Upper Ocean Response of the Maritime Continent to an MJO Event in a Regional Coupled Model

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Objectives

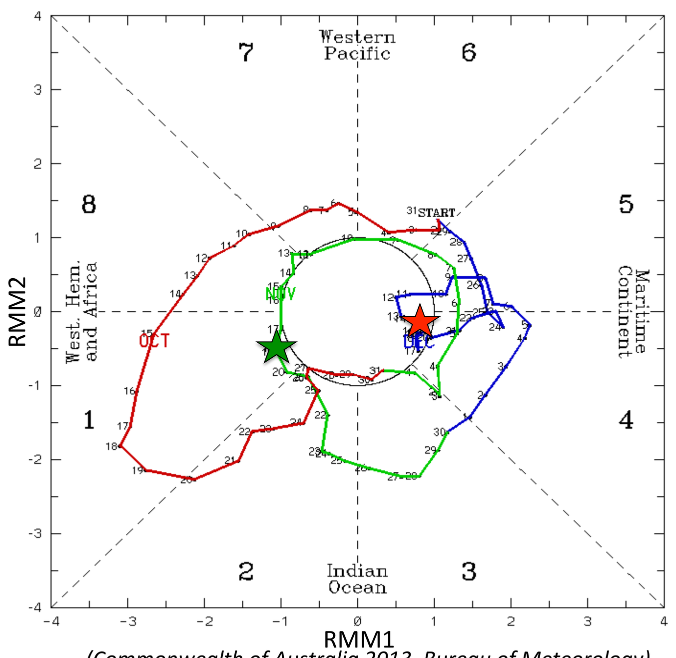
1. Analyze upper-ocean response to MJO2 atmospheric forcing using coupled WRF-ROMS model simulations
2. Determine leading terms of mixed layer heat budget during different phases of MJO
3. Quantify magnitude and timing of diurnal SSTs within the Maritime Continent

Introduction

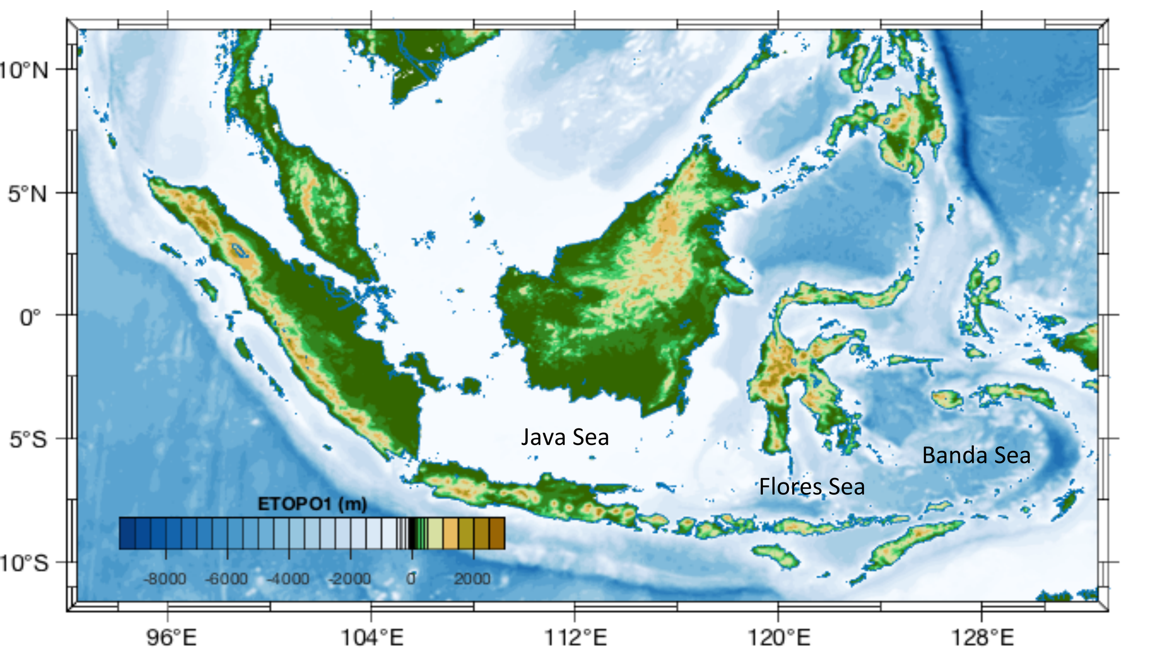
The Madden-Julian Oscillation (MJO) is the dominant source of intraseasonal variability in the tropics and coupled, air-sea interactions are fundamental to its initiation and eastward propagation. The Dynamics of the Madden-Julian Oscillation (DYNAMO) field campaign has allowed for extensive research into the role upper-ocean processes play in sustaining MJO deep convection. Diurnal sea surface temperature (SST) fluctuations have been shown to raise the intraseasonal SSTs in the Indian Ocean and increase surface heat fluxes, which are important for pre-conditioning the atmosphere for MJO convection.

