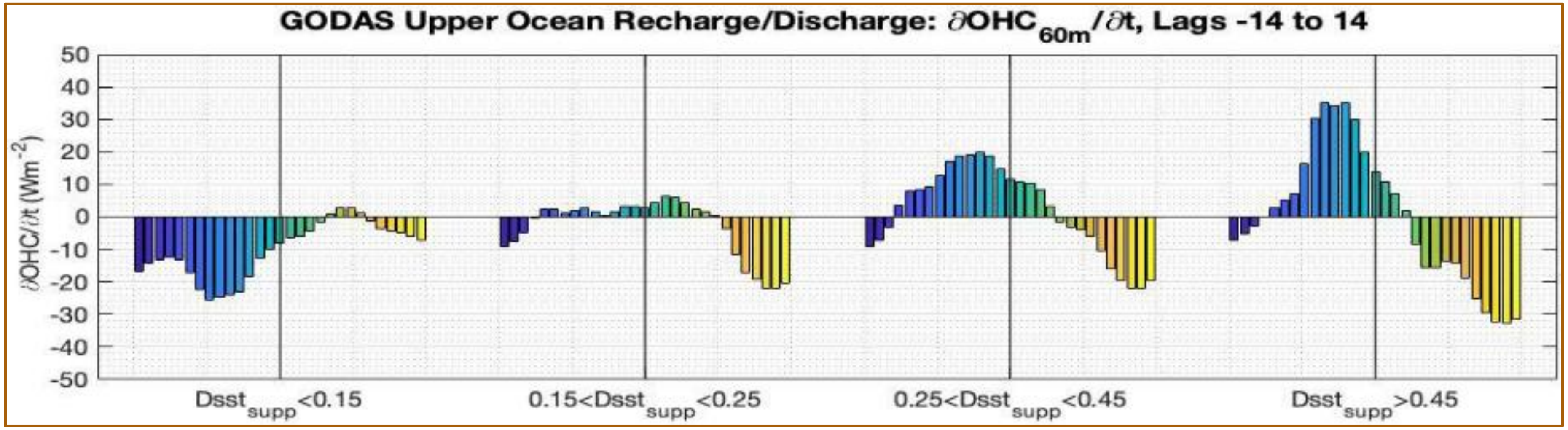
Indian Ocean as MJO Capacitor

Hypothesis: The initialization and strength of MJO convection in the Indian Ocean is (partially) governed by the oceanic storage of energy during the suppressed phase and release of this energy during the active phase.



Results: OHC Change, Net Heat Flux.





