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Pathways to Better Prediction of MJO Initiation over the Indian Ocean

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Introduction

- The Madden-Julian Oscillation (MJO) is a complex multi-scale phenomenon and its initiation and eastward propagation over the Indian Ocean (IO) are not well understood. It is poorly represented by numerical models.
- A coupled atmosphere-ocean model (UWIN-CM) is used to simulate an MJO event that occurred in November-December of 2011, and was well-observed during the DYNAMO (Dynamics of MJO) field campaign.
- The MJO initiation and eastward propagation are studied using a cloud-permitting (4km) coupled model experiments by varying individual physical processes, so we can examine the effects of model resolution, cumulus parameterization, and air-sea coupling on the MJO.

Model Configuration and Experiments

UWIN-CM (Unified Wave Interface - a Coupled Model):

- Weather Research Forecasting (WRF-ARW) v.3.6.1 with 36 vertical levels,
  - initial and lateral boundary conditions: ECMWF analysis,
  - cumulus parameterization: Kain-Fritsch; PBL scheme: YSU.
- Hybrid Coordinate Ocean Model (HYCOM) v.2.2.98 with 32 vertical levels,
  - uniform 0.08° horizontal resolution,
  - initial and lateral boundary conditions: HYCOM global analysis.

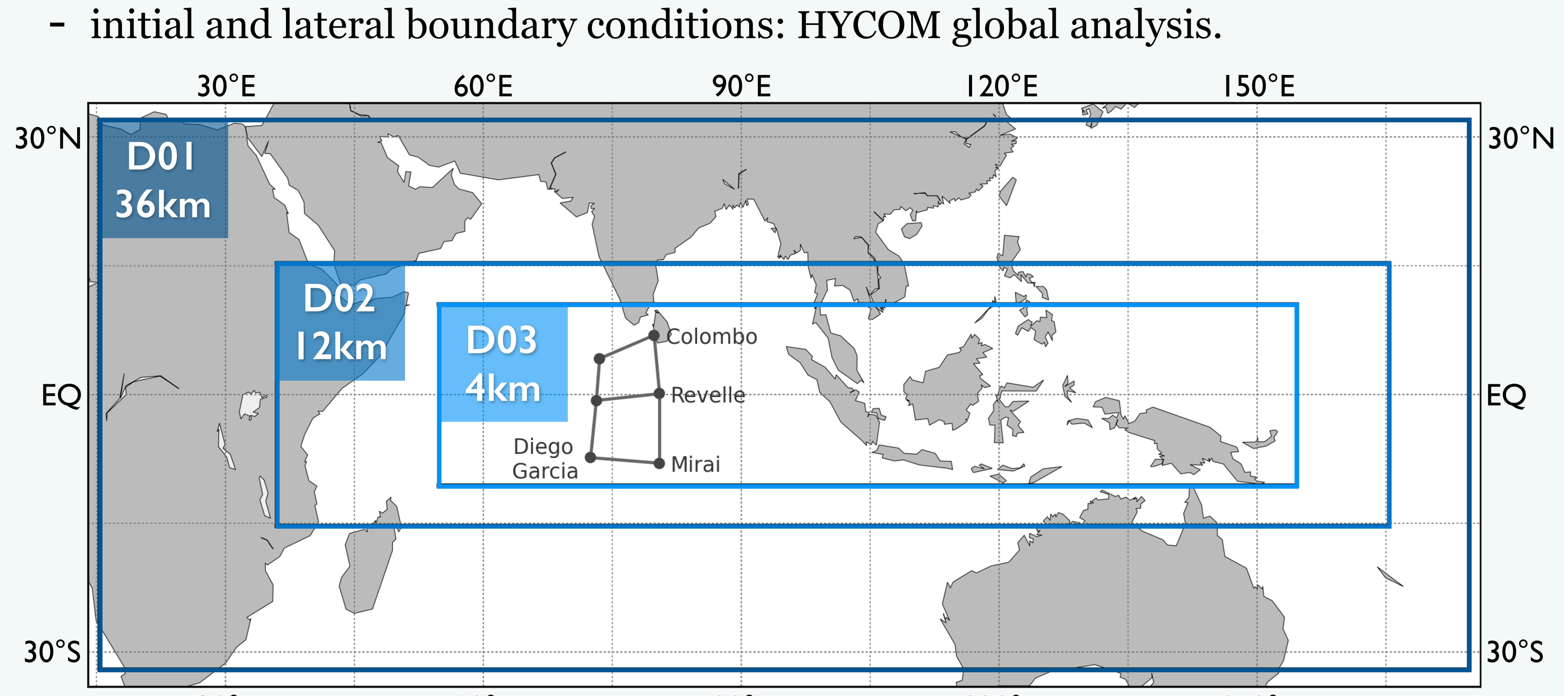

Figure 1: UWIN-CM atmosphere (WRF-ARW) model domain configuration and resolutions. Marked points indicate locations of DYNAMO field campaign data collection sites.

