Changes to the MJO in coupled and uncoupled aquaplanet simulations with 4xCO_2

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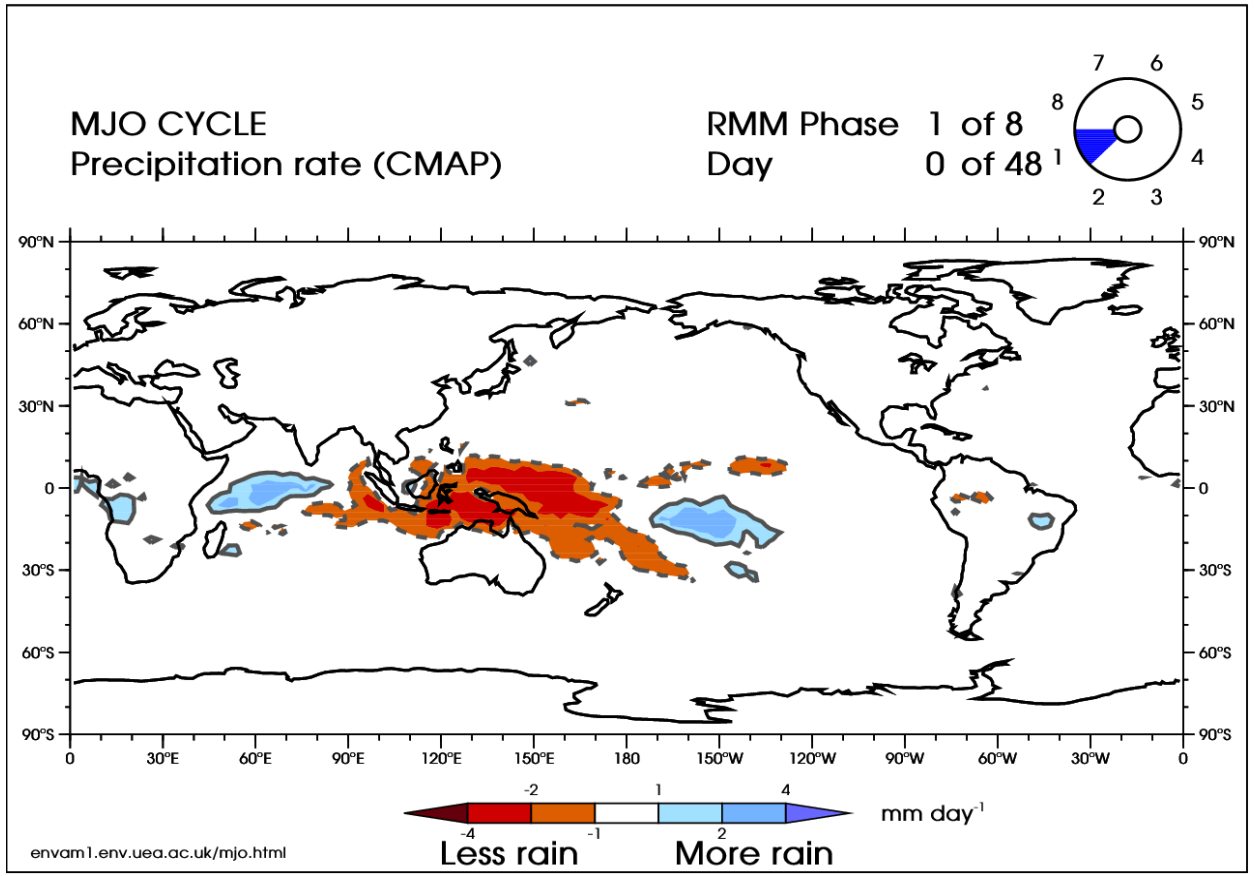
Madden-Julian oscillation (MJO) …

What

- Eastward propagating
- Zonal wavenumber 1-3
- Favor boreal winter conditions
- First baroclinic mode
- Moisture mode

Why

- Affecting the rainfall, monsoon
- Modulate tropical cyclone, atmospheric river …
- Teleconnection to other part of the globe …