An MJO Event

Conceptual

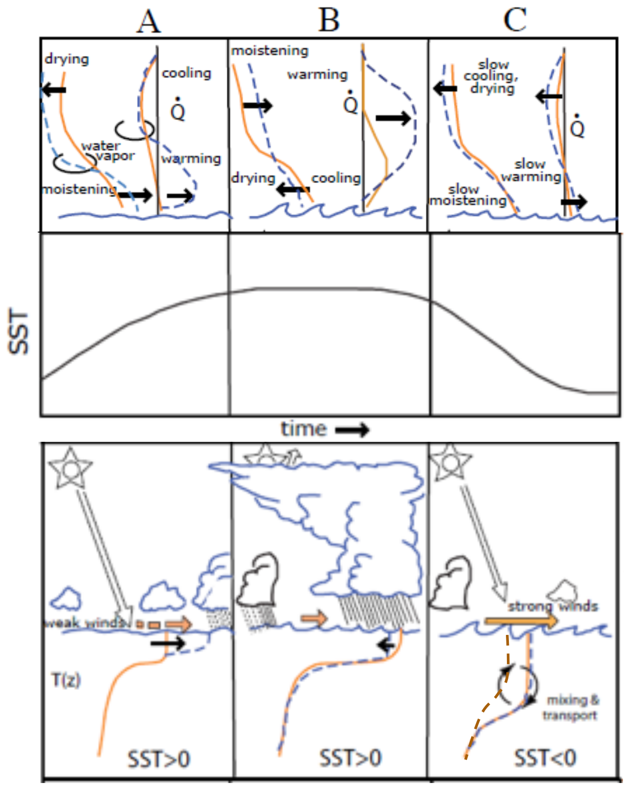
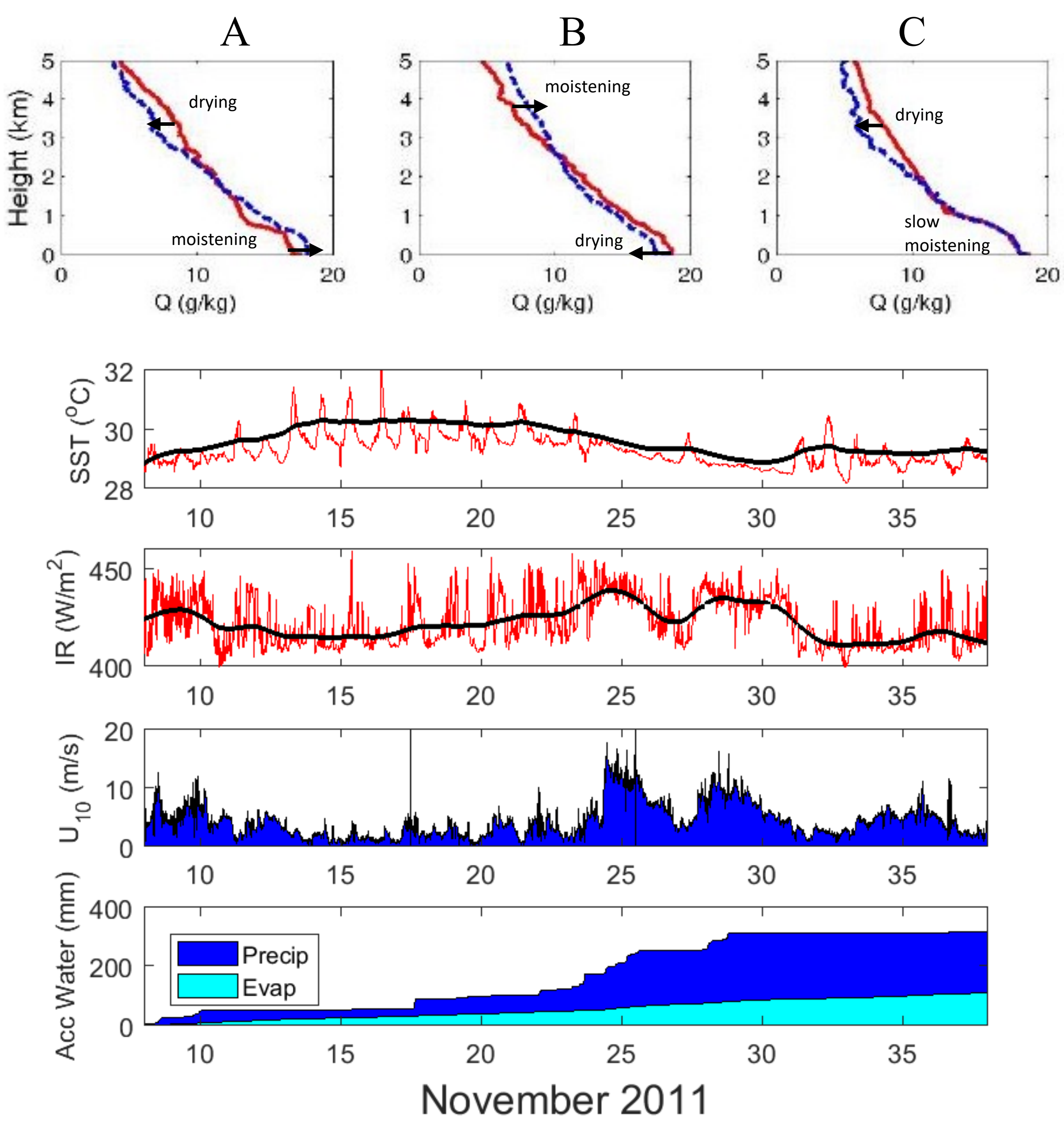


