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A1-05

MJO-Atmospheric River Connections and their Sensitivity to Air-sea Coupling across a CESM2 hierarchy

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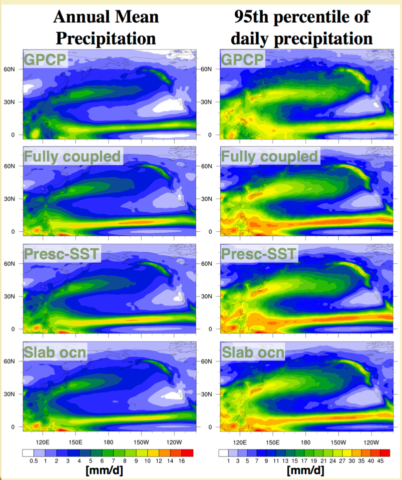
Background & Motivation

Extreme precipitation—here defined as episodes in which daily precipitation exceeds the 95th percentile locally—has profound impacts on water management/control, agriculture, and transportation interests. Many studies focus either on the mesoscale to synoptic drivers of precipitation extremes[1], while others examine bulk/global extreme statistics[2]. Here, we investigate two prominent subseasonal phenomena—the **Madden-Julian oscillation** (**MJO**) and **atmospheric rivers** (**ARs**)[3]—and their impact on extreme precipitation probabilities. We review these phenomena using a hierarchy of ocean model complexity to understand potential influences from the model representation of air-sea interaction.

Motivating Questions

- **(1)** ***What impact does air-sea interaction have on extreme precipitation?***
- **(2)** ***How well does CESM2 simulate the MJO, ARs, and MJO-AR interactions?***
- **(3)** ***How does the model's representation of the MJO, ARs, and MJO-AR interactions influence precipitation extremes, and how do these behaviors change across a CESM2 hierarchy of ocean model complexity?***

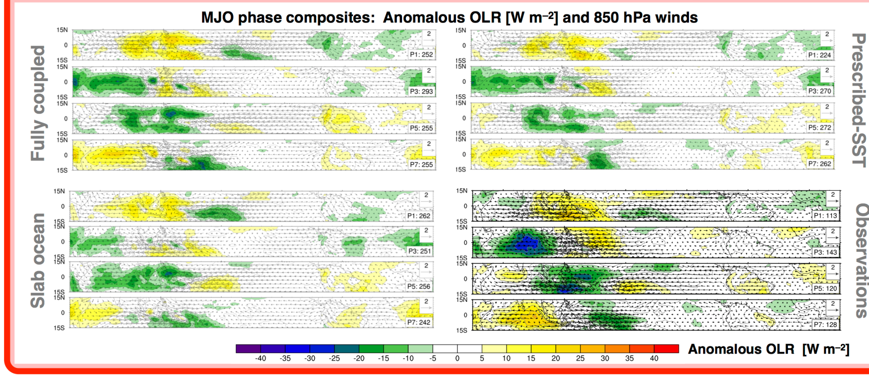


Greatest (qualitative) CESM2 agreement of mean, extreme precipitation in extratropics; less agreement in tropics

Why larger extreme thresholds in coupled CESM2? Partially due to larger SST variance vs. prescribed-SST and slab-ocean runs. The slab ocean run has a cooler climate, making interpretation of extremes less clear.

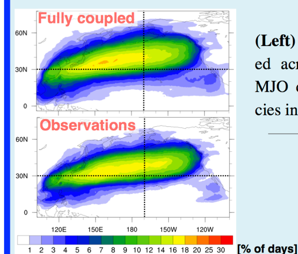
What are the subseasonal influences on extreme precipitation patterns/probabilities?

Model MJO Depiction



- Overall, OLR anomaly amplitudes are lower across CESM2 hierarchy; wind anomaly amplitudes are more realistic (a common feature of many GCMs)
- Despite biases, fully coupled CESM2 shows significantly improved MJO signals compared to previous CAM versions
- Multiple metrics (some omitted here) suggest more realistic air-sea coupling improves MJO depiction in CESM2 framework; the slab-ocean run produces a slightly slower and stronger MJO than the prescribed-SST run despite the SOM's cooler climate.
- Source of MJO improvement is under investigation

Atmospheric River Frequency

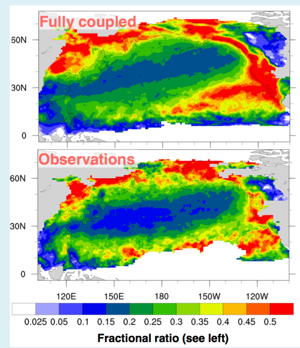


Frequency of Occurrence (Annual)

