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Madden–Julian Oscillation, Tropical Cyclones, and precipitation extremes in E3SMv1

Daehyun Kim (Lead PI), Yumin Moon, and Daehyun Kang

University of Washington

Ruby Leung, Samson Hagos, and Phil Rasch

Pacific Northwest National Laboratory

Collaborators: Min-Seop Ahn, Jiwoo Lee, Peter Glecker, and Ken Sperber

Lawrence Livermore National Laboratory

RGMA Virtual PI Meeting
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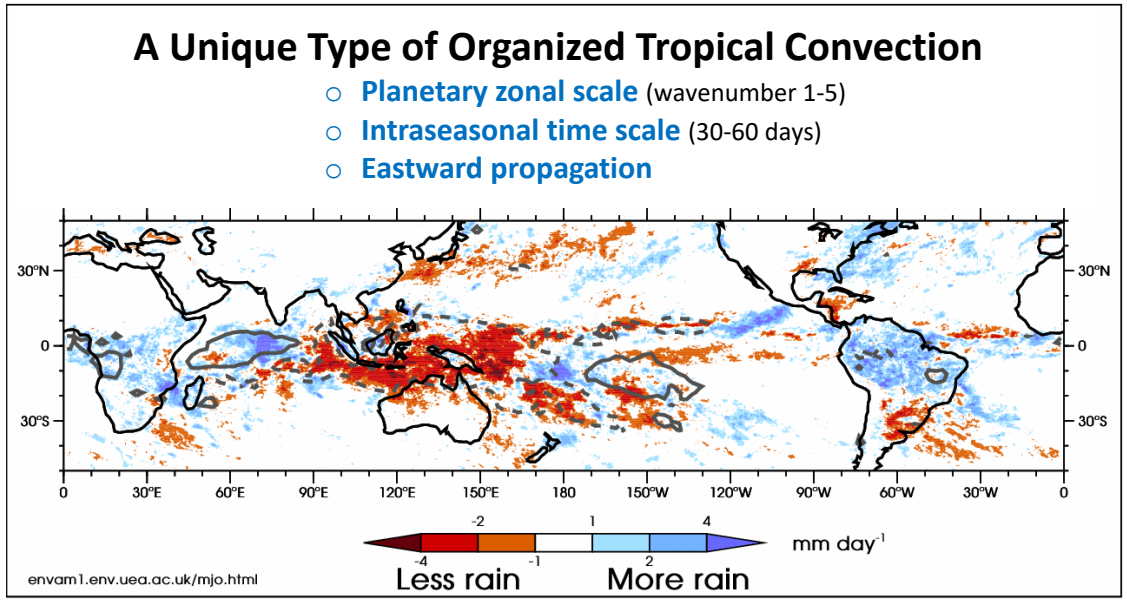
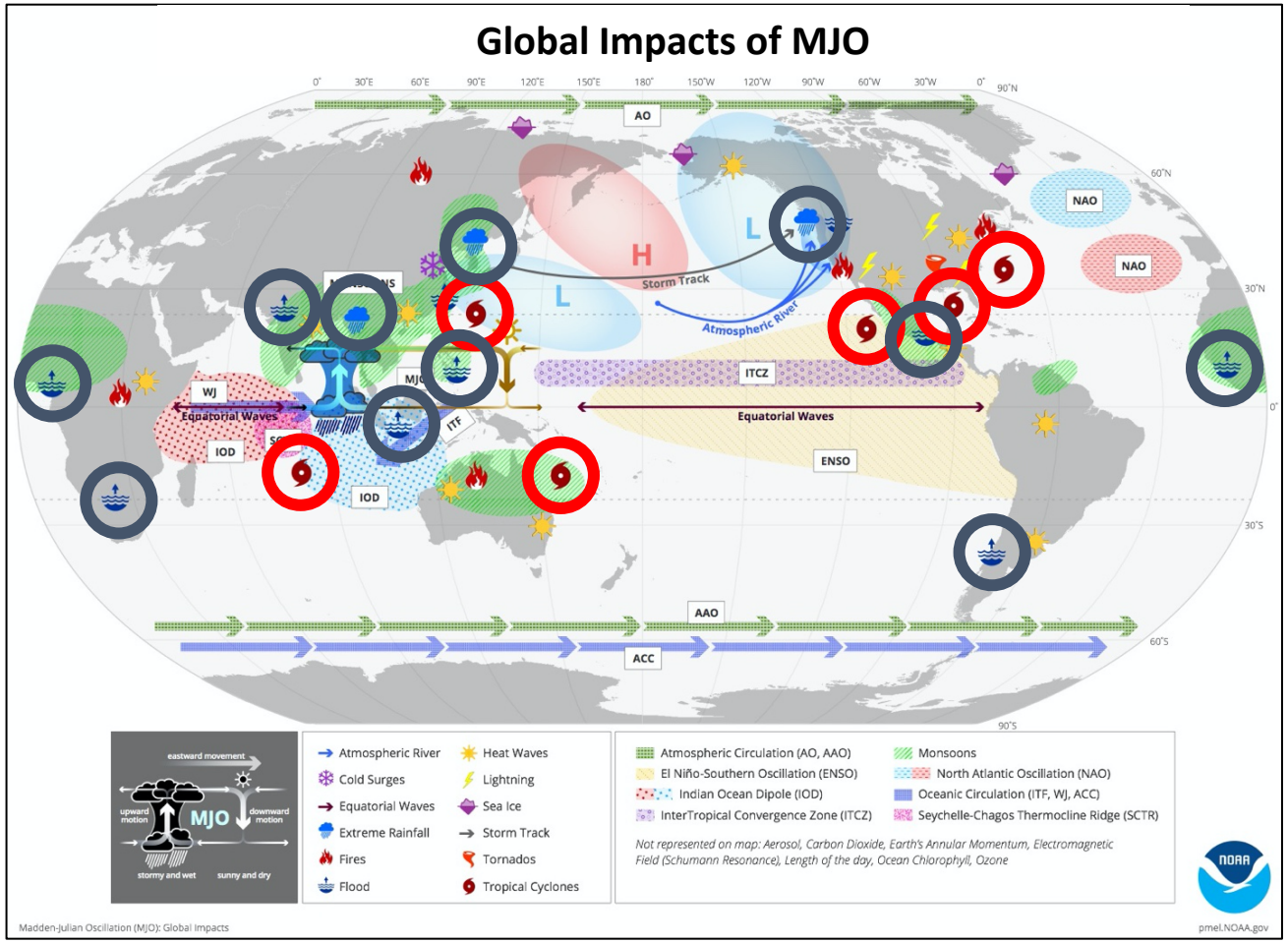
Madden-Julian Oscillation

