18B.9 THE ROLE OF ATMOSPHERE-OCEAN COUPLING IN EASTWARD PROPAGATION OF THE MJO CONVECTION

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1. Introduction

Understanding the key processes controlling the convective initiation of the Madden-Julian Oscillation (MJO) and its eastward propagation across the Maritime Continent (MC) remains a major challenge despite recent observations and advancements in numerical weather prediction models.

Previous studies have shown that the accurate representation of sea surface temperature (SST) on diurnal timescales improves the prediction skill of the MJO, and has an effect on its eastward propagation (Woolnough et al., 2007; Kim et al., 2010). In this study, we examine the physical process of atmosphere-ocean coupling and its impact on the MJO structure and propagation from the Indian Ocean (IO), through the MC, into the western Pacific.

2. Methodology

The role of atmosphere-ocean coupling on the eastward propagation of the MJO is investigated through a set of three model experiments generated by the Unified Wave Interface – Coupled Model (UWIN-CM). UWIN-CM consists of the Weather Research and Forecasting (WRF v3.6.1) model with triply nested grids of 36-, 12-, and 4-km horizontal resolutions (Figure 1), coupled to the Hybrid Coordinate Ocean model (HYCOM v2.2.98) with a uniform resolution of 0.08°. The innermost domain allows for explicit treatment of convection, and Kain-Fritsch cumulus parameterization is used in the outer two domains.

An MJO event in November-December 2011 is simulated using three model experiments: an uncoupled atmosphere (UA4), a coupled atmosphere-ocean (AO4), and a coupled atmosphere-ocean with a modified surface layer parameterization (AO4-VC). All simulations start on 22 November 2011 at 0000 UTC, and are integrated for 15 days using the ECMWF and HYCOM analyses as initial and boundary conditions.

In UA4, the SST field from the initial HYCOM analysis is kept constant throughout the simulation. In AO4, the atmosphere is coupled to the ocean model, and SST evolves due to both atmospheric and oceanic processes. In AO4-VC, the WRF surface layer parameterization is modified to reduce air-sea fluxes based on observations from the Dynamics of MJO (DYNAMO) field campaign (Figure 5; Moum et al., 2014; Chen et al., 2016). The modification is implemented by scaling down the convective velocity (V^c) parameterization over water:

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

$$V_m^c = 2\sqrt{\frac{\partial \theta_v}{\partial z}} \rightarrow V^c = \begin{cases} V_m^c & \text{in AO4} \\ 0.5 \cdot V_m^c & \text{in AO4-VC} \end{cases} \quad (1)$$

where LHF is the latent heat flux (same applies to the sensible heat flux), q is specific humidity, V_{10} is the wind at 10 m, and θ_v is the virtual potential temperature. The subscript m identifies the initial model parameterization.

The MJO simulations are evaluated using in-situ observations collected during DYNAMO and satellite observations of precipitation, winds, and SST.

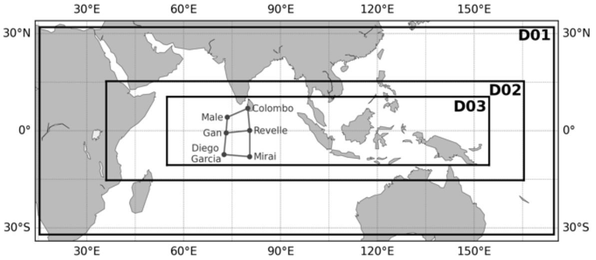

FIGURE 1: WRF domain configuration. D01, D02, and D03 boxes mark the boundaries of the 36-, 12-, and 4-km grid resolution domains, respectively. HYCOM model domain is collocated with D01. DYNAMO data collection sites are labelled in the Indian Ocean.

3. Results

a. MJO event in UWIN-CM

Compared to observations of rain rate (TRMM 3B42), surface zonal winds (ECMWF analysis), and SST (TMI/AMSR-E), the model generally reproduces the eastward propagation of the MJO convective envelope, and the surface westerly winds (Figure 2). AO4 and AO4-VC are closer to observations than UA4, although UWIN-CM overproduces the amount of precipitation in all experiments. The positive rain bias is largest in UA4 and smallest in AO4-VC.