MJO changes under global warming …

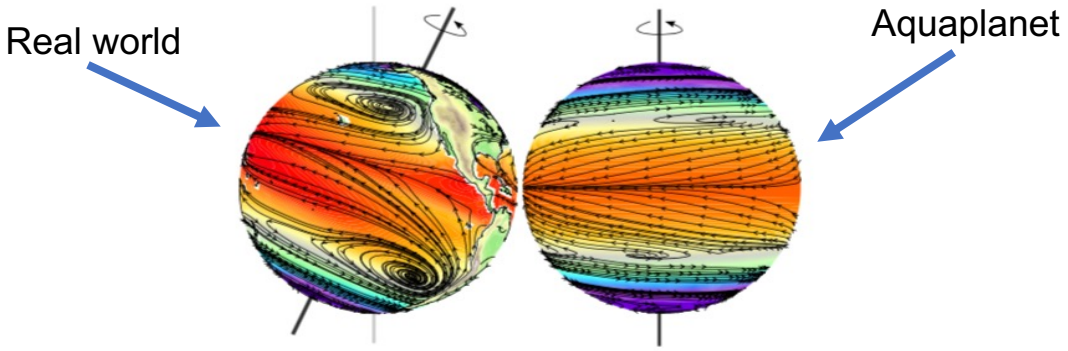
Temperature vs. CO_2?

- IPCC CMIP models → change in MJO amplitude
  - Increased MJO precipitation, weaker winds, increased atmospheric stability
  - Forcing (GHG,…) and response (temperature,…) are combined
- However, direct effect of CO_2 → fast adjustments
  - Reduce convection, precipitation

Coupled vs. uncoupled?

- Coupling → MJO maintenance, propagation
  - Improve model ability to simulate MJO
  - Enhance MJO propagation speed
- However, effect of coupling in a warmer climate …

Aquaplanet simulation



Medeiros et al. (2015, Climate Dynamics)

Moist static energy budget

vertical advection — latent heat — longwave

$$\langle\frac{\partial m}{\partial t}\rangle_{MJO} = -\langle\omega\frac{\partial m}{\partial p}\rangle_{MJO} - \langle\mathbf{v}\cdot\nabla m\rangle_{MJO} + LH_{MJO} + SH_{MJO} + LW_{MJO} + SW_{MJO}$$

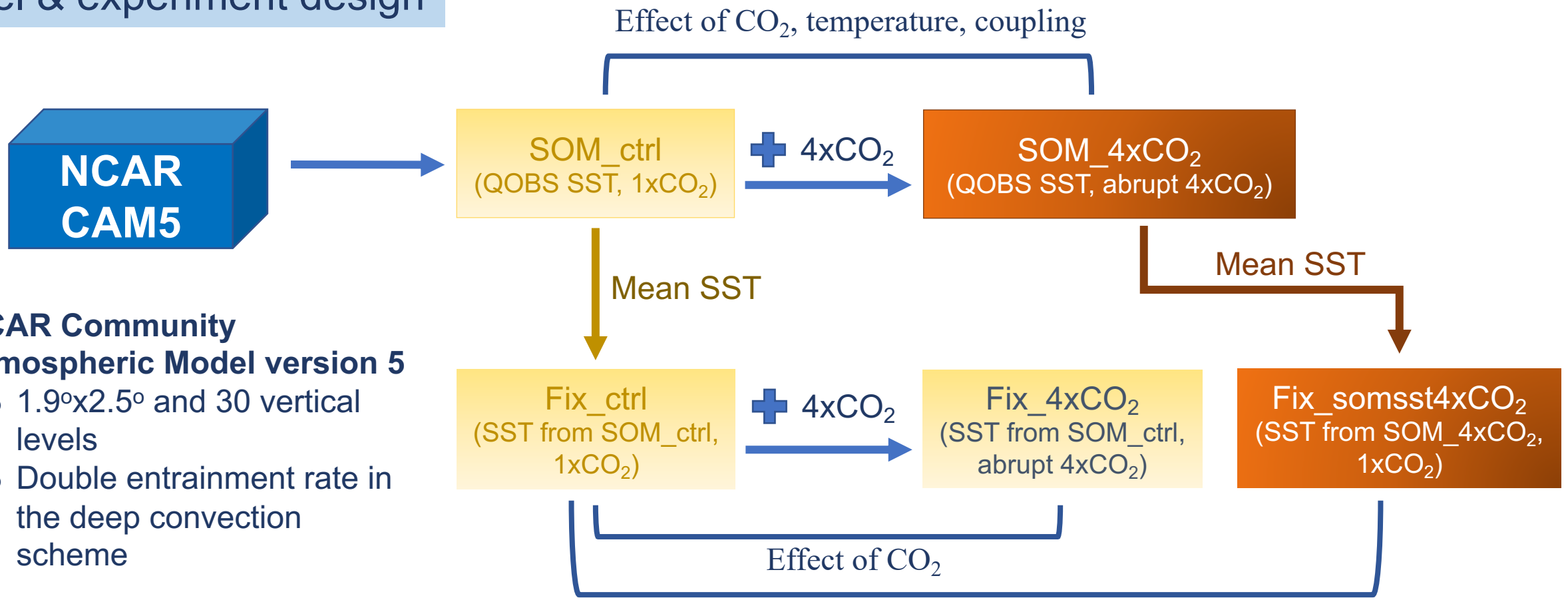
total MSE change — horizontal adv. — sensible heat — shortwave