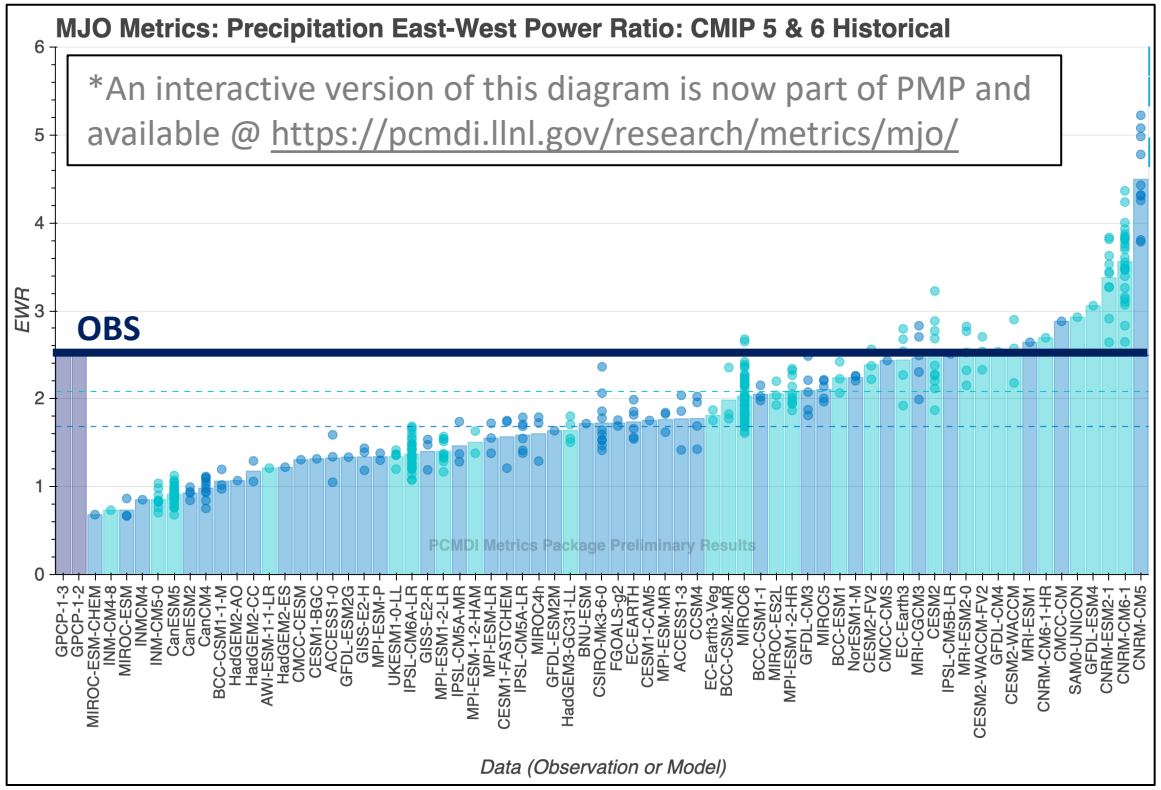




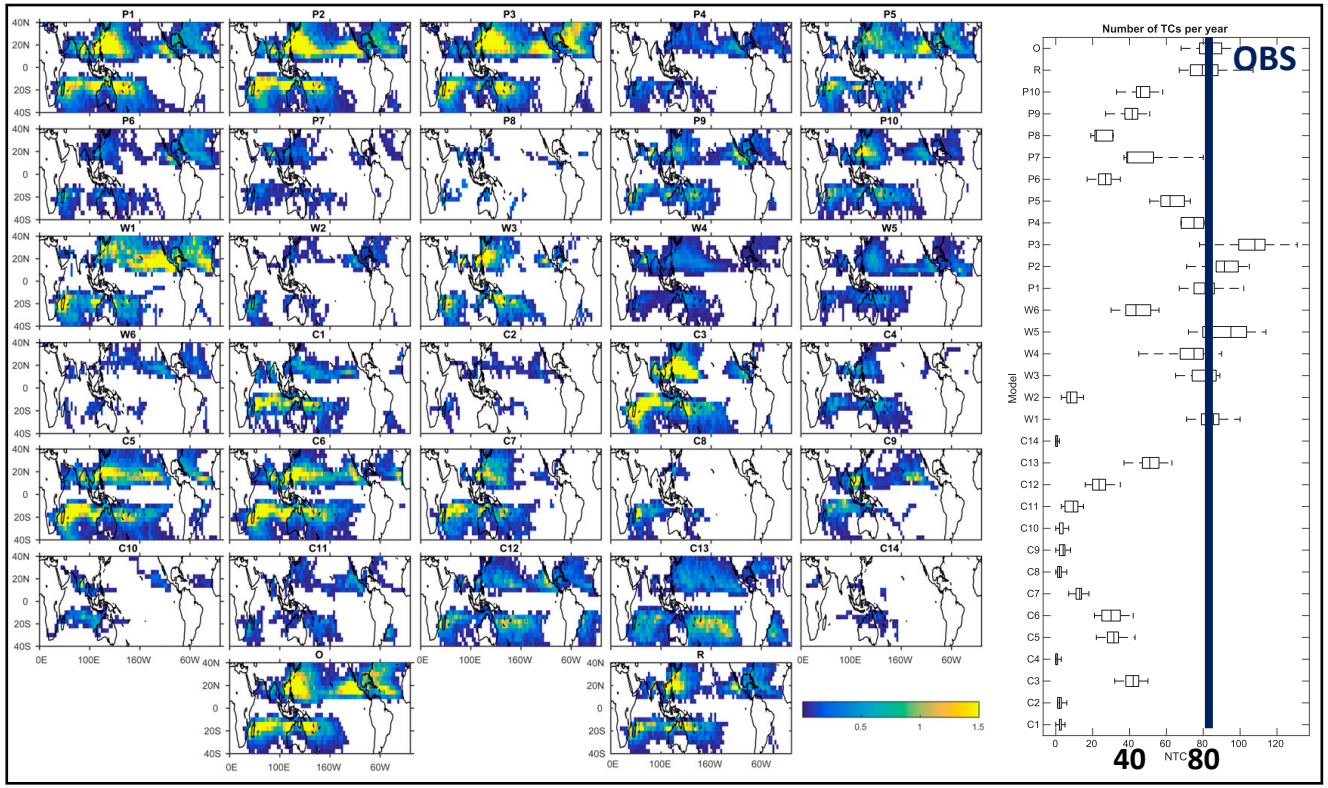
- A main source of Earth system predictability on the S2S timescale
- Interacts with a wide range of Earth system phenomena, including tropical cyclones and extreme precipitation events

MJO and TCs in Earth System Models

Madden-Julian oscillation



Tropical Cyclones



*Camargo, Giulivi, Sobel, Wing, **Kim**, **Moon** et al. (2020)*

- A wide range of model performance
- Many models struggle (even basic characteristics)
- Why are the good models good?

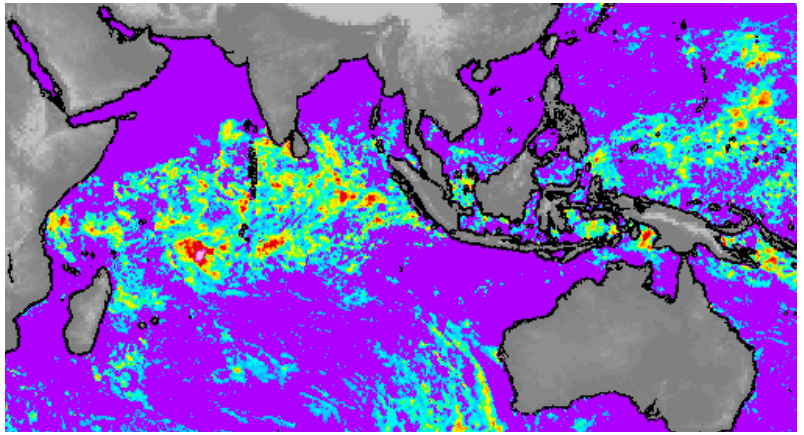
Project Goals and Objectives

Goals

- Identify process-level sources of model biases in MJO, TCs, and their associated extreme precipitation events
- Use E3SMv1 as a tool to better understand MJO and TCs

Objectives

- Analyze key processes associated with
  - MJO propagation and maintenance
  - TC genesis and intensification
- Examine multiscale connections among our target phenomena
  - MJO modulation of TC genesis
  - Association of precipitation events in the US with the MJO and TCs
- Perform hypothesis-driven simulations using E3SMv1
  - Role of Maritime Continent land diurnal cycle on MJO
  - Role of air-sea coupling and AEW on TCs



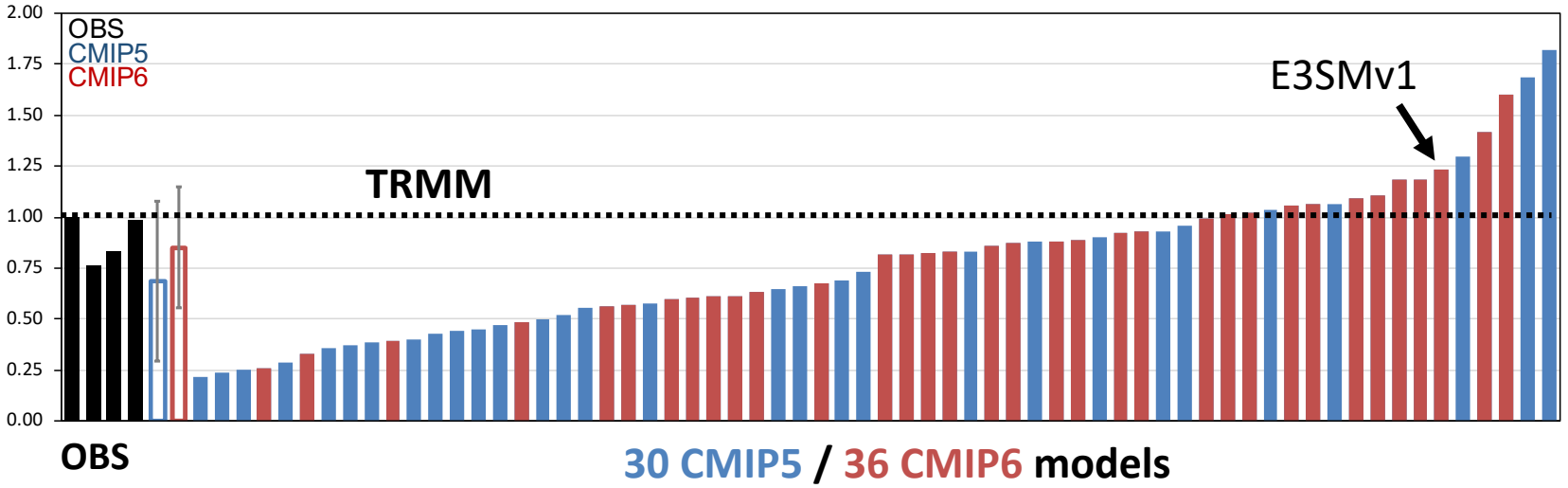
A Madden-Julian Oscillation event in April 2002 *(source: remss.com)*

Hurricane Isabel (2003)
(source: NASA)