Model Experiments

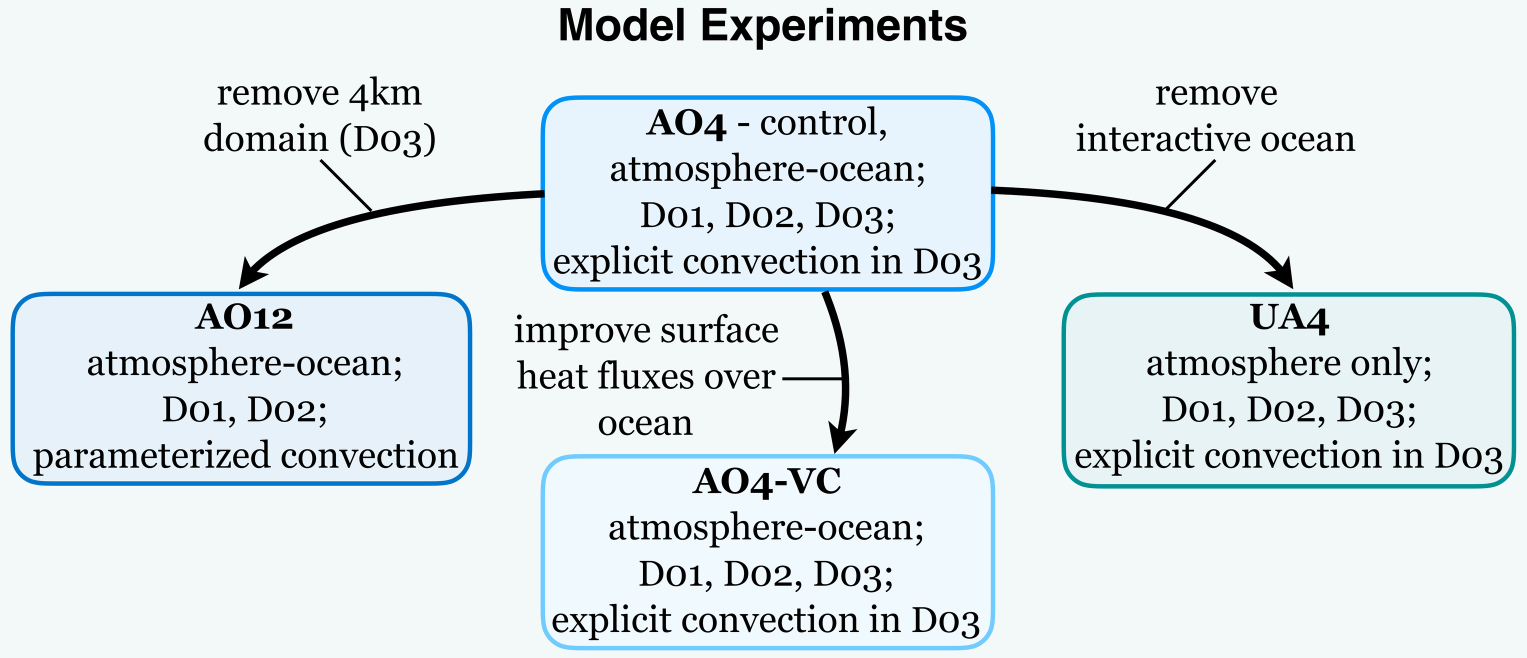

Figure 2: Relationships between model experiments, where AO4 (atmosphere-ocean, 4km) represents the control run. AO12 results from removing the high-resolution, convection-permitting D03; UA4 (uncoupled atmosphere, 4km) from removing the ocean component of the model, and AO4-VC by improving surface heat fluxes over the ocean.