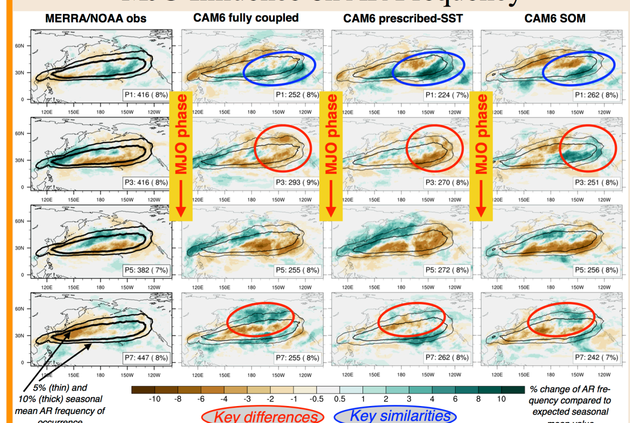
(Left) Pattern of AR activity generally well represented across CESM2 hierarchy despite differences in MJO depiction. CESM2 overestimates AR frequencies in south Alaska and off the west coast of Mexico.

AR control of extreme rain probabilities

(Right) This ratio (R) shows probability of exceeding 95th percentile of precipitation (P95) within any AR event. If ARs had **no** influence on extremes, R would be 0.05 everywhere. Instead, the $R > 0.1$ where ARs are most active and can exceed 0.5—there, the probability of exceeding P95 is 10x more likely during AR events! *Note: prescribed-SST and SOM results similar.*



MJO Influence on AR Frequency



- Plot depicts change in AR frequency (relative to Nov-Apr mean) for given MJO phase
- Despite similar AR Nov-Apr mean frequencies, large intraseasonal fluctuations
- Most intramodel similarity when MJO convective anomalies over Indonesia (phase 1, 5)
- Larger intramodel differences when MJO convective anomalies are over central Indian Ocean, far West Pacific (phase 3, 7)

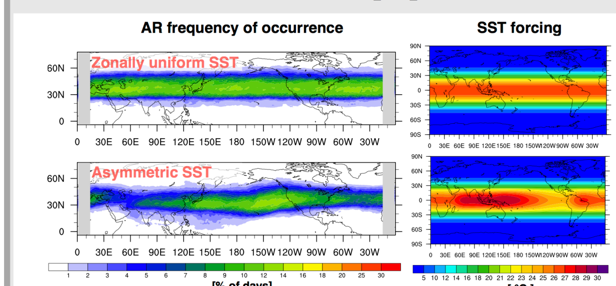
Modeling Strategy

- Public-release version of CESM2 (cesm2_0_1); 3 total simulations
- All runs use pre-industrial ("1850") radiative forcing on a 1° finite-volume grid
- Each run is a single realization spanning ~22 yr (excludes 2 yr spinup)
- **(1) Fully coupled**: Dynamic ocean model; dynamic sea ice model
- **(2) Prescribed-SST**: Time-evolving monthly mean SST and sea ice from (1)
- **(3) Thermodynamic/"slab" ocean**:
  Sea ice: Prescribed, from time-evolving monthly means from (1)
  Implied ocean heat transport:

$$Q_{flx} = F_{net} - \rho c_p h_{mix} \frac{dSST}{dt}$$

where Q_{flx} represents time-evolving monthly means and all terms are derived from monthly means of (1) except F_{net}, derived from daily means of (1).

Generalization: Aquaplanets



- Atmospheric rivers (as defined[4]) are a fundamental feature of aquaplanets; AR activity is influenced by zonal asymmetries in tropical SST despite unchanged midlatitude SST
- Equatorward shift of AR frequency occurs where SSTs are warmest
- We plan to add simple topography to explore terrain influences on ARs

Key Findings & Next Steps

- **(Q1)** Air-sea coupling, ocean model complexity impact extreme precipitation via local air-sea interactions and through subseasonal variability phenomena.
- **(Q2)** Fully coupled CESM2 shows improved MJO depiction, prescribed-SST CAM6 produces marginally weaker MJO; adding slab ocean improves CESM2's MJO
- **(Q3)** Both the MJO and ARs strongly influence extreme precipitation probabilities
- CESM2 AR probabilities fluctuate on intraseasonal time scales linked to MJO phase; ***differences in fluctuations among model hierarchy highlight importance of air-sea coupling for predictions of MJOs, the location of ARs, and thus probability of extremes.***
- **Next:** Examine MJO-AR connections and midlatitude features that precede ARs in CESM2; add complexity ("topography") to aquaplanet, examine AR response

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