Decrease in MJO predictability following Indo-Pacific Warm Pool expansion

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Kim (2024, GRL)

ABSTRACT

Key Points

- A sensitivity experiment was performed using CESM2 aquaplanet with different prescribed SSTs.
- Expanding the Indo–Pacific warm pool makes the MJO-like waves less organized.
- The warm pool expansion quickens the forecast error increase and predictability decrease.

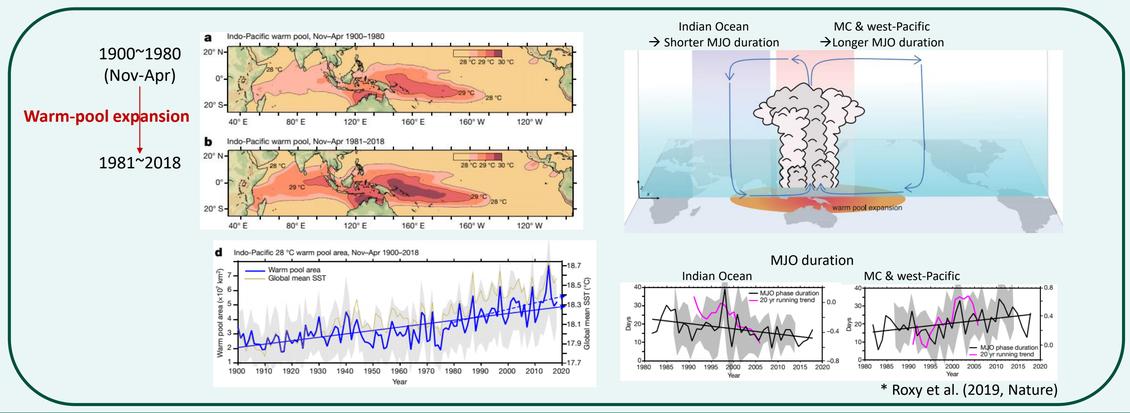
The characteristics of the MJO have changed and are projected to continue changing with the expansion of the Indo–Pacific warm pool, which is the Earth's largest region of warm SST. However, the likelihood of a change in MJO predictability following warm pool expansion remains unaddressed. This study investigated the effect of warm pool expansion on MJO variability and predictability using the highly idealized aquaplanet configuration of CESM2. By expanding the warm pool in the Indo–Pacific, MJO-like waves become more regionally confined, short-lived convective events with weaker magnitude and less robust eastward propagating signals, possibly due to stronger zonal SST gradients and wider meridional widths of the warm pool. Perfect-model ensemble forecast experiments revealed that the MJO predictability decreased by approximately five days, the forecast error proliferated, and the signal rapidly reduced following warm pool expansion.

(Previous studies) By warm-pool expansion:

→ Shorter MJO duration over Indian Ocean

→ Longer MJO duration over Maritime Continent & west-Pacific

Q: How much of MJO predictability is altered by the warm-pool expansion?



* Roxy et al. (2019, Nature)

CESM2 Aqua-planet Experiment

CESM2 CAM6 Aqua-planet:

- 1.25°x 0.9° resolution, 32 vertical levels
- Earth is completely covered by water.
- Prescribed SST
- CO_2 = 348 ppm

"CTRL" run

- Reasonable warm pool pattern
- Tropical intraseasonal variability
- Warm-pool size: 2×10^7 km^2

"Warm Pool Expansion (WPE)" run

- ~3 °C warmer SST at maximum
- Expanded Warm Pool area
- Warm-pool size: 6×10^7 km^2
- Stronger SST zonal gradient
- Westerlies appear in the equatorial warm pool
- Enhanced Walker circulation