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Large-Scale Structure

Observations used for comparison:

- precipitation: TRMM 3B42 - 3-hourly, at .25° resolution
- surface zonal wind (U10): ECMWF analysis - 6-hourly, at .25° resolution
- sea surface temperature (SST): TMI/AMSR-E - daily (local noon), at .25° resolution

Hovmöller Diagrams of Rainfall Rate, U10, and SST

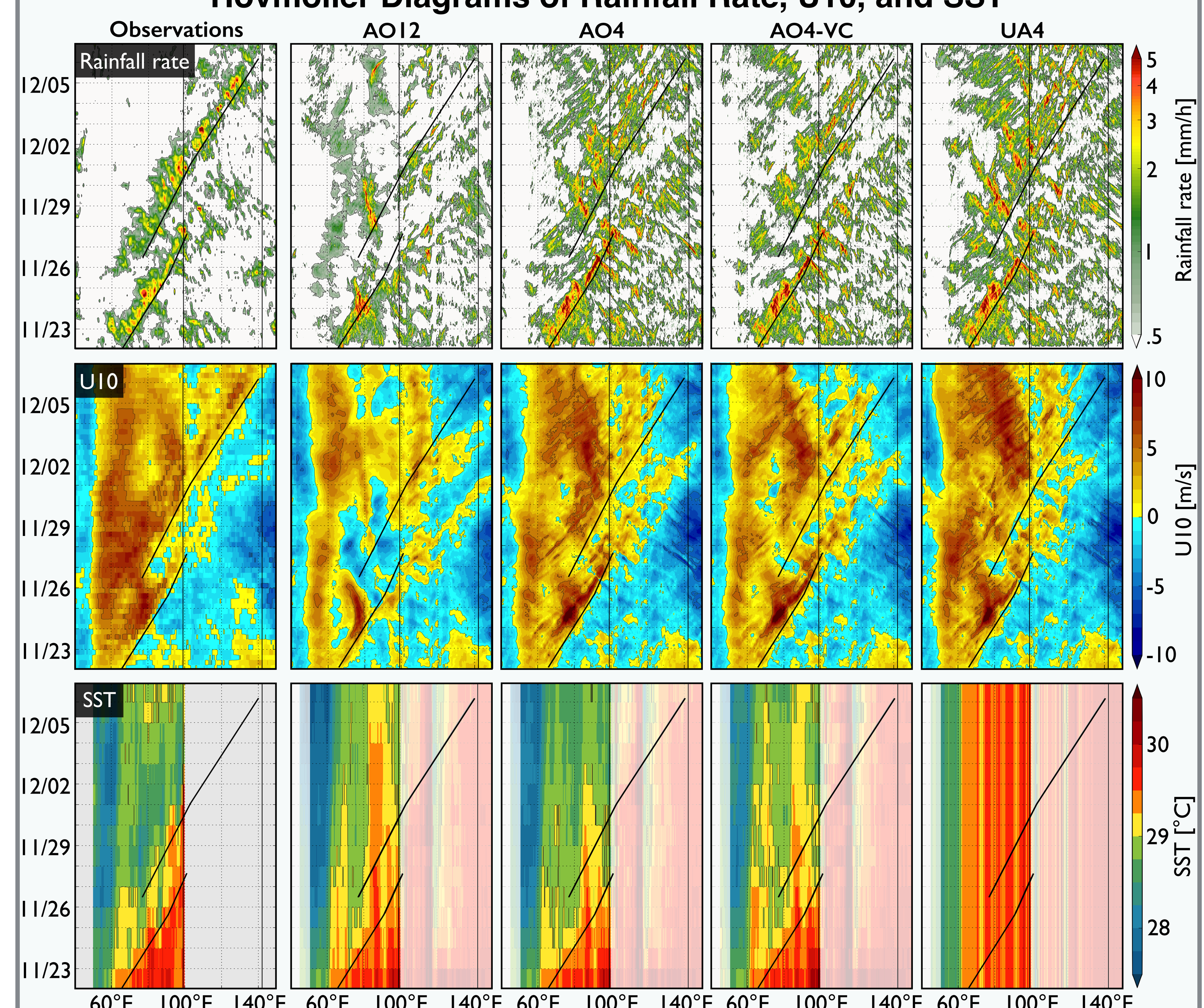


Figure 3: 5°S - 5°N Hovmöller diagrams of rainfall rate (top), U10 (center), and SSTs (bottom). Tilted black lines in every panel follow the leading edge of convection propagating eastward in TRMM observations (top left). Shaded areas in the bottom panels indicate areas where observations are not available.