The Maritime Continent (MC) acts as a natural barrier to MJO propagation due to reduced surface fluxes by islands, flow interactions with steep topography, and competition from diurnally-driven convection. However, there has been relatively little focus on intraseasonal ocean variability in the MC and how the ocean may modulate convection.

Therefore, we investigate the diurnal and intraseasonal variability of the upper ocean in the MC during the second MJO (MJO2) of DYNAMO. Our high-resolution SCOAR (WRF-ROMS) coupled model simulations highlight regional differences between the Java, Flores and Banda Seas where in situ data are sparse.



(Commonwealth of Australia 2013. Bureau of Meteorology)



Bathymetry and Topography of the Maritime Continent region, with the Java Sea, Flores Sea and Banda Sea locations

SCOAR Model

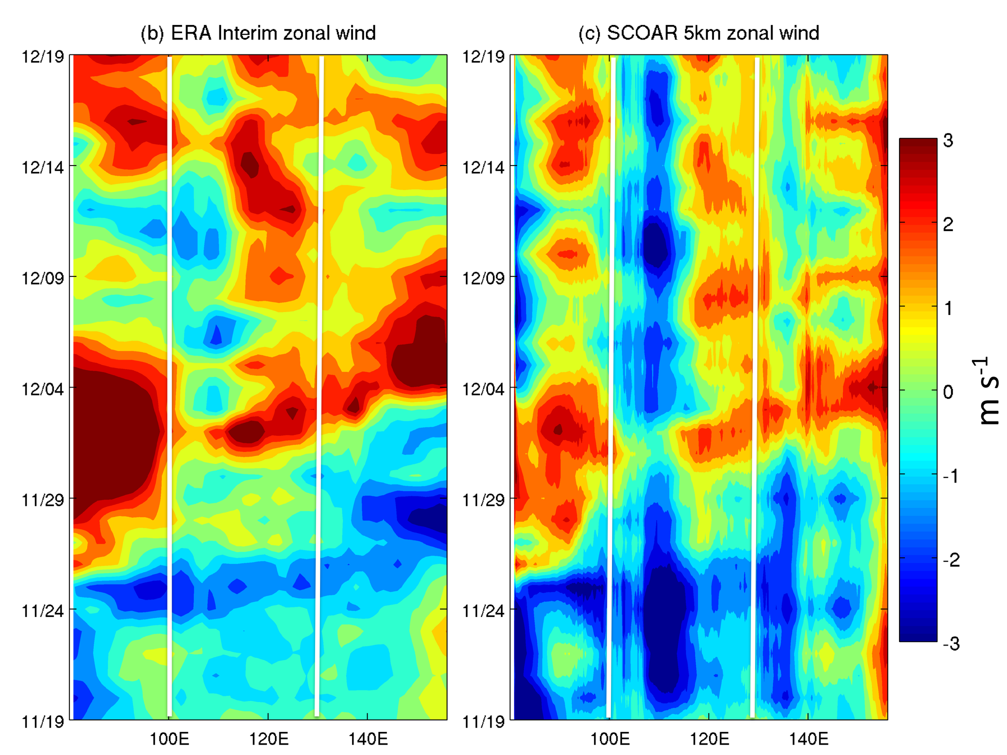
The Scripps Coupled Ocean Atmosphere Regional (SCOAR) model is a portable, regional model used to study process-modeling of coupled air-sea interactions (Seo et al. 2007, 2014). For this study, the SCOAR model implements WRF-ROMS coupling to study the MJO2 event during DYNAMO. The model integration is for one month (Nov. 19-Dec. 19, 2011) with a one-hour coupling interval. Both WRF and ROMS share the same 5 km grid which encloses the MC region. Despite being near the "gray zone" for convection resolving resolution, the WRF cumulus parameterization is turned off. A Hovmöller diagram of zonal surface wind anomalies show that the model accurately depicts MJO propagation.