m: moist static energy

MJO: 20-100-day and eastward wavenumber 1-5 filtered

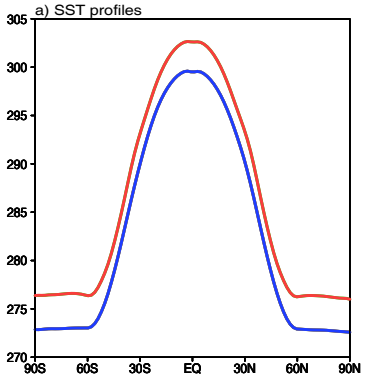
$\langle\ \rangle$: mass integration through the troposphere

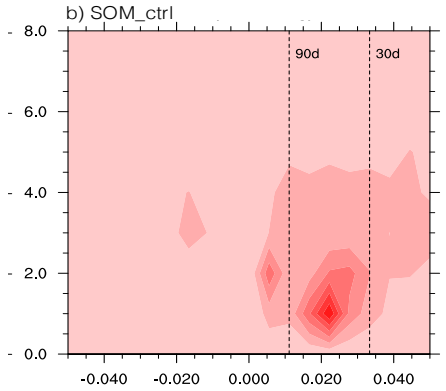
Model & experiment design



- **NCAR Community Atmospheric Model version 5**
  - 1.9ºx2.5º and 30 vertical levels
  - Double entrainment rate in the deep convection scheme
- **Aqua Planet Experiment (APE) protocol**
  - No seasonal cycle
  - QOBS SST profile of Neale & Hoskins (2000)
- 20 years simulation

Effect of temperature





When it warms, how will the MJO change?

- MJO is defined as 20-100-day and eastward wavenumber 1-5 filtered field

Fix(4xCO2-ctrl)