10-year perpetual runs

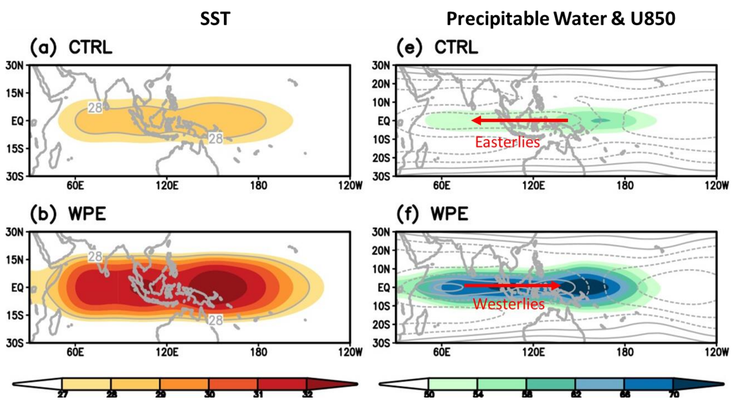
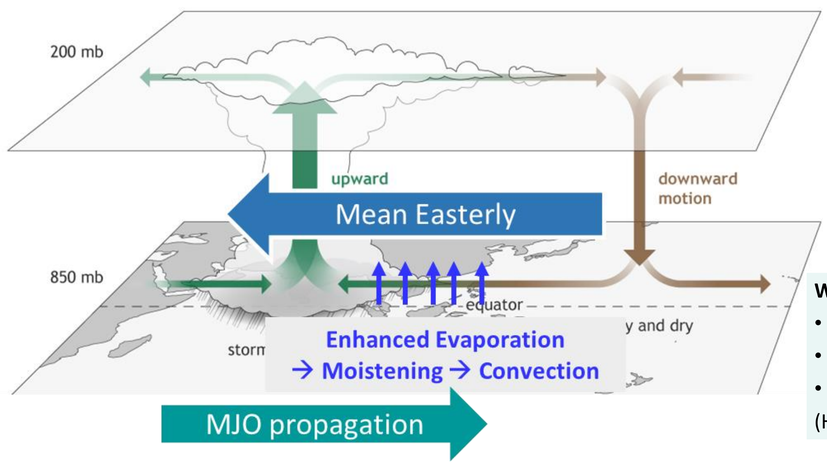


Figure. 1. Climatology of SST (°C) in the (a) CTRL, (b) warm-pool expansion (WPE) runs. Climatological 28 °C isotherm is marked as gray contour in (a, b). The right panel shows the total precipitable water (TPW) (shading, kg m^{-2}) and U850 (contour).

Dynamical processes

Q: Why is MJO activity suppressed by the warm-pool expansion?

Wind-induced Surface Heat Exchange (WISHE) theory



Warm-pool expansion induces:

- Stronger zonal SST gradient
- Mean westerly
- Suppressed MJO activity

(Hypothesis based on WISHE theory)

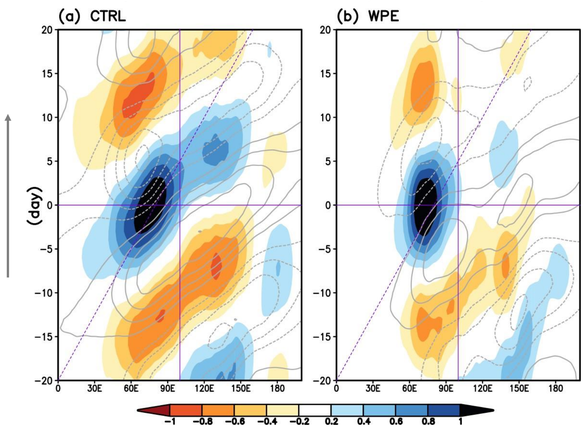
- WISHE in aqua-planet: Fuchs and Raymond (2017), Khairoutdinov and Emanuel (2018), Shi et al. (2018)
- Westerly wind-MJO: Suematsu and Miura (2018, 2022) ; Pohl & Matthews, (2007); Wang and Wang (2023)

MJO simulation

Q: How does the MJO characteristics change by the warm-pool expansion?

Lag regression

(filtered OLRa and U850a, 10°S-10°N)



- OLRa (shading), U850a (contour)
- Dashed lines: 5m/s phase speed.
- Reference point: filtered OLR over Indian Ocean (60°-90°E, 10°S-10°N)

Figure 2. Lag regression coefficients of anomalous OLR and U850.