Selected WRF model parameterizations

Microphysics	WRF Single-Moment 6-class
Longwave Radiation	RRTMG scheme
Shortwave Radiation	RRTMG shortwave
Surface Layer	MM5 Similarity
Land Surface	Noah Land Surface Model
Planet. Bound. Layer	Yonsei University scheme
Cumulus	Off

WRF/ ROMS – Initial & Boundary Conditions

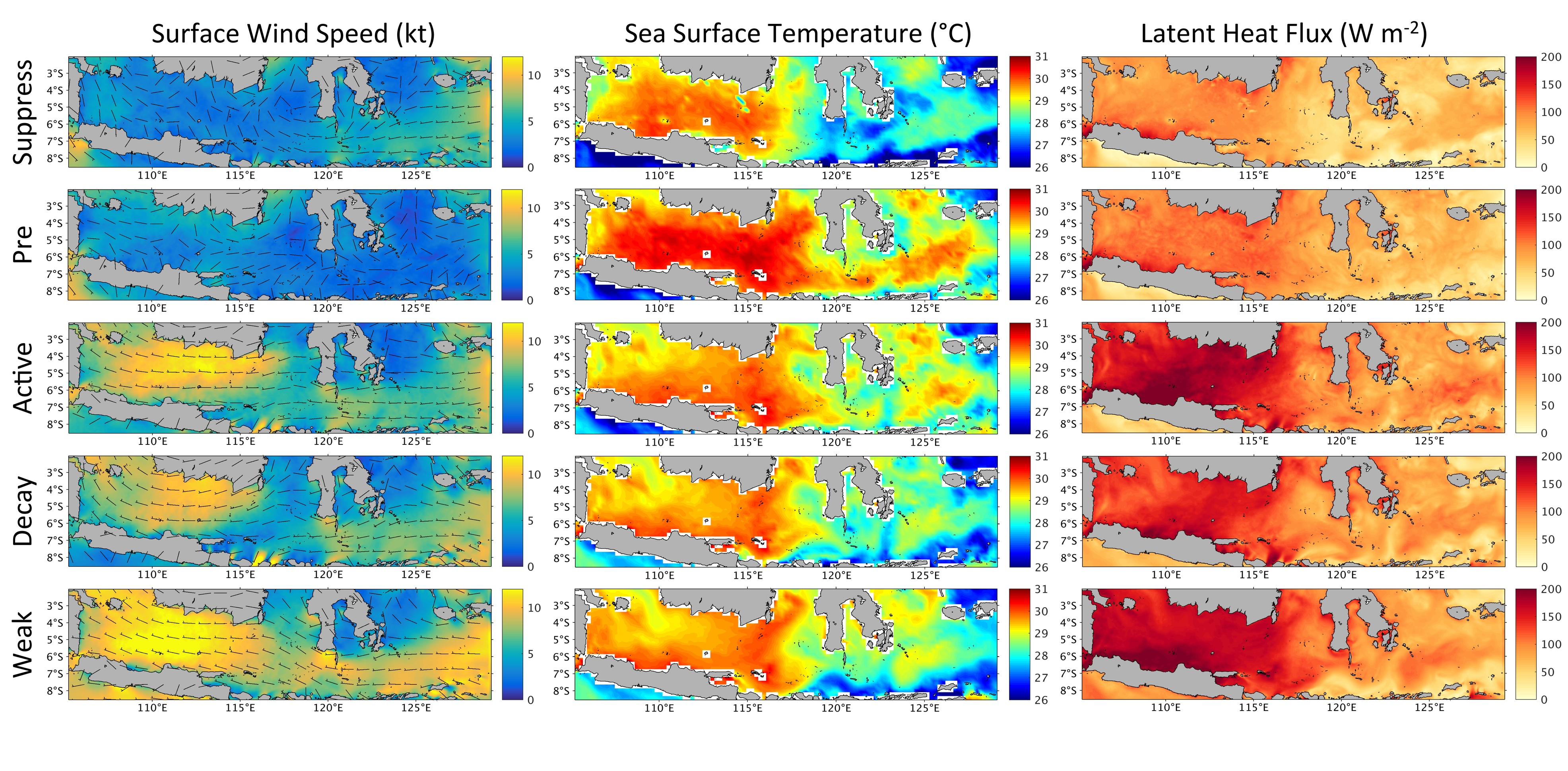
6-hourly ERA-Interim (Dee et al. 2011)
Daily Hybrid Coordinate Ocean Model (HYCOM) ocean analysis (Cummings 2005)



