Modeling Ocean Diurnal Cycle and its Scale Interaction to Longer Scale Climate Variabilities

Authors: Maheswar Pradhan[1], Suryachandra A. Rao[1], Amitabh Bhattacharya[2]

Air-sea interaction takes place by exchanging momentum and heat fluxes across ocean and atmosphere. Also, the interfacial ocean temperature (SST) is a crucial boundary condition that is exchanged between the ocean and the atmosphere. Although many efforts have been made to achieve accuracy in fluxes in observation and reanalysis products, less attention has been paid to achieving similar accuracy in coupled model simulations. The present study attempts to improve the representation of thermodynamic air-sea interaction in CFSv2, primarily used for India's operational forecasts at different temporal/spatial scales. In this direction, the diurnal warm layer and cool skin temperature correction scheme are implemented along with the surface flux parameterization scheme following Coupled Ocean-Atmosphere Response Experiment (COARE) v 3.0.

Rationale

❖ **To improve air-sea interaction in coupled model aiming**

- ☞ To limit the uncertainties in atmospheric boundary condition i.e., ocean skin temperature
- ☞ To limit the uncertainties in ocean boundary conditions i.e., turbulent momentum and heat fluxes

❖ **Addressing some of the long-standing coupled model problems such as**

- ☞ Improper diurnal cycle in ocean-atmosphere
- ☞ Large biases in surface fluxes and precipitation.
- ☞ In-adequate representation of ENSO, IOD characteristics and their relationship with monsoon.

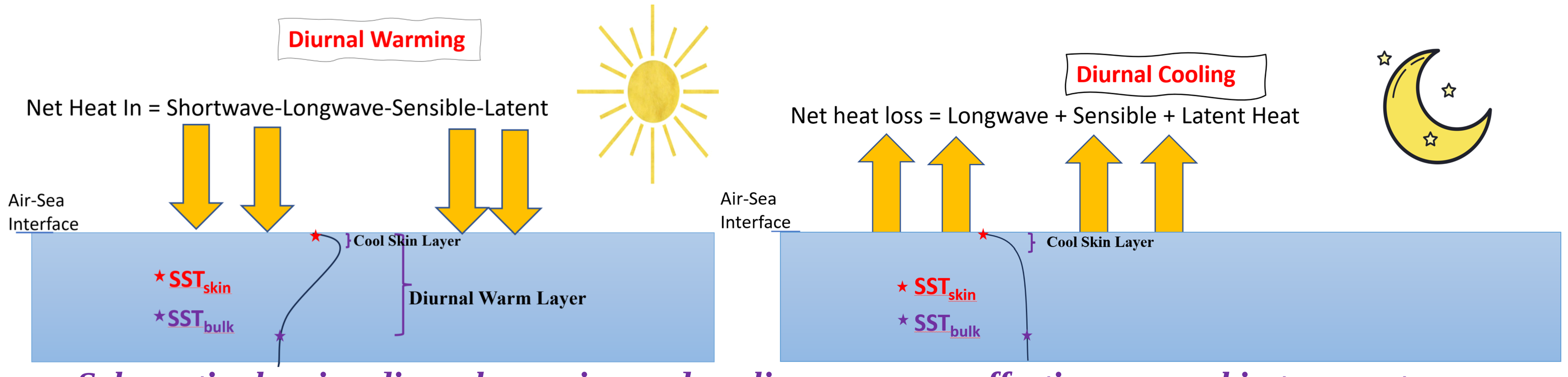
Ocean Skin Temperature Variability

❖ **Diurnal Warming**

- ☞ During the daytime, the ocean surface absorbs a large amount of solar radiation. In the absence of buoyancy or shear-driven mixing of the layer, the temperature can rise by as much as 2K (Fairall et al., 1996).
- ☞ The rise in temperature can lead to a stably stratified surface layer. A significant amount of energy is required to break this stability and create turbulent mixing, which can only come from strong winds.
- ☞ Therefore, in light wind conditions, the depth of the warm layer is smaller, and the increase in temperature within the warm layer is greater.
- ☞ Under strong wind conditions temperature increase in warm layer is small, as turbulent mixing tends to distribute the temperature over a larger depth.