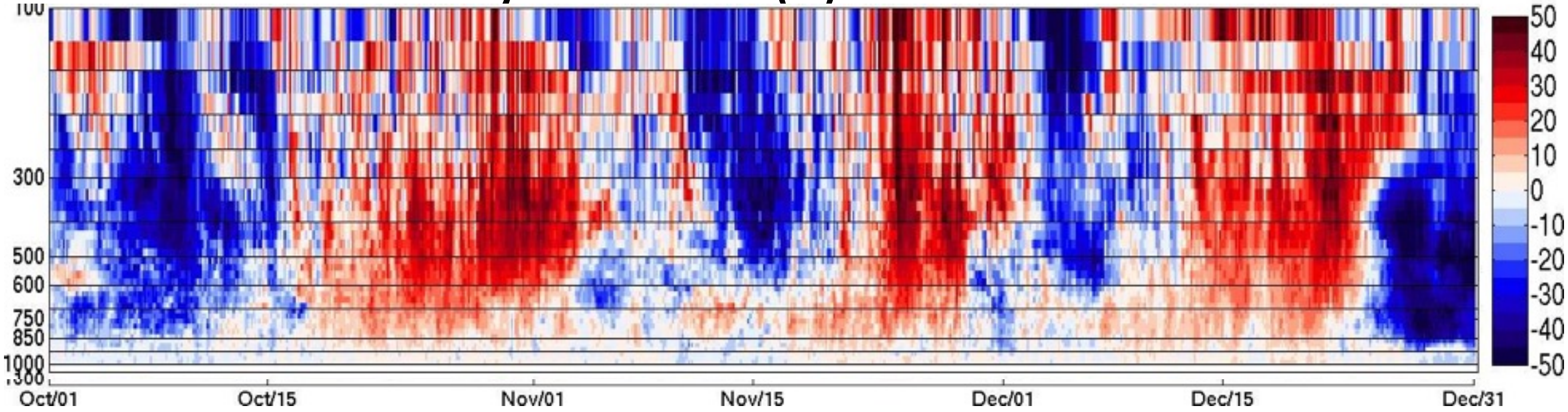
Figure 4 Schematic of a conceptual model for MJO initiation processes at a fixed location over the Indian Ocean. Upper panels illustrate tendency of moisture and diabatic heating profiles; middle panels depict cloud compositions, surface winds, and upper-ocean temperature profiles; lower-panel shows the SST evolution. (After Stephens et al. 2004)

Actual



Motivation: MJO and Air-Sea Coupling

Diurnally-resolved RH (%) from the DYNAMO



- Ruppert Jr. and Johnson (2015), using DYNAMO sounding array data together with ship observations, found a significant diurnal component to the 3-hourly resolved moisture tendencies.
  - *"… diurnal cycle of SST and air-sea fluxes drive a net boost to convective activity and cumulus moistening ... which would not exist without such a diurnal cycle"*