Hovmöller diagrams of zonal surface wind (averaged from 5°S to 5°N) from ERA-Interim (left) and SCOAR model (right). Vertical, white lines bound the entrance and exit regions of the MC

MJO Phases over the Java Sea

The strong MJO2 event in the Indian Ocean produced a relatively quiescent period over the MC from November 19-30 (suppressed and pre-MJO phases), characterized by light wind speeds (< 3 m s^{-1}), suppressed convection and strong insolation. During this time, SSTs in the Maritime Continent warmed by several degrees, with the highest SSTs (> 30°C) located in the Java Sea. The active phase of the MJO was short-lived over the Java Sea, but produced strong westerly surface winds (> 5 m s^{-1}) and enhanced latent heat flux (LHF, > 200 W m^{-2}). The strength of the MJO2 collapsed over the MC region from December 5-10 (decay phase) and remained weak for the remainder of the simulation. Despite the weak MJO amplitude, westerly surface winds remain strong during this period, possibly due to a synoptic-scale cold surge through the South China Sea. MJO activity would later strengthen and exit the MC region towards the end of December.



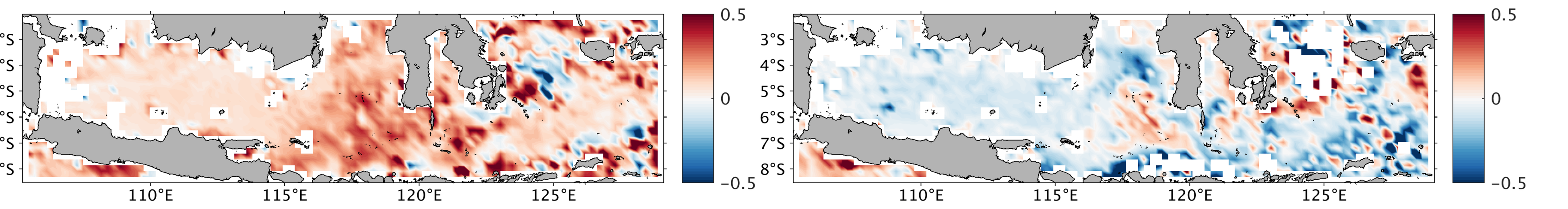
Mixed Layer Heat Budget

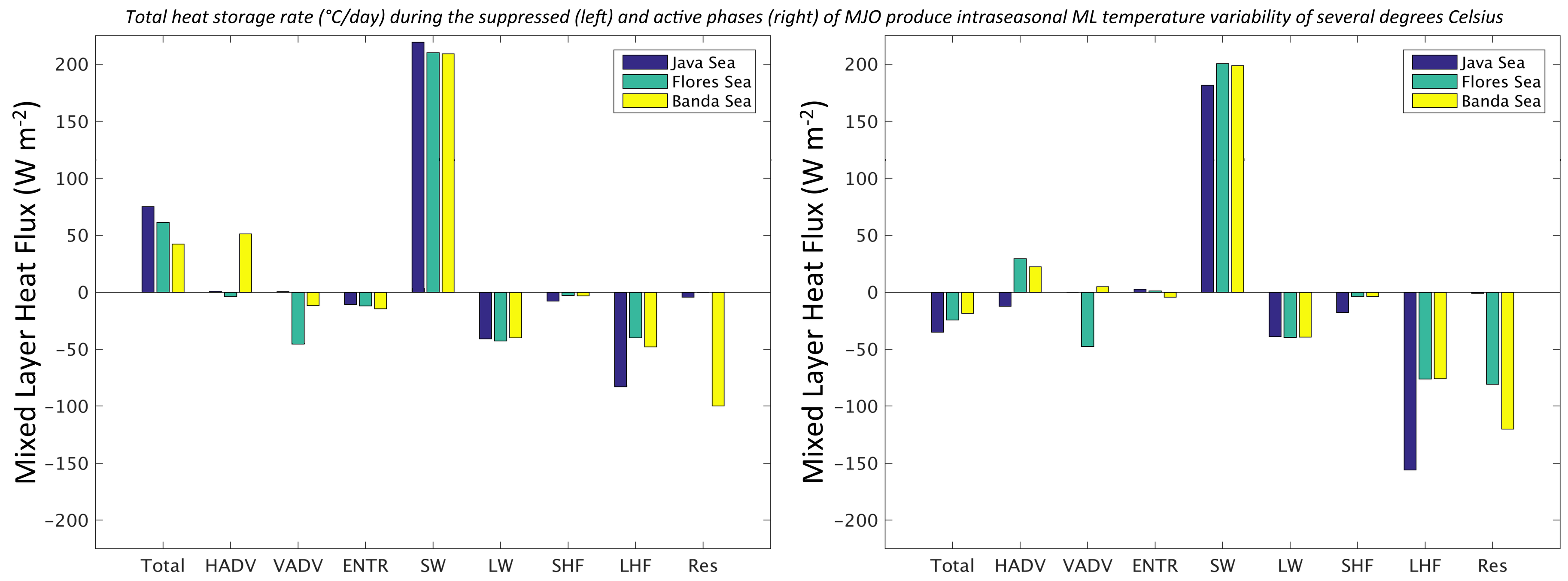
We implement a mixed layer (ML) heat budget analysis (Stevenson & Niiler, 1983; Prend et al. 2018 and many others) for the marginal seas of the Maritime Continent using WRF-ROMS model output. The goal is to determine the leading terms (and relative magnitudes) of the ML heat budget during different phases of MJO. The total heat storage rate is balanced by the effective surface heat flux (1), horizontal (2) and vertical (3) advection, vertical entrainment (4) and a residual (5) that accounts for diffusion, numerical errors and other physical processes.

$$\frac{\partial T}{\partial t} = \underbrace{\frac{Q_{eff}}{\rho_w C_p h}}_{1} - \left[\underbrace{\left(u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} \right)}_{2} + \underbrace{\left(w_h + \frac{\partial h}{\partial t} \right)}_{3\quad 4} \frac{(T - T_h)}{h} \right] + \underbrace{RES}_{5}$$