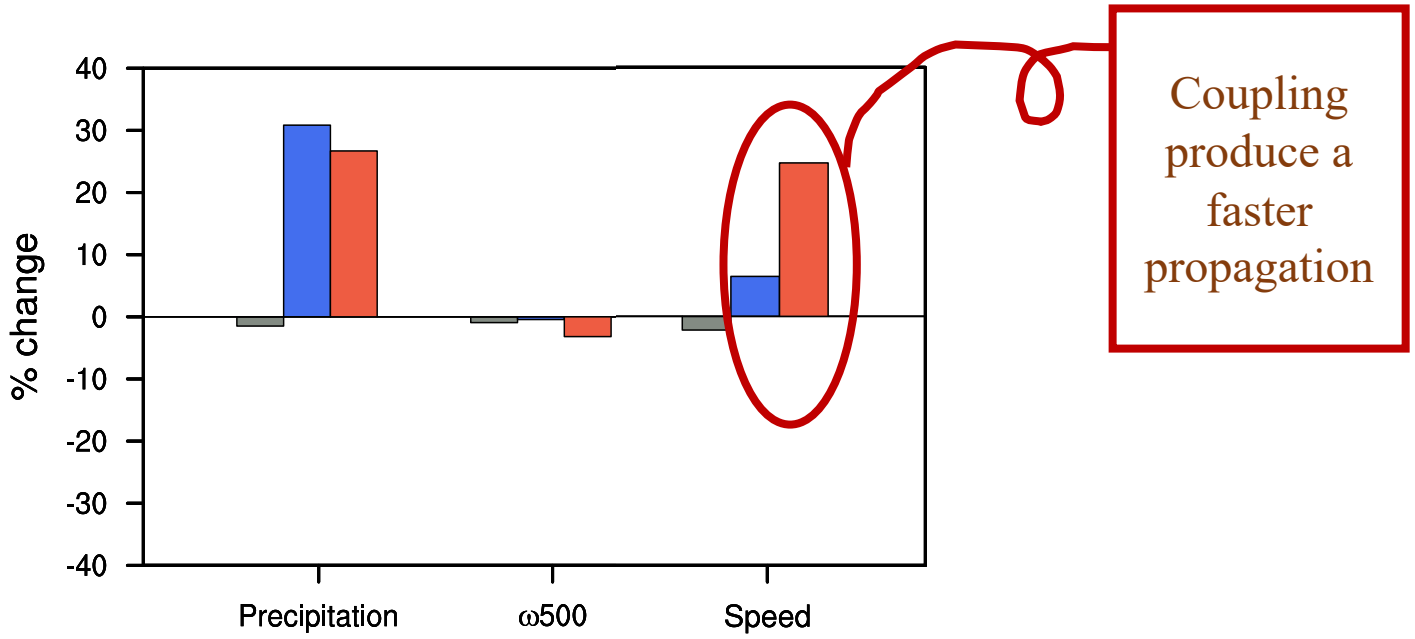
CO_2 effect

Fix(sstsom4xCO2-ctrl)

Temperature effect

SOM(4xCO2-ctrl)

