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Ocean Model Working Group

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

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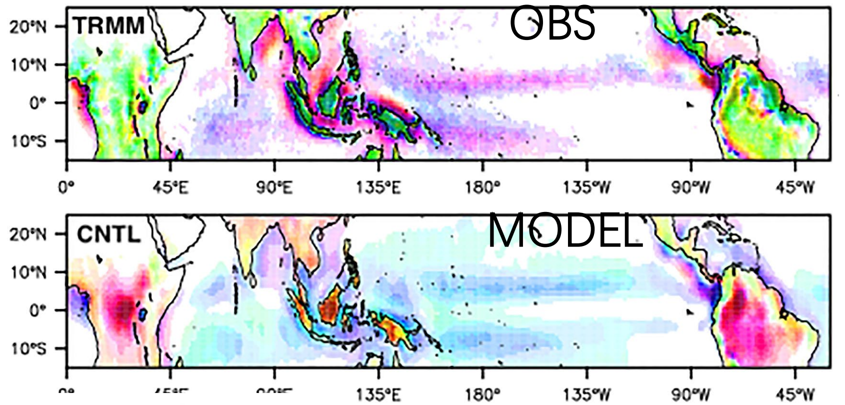
Why to Improve Ocean Diurnal Cycle?

There are several challenges using models as forecasting/prediction tool.

A. Models' inability to simulate realistic phase and amplitude of diurnal cycle in ocean-atmosphere



I. Precipitation occurs earlier than reality
II. Diurnal amplitude is underestimated

Xie et al., (2019): Improved Diurnal Cycle of Precipitation With a *Revised Convective Triggering Function.*

✓ Timing of diurnal precipitation has shown improvements.
✓ No significant improvement in diurnal amplitude of precipitation

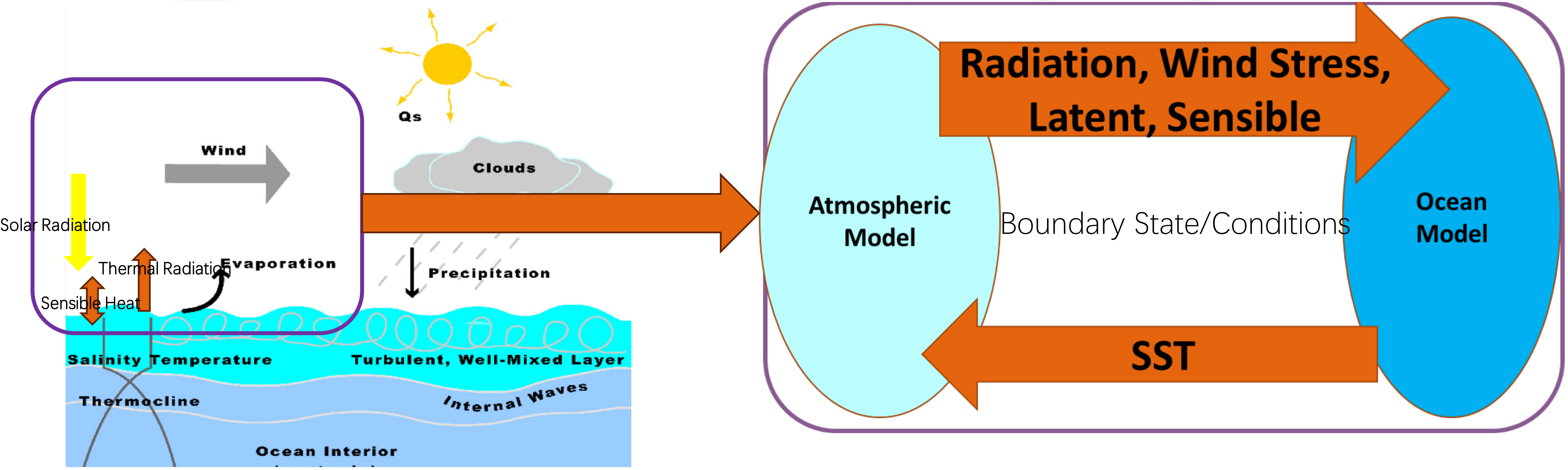
Amplitude (color density)
Timing phase (color)

B. Intra-Seasonal Scale

- Errors in diurnal cycle can lead to improper intra-seasonal rectification. (Bernie et al., 2005)
- Mean state bias of air-sea interaction can deteriorate MJO phase and amplitude simulations. (Klingaman and Woolnough (2014), Seo et al., 2014)
- Simulation of MISOs depend on models' capability to represent air-sea interaction (Sharmila et al., 2013, George et al., 2016)
- ISO predictability can be improved by improving flux-SST feedback to organisation of convection. (Fu et al., 2003, Lie et al., 2018)

- **Representation of diurnal air-sea interaction for organised convection** Dai and Trenberth (2004)
- **Atmospheric model is sensitive to diurnal variations in SST, and flux** Clayson and Chen (2002)