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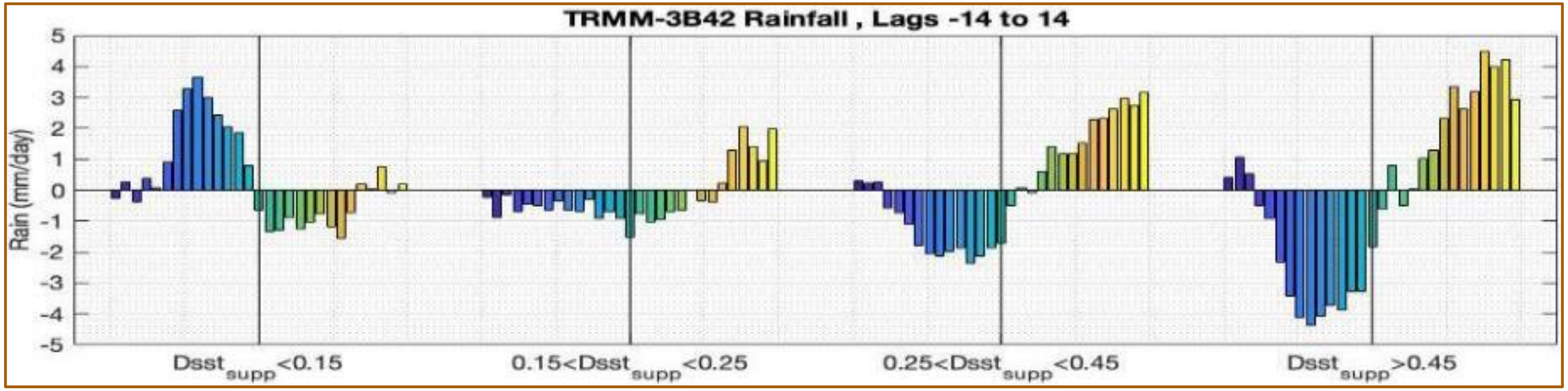
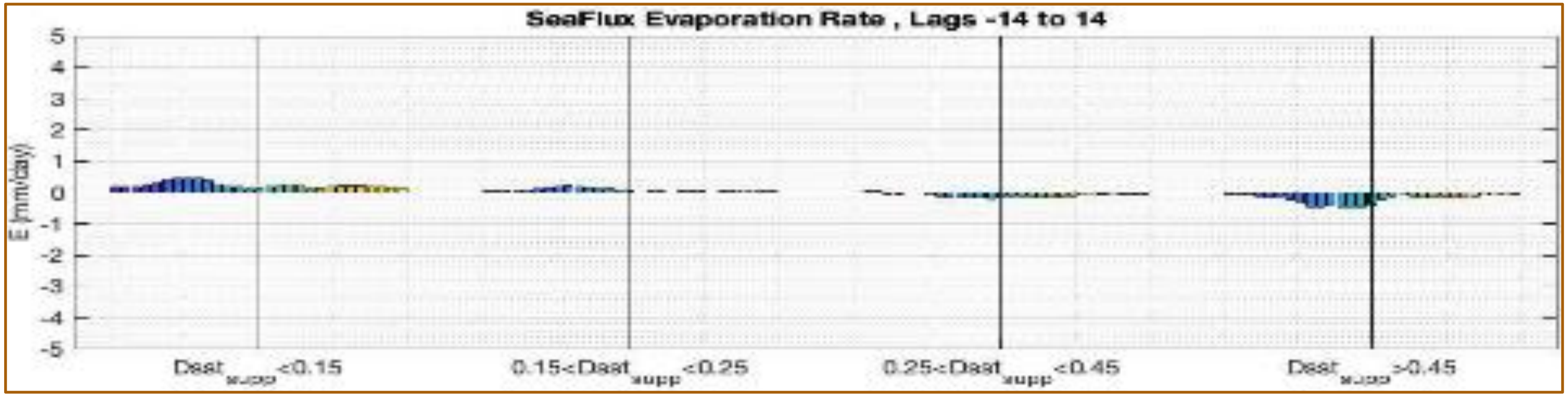
1. Is this preferential moistening observable over a more broad area?

2. If so, can we identify the importance of local surface evaporation vs. dynamical convergence to the observed moistening?