❖ **Diurnal Cooling**

- ☞ The surface of the ocean experiences cooling due to the combined effect of sensible heat, latent heat, and outgoing long-wave radiation. The cooling is confined to the upper few millimetres of the ocean.
- ☞ The cool skin is almost always present and is of the order of 0.1-0.5 K. The cool skin model is based on the study by Saunders (1967).



Schematic showing diurnal warming and cooling processes affecting ocean skin temperature

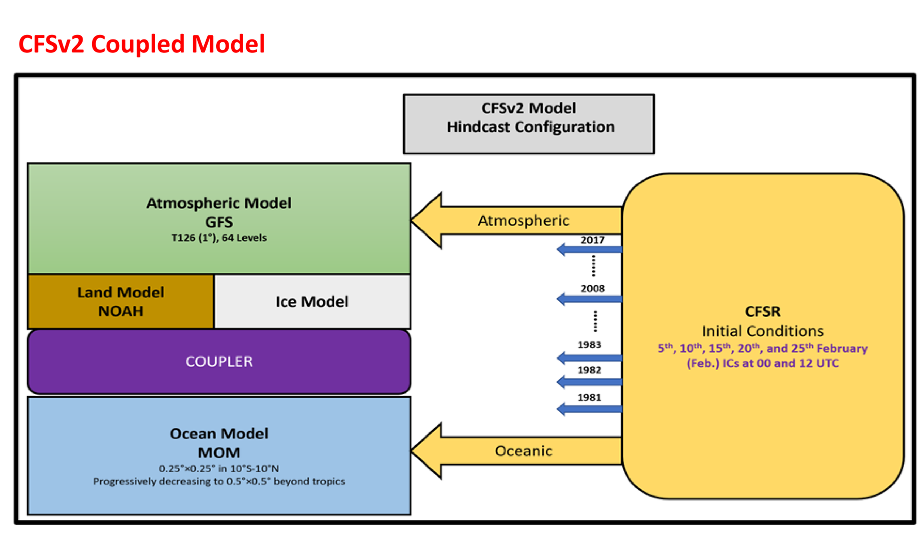
Design of Experiments

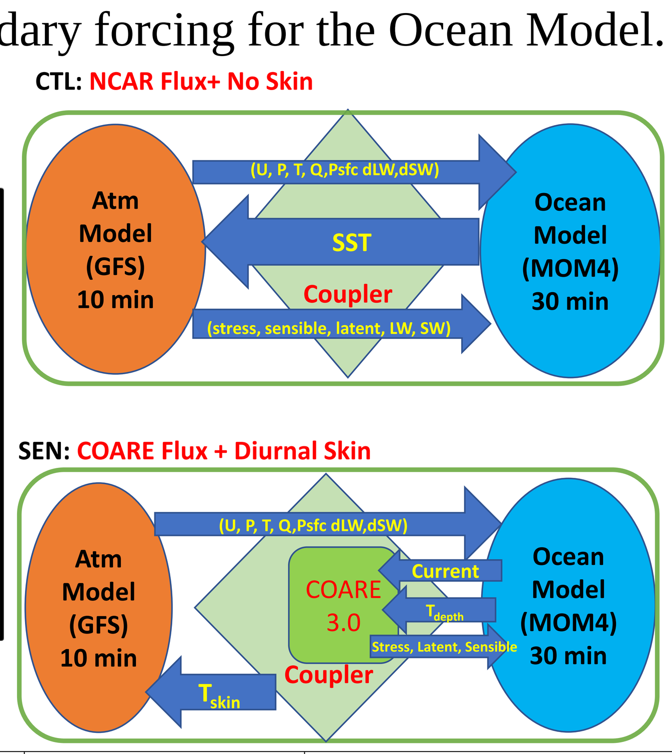
❖ **Cool skin and Warm layer Corrections**

- ☞ One of the major components of COARE algorithm is implemented in CFS coupler to compute the diurnal cool skin and warm layer temperature corrections in bulk ocean temperature.
- ☞ The corrected ocean temperature is then passed to atmospheric model as the boundary forcing.