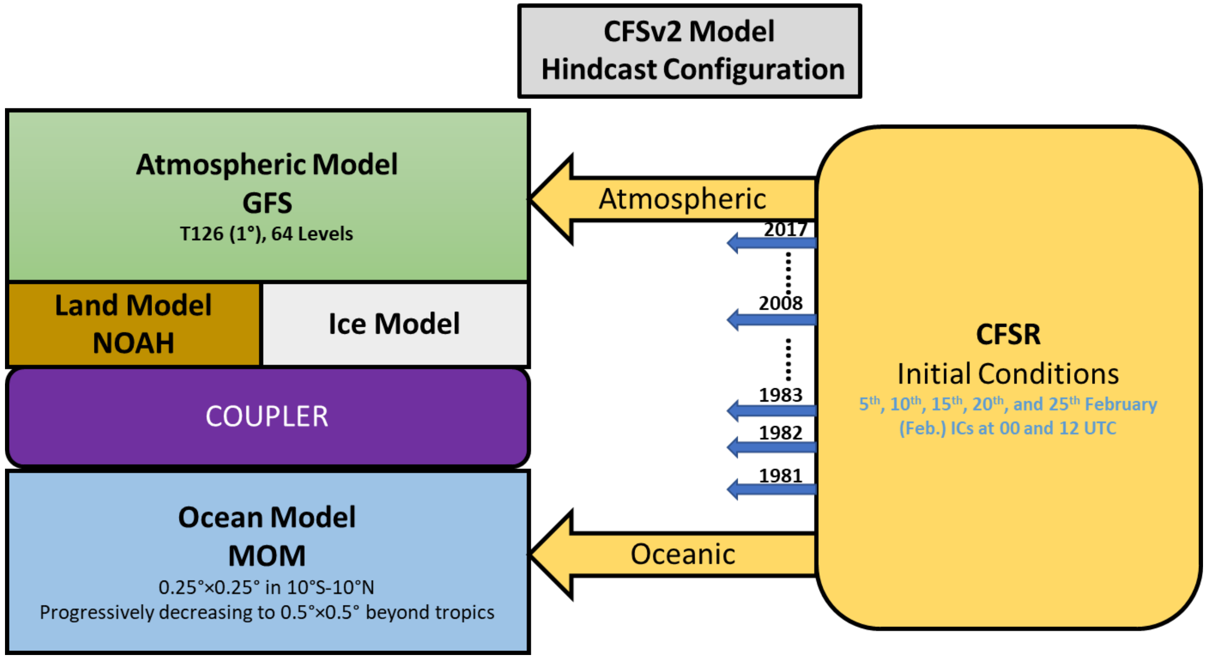
Ocean-Atmosphere Interaction in Models

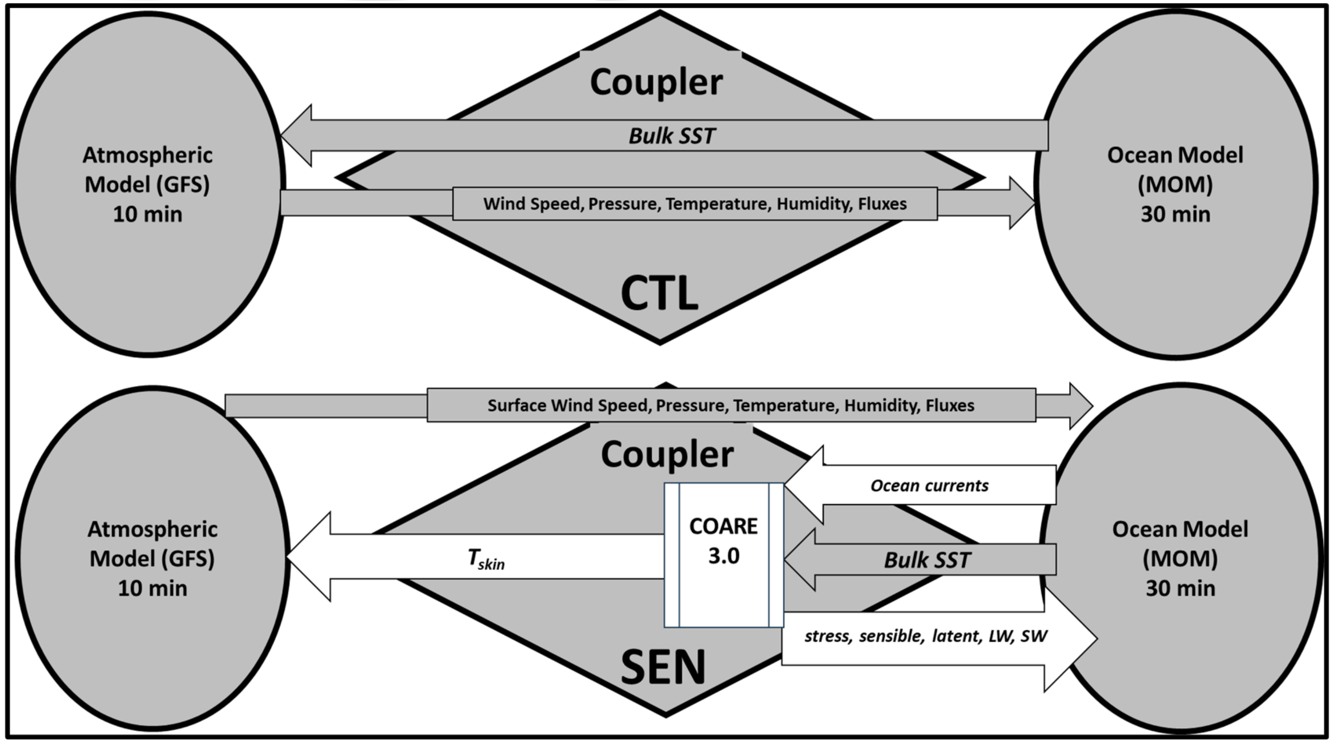


- Radiative and turbulent fluxes acts as boundary condition for the ocean model
- SST acts as boundary condition for the atmospheric model

Therefore, we propose that improving surface flux and SST representation in model can resolve some of the multi-scale problems.

Design of Coupled Model Experiments





(a) *Cool skin and Warm layer Corrections: Atmospheric boundary condition*

- One of the major changes between CTL and SEN
- The corrected ocean temperature is then passed to atmospheric model as the boundary forcing.

(b) *Fluxes from COARE: Oceanic Boundary Conditions*

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

Improving SST: Bulk vs. Skin: Diurnal Variability

$$T_s = T_m(z_r) + \Delta T_w(z_r) - \Delta T_c$$

Z_r first layer at which model calculates ocean temp. (SST)

- Cool Skin Correction

$$\Delta T_c = \frac{Q_{net}\delta}{k}$$

- **Temperature Correction bulk temp. at z_r**

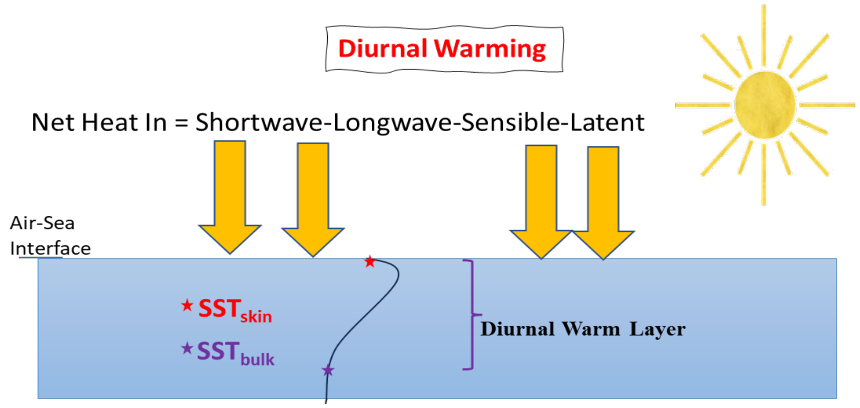
$$\Delta T_w(z_r) = \frac{\Delta T_w \times z_r}{D_T}$$