20-100d filtered U850 [10°S-10°N]

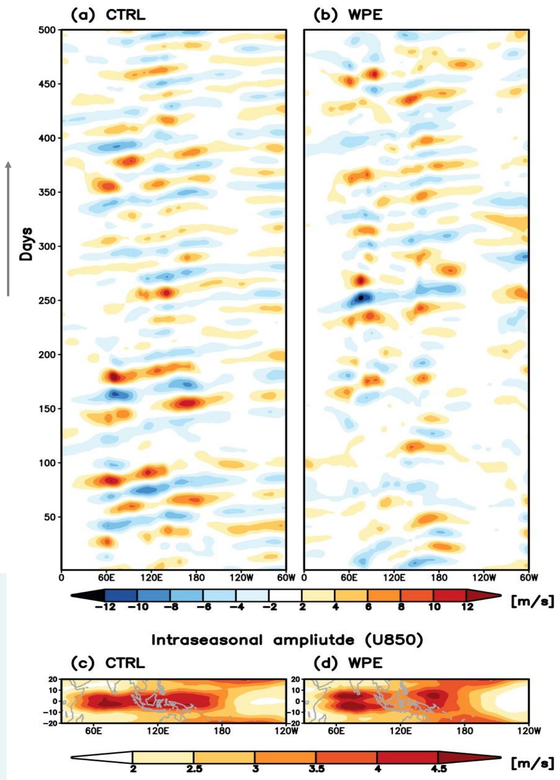


Figure 3. (a, b) Daily U850 (m/s) anomaly (10˚S–10˚N). (c, d) Intra-seasonal amplitude (STD of filtered U850)

CTRL run:

- Kelvin wave & equatorial Rossby wave: weaker than observed.
- MJO wave (wave#1-3): stronger power, shorter period (~25d)
- Weaker E/W ratio than observed.
- Robust eastward propagation.
- Circulation & convection quadrature phase relation.

Warm Pool Expansion (WPE) run:

- MJO wave: weaker power, shorter period (~20d)
- Weaker E/W ratio than CTRL run.
- Eastward-moving intraseasonal events: weaker and less frequent
- Intraseasonal amplitude is comparable to CTRL
- Regionally confined, short-lived convective events, less robust eastward-propagating signal

Wavenumber-frequency spectrum (daily OLR, 15°S–15°N)

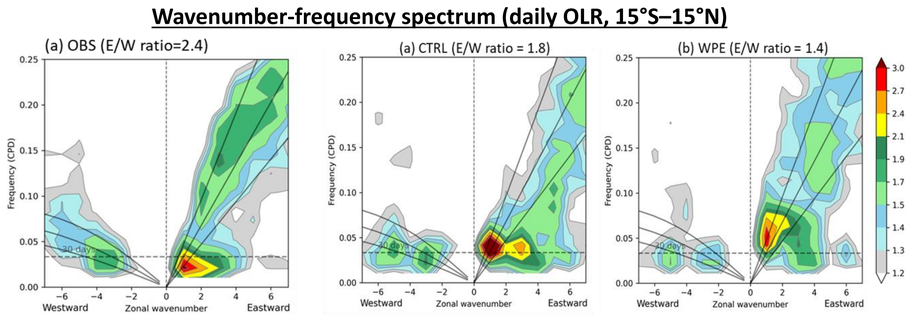


Figure 4. The symmetric OLR power spectrum ratios of tropical waves to the background power in the wave number–frequency domain for (a) CTRL and (b) WPE simulations. The E/W ratio is added on top of each figure.

Perfect-model Ensemble Forecast Experiment

Q: How much of MJO predictability is altered by the warm-pool expansion?