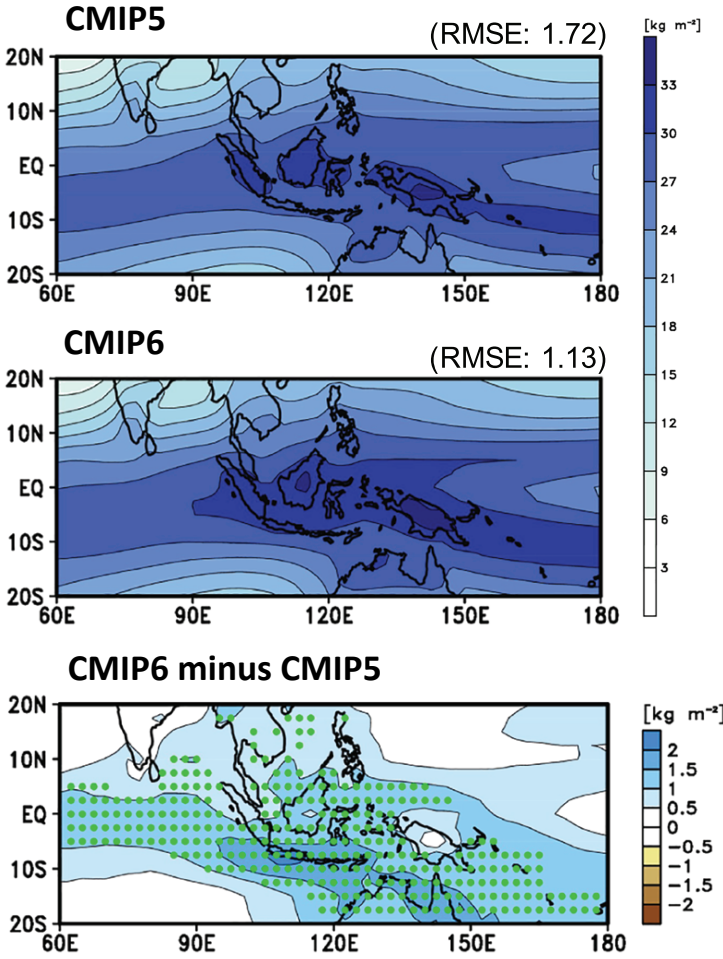
Heavy rain events in Oklahoma (May 2019)
(source: usatoday.com)

MJO Propagation over Maritime Continent

MJO MC propagation metric



Mean CWV (Nov-Apr)

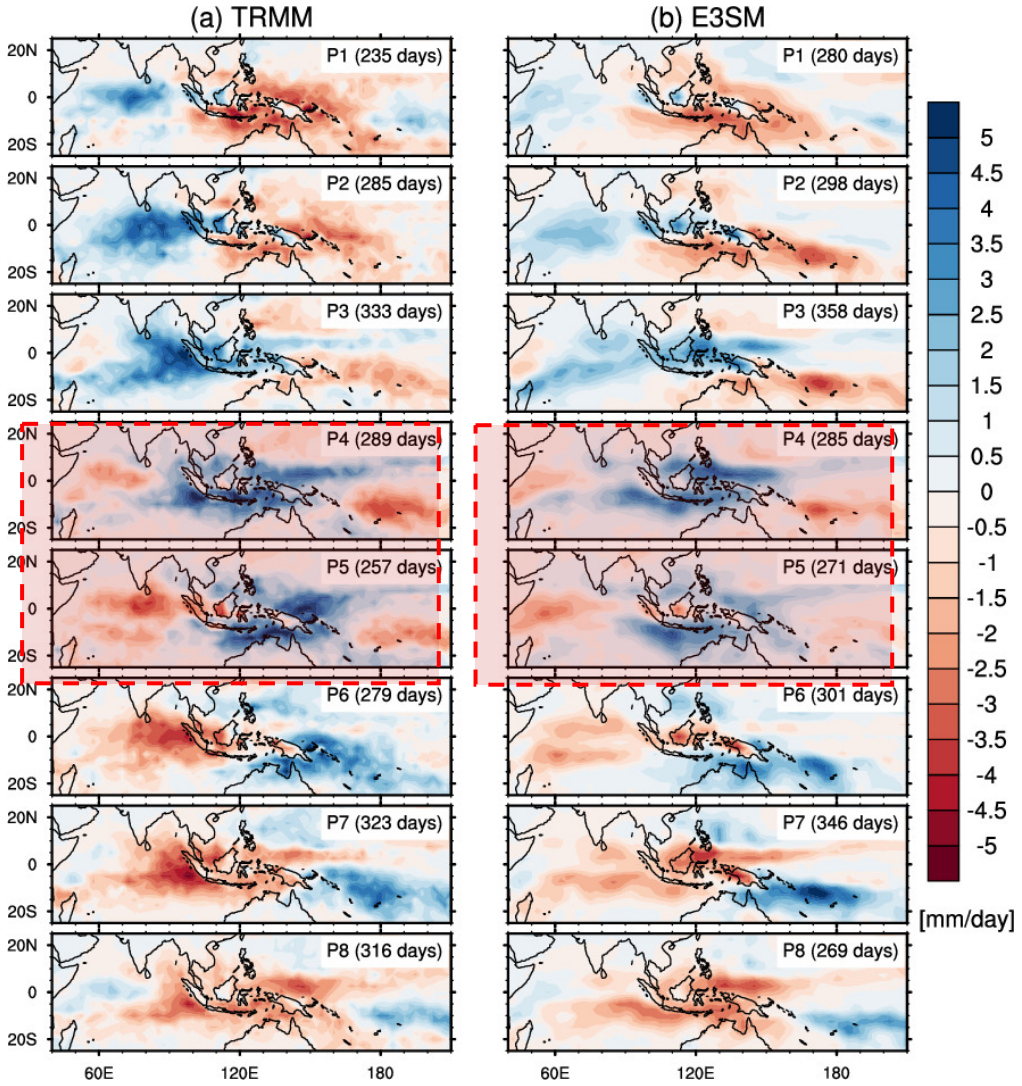


- A new metric that represents the robustness of MJO propagation over the Maritime Continent (MC) was developed and used to evaluate 66 CMIP5/6 models.
- CMIP6 models simulate MJO propagation over the MC more realistically than the CMIP5 models and with improved **mean state moisture gradient** in the MC region.

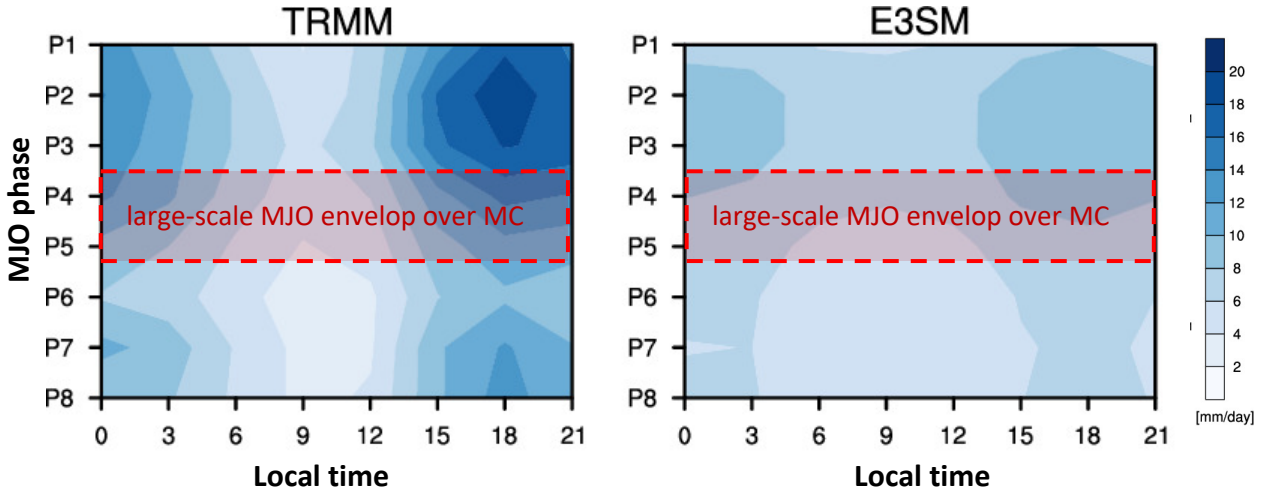
Ahn, M.-S., Kim, D., Kang, D., Lee, J., Sperber, K. R., Gleckler, P. J., Jiang, X., Ham, Y.-G., & Kim, H., 2020: MJO Propagation Across the Maritime Continent: Are CMIP6 Models Better Than CMIP5 Models? *Geophysical Research Letters*, *47*(11), e2020GL087250. https://doi.org/10.1029/2020GL087250