Warm Layer Temperature

$$\Delta T_w = \frac{\int(\delta Q_{SW} - Q_{net})dt}{\rho c_p D_T}$$

Q_{net} = LW+Q_{lat}+Q_{sen} = cools the surface

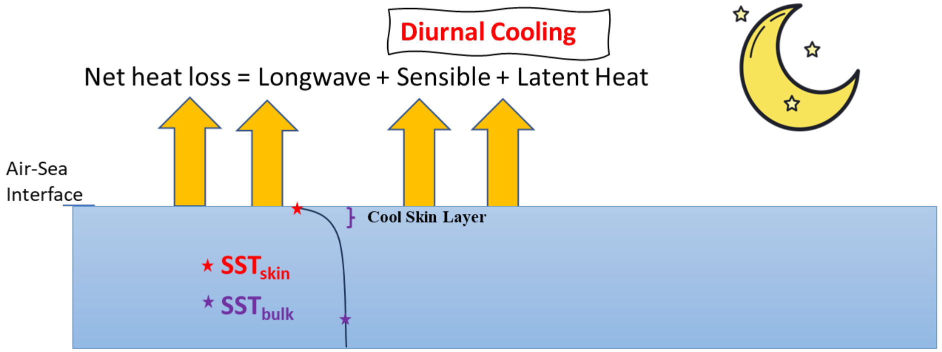
Q_{SW} net solar radiation absorbed



Factors

Seasonality Solar Insolation

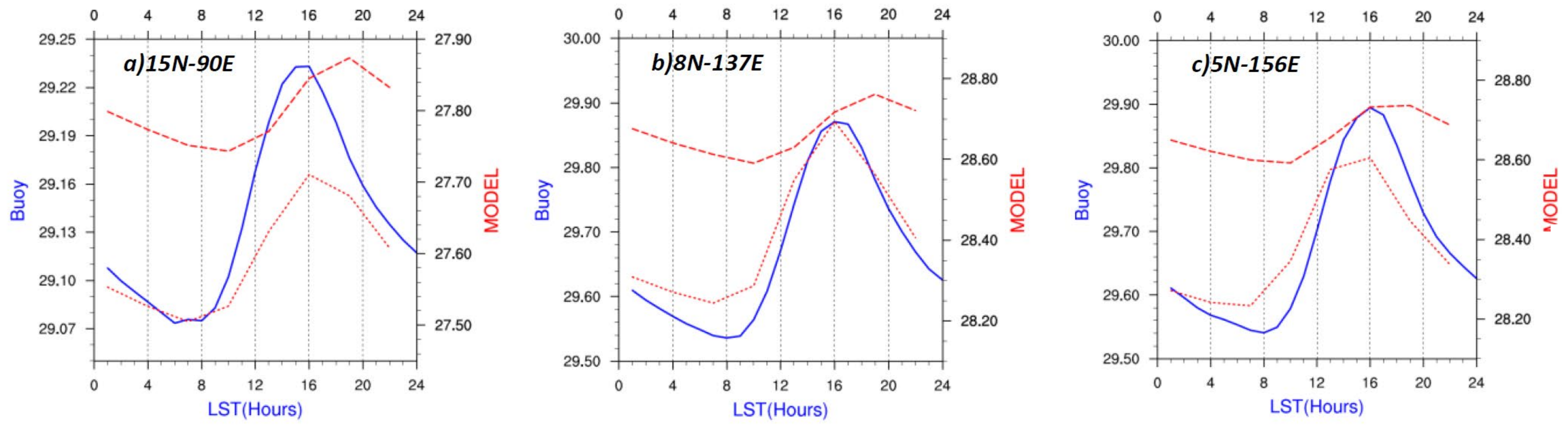
Wind/Current Cloud Cover



present almost every time

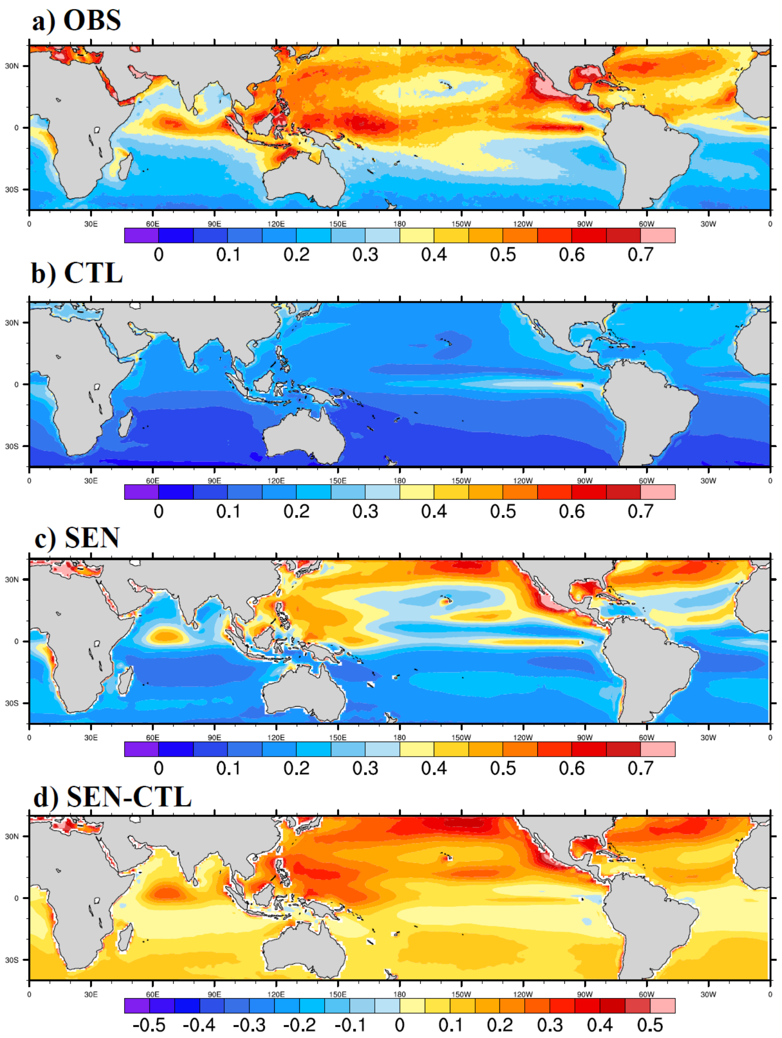
Therefore, using a diurnal skin temp. parameterization can improve the feedback from ocean to atmosphere.