The observed SST cooling following the passage of MJO precipitation is present in coupled experiments (AO4 and AO4-VC), but is weaker than observed in both. Compared to AO4, reducing air-sea fluxes in AO4-VC leads to weaker surface wind and warmer SST.

b. Eastward Propagation of the MJO

To further examine the structure of the MJO convection and its eastward propagation, we use the large-scale precipitation tracking (LPT) algorithm developed by Kerns and Chen (2016). LPT identifies precipitation features that sustain a rainfall rate above a chosen threshold over a period of at least three days, and over hundreds to thousands of kilometers in horizontal

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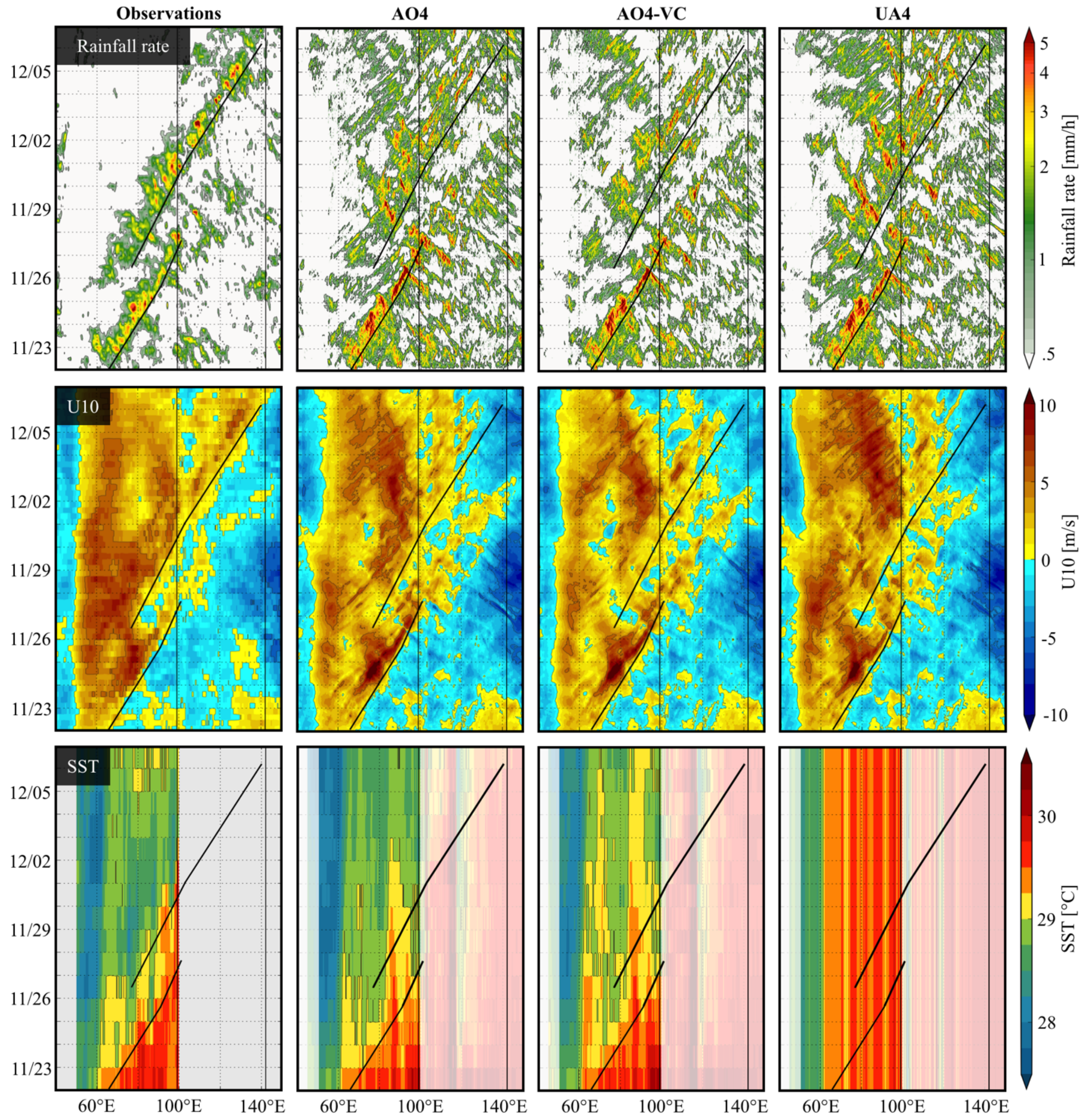

FIGURE 2: 5°S-5°N Hovmöller diagrams of rainfall rate (top), surface zonal wind (U10, middle), and SST (bottom) showing observations (leftmost column) and model simulations (from left to right): AO4, AO4-VC, and UA4, respectively. The greyed out areas in SST panels correspond to missing data in observations. Thin vertical lines at 98E and 145E mark the bounds of the MC. Thick black lines in every panel are identical and follow the leading edge of convection in TRMM (top left).

extent. We use 12 mm/day as the precipitation threshold for TRMM data, and compare the features to a 13 mm/day threshold in UWIN-CM since the model produces higher rainfall overall.

