How Will the Madden-Julian Oscillation Change in a Warmer Climate?

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We use CMIP5 models to assess Madden-Julian oscillation (MJO) changes at the end of the 21st Century in RCP8.5. Previous CMIP3 analyses suggest a spread in the amplitude and sign of future MJO precipitation amplitude changes with warming (Takahashi et al. 2011). Our study also explores reasons for MJO precipitation amplitude changes, and why wind and precipitation amplitude changes do not scale together.

Precipitation and Wind Amplitude Changes

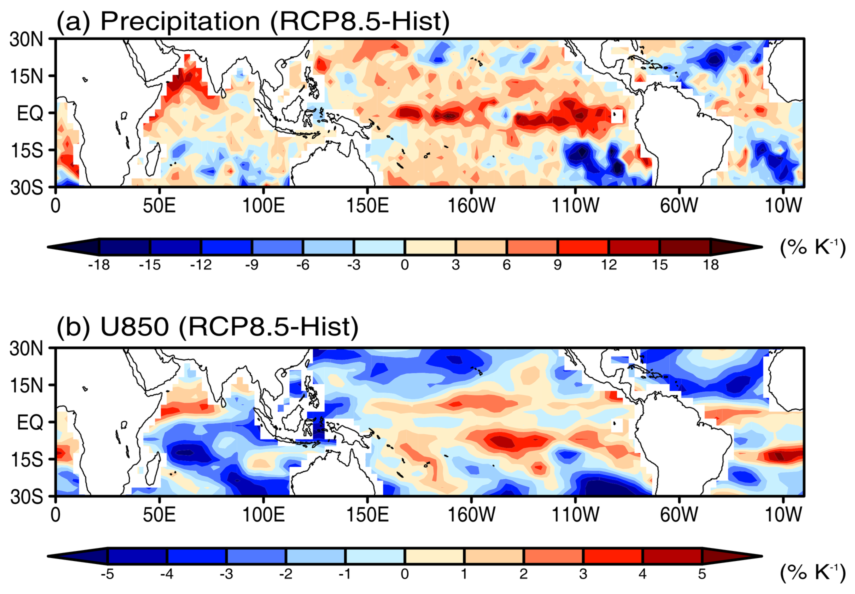


Figure 1: Multimodel mean November-April 30-90 day precipitation and wind amplitude changes with warming.

CMIP5 Models Analyzed

Models assessed to have a good MJO as in Henderson et al. (2017) :
BCC-CSM1-1, CNRM-CM5, GFDL-CM3, MIROC5, MRI-CGCM, NorESM1

Differences are expressed between these two periods:
Historical run: 1986-2005
RCP8.5: 2081-2100

- Multimodel model (MM) mean 30-90 day precipitation variance increases, but with a large spread across models.
- MM mean 30-90 day wind variance over the warm pool decreases. ***Warm pool precip. and wind amplitude changes do not scale together.*** Why? Static stability change

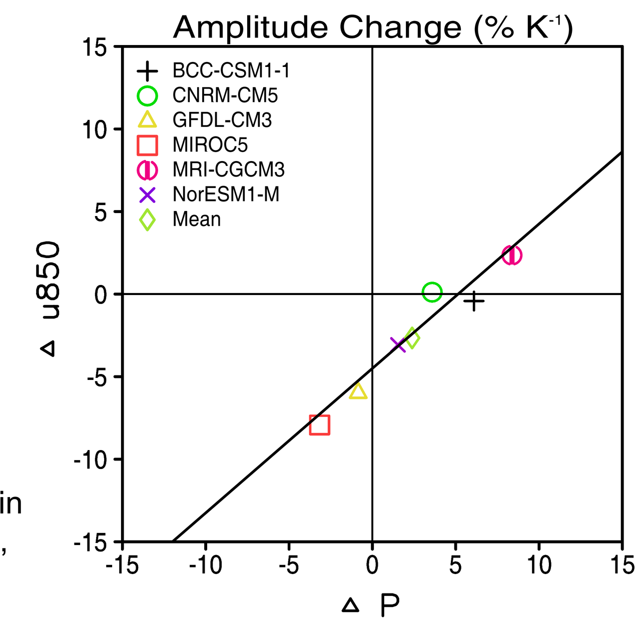


Figure 2: Differences in the November-April 30-90 day standard deviation of precipitation (x axis) and 850 hPa zonal wind (y axis) in RCP8.5 relative to the historical simulation over the region 10°S-0, 90°E-180.