Key Results

- All experiments produce eastward propagation of precipitation and surface westerlies, although it is most distinct in AO4 and AO4-VC and weakest in AO12.
- Model produces less SST cooling than observed over IO, causing precipitation to linger over the IO instead of re-forming farther eastward.

Large-Scale Precipitation Tracking (LPT)

LPT identifies precipitation features that accumulate a significant amount of rainfall over at least 3 days, with hundreds to thousands of kilometers in horizontal extent.

- the precipitation threshold is 13mm/day for model, 12mm/day for observations

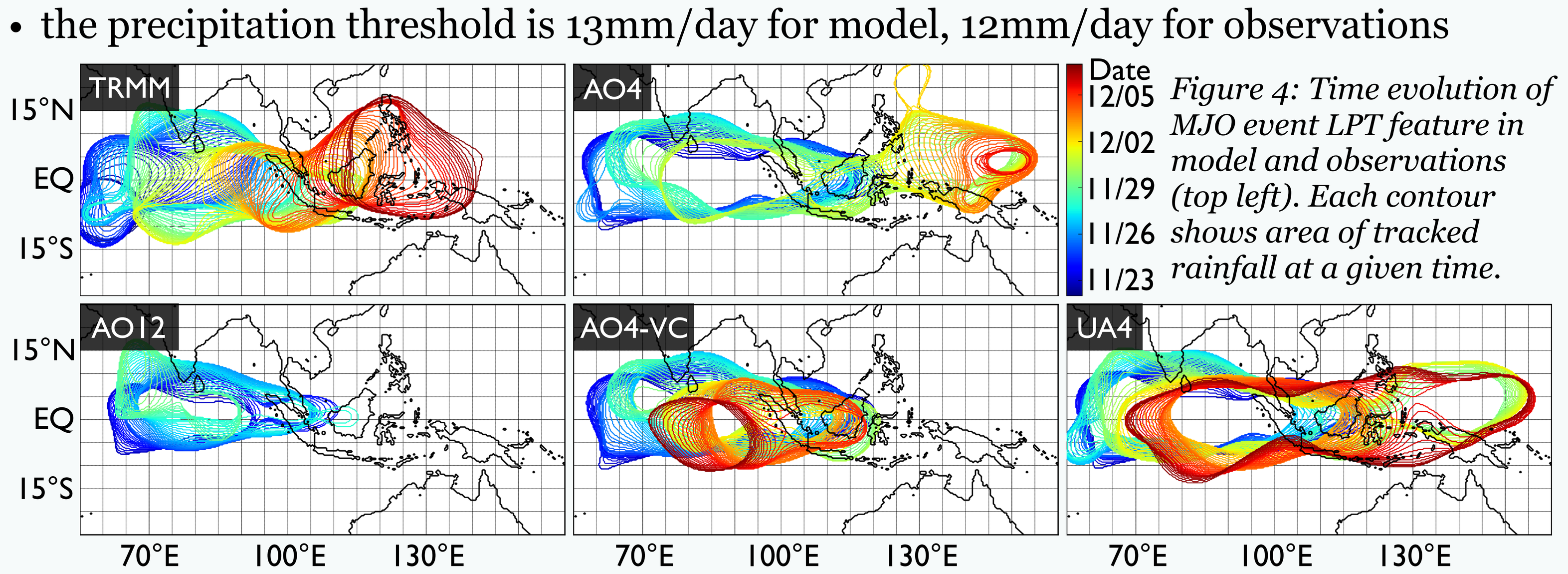


Figure 4: Time evolution of MJO event LPT feature in model and observations (top left). Each contour shows area of tracked rainfall at a given time.