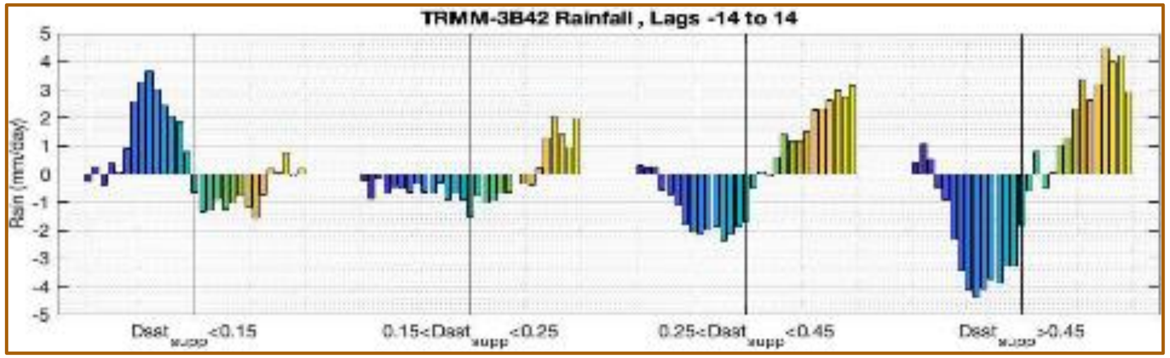
Results: Rainfall and Evaporation

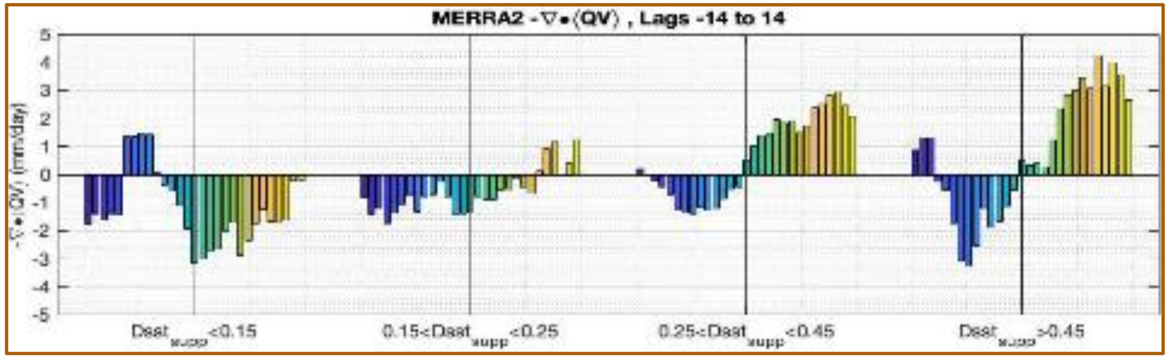


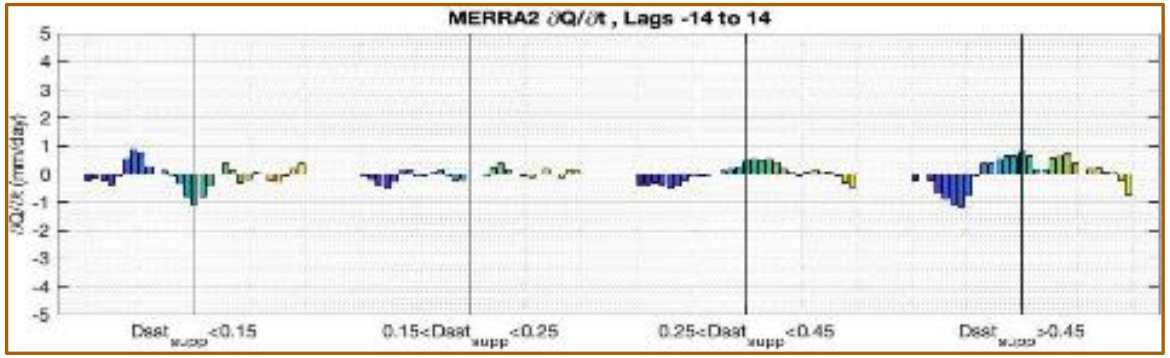


- These composites indicate that the regions with the strongest suppressed phase diurnal warming tend to correspond to the regions with the strongest convection/rainfall activity during the peak phase.
- The composite for evaporation show that it is significantly smaller than precipitation. This is consistent with other studies.