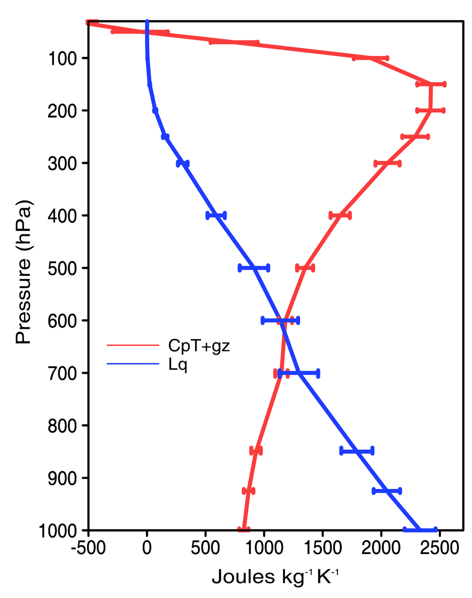


Figure 3: Changes in the multimodel CMIP5 mean vertical structure of dry static energy and latent heat relative to the historical simulation in RCP8.5 relative to the historical simulation over the region 10°S-0, 90°E-180, per unit global mean surface temperature warming. The bars at each level represent +/- one standard deviation calculated across all models relative to the multimodel mean.

- The static stability and vertical moisture gradient increase across models

- Under WTG balance, $\omega\frac{\partial s}{\partial p} = Q_1$
- Given this, Figure 4 asks whether changes in static stability can predict the ratio of P and ω (i.e. $\Delta\frac{\partial s}{\partial p} = \Delta\left(\frac{Q_1}{\omega}\right)$).
- It does reasonably well.

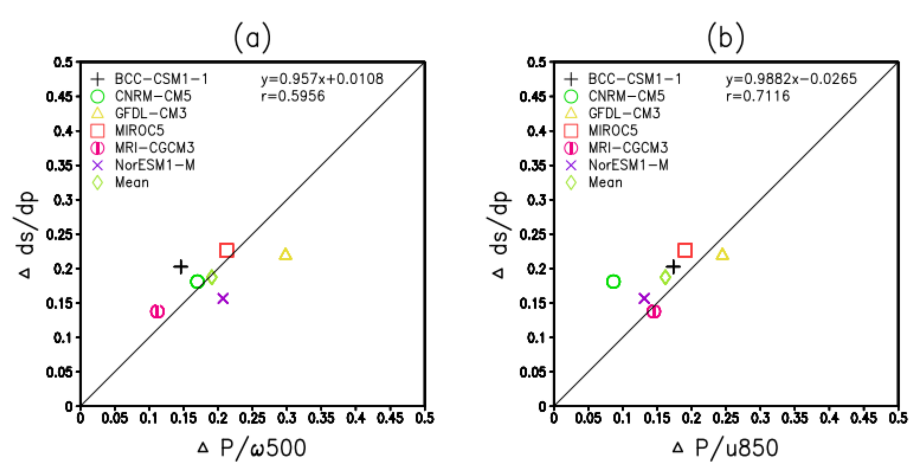


Figure 4: RCP8.5 fractional differences relative to the historical simulation in *ds/dp* averaged from 400 to 600 hPa (y axis) and the ratio of the standard deviations of 30-90 day precipitation anomalies and (a) 500 hPa omega anomalies and (b) 850 hPa zonal wind anomalies (x axis).