❖ **Fluxes from COARE**

- ☞ COARE computed fluxes are used as a boundary forcing for the Ocean Model.





Name of the Experiment	Bulk Flux Scheme	Warm Layer Correction	Cool Skin Correction	Stability Classes	Gustiness	Roughness Length
CTL	NCAR (Large and Yeager, 2008)	No	No	1. Stable 2. Unstable (Dyer, 1974)	No	1. Momentum: Wind Dependent 2. Moisture: Constant (9.5×10^{-5}m) for all stability regime 3. Heat: Different constants for stable (2.2×10^{-9}m) and unstable (4.9×10^{-5}m) regime
SEN	COARE 3.0 (Fairall et al., 2003)	Yes	Yes	1. Stable (Beljaars and Holtslag, 1991) 2. Unstable (Dyer, 1974) 3. Very Unstable (Fairall et al, 1996)	Proportional to boundary layer convective velocity scale	1. Momentum: Charnock's expression plus smooth flow limit (Smith, 1988) 2. Moisture and Heat: (Fairall et al., 2003)

Schematic representation of CFSv2 coupled model, and the changes made in CFSv2 coupled configuration for the CTL and SEN simulations

Impact on Diurnal Variability

❖ **Diurnal SST**

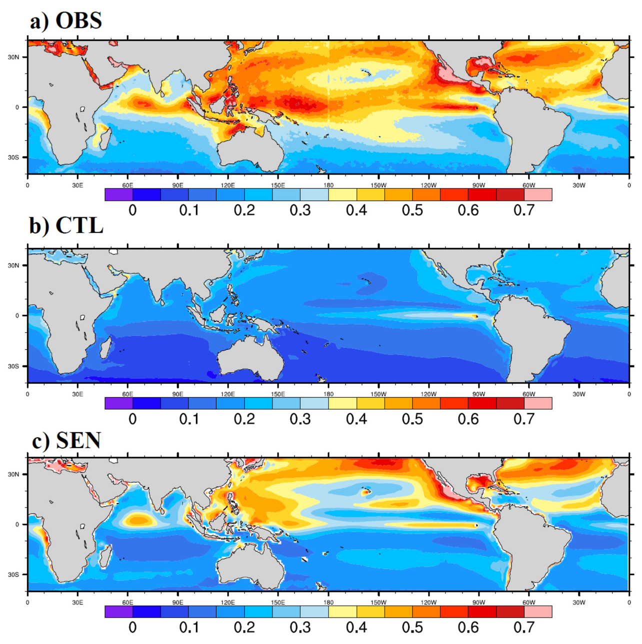
☞ COARE3.0 algorithm helped in improving the diurnal warming/cooling of the surface ocean, thereby increasing the diurnal range of ocean temperature.

❖ **Diurnal MLD**

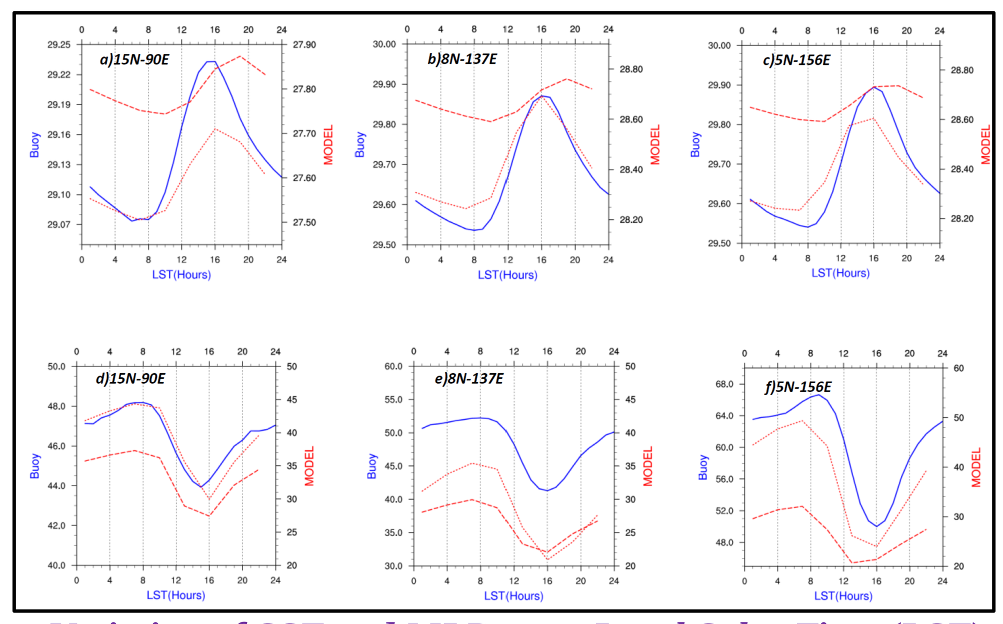
☞ Due to the alteration in surface heat budget in presence of COARE, the timing and amplitude of intra-daily MLD variability is improved similar to that in SST.