Perfect-model Ensemble Forecast Experiment

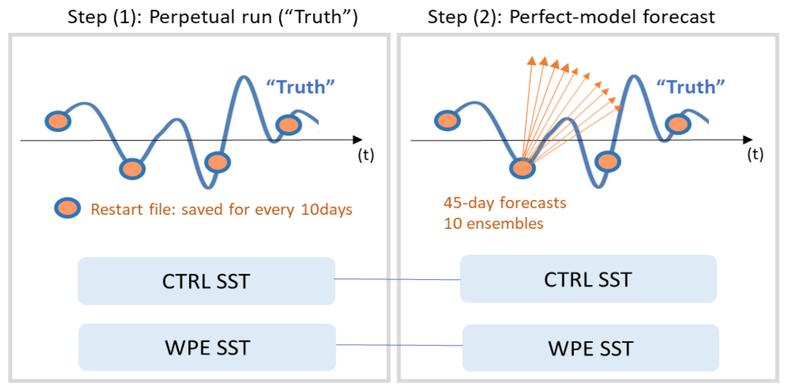


Figure 5. Schematic of experiments: Step (1) perpetual run and Step (2) perfect-model ensemble forecast experiment. The blue line represents the 10-year perpetual simulation, regarded as "truth". Brown dots are the restart files output every 10 days, which are used for initial conditions in Step (2). Brown arrows are the 10 ensembles of 45-day forecasts. Blue shading represents the prescribed SST.

Predictability (MJO index)

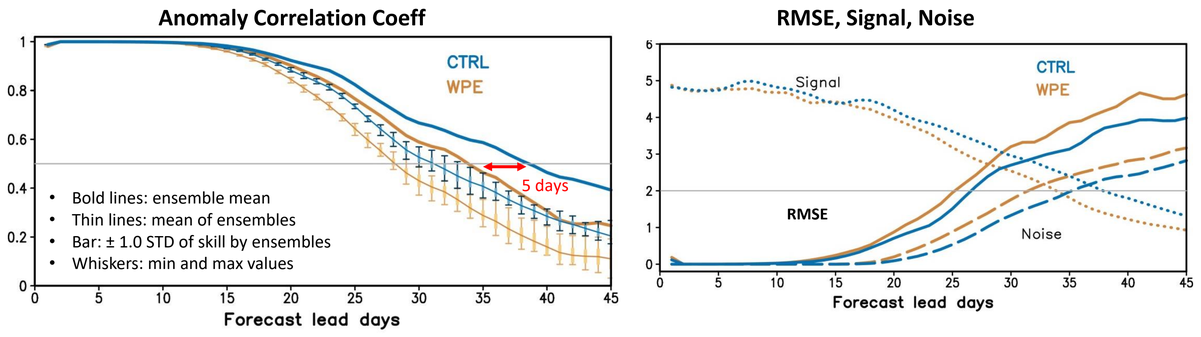


Figure 6. MJO predictability assessed by (a) BCOR, (b) BMSE (solid), signal (dot lines), and noise (dashed lines).

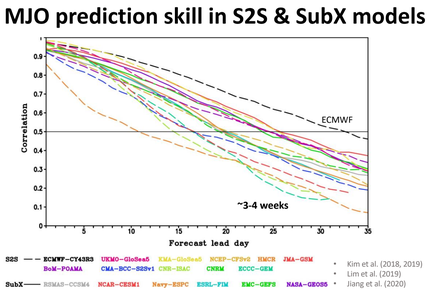
Warm Pool Expansion (WPE) run:

- RMSE increase faster (2-3 days earlier than CTRL)
- Forecast noise (ensemble spread) increases faster
- Forecast signal (variability of ensemble–mean) decrease faster
- Both ensemble forecast systems are under-dispersive (RMSE> Noise)

Q: What is the upper limit of the MJO prediction? ~ 6 weeks if model is perfect (S2S/SubX models: 3-4wks)

Q: How much skill is changed by the warm pool expansion? ~ 5 days decrease

MJO prediction skill in S2S & SubX models



▪ H. Kim, 2024: Decrease in MJO predictability following Indo-Pacific Warm Pool expansion, Geophys. Res. Lett., e2024GL108849 http://dx.doi.org/10.1029/2024GL108849

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