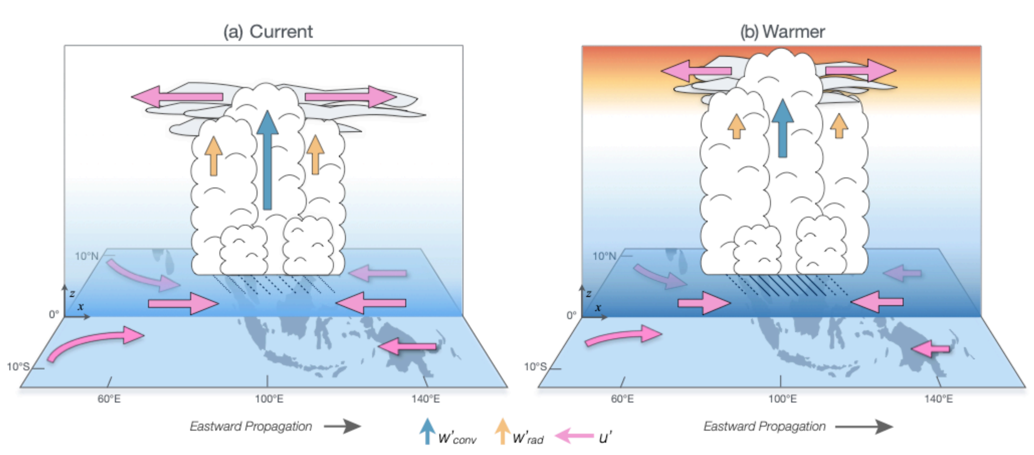


Figure 5: Schematic summarizing our best understanding of changes in MJO convective anomalies and the anomalous large-scale circulation. Current climate is represented in (a), and a warmer climate in (b).

Understanding MJO Precipitation Amplitude Change

- Using $\omega\frac{\partial s}{\partial p} = Q_1$, the efficiency with which a diabatic heating anomaly drives vertical moisture (latent heat) advection is diagnosed (e.g. Chikira 2014):

$$-\omega\frac{\partial Lq}{\partial p} = -Q_1\left(\frac{\partial s}{\partial p}\right)^{-1}\frac{\partial Lq}{\partial p} = \alpha Q_1 \qquad (1)$$

Where:

$$\alpha = -L\left(\frac{\partial s}{\partial p}\right)^{-1}\frac{\partial q}{\partial p} \qquad (2)$$

- ***α gives the efficiency with which a diabatic heating anomaly moistens the column through vertical advection and*** has been hypothesized to regulate MJO strength (Chikira 2014; Wolding and Maloney 2015).
- α increases in all models in a warmer climate (Figs. 6-8)

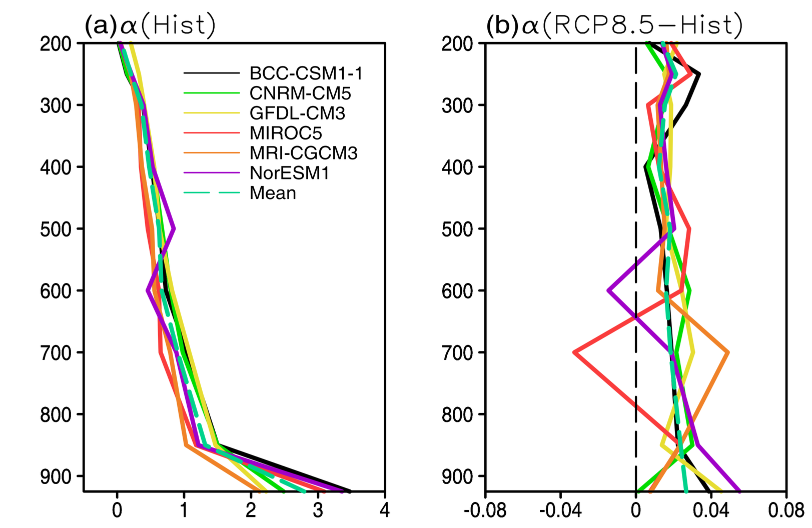


Figure 6: Vertical profiles of (a) historical time-mean α averaged over the domain 10°S-0, 90°E-180 during the boreal winter, and (b) changes of α between the RCP8.5 and historical simulations per unit global mean surface temperature warming (units are K⁻¹). The black dash line corresponds to zero.

- Under global warming, the increased vertical moisture gradient (Fig. 3) makes α larger in models, despite increased static stability.