❖ **Diurnal Precipitation**

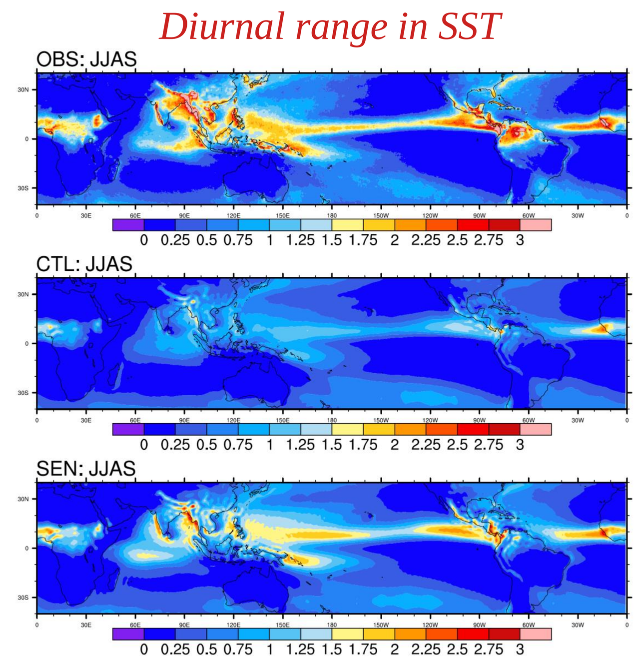
☞ Enhancement in diurnal SST warming helps in triggering more shallow clouds which results enhanced diurnal range of precipitation.