MJO-MC interaction in LR-E3SMv1

MJO precipitation anomalies

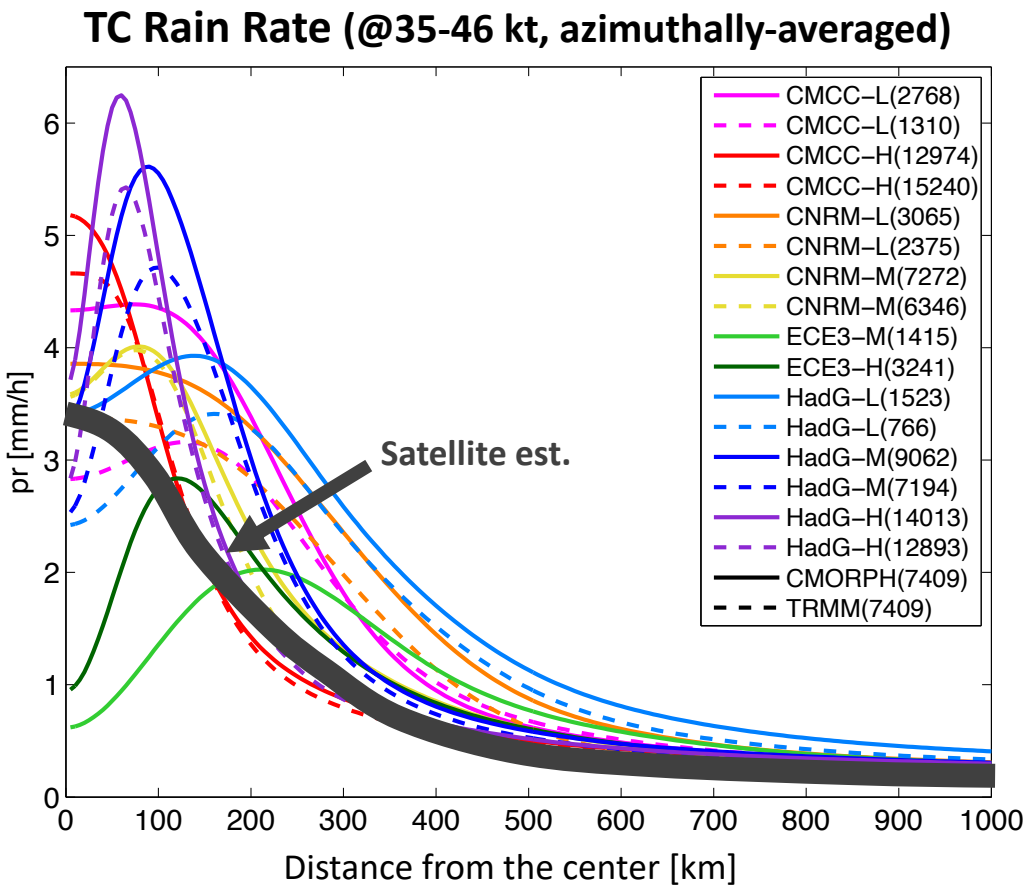


MJO modulation of diurnal cycle precipitation in Borneo



- E3SMv1 reasonably simulates the large-scale MJO precipitation anomaly patterns as well as the modulation of diurnal cycle over the Maritime Continent islands
- Horizontal moisture advection plays an important role in the MJO modulation of MC land diurnal cycle
- Work in progress: diurnal cycle vs. background moisture gradient (Daehyun Kang, Tues Breakout Session)

TC Rainfall in HighResMIP Models

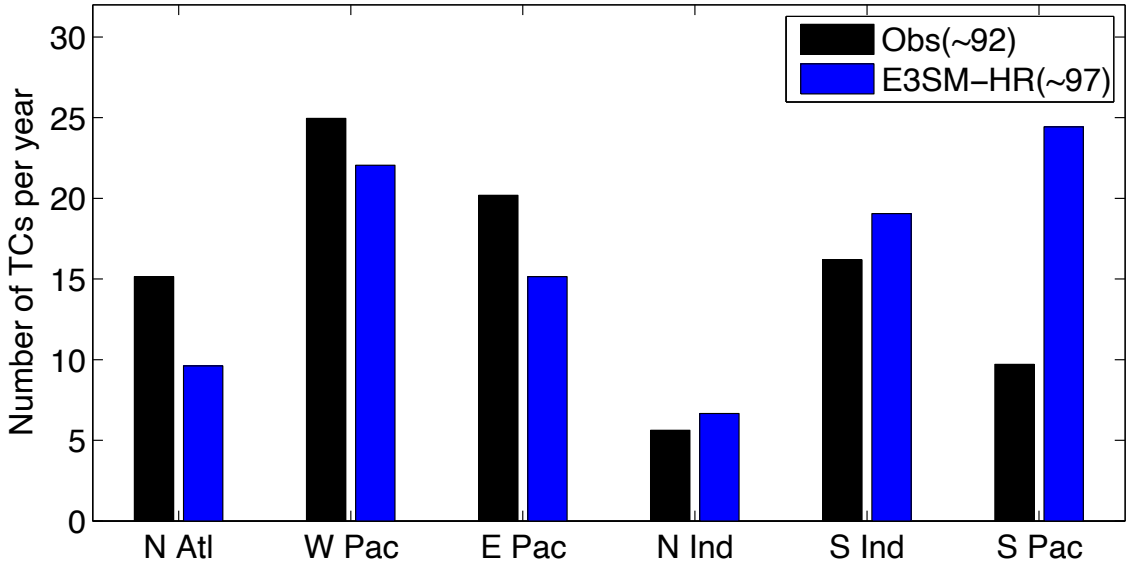


- Many HighResMIP simulations tend to overproduce the rain rates around TCs, in terms of the maximum rain rate magnitude and area-averaged rain rates.
- As model horizontal resolution increases, the magnitude of the peak rain rate appears to increase.

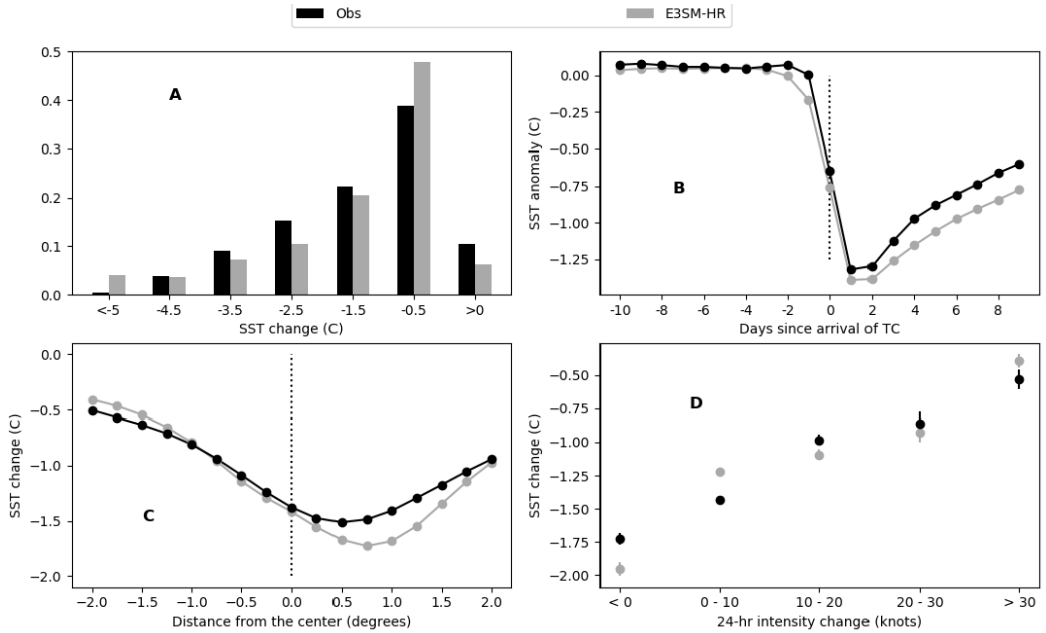
Moon, Y., D. Kim, A.A. Wing, S.J. Camargo, M. Zhao, L.R. Leung, M.J. Roberts, 2020: An evaluation of GCM-simulated tropical cyclone rainfall structures in the HighResMIP simulations against satellite observations. J Climate, to be submitted.

Tropical Cyclones in HR-E3SMv1

of TCs per year



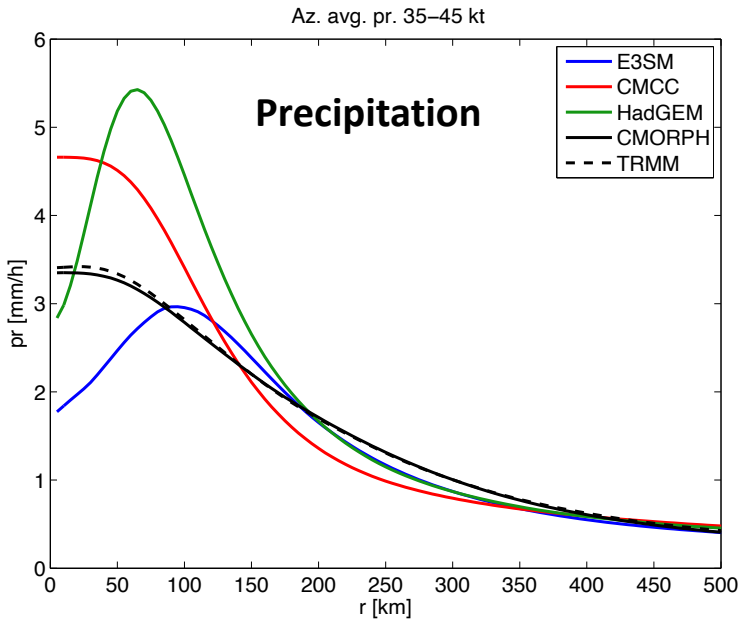
TC-induced SST cooling in HR-E3SMv1



- HR-E3SMv1 (0.25˚) simulates the global TC activity reasonably well, in terms of the total global number of TCs and TC track density
- TC-ocean interactions are realistically represented in HR-E3SMv1
- Work in progress: MJO modulation of TC genesis, the role of seed disturbances (Yumin Moon, Tues Breakout session)

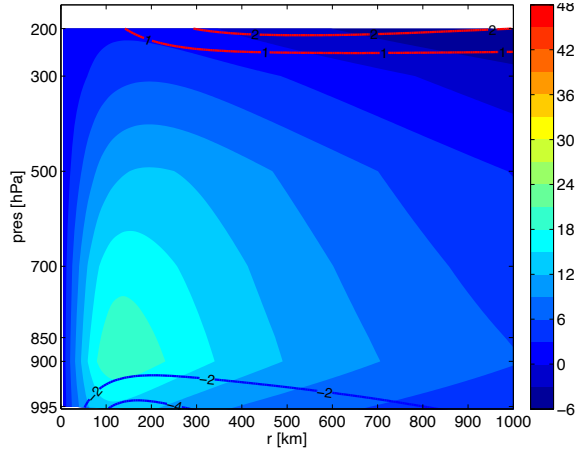
Balaguru, K., **Leung, L. R.**, Van Roekel, L. P., Golaz, J.-C., Ullrich, P. A., & Caldwell, P. M., et al., 2020: Characterizing tropical cyclones in the Energy Exascale Earth System Model version 1. *Journal of Advances in Modeling Earth Systems*, 12, e2019MS002024.