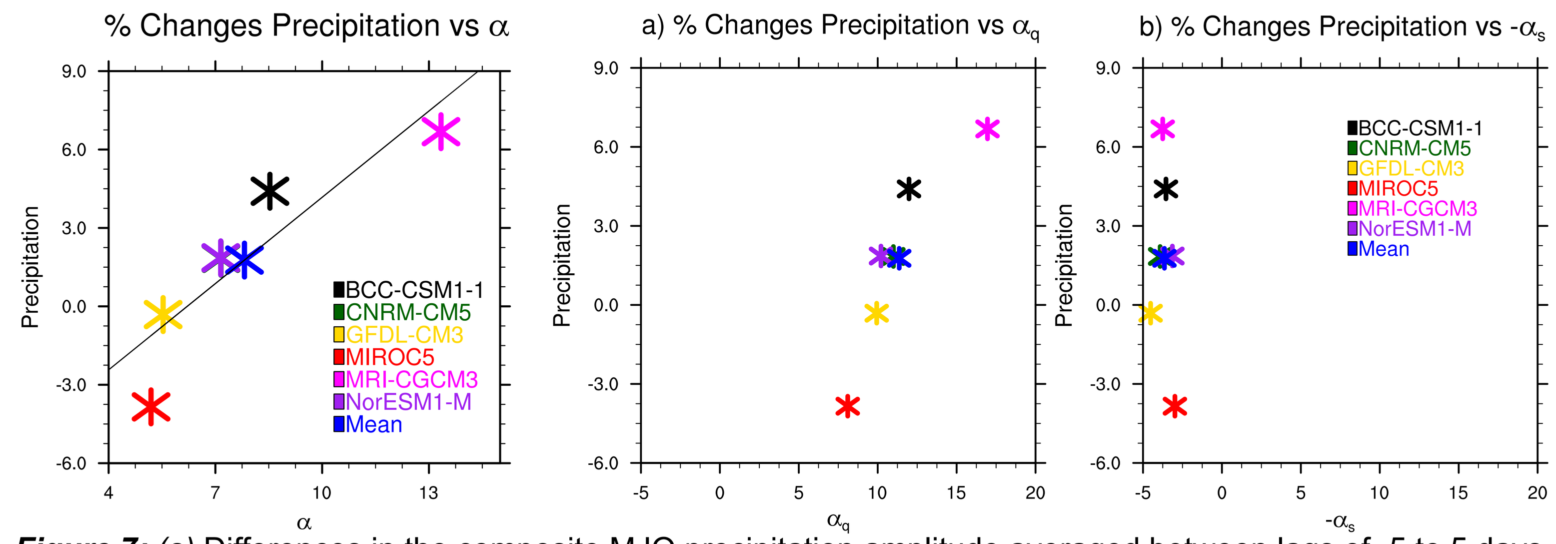


Figure 7: *(a)* Differences in the composite MJO precipitation amplitude averaged between lags of -5 to 5 days over the warm pool (x-axis) and α, mass-weighted vertically averaged from 850 to 100 hPa, (y-axis) in the RCP8.5 relative to the historical simulations averaged over the warm pool. Units are % K⁻¹. (b) and (c) are similar to (a), but for α changes driven by humidity gradient changes and static stability changes, respectively.

α and Δα

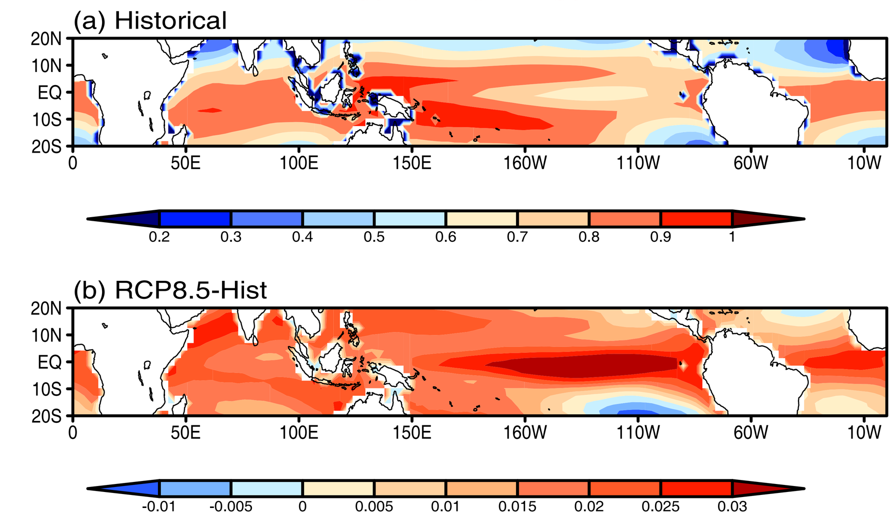


Figure 8: Spatial distribution of the multimodel mean November α, mass-weighted vertically averaged from 900 to 100 hPa for (a) historical simulation and (b) differences between the RCP8.5 and historical simulations (units is K⁻¹).

- Under global warming, multimodel mean α increases everywhere, preferentially over the east Pacific where SSTs warm most.