Results: Atmospheric Moisture Budget





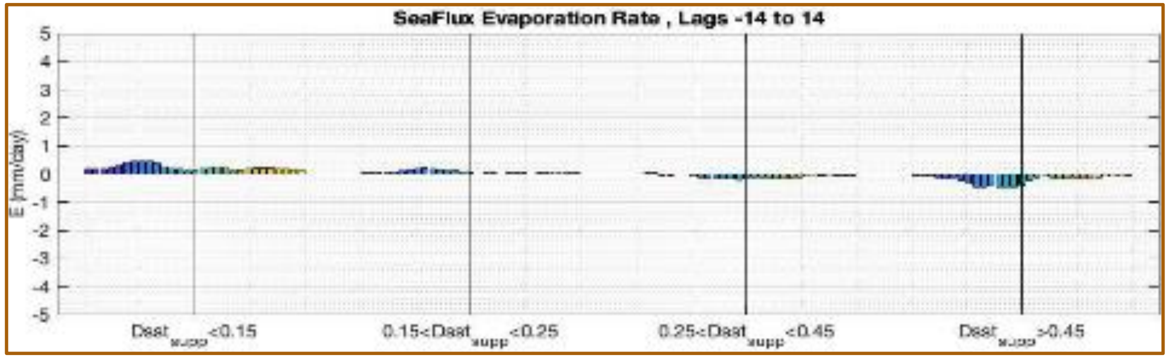


$$\frac{\partial Q}{\partial t} + \frac{\partial (uQ)}{\partial x} + \frac{\partial (vQ)}{\partial y} = E - P$$

Precipitation: Essentially we are seeing a two-way balance between moisture convergence and precipitation. Evaporation makes a small contribution

Moisture Convergence: This is the dominant term driving the moistening.

dQ/dt (Storage): Note the small tendencies; cancellation between large moisture convergence, precipitation, and evaporation terms



Summary: MJO and Diurnal Air-Sea Coupling

- Numerous studies have shown atmosphere-ocean coupling may play an important role in modifying the intensity, duration, and/or propagation of MJO events (DeMott et al. 2015)

- In particular, modeling studies have shown that resolving the diurnal cycle of the upper ocean mixed layer may be a critical component of the coupling

- However, the exact mechanism by which diurnal coupling is rectified onto the MJO time scale is not as well understood
    - *"[…] The suppressed phase ocean feedback to the atmosphere on diurnal time scales seems clear, but the mechanisms that rectify the diurnal moistening onto MJO time scales are not" – DeMott et al. 2015*