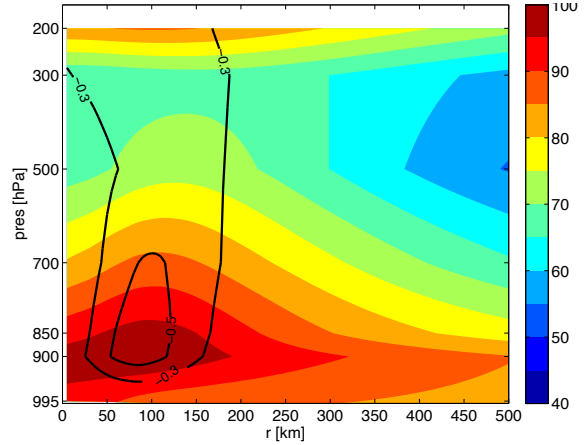
TC Structure in HR-E3SMv1



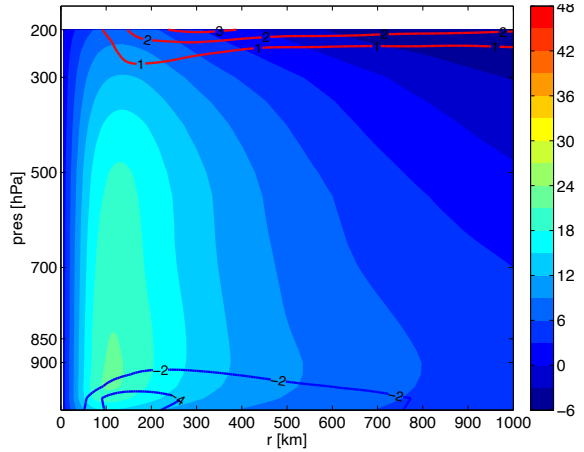
- In E3SMv1, precipitation near TCs is lower than in other simulations made with a similar resolution
- E3SMv1 TCs are shallower with a drier upper troposphere, which may inhibit the vertical growth of convection and TC circulation

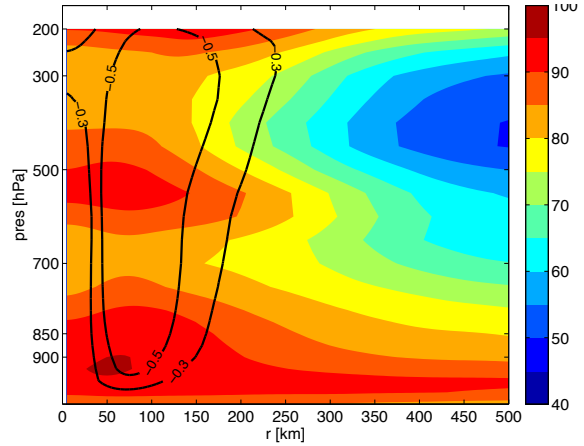
E3SMv1 (35-45 kts)





ERA5 (35-45 kts)





Tangential (shaded) and radial (contours) winds

Relative humidity (shaded) and omega (contours)

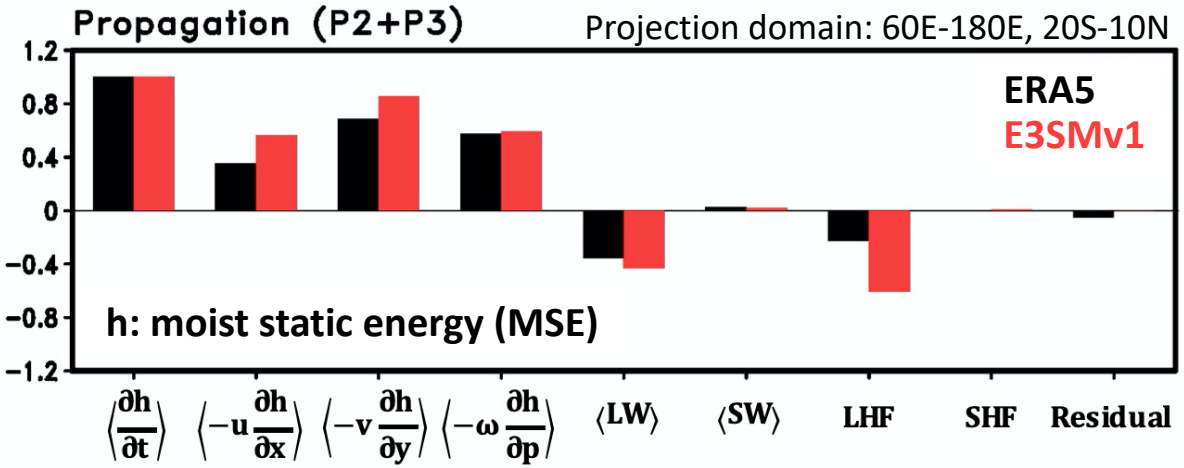
Summary

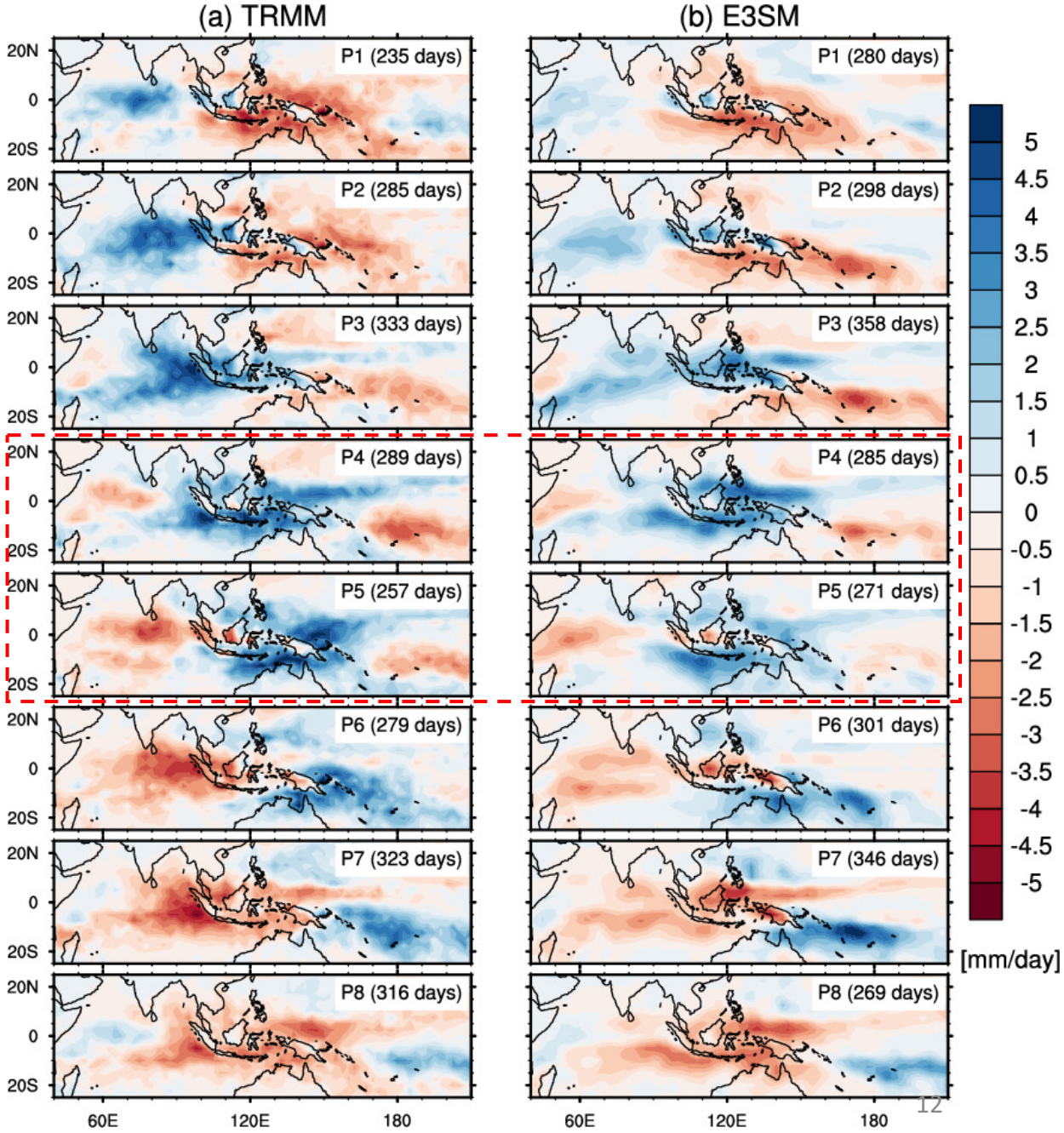
- Finding
  - Moisture gradient is a key aspect of the mean state that affects MJO
  - Many models overestimate TC rainfall, air-sea coupling improves the bias
- Analysis
  - Structure, moist static energy budget, and seasonality of the MJO
  - MJO teleconnections to mid-latitude and MJO-MC interactions
  - TC rainfall, wind, and thermodynamic structure and TC-induced SST changes
- Metrics
  - MJO East/West power ratio implemented in the PCMDI metrics package
  - MJO MC propagation metric developed and applied to CMIP5/6 models
  - A horizontal resolution-dependent TC wind speed adjustment factor developed for model evaluation
- Data
  - 20-year E3SMv1 coupled simulation performed outputting *many* variables. Data is available.