The propagation of the MJO convective envelope is represented by LPT as shown in Figure 3, where different colors outline the MJO convective area at different times. The observed MJO propagation (top left) is smoother and more continuous than the propagation produced in model experiments. AO4 produces a better eastward-propagating LPT across the MC than UA or AO4-VC. One possible contributing factor is that the MJO-induced SST cooling is better resolved in AO4, which reduces excessive convection over the IO. In AO4-VC, the precipitation field is less noisy (Figure 2), resulting in a smoother eastward propagation for the first half of the simulation. However, where the SSTs are warmer over the IO than in AO4, convection redevelops

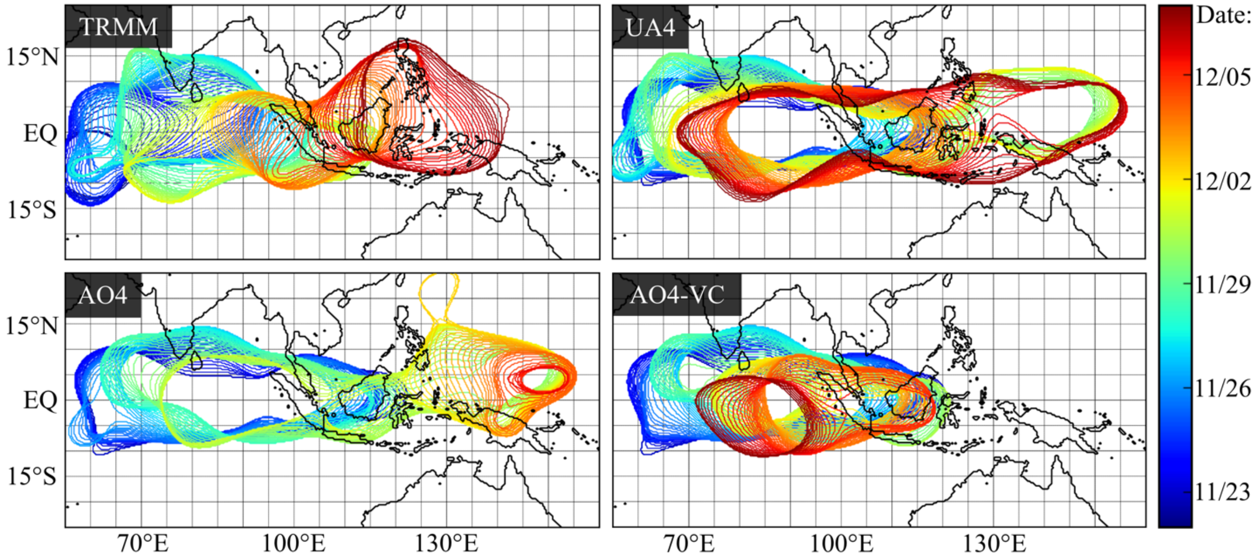

FIGURE 3: Time evolution (colors progressing from blue to red) of the LPT algorithm-tracked MJO precipitation. Each contour represents the area within which the three-hourly precipitation accumulation exceeds the chosen threshold. TRMM observations are shown on top left, and model experiments as follows: UA4 (top right), AO4 (bottom left), and AO4-VC (bottom right).

and produces a westward-propagating feature shown in the LPT (Figure 3, bottom right).

In UA4, the back edge of the MJO precipitation hangs over the constantly warm (compared to coupled experiments and observations) SSTs in the western IO. The strong winds and warm water continue to moisten the atmosphere through evaporation (Figure 4), creating conditions that continue to support precipitation. In the coupled experiments, the SST cooling creates an environment that is unfavorable for maintaining intense precipitation, making it easier for the MJO convection to reform further east, over the MC.

4. Conclusions and Discussion

Three simulations of the November-December 2011 MJO event were examined to determine the role of air-sea coupling on the eastward propagation of the MJO convection. It was found that the SST cooling induced by intense precipitation and strong surface winds of the MJO create an environment unfavorable for sustaining MJO precipitation. This causes the precipitation to form further eastward, over the MC, where conditions are more favorable.

In AO4-VC, the improved air-sea fluxes reduce the amount of precipitation. However, even though the air-sea flux bias over water is reduced by 10% (30% for winds less than 5 m/s) when compared to observations taken at RV Revelle (Figure 5), that change impacts other components of the coupled system. Less evaporation leads to weaker SST cooling in the ocean, and the relatively-warmer SSTs (compared to AO4) can support higher evaporation rates for a longer time. This somewhat counteracts the reduction of precipitation by reducing the fluxes themselves. Atmosphere-ocean coupling improves the eastward propagation of the MJO envelope, reducing the precipitation bias from an