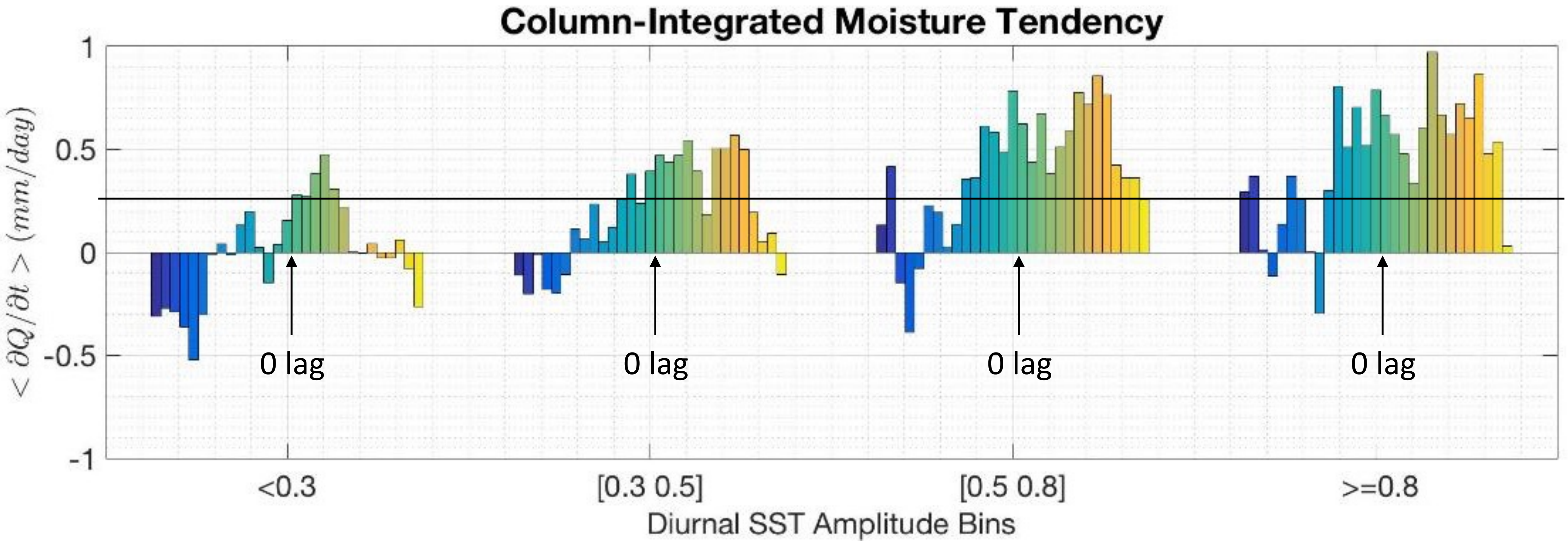
Extra Slides

Summary

1. **Is this preferential moistening observable over a more broad area?**
   - Yes , we see preferential moistening as a function of the diurnal SST amplitude
   - Yes , we see enhanced daytime convection as a function of the diurnal SST amplitude
   - Due to the limited temporal sampling from MODIS, it is not possible to observe the afternoon development

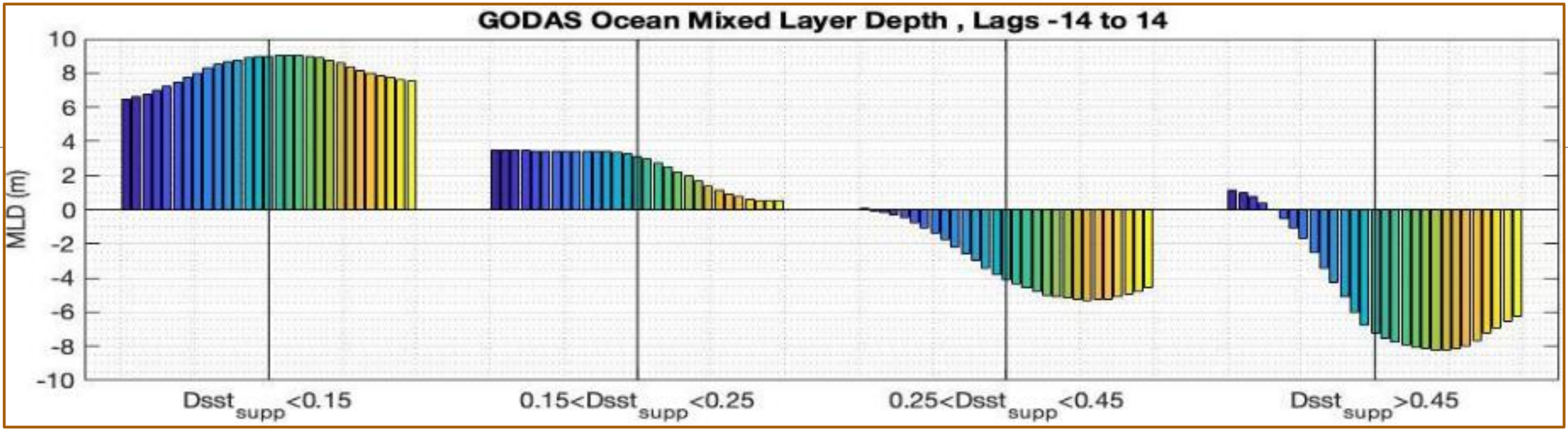
2. **If so, can we identify the importance of local surface evaporation vs. dynamical convergence to the observed moistening?**
   - Maybe, local evaporation remains a steady contributor for different diurnal warming amplitudes due to offsets between U10 & (Qsfc-Qair). Thus it should become relatively more important to the observed total moistening.
   - Caveat 1: Turbulent flux estimates from space can be largely uncertain. The budget as estimated remains out of balance.
   - Caveat 2: Reanalyses (such as MERRA-2) do not include high-frequency SST forcing, so their dynamics are not going to capture response to diurnal SST warming.