Diurnal Cycle: Impact on Surface Ocean



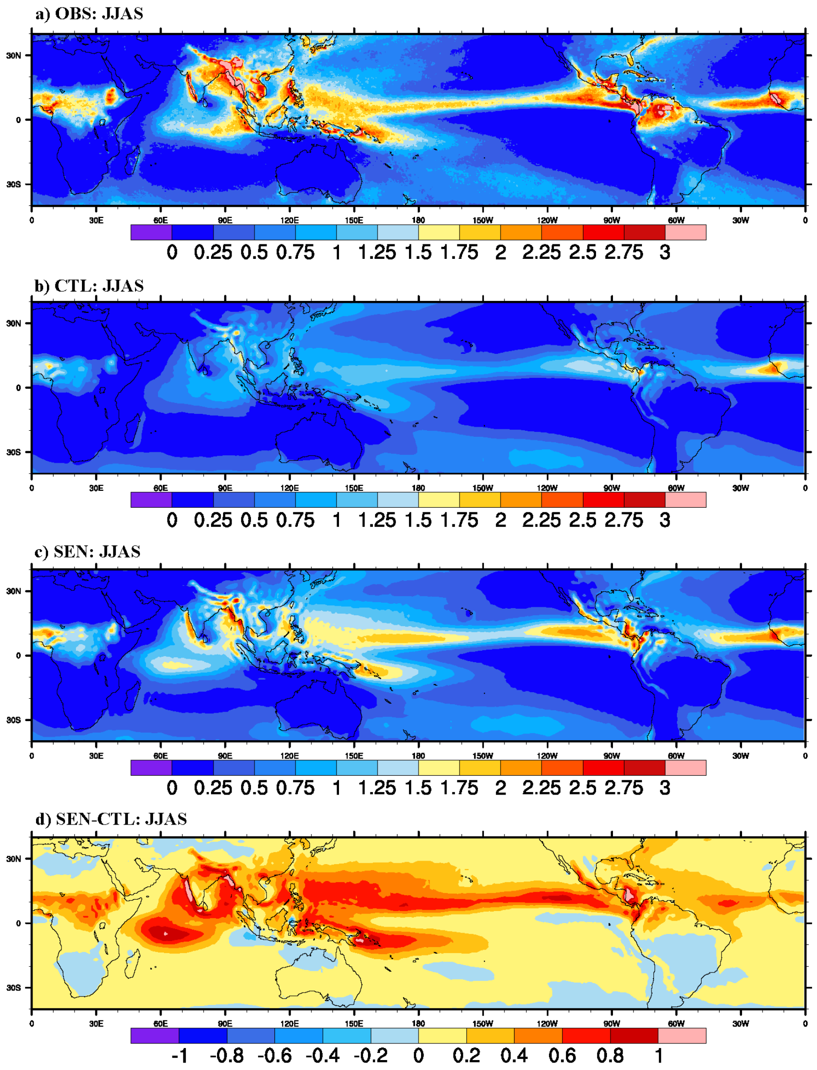
Buoy (Blue), CTL (red dashed), SEN (red dotted)

- ○ **Timings of maxima and minima are significantly improved and agree with the observation**
- ○ **Amplitude of diurnal SST (maxima-minima) also improved at local solar cycle**



- The diurnal range in SST is significantly weaker in the CTL run, the seasonal mean maximum *dSST* reaches 0.35°C
- In SEN run, diurnal SST is significantly improved over by 0.2-0.3°C over the tropical Indian Ocean and by 0.4-0.5°C over the north Pacific and Atlantic Oceans

Impact on Diurnal Range of Precipitation



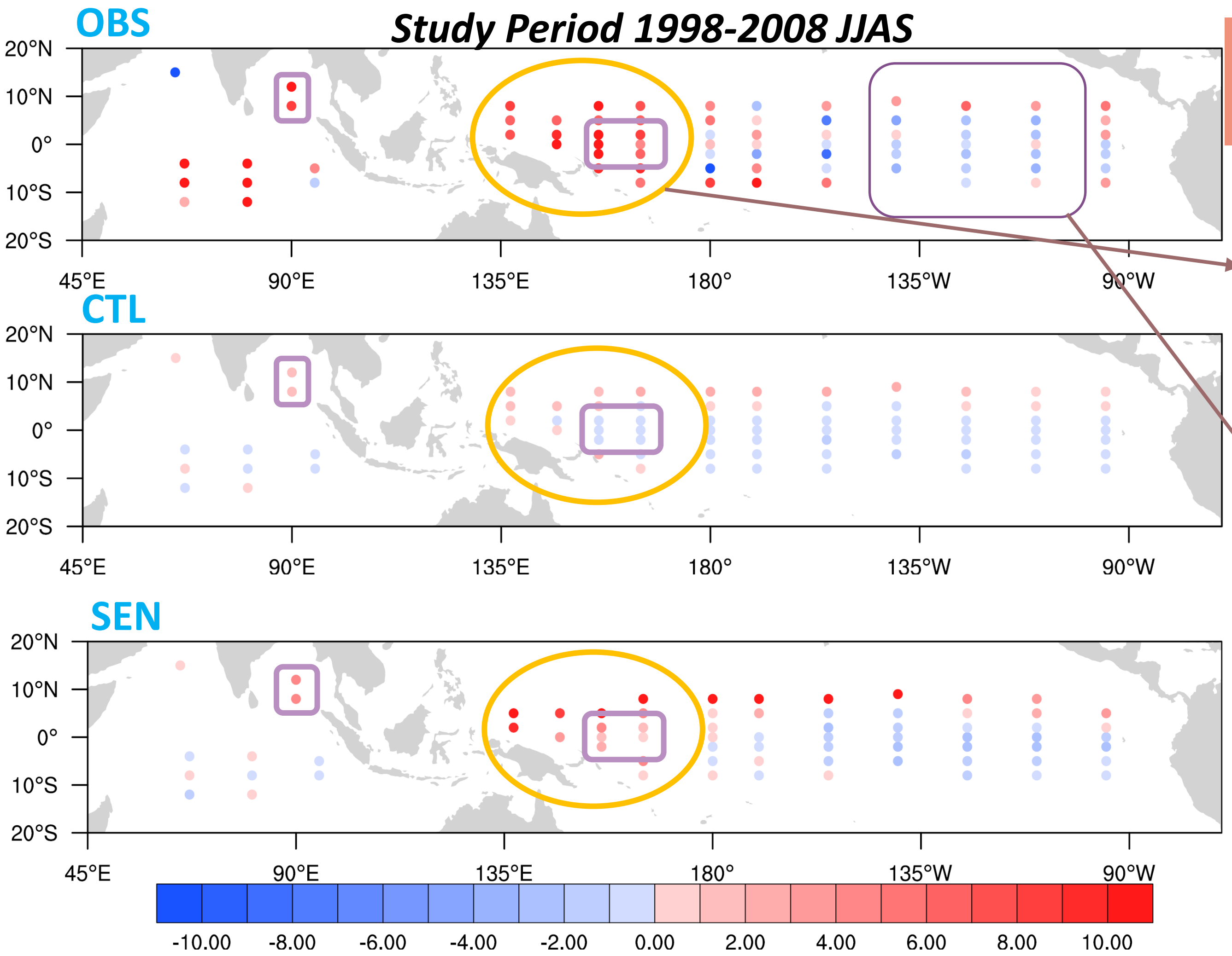
Seasonal (JJAS) Mean diurnal range of prate (dPRATE=maximum-minimum during 24-hour cycle in mm/hr) for the period 1998-2008.