- ***Although α increases in all models, warm pool MJO precipitation amplitude decreases in some models***, contrary to expectations. Why? Let's look to changes in composite MJO vertical heating profiles

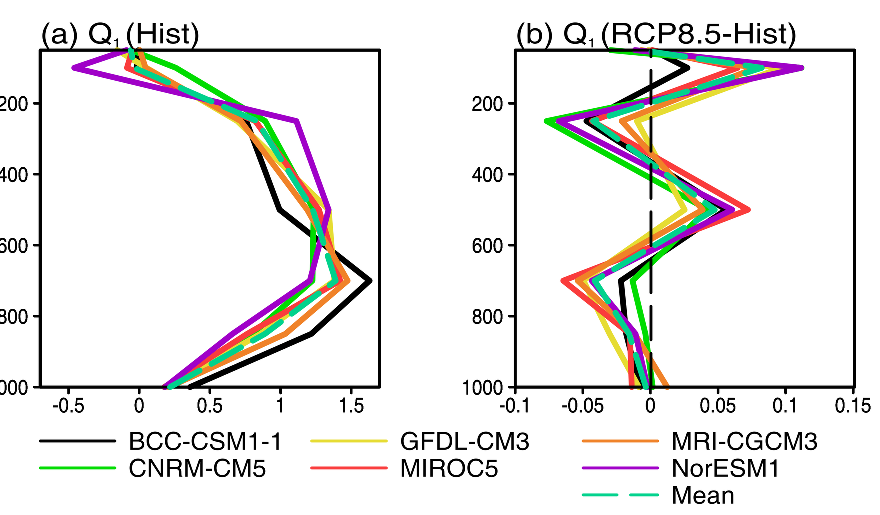
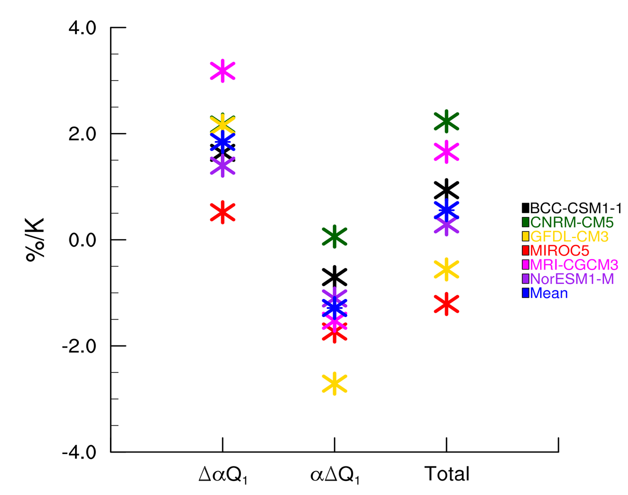


Figure 9: Changes in vertical structure of MJO Q_1 anomalies over the warm pool for the (a) historical simulation (units are W m⁻²) and (b) differences between RCP8.5 and historical simulation (units are W m⁻² K⁻¹). The black dash line corresponds to zero.

- When normalized by the vertical integral of heating, Q_1 is reduced in the lower troposphere and increases in the middle troposphere, effectively becoming more top-heavy. This would move heating and its associated vertical velocity away from the strong low-level moisture gradient and high α, reducing (1)

Figure 10: Fractional changes in the column integrated (from 925 to 500 hPa) of (left) $\Delta\alpha Q_1$, (middle) $\alpha\Delta Q_1$, their sum (right) between the RCP8.5 and historical simulations at the time of peak MJO precipitation over the warm pool. Q_1 is normalized as in Figure 8. Units are % K⁻¹.



- ***The combination of vertical Q_1 profile and α changes better explain the spread in MJO precip. change across models***

Conclusions

- MM mean Indo-Pacific warm pool MJO precipitation amplitude increases in a warmer climate across CMIP5 models, although substantial spread exists in the magnitude and even sign of the change
- MM mean MJO wind amplitude over the warm pool decreases, and can even decrease for models where MJO precipitation amplitude increases
- MJO precipitation amplitude changes with warming can be explained through a combination of vertical moisture gradient, static stability, and vertical heating profile changes

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For more details see Bui and Maloney (2018, GRL); Maloney et al. (2019, Nature Climate Change); Bui and Maloney (2019, J. Climate) at ***https://tropical-dynamics.atmos.colostate.edu/publications***