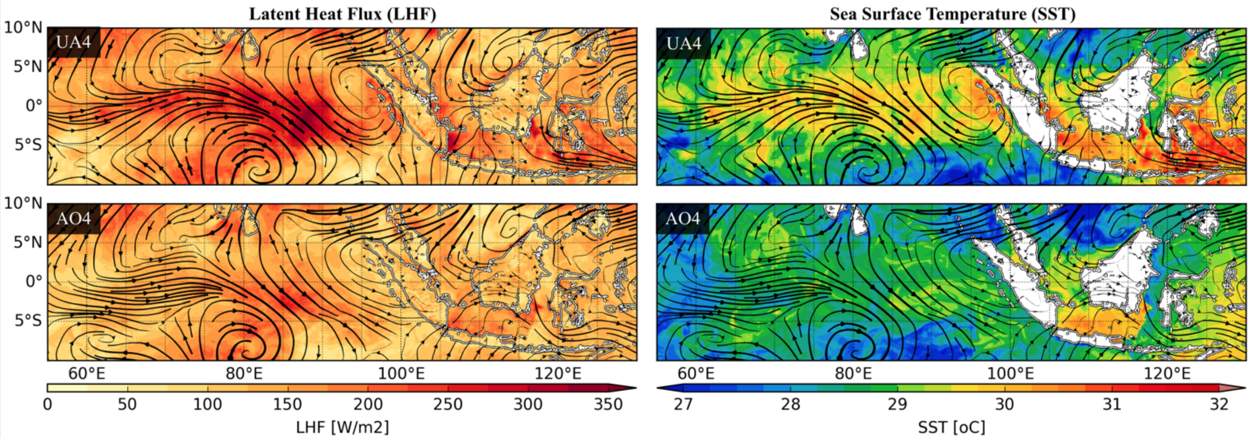

FIGURE 4: 5 December 2011 daily-averaged LHF (evaporation, left) and daily-averaged SST (right) for UA4 (top) and AO4 (bottom) experiments. The streamlines indicate the daily-averaged wind speed and direction at the surface.

average of 61% (0.23 mm/h) in UA4 to 45% (0.16 mm/h) in AO4 (Figure 6).

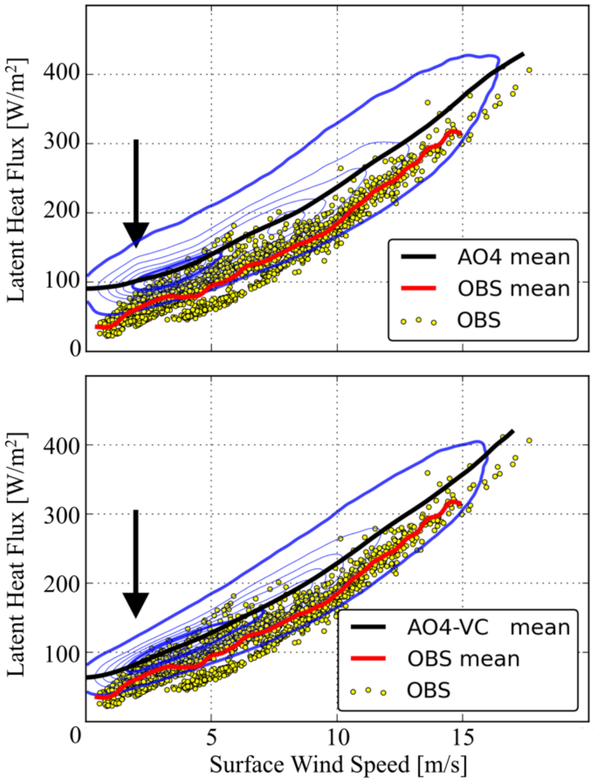

FIGURE 5: LHF distribution as a function of surface wind speed in RV Revelle in-situ measurements (yellow) and in AO4 (top) and AO4-VC (bottom) in blue contours. Only points within one degree of the ship's location are used for model distributions.

Improving air-sea fluxes in AO4-VC further reduces the precipitation bias to 30% (0.11 mm/h), showing that an accurate representation of coupling processes is also important for MJO prediction.

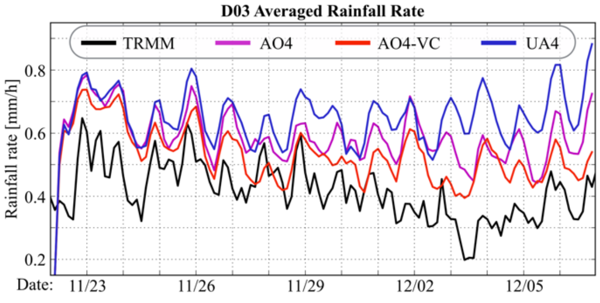

FIGURE 6: Time series of D03-averaged rainfall rate in TRMM observations (black) and model experiments.

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