- In observations, the diurnal range in rainfall is significant over the equatorial oceans and landmasses.
- In CTL amplitude of the diurnal range is significantly lower run throughout the global Oceans and landmasses
- In SEN run the amplitude of *dprate* is closer to observation over the eastern Indian Ocean, north BoB, western Ghats, foothills of Himalaya.
- The enhancement in *dprate* is as large as 0.5-1.0 mm/hour in SEN run compared to CTL run for most tropical Oceans and Indian landmass

- Clayson and Chen (2002) – Atmospheric model is sensitive to skin effect, diurnal variations in SST, and choice of bulk flux algorithm.
- Chen and Houze (1997) - Diurnal heating of the sea surface is essential for convection over the western Pacific warm pool region.
- Sui *et al.*, 1997; Johnson *et al.*, 1999; Slingo *et al.*, 2003- Diurnal SST rise during the suppressed convection phase can lead to the formation of convective clouds.

Rectification

The enhancement/reduction of intra-seasonal variability by the diurnal cycle



$$Rectification(\%\,age) = \frac{ISV_{with} - ISV_{without}}{ISV_{with}} \times 100$$

Atmosphere forces the ocean

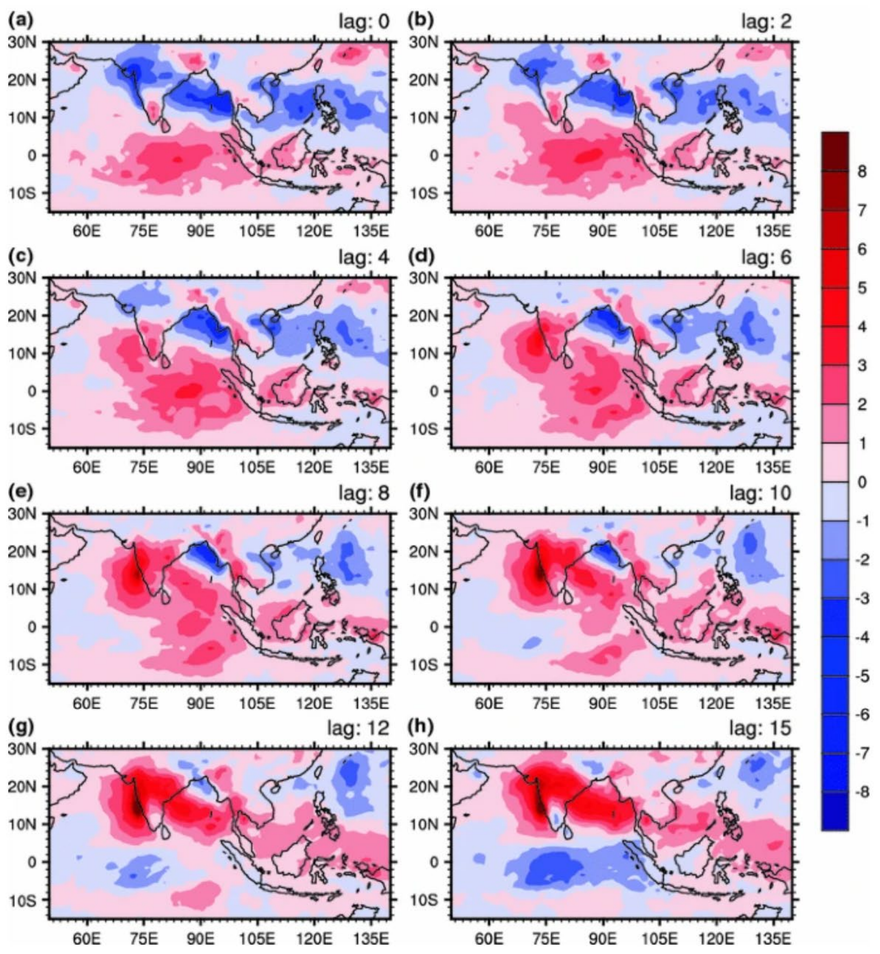
- SST-Wind out-of-phase
- dSST-Wind out of phase
- dSST-Wind in-phase

Ocean forces Atmosphere

- SST-Wind in-phase
- dSST-Wind out of phase
- dSST-SST out of phase

- Enhanced rectification in SEN (3-10%) run compared to CTL run (2-5%) over Indo-Pacific warm pool region.
- At locations (between 5°S-0°N and 150°E-170°E) over the western Pacific Ocean which is not realistic in CTL run.

How can SST rectification modulate MISO?