Key Results

- Only AO4 produces a trackable, eastward-propagating MJO precipitation from IO-WP.
- AO4-VC has a more continuous propagation of MJO precipitation

Ocean Coupling

Improving Air-Sea Fluxes using DYNAMO Observations

- Air-sea fluxes in AO4 (LHF, Fig. 5, left panel) show a strong positive bias compared to observations, especially in low winds.
- Improved flux parameterization by reducing convective velocity (V^C):

$$LHF_m = C_e(q_s - q_a)(||\overrightarrow{V_{10}}|| + V^c)$$

$$V_m^c = 2\sqrt{\frac{\partial \theta_v}{\partial z}} \rightarrow V^c = \begin{cases} V_m^c & \text{in } AO4 \\ .5V_m^c & \text{in } AO4\text{-}VC \end{cases}$$

** m refers to WRF 3.6.1 parameterization*

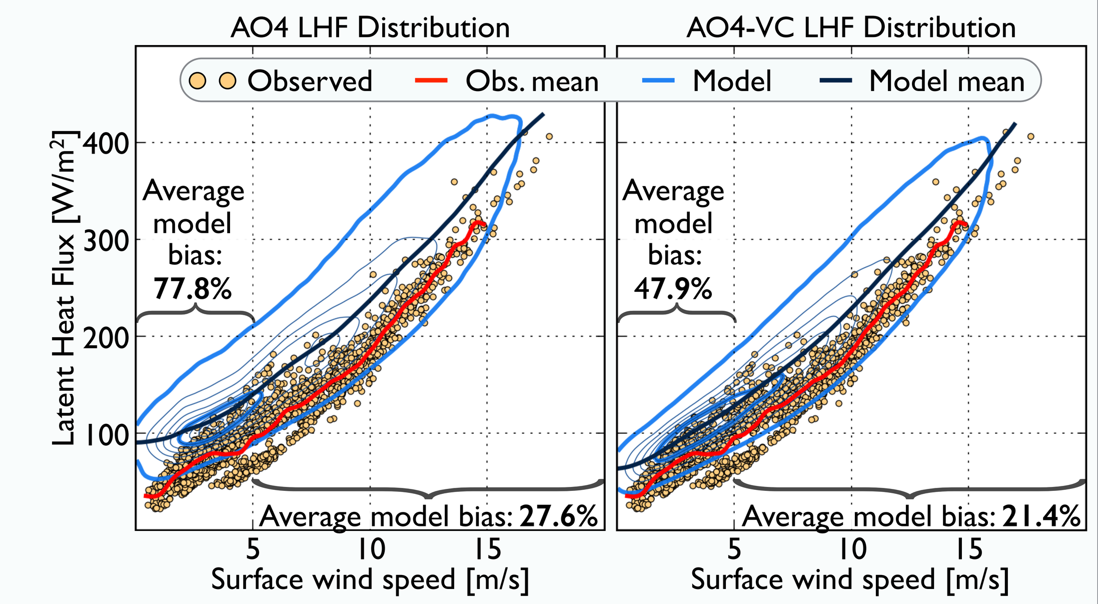


Figure 5: Latent heat flux distribution in observations (from RV Revelle, DYNAMO, red and orange), AO4 (control, left), and AO4-VC (reduced flux, right). Model fluxes considered lie within 2° of the ship's location (see Fig. 1).

Uncoupled from Ocean

- SST remains constant throughout UA4.