Extra Slides

MJO in E3SMv1

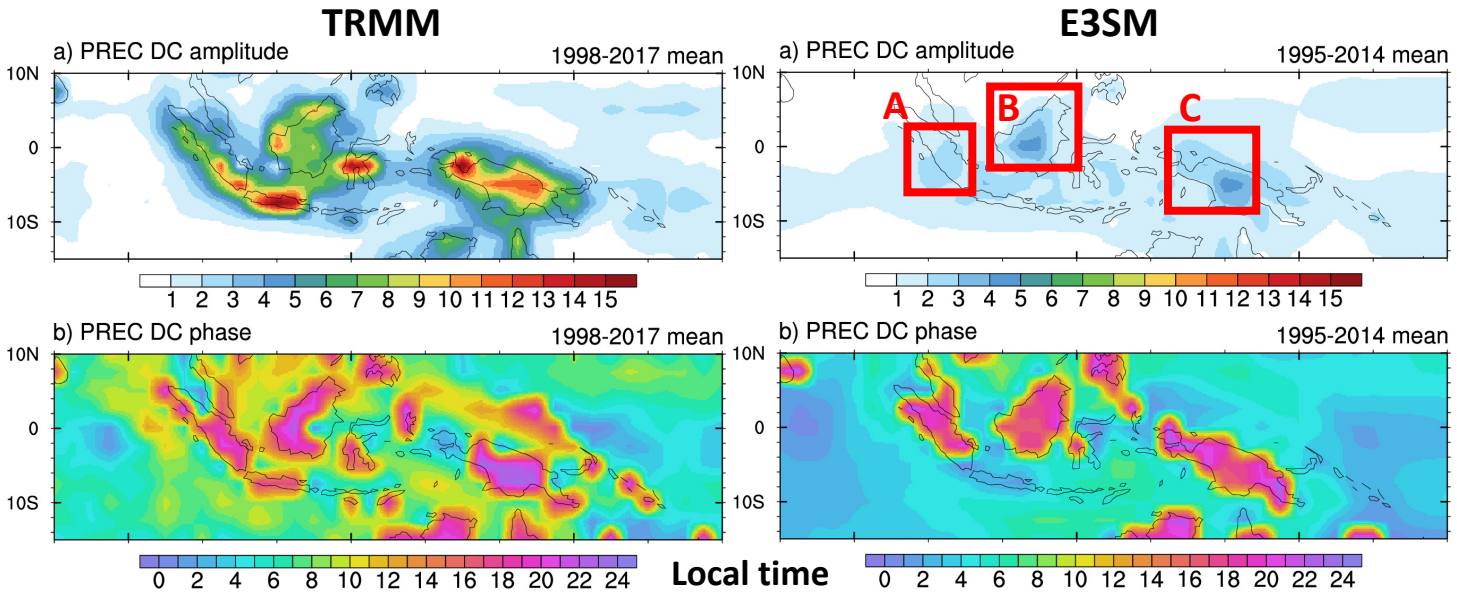
- E3SMv1 realistically simulates MJO's eastward propagation, including the spatial pattern of precipitation anomalies around the Maritime Continent (phases 4 and 5)
- MJO MSE budget shows that horizontal and vertical advection terms are responsible for the eastward propagation, as in observations and consistent with the moisture mode framework