Evolution from break phase to active phase over the ISM domain is depicted using the composite of 25–90 day filtered rainfall anomalies (mm/day) for the 1997–2008 JJAS seasons at eight different lags

Suhas et al., (2010)

MISO: Monsoon Intra-seasonal Oscillation

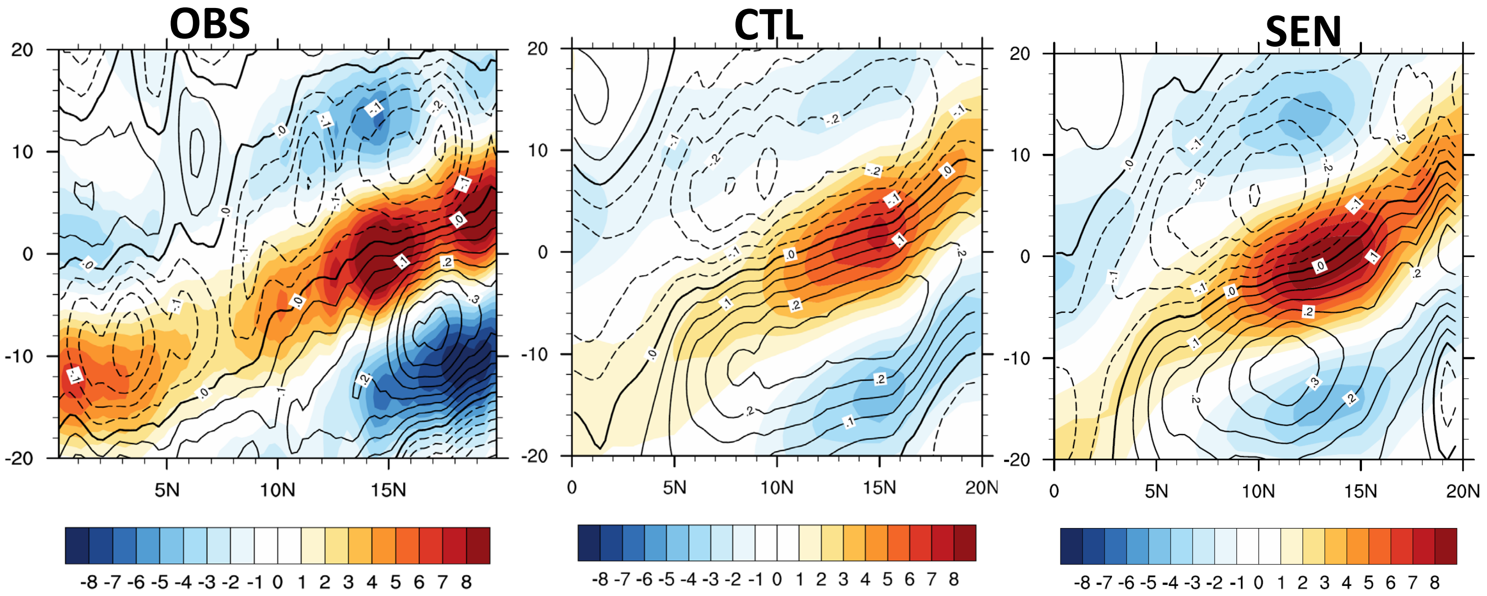
- MISOs are the periodic oscillation of dry (break) and wet(active) spells of precipitation which have a time scale longer than diurnal and synoptic variability but shorter than a season.
- Over Indian region MISOs propagate northward (Sikka and Gadgil, 1980).

How can SST rectification modulate MISO?

Study Period 1981-2017 JJAS

20-90 day filtered anomalies longitudinally averaged over BoB

X axis latitude, Y axis days w.r.t peak active day

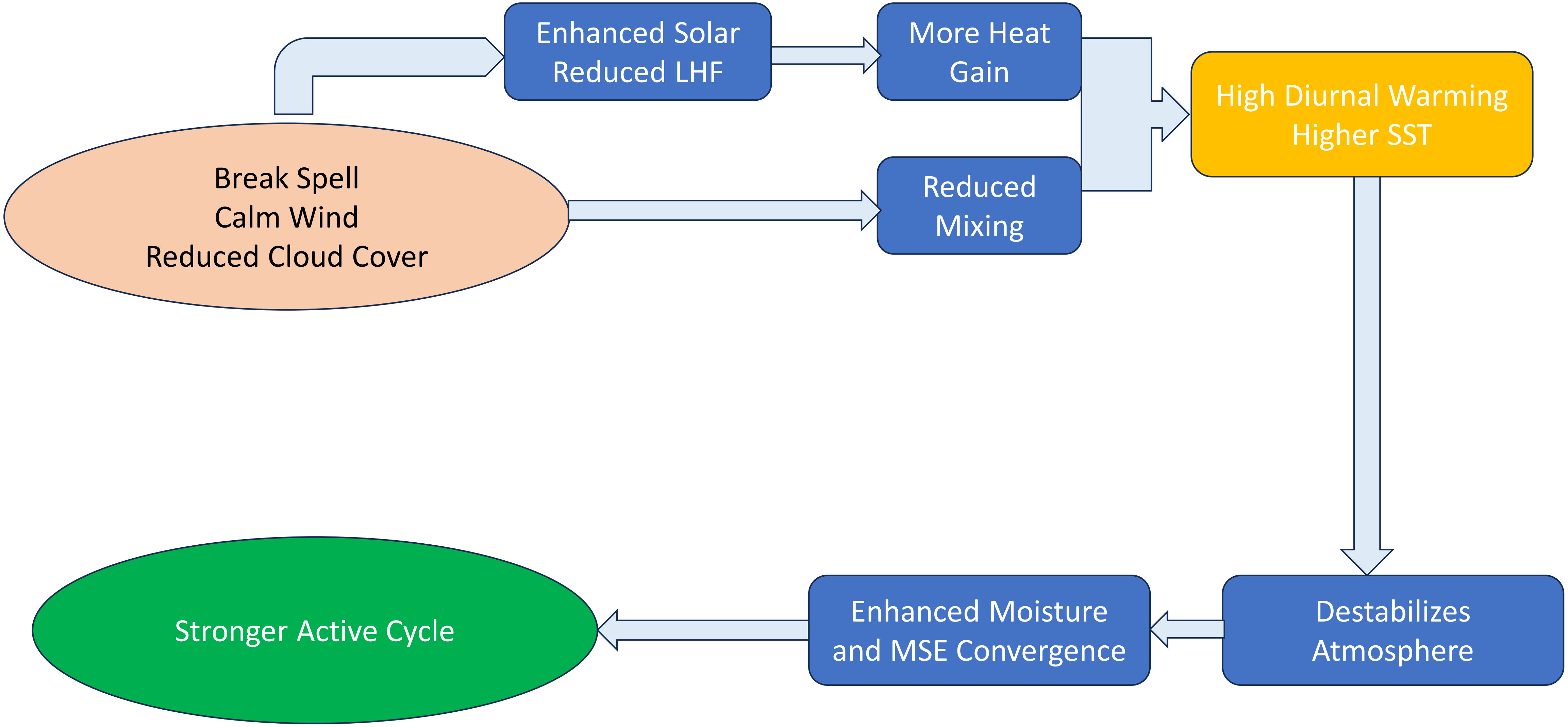


Rainfall (Shading) and SST (Contour)