The effective surface heat flux (1) accounts for shortwave radiation that penetrates below the mixed layer. The penetrative heat flux (Q_{pen}) is estimated using the double exponential model by Paulson and Simpson (1977), where the constants (R=0.58, ζ_1=0.35 and ζ_2=23) are based on Type I water from Jerlov (1968).

$$Q_{eff} = Q_{net} - Q_{pen} \quad \Rightarrow \quad Q_{net} = Q_{SW} + Q_{LW} + Q_{SHF} + Q_{LHF} \quad — \quad Q_{pen} = Q_{SW}\left[R \cdot e^{-h/\zeta_1} + (1-R) \cdot e^{-h/\zeta_2} \right]$$

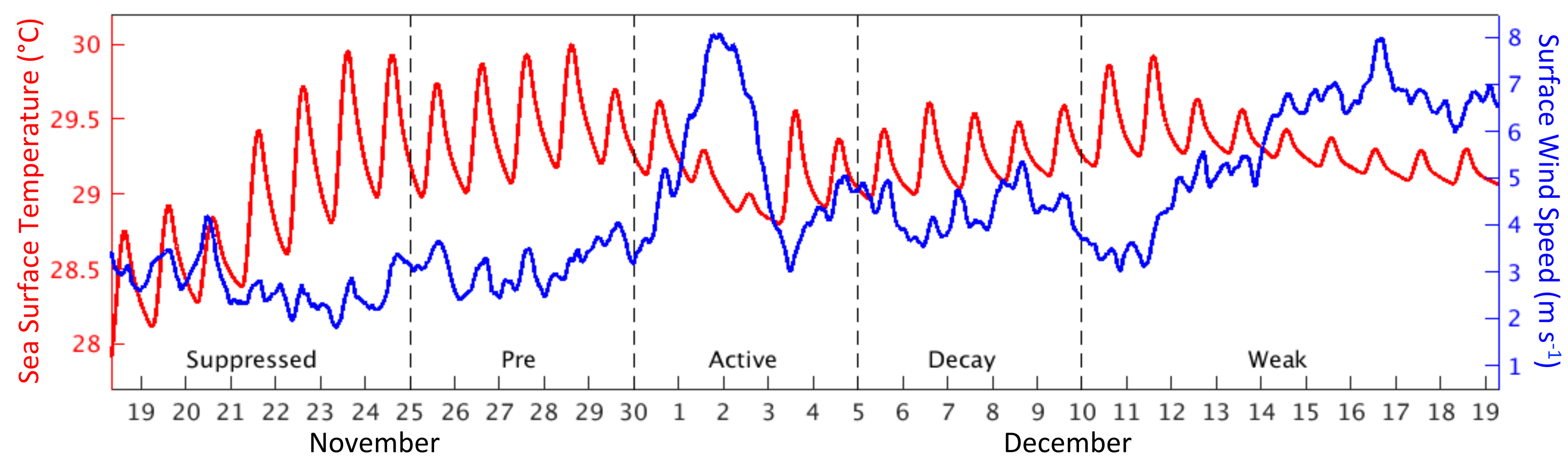

Total heat storage rate (°C/day) during the suppressed (left) and active phases (right) of MJO produce intraseasonal ML temperature variability of several degrees Celsius