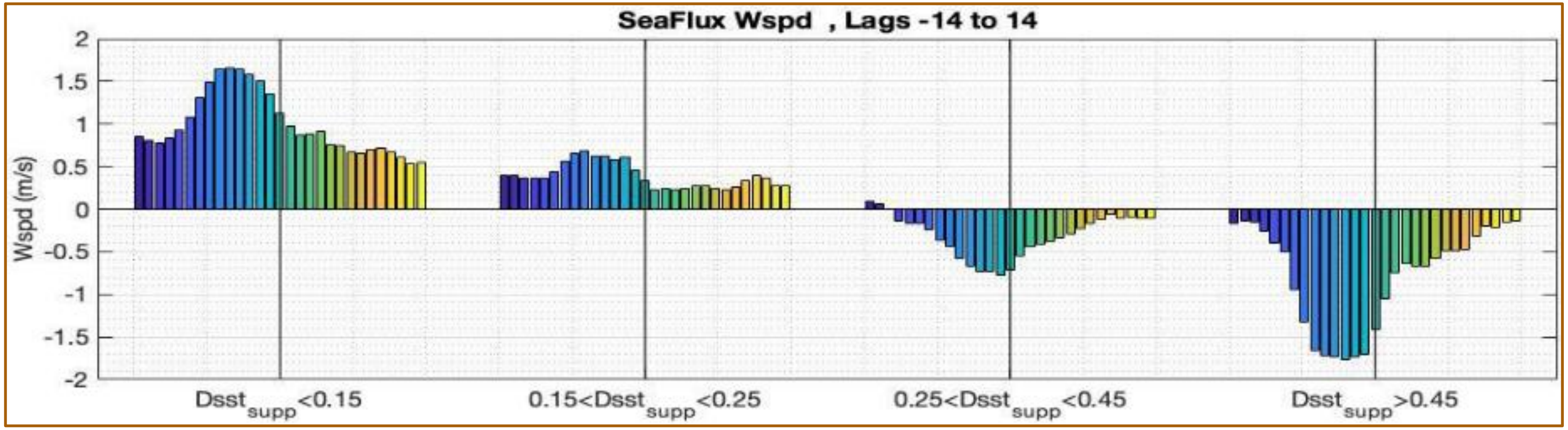
Do we see a signal of preferential moistening?



- Stratified by lag the moisture tendency — from MERRA-2 precipitable water — all pixels by diurnal SST amplitude bins
- There is a generally enhanced atmospheric moistening of ~0.1 mm/day for each category; that moistening begins earlier and is more sustained in the suppressed & transition phase for locations experiencing higher diurnal warming.

Results: Ocean Mixed Layer, Wind Speed





I thought this was interesting that the OML depth mix out faster after the end of the suppressed phase.