Diurnal range in SST

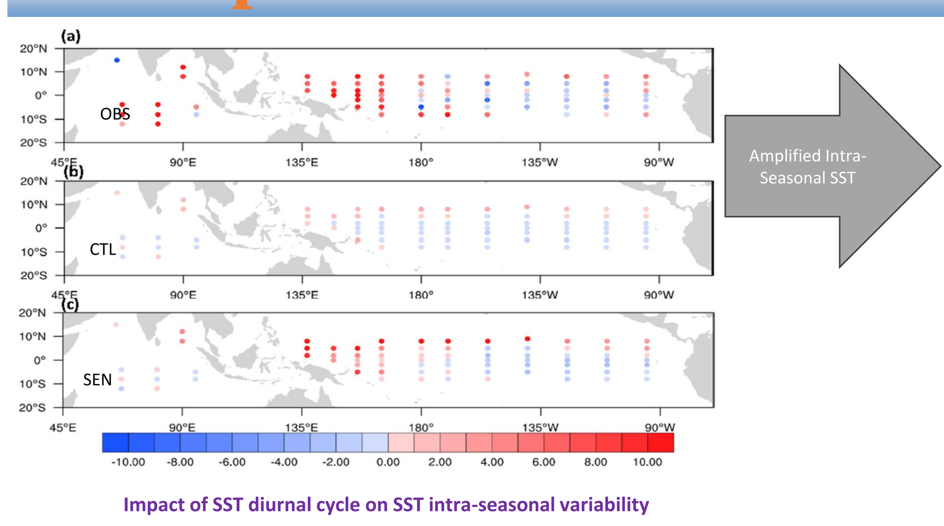


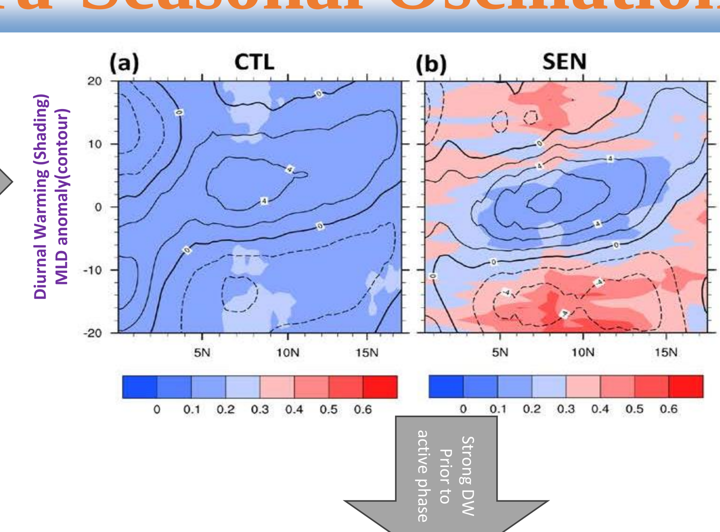
Variation of SST and MLD w.r.t. Local Solar Time (LST)



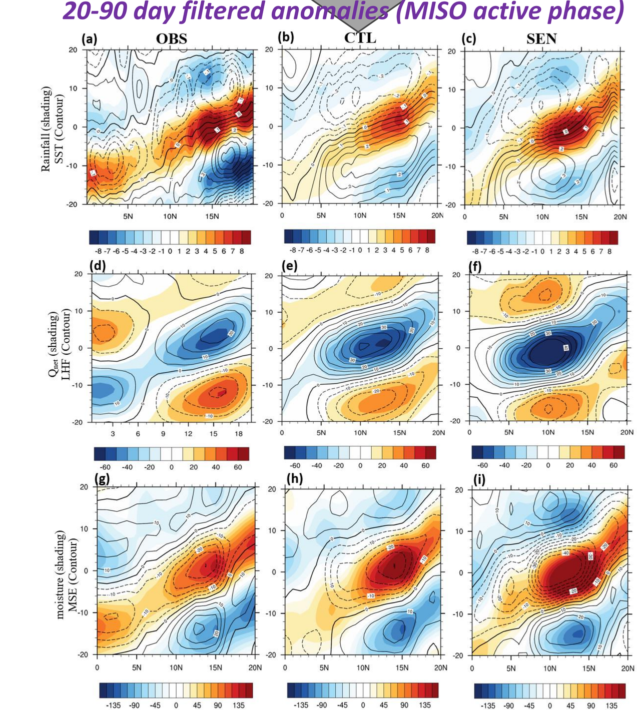
Diurnal range in prate

Impact on Monsoon Intra-Seasonal Oscillations





20-90 day filtered anomalies (MISO active phase)