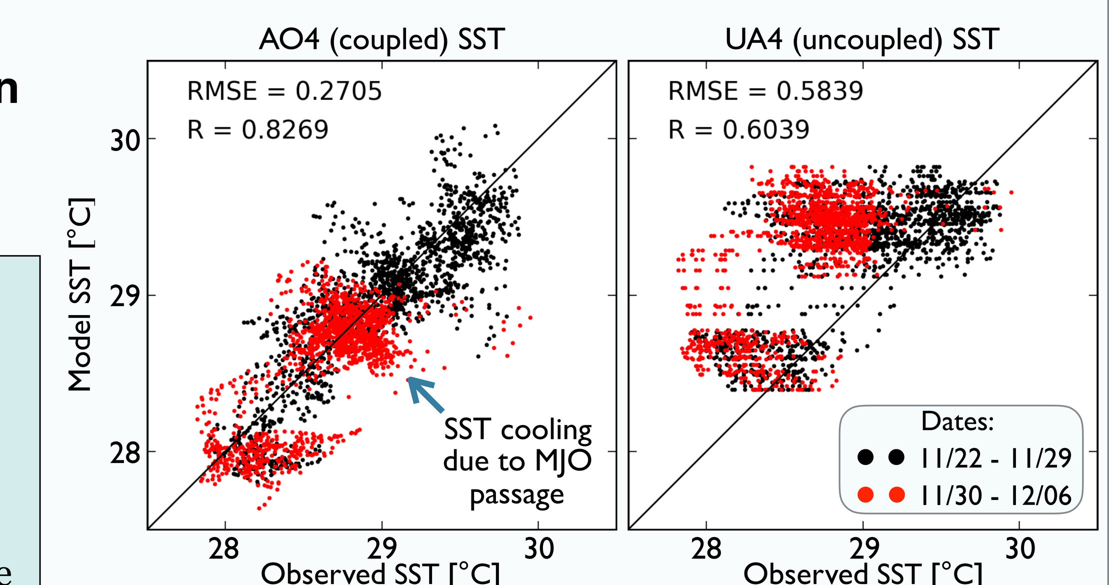
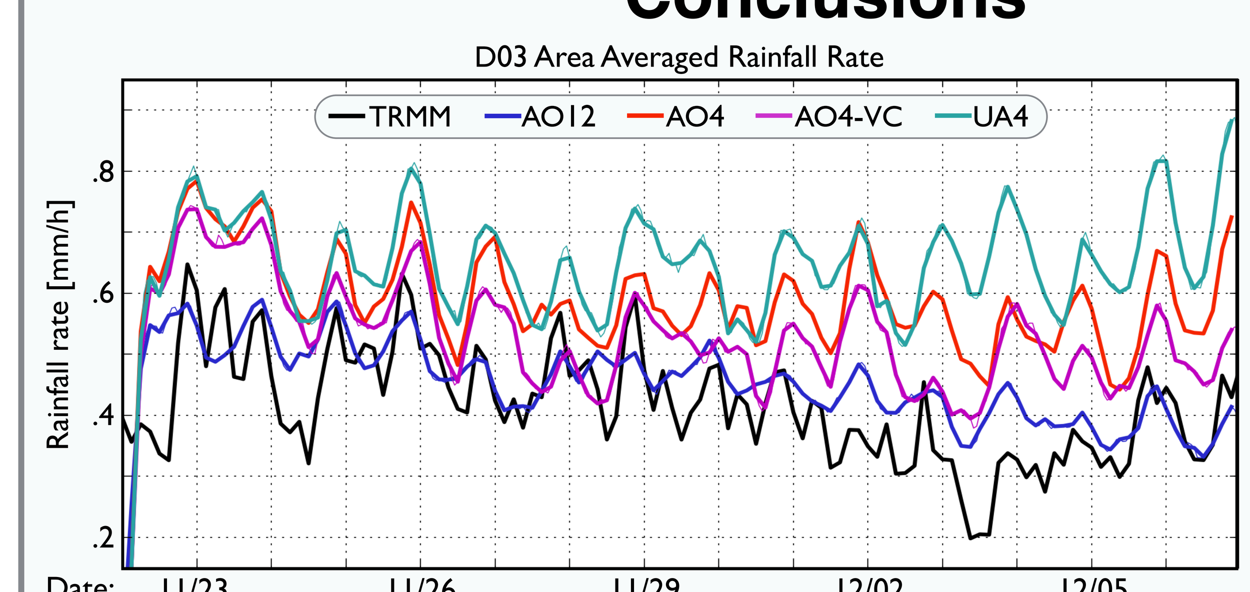


Figure 6: Indian Ocean SSTs in coupled (AO4, left) and uncoupled (UA4, right) experiments compared to observations. Model data has been degraded to match the resolution of observations.

Key Results

- AO4-VC reduces flux bias, particularly at low winds, and reduces rainfall, so MJO circulation is weakened.
- Anomalously warm SSTs in UA4 overproduce rainfall over the IO persistently.

Conclusions



Average Precipitation Bias [mm/h]

AO12	0.035
AO4	0.168
AO4-VC	0.109
UA4	0.229

Table 1 (above): average model precipitation biases over D03.
Figure 7 (left): Rainfall rate averaged over D03.

- MJO-induced SST cooling in IO helps in eastward propagation of the MJO (Fig. 3).
- Model overproduces precipitation in all experiments (Fig. 7).
- A fully coupled atmosphere-ocean model reduces the high precipitation bias by 25%.
- Improving (reducing) the air-sea fluxes reduces the precipitation bias by an additional 35% - a 52% bias reduction compared to UA4.
- All else remaining equal, a convection-permitting (or resolving) configuration is necessary for UWIN-CM to reproduce the November-December 2011 MJO event.

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