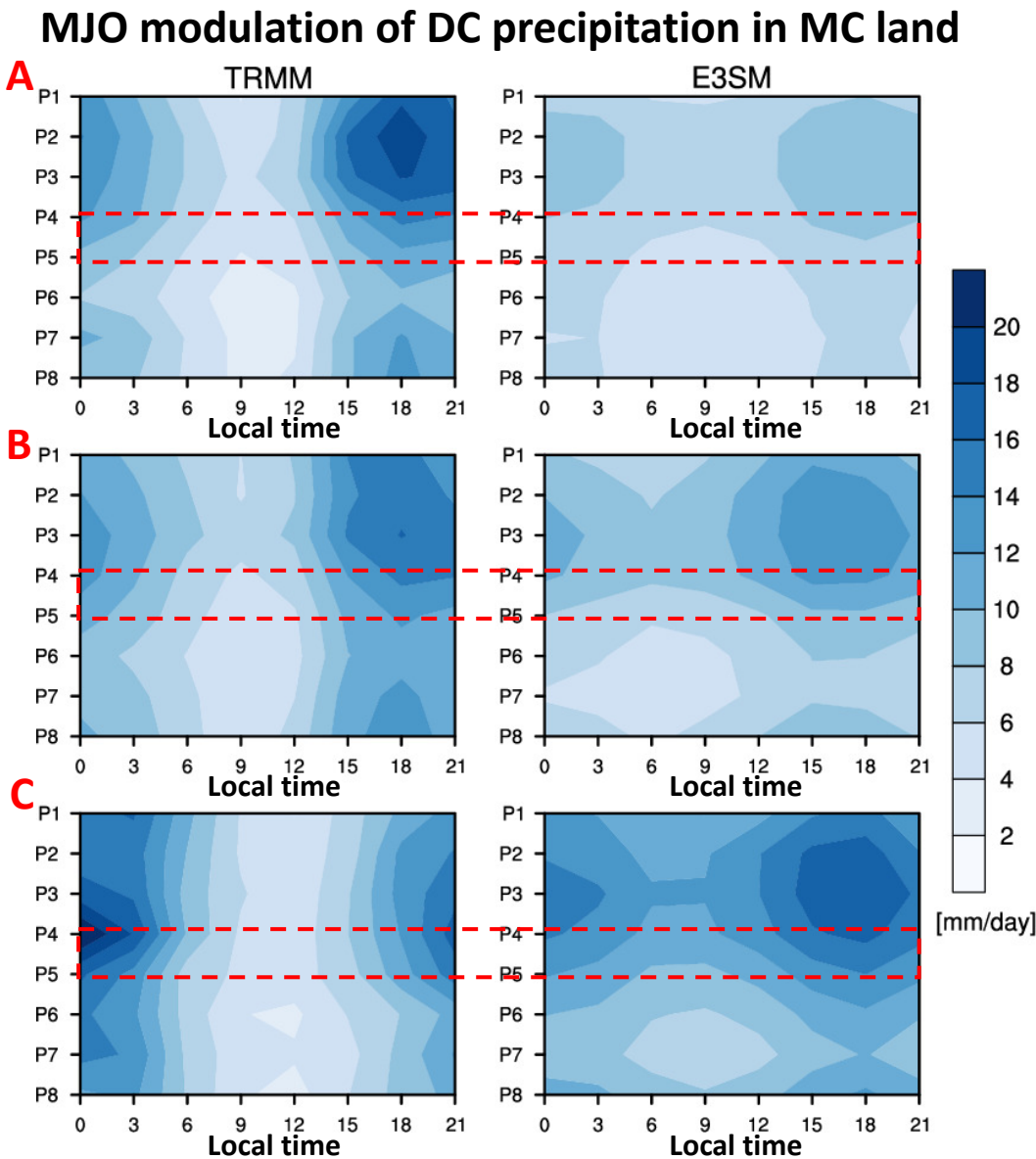




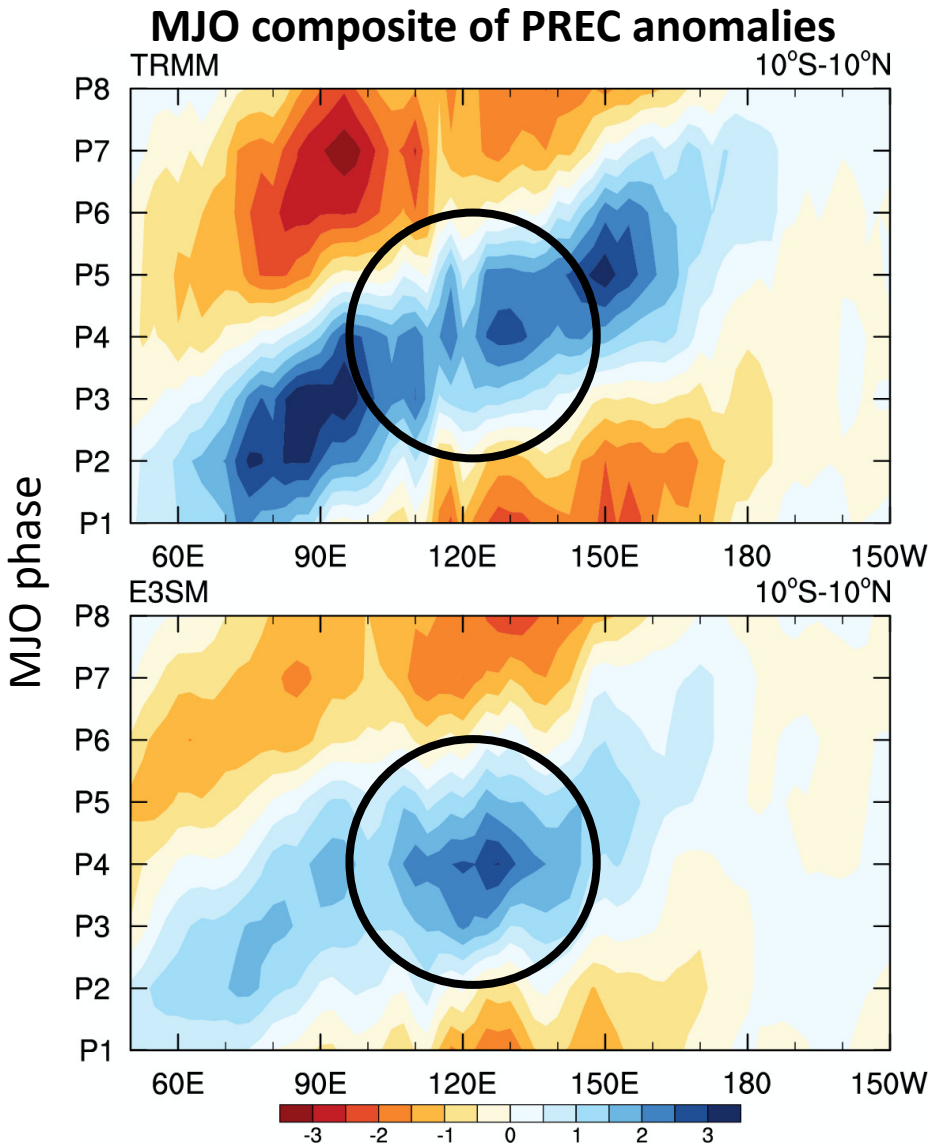
MJO Modulation of MC Diurnal Cycle

- The role of MC diurnal cycle (DC) on the propagation of the MJO is poorly understood
- E3SM exhibits much weaker DC amplitude than the observed (20-30%), whereas DC phase is realistic (evening peak in land, morning peak in the ocean)
- Despite the amplitude bias, increase in diurnal precipitation before the main envelop of MJO is realistically captured in the model



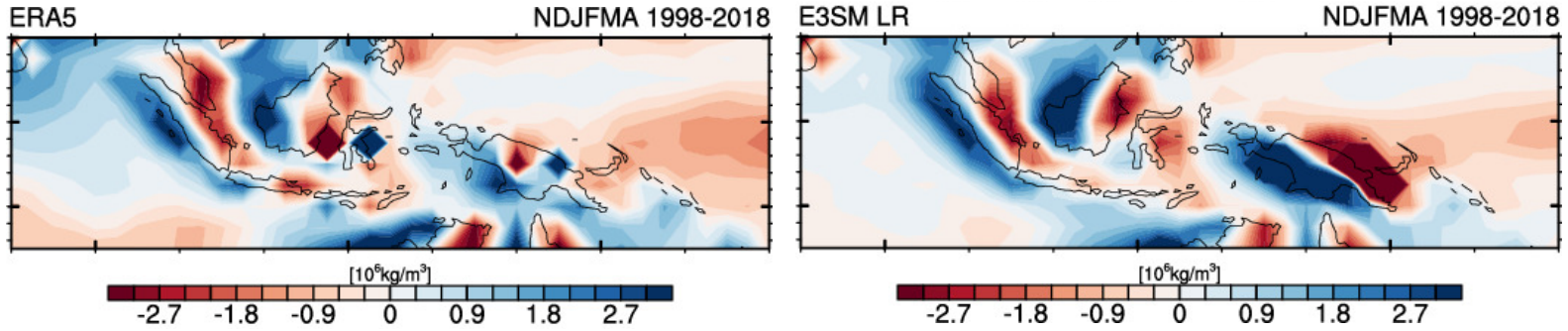


MC Barrier Effect on MJO



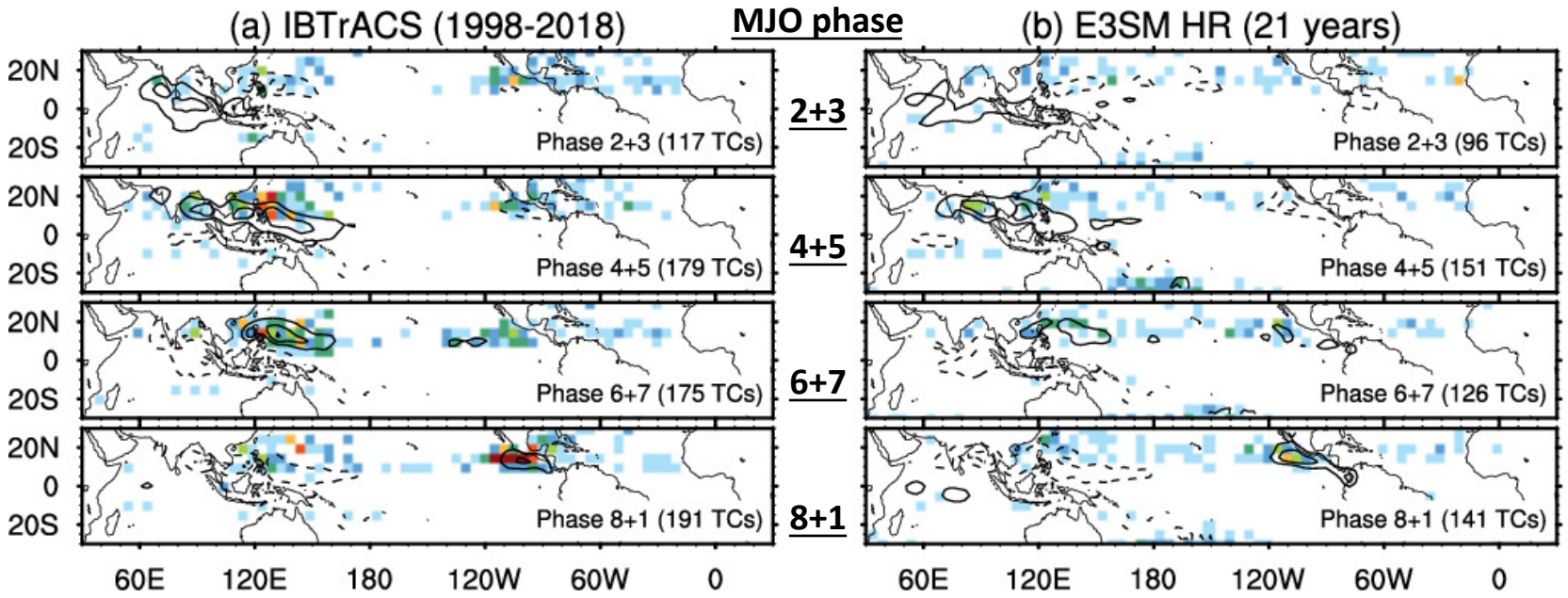
- The MC barrier effect on MJO is not fully understood and is poorly represented in many climate models
- The MC barrier effect does not present in E3SM, in which MJO precipitation anomalies are stronger in the MC than in the adjacent ocean basins
- Jiang et al. (2019) argued that MJO weakens in the MC region due to the steep negative zonal moisture gradient to the east of Sumatra and Borneo, which is contradictory to our results
- The weak MC barrier effect in E3SM might be due to the weak diurnal cycle amplitude

Climatology of zonal moisture gradient (integrated between 925-700 hPa)



Modulation of TC genesis by MJO

RMM composite (amplitude > 1) and TC genesis in 5˚ x 5˚ grid (MJJASO)

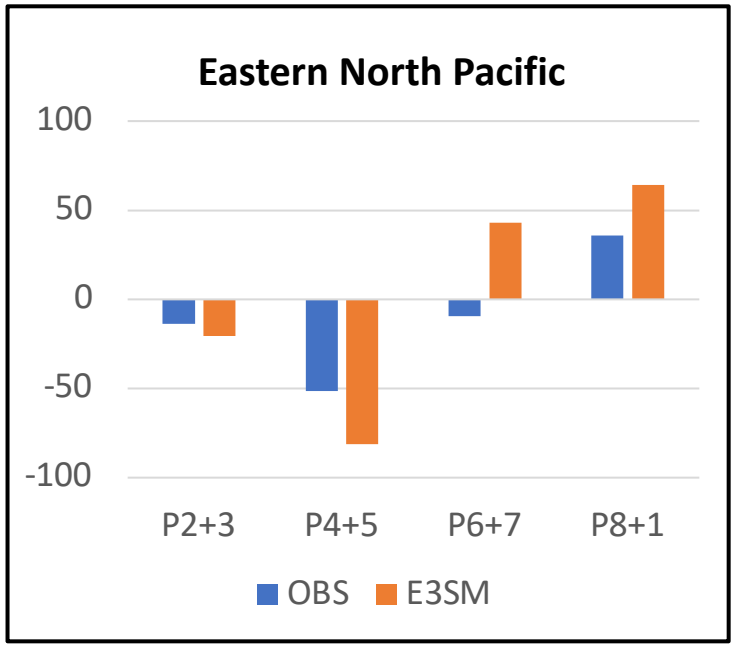


Contour (interval: 2 mm/day)
TRMM precipitation anomalies

precipitation anomalies

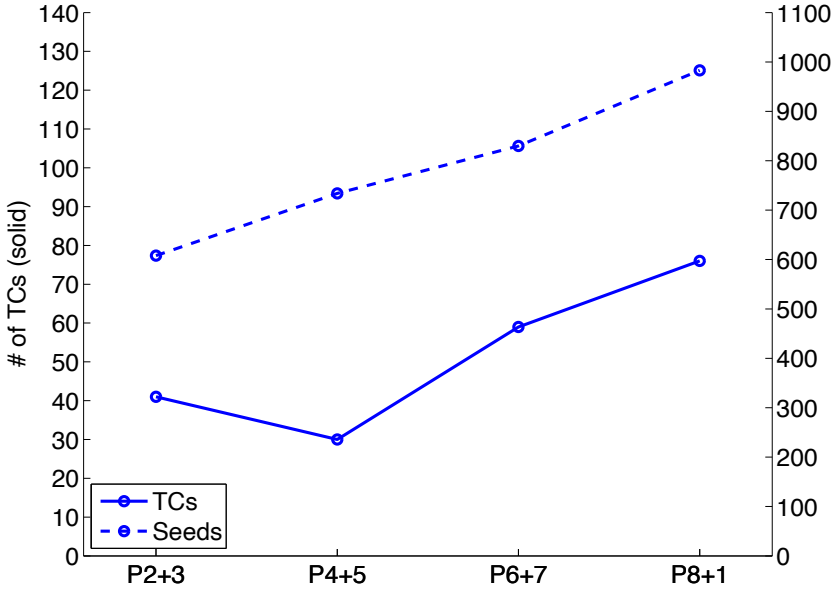
Contour (interval: 1 mm/day)
E3SM precipitation anomalies