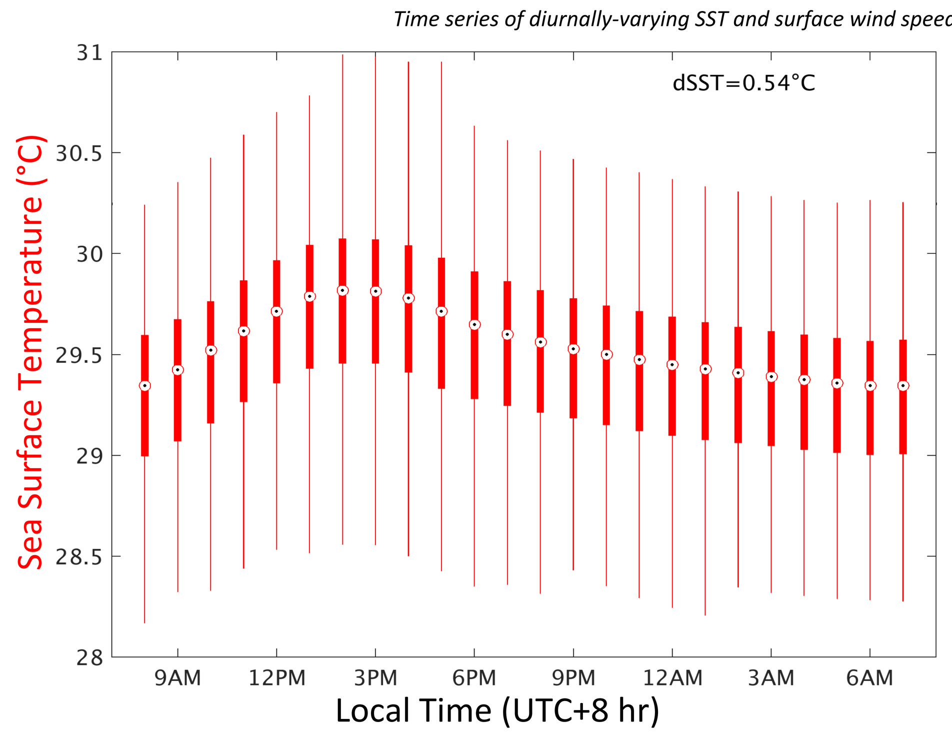
Total heat storage and individual ML heat budget terms during the suppressed (left) and active phases (right) of MJO, area-averaged over the Java (blue), Flores (green) and Banda Seas (yellow)

- ML heat budget is largely balanced by 1-dimensional term (Q_{eff}), where SW (+), LHF (-) and LW (-) are the leading terms. Net ML warming (cooling) occurs during the MJO suppressed (active) phases.
- During the active MJO in the Java Sea, SW is reduced by 17.3% and LHF increases by 88.0%
- Residual term is large in the Flores and Banda Seas during the active MJO phase

Intraseasonal Modulation of Diurnal SST



Time series of diurnally-varying SST and surface wind speed in the Java Sea throughout the 1-month long MJO simulation



- Area-averaged SST within the Java Sea increases by ~1°C during suppressed and Pre-MJO phases (light winds + enhanced SW)
- Diurnal SST fluctuations reach 1°C
- Periods with largest MJO wind forcing result in SST cooling and a reduction in diurnal SST

- Time-average diurnal SST in Java Sea is 0.54°C
- Peak in diurnal SST occurs at 2-3 PM local time, consistent with observations
- Diurnal SST raises average SST and increases surface heat fluxes

Conclusions

The intraseasonal variability of the marginal seas within the MC region is largely dictated by the progression of large-scale convective phases associated with the MJO2 event. During the suppressed and pre-MJO phases, light winds and enhanced insolation allows the ML to warm dramatically. Diurnal SSTs are largest during this 11-day period, with a magnitude of ~1°C. Diurnal fluctuations of SST further increase the intraseasonal SST anomaly, which pre-conditions the atmosphere for convection. The active phase is characterized by enhanced convection and strong westerly winds, which reduces the insolation and increases LHF. In the Java Sea, LHF nearly doubles during the active phase. The ML heat storage rate reverses sign, resulting in net cooling. The ML heat budget within the MC is largely balanced by the 1-dimensional terms, with very little contribution from advection. Overall, the Java, Flores and Banda Seas show substantial intraseasonal SST variability related to MJO, which likely influences regional convection within the MC.

Future Work

- Develop a WRF-ROMS coupled modeling study to examine the sensitivity of MJO convection to diurnal SST (Seo et al. 2014) within the MC. **Observations are needed for model validation!**
- Assess the impact of tidal mixing on SST variability within the Banda Sea and its influence on convection
- Determine sources of MCS formation in the Java Sea under different background wind conditions

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