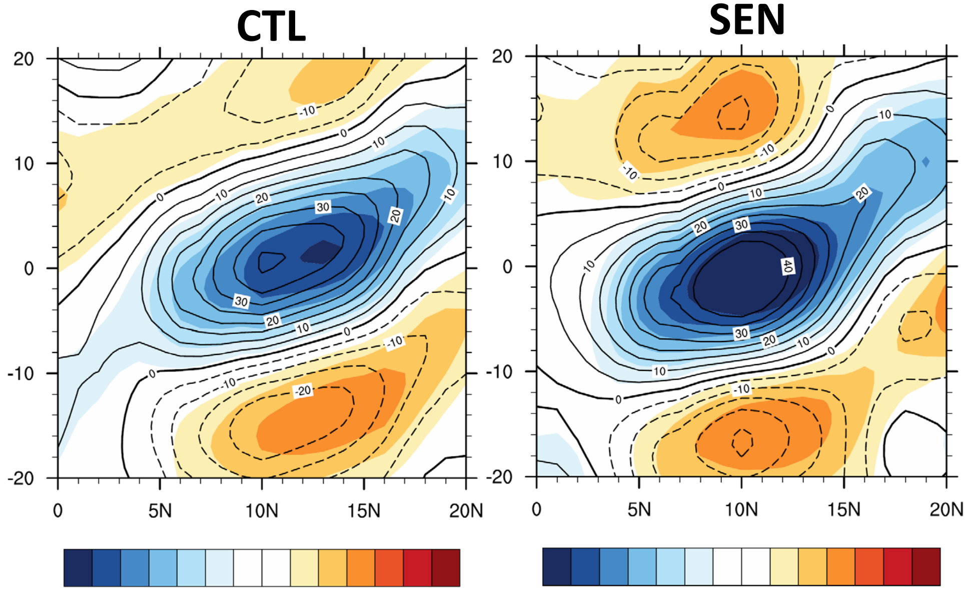
Li et al., (2018) suggested inclusion of skin temperature feedback may resolve the problem of weaker simulation of active phase in CFSv2.

✓ SST and Rainfall Anomalies during the active phase is stronger in SEN run tha CTL run.

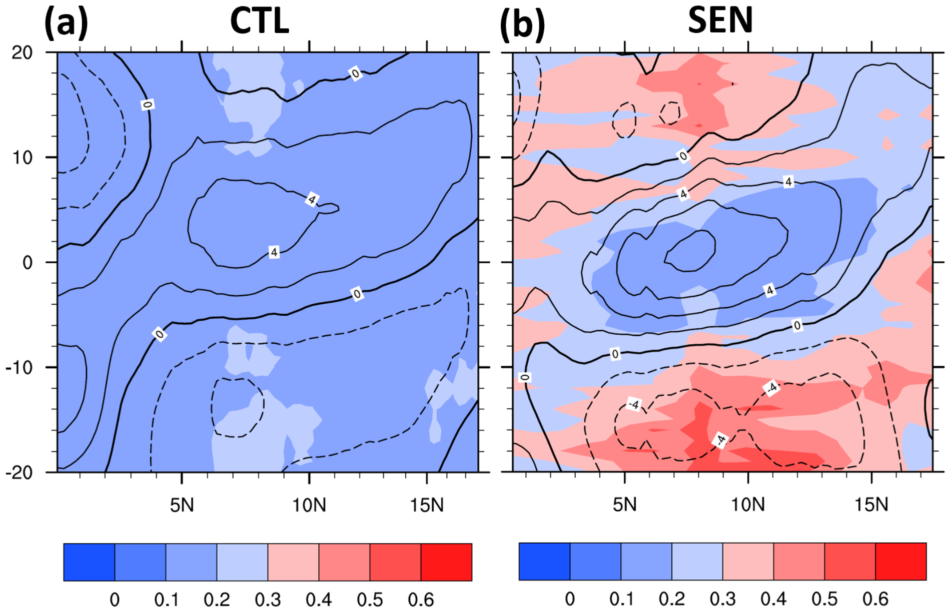
Why SEN simulates stronger active following a break!!



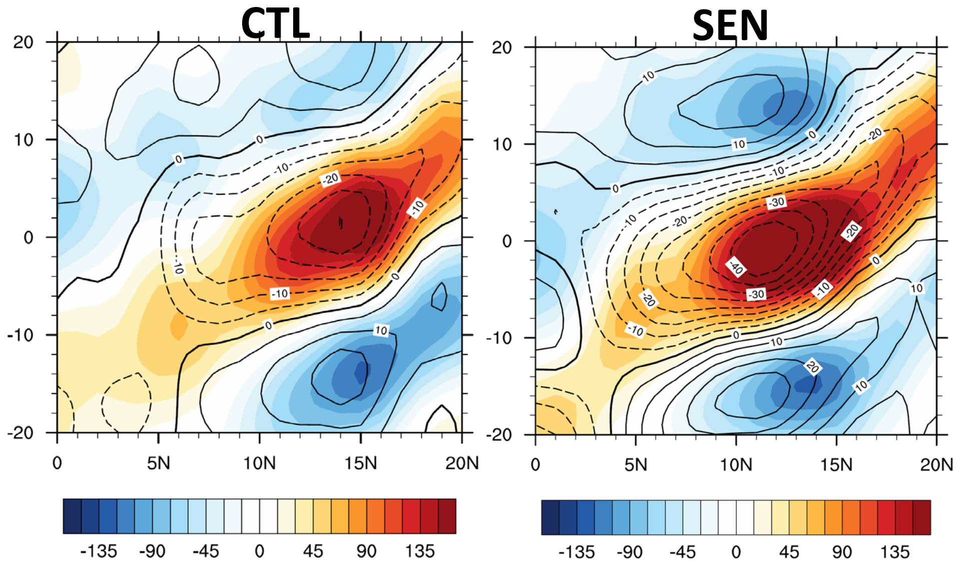
Why SEN simulates stronger active following a break..