% changes in TC genesis frequency

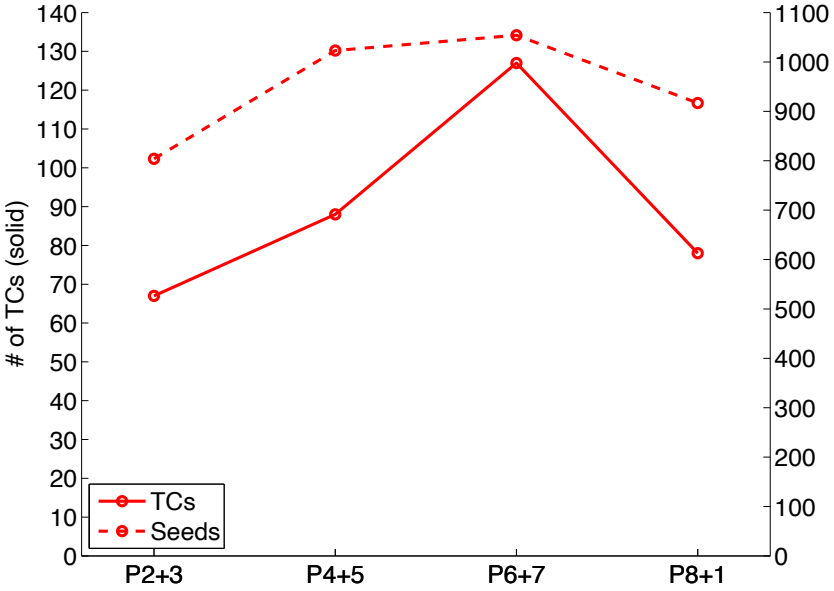


- Since the E3SM can simulate both MJO and TCs reasonably, it is a good tool to further elucidate physical processes responsible for the MJO-TC modulation.
- MJO modulation of TCs is reasonably represented, especially in the Eastern North Pacific
- When the MJO reaches EPac (Phase 8+1), TC genesis rate is greatly enhanced as in observations

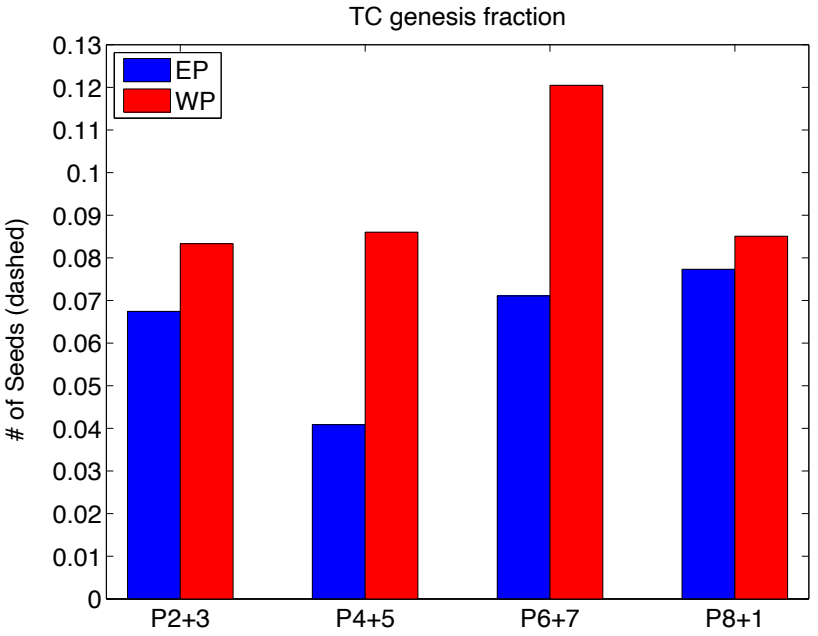
Role of 'seed' disturbances on the MJO–TC relationship



EP: # TCs (solid) and # seeds (dashed)



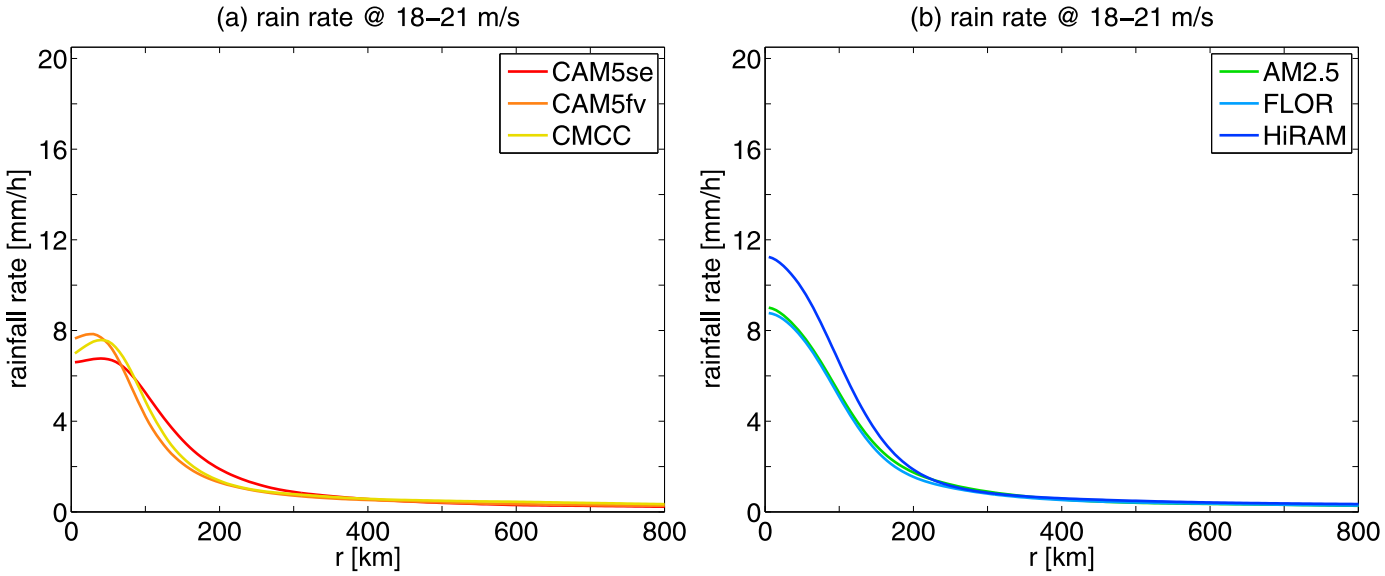
WP: # TCs (solid) and # seeds (dashed)

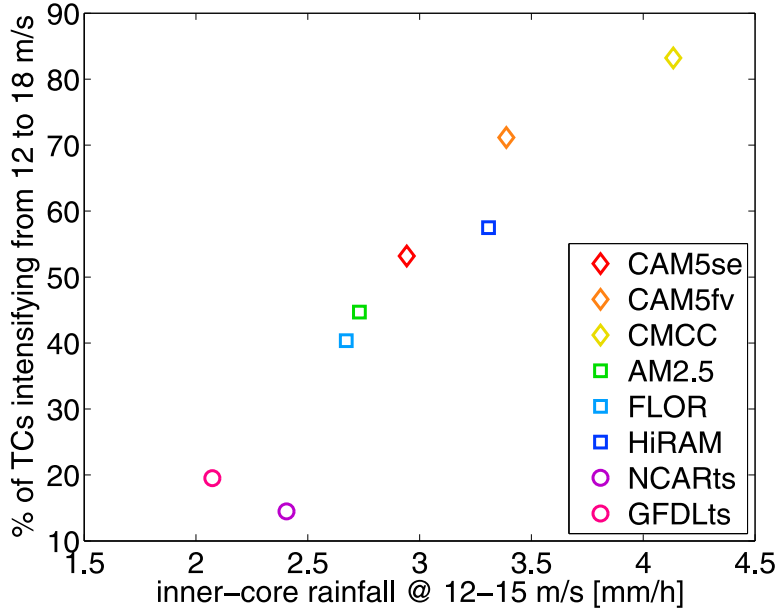


Fraction of seeds developing into TCs

- In **EP (blue)**, TC genesis is enhanced during MJO phases 8 and 1 by increasing the number of seed disturbances generated and by a greater fraction of them developing into TCs.
- In **WP (red)**, TC genesis is also modulated by different phases of MJO (e.g., 6+7 vs. 4+5) by the greater number of seed disturbances and greater fraction of them developing into TCs.
- MJO affects TC genesis in two ways: the population of seed disturbances and the fraction of them developing into TCs.

TC Rain Rate and Intensification Rate





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