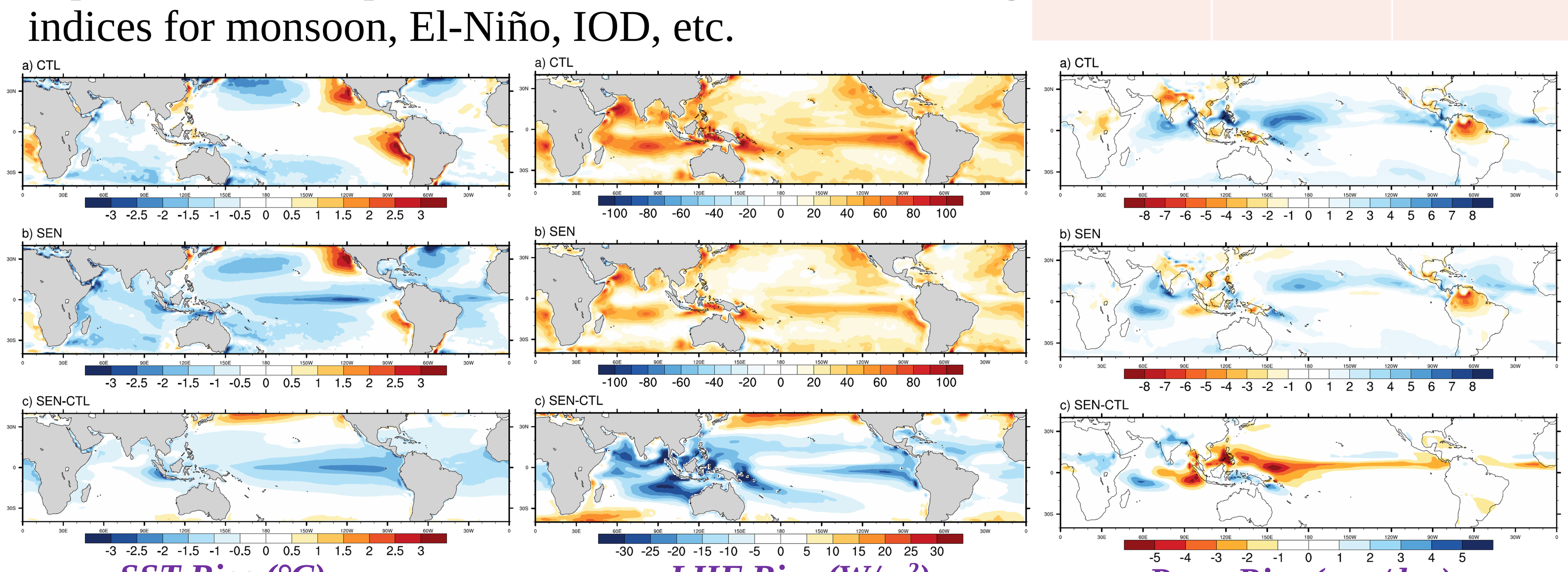
During break spell

- ☞ Shallower MLD
- ☞ Reduced LHF (due to calm winds)
- ☞ Higher Q_{net} into the ocean (due to higher solar insolation and reduced LHF)
- ☞ Higher diurnal SST warming (due to all above)
- ☞ Enhanced recharge of MSE and moisture to favor a stronger active.

Impact on Seasonal Mean Biases and Prediction Skill

- ☞ Cooler SST biases in SEN run compared to the CTL run due to
  1) Enhanced diurnal and seasonal mixing
  2) More cool skin events than warm layer events
  3) More equatorial (coastal) upwelling because of stronger zonal (meridional) wind stress
- ☞ Overestimation of LHF is reduced by 15-30 W/m2
- ☞ Wet bias over equatorial Oceans and dry bias over Indian and African landmass is reduced by 2-5 mm/day. Can be attributed to
  1) Enhanced diurnal rainfall activities
  2) Strengthened monsoon south-Westerlies
  3) Modification of regional Hadley cell over the Indian Ocean.
- ☞ Improved seasonal prediction skill of climate monitoring indices for monsoon, El-Niño, IOD, etc.

Skill (ACC)	CTL	SEN
Niño3.4	0.52	0.60
Niño3	0.55	0.63
DMI	0.03	0.07
ISMR	0.29	0.41



SST Bias (°C) *LHF Bias (W/m²)* *Prate Bias (mm/day)*

Future Direction

- ☞ Impact on intra-seasonal rectification in presence of COARE fluxes and diurnal skin temperature.
- ☞ To test the sensitivity of convection schemes with COARE 3.0
- ☞ To further improve ocean diurnal variability by implementing COARE with river routing/runoff model.

For more details

Pradhan et al., (2022)

Pradhan et al., (2024)

[1]Indian Institute of Tropical Meteorology, Pune, India,
[2]Department of Applied Mechanics, Indian Institute of Technology, Delhi, India