Q_{net} (Shading) and LHF (Contour) (W/m^2)



dSST (Shading) and MLD (Contour)

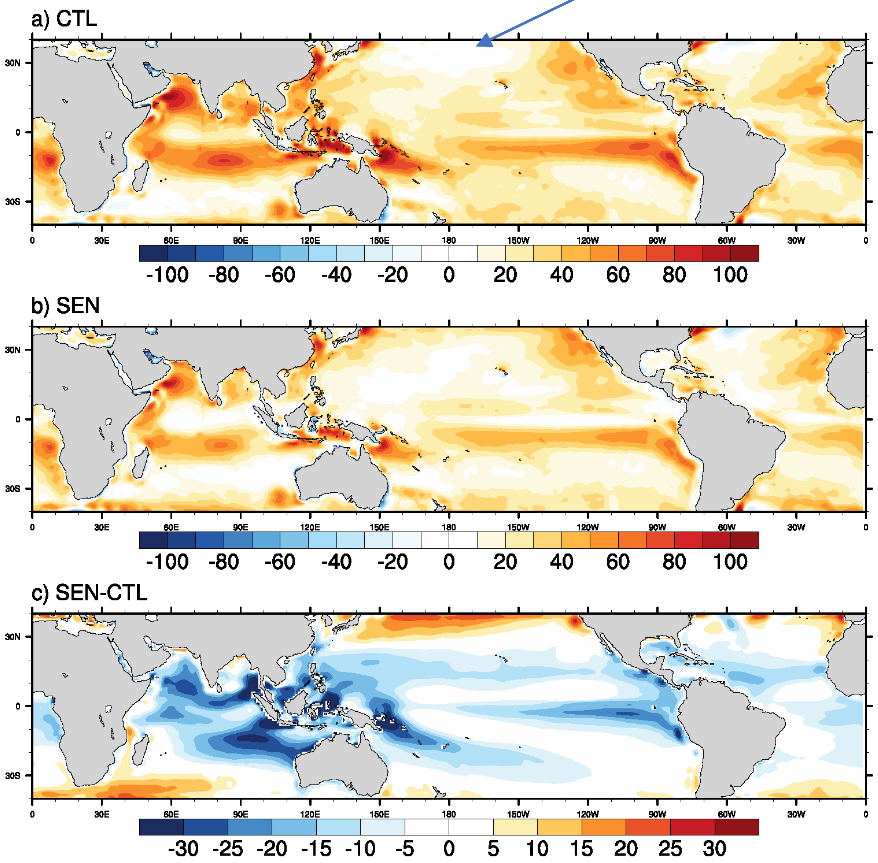


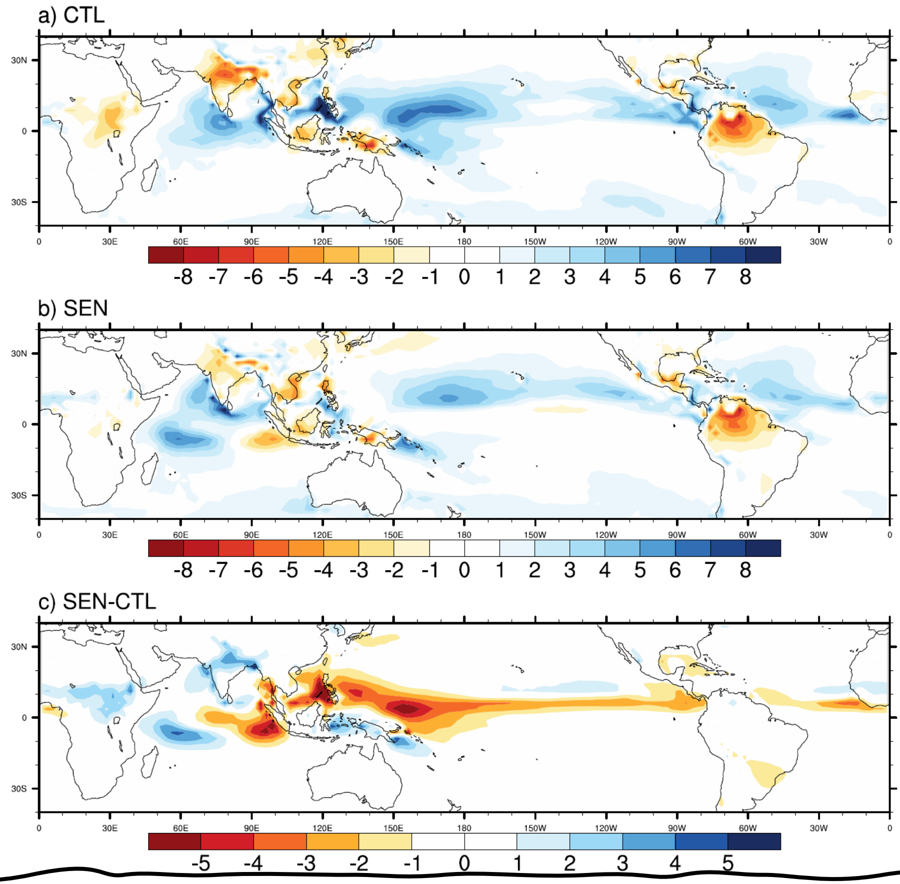
MSE (Shading) and Moisture (Contour) convergence term (W/m^2)

- Therefore, in presence of skin temp. parameterisation, diurnal warming and the related feedbacks are pronounced the SEN run.
- On the other hand, CTL run could not reproduce the warming and related after-effects.

Seasonal Mean LHF and Rainfall Bias

Study Period 1981-2017 JJAS





- Bonino *et al.* (2020) have shown that skin temperature parameterization can also reduce the evaporation and hence turbulent heat fluxes significantly.
- Better simulation of LHF during strong warm layer events in SEN run.

- The oceanic biases over northeastern and western Pacific Ocean, eastern and central Indian Ocean, northern Atlantic Ocean regions are reduced by 3-5 mm/day.
- Dry bias over African and Indian landmasses are reduced by 2-3 mm/day whereas remained unchanged over South American

Summary: Ocean Diurnal Cycle impacts multi-scale

Diurnal	Intra-Seasonal	Seasonal	Prediction Skill
• Improved phase(timing of maxima, minima): SST, MLD • Higher diurnal amplitude: SST, MLD, Rainfall	• Better response of SST to fluxes. • Better response of convection to SST during MISO	• Reduced LHF, Q_{net} overestimation • Reduced dry(wet) biases over land(ocean)	• Improved ENSO, IOD, ISMR skill • Improved ENSO-Monsoon, IOD-Monsoon relations

An effective approach towards addressing multi-scale coupled model problems without modifying convection schemes

Thank You…

Pradhan et al., (2022)

Pradhan et al., (2024)