Coupling effect

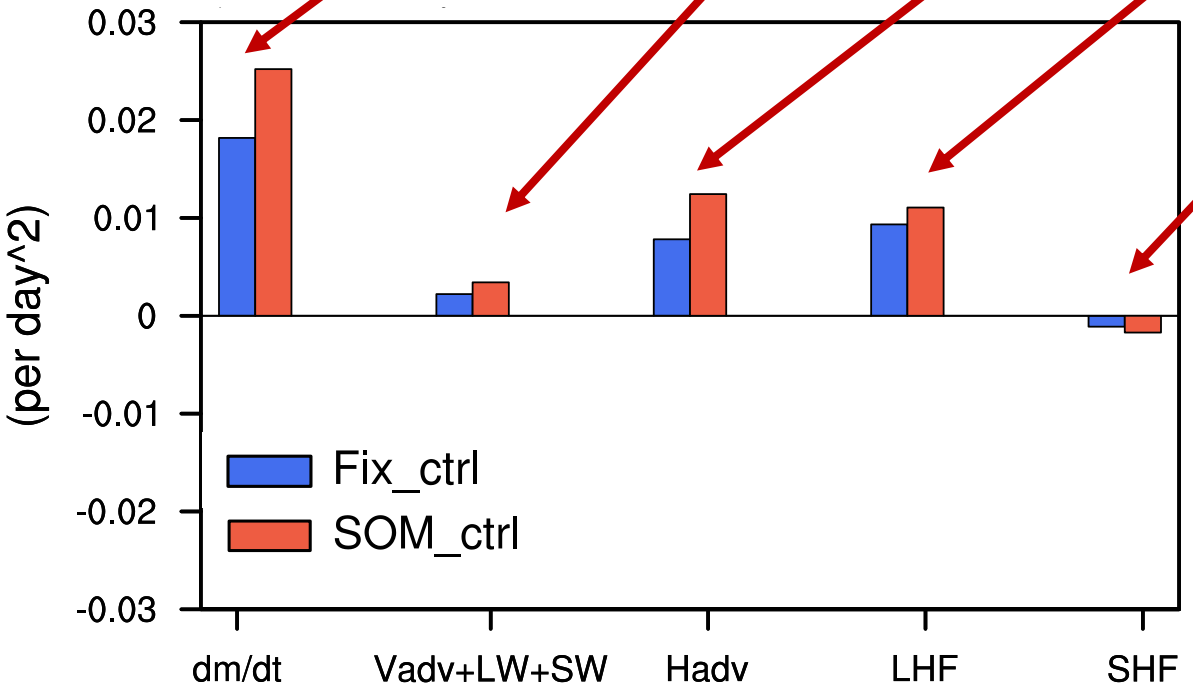


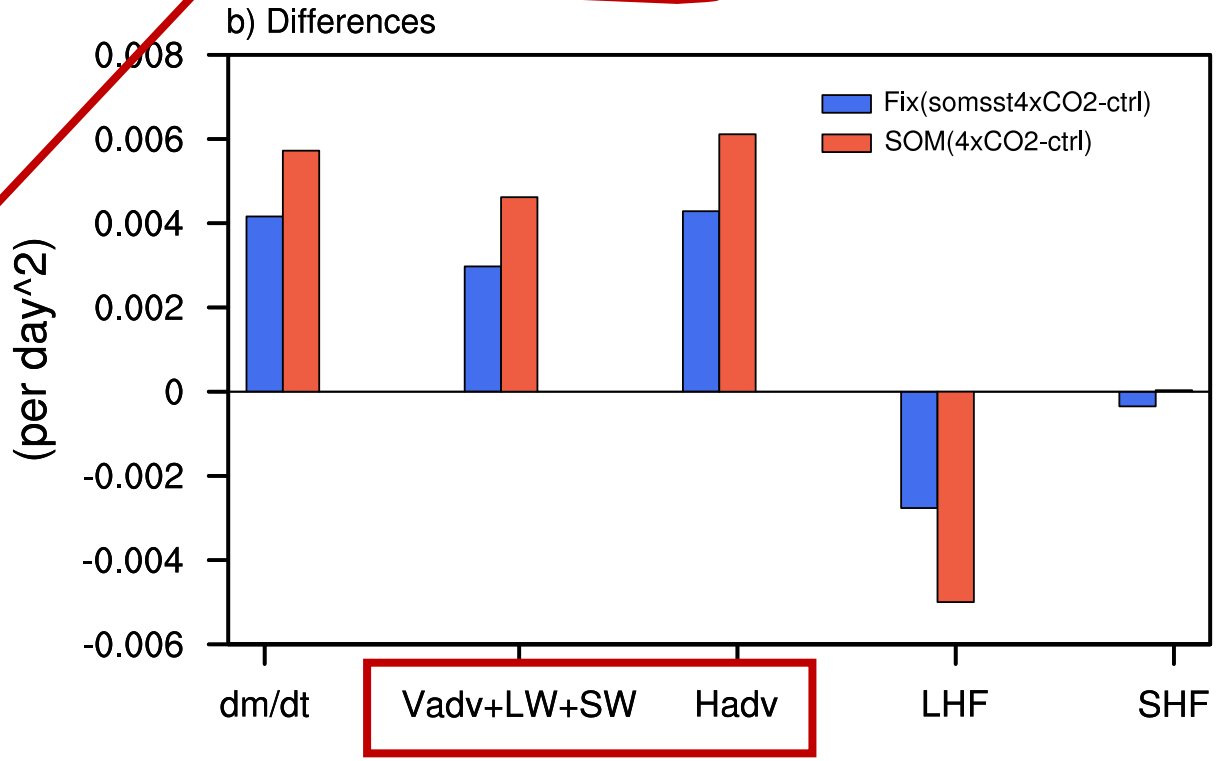
- **CO_2 effect**: Small, insignificant
- **Temperature effect**: Increased precipitation, weaken winds
- **Coupling effect**: Increased precipitation, weaken winds, faster propagation speed

Why MJO propagates faster in the coupled model?

Moist static energy (m) variance budget:

$$\langle \frac{\partial m}{\partial t} \rangle_{MJO} = -\langle \omega \frac{\partial m}{\partial p} \rangle_{MJO} - \langle \mathbf{v} \cdot \nabla m \rangle_{MJO} + LH_{MJO} + SH_{MJO} + LW_{MJO} + SW_{MJO}$$





- Column process and horizontal advection make positive contributions to the MSE tendency changes → favoring faster eastward propagation

Results

Contours are dm/dt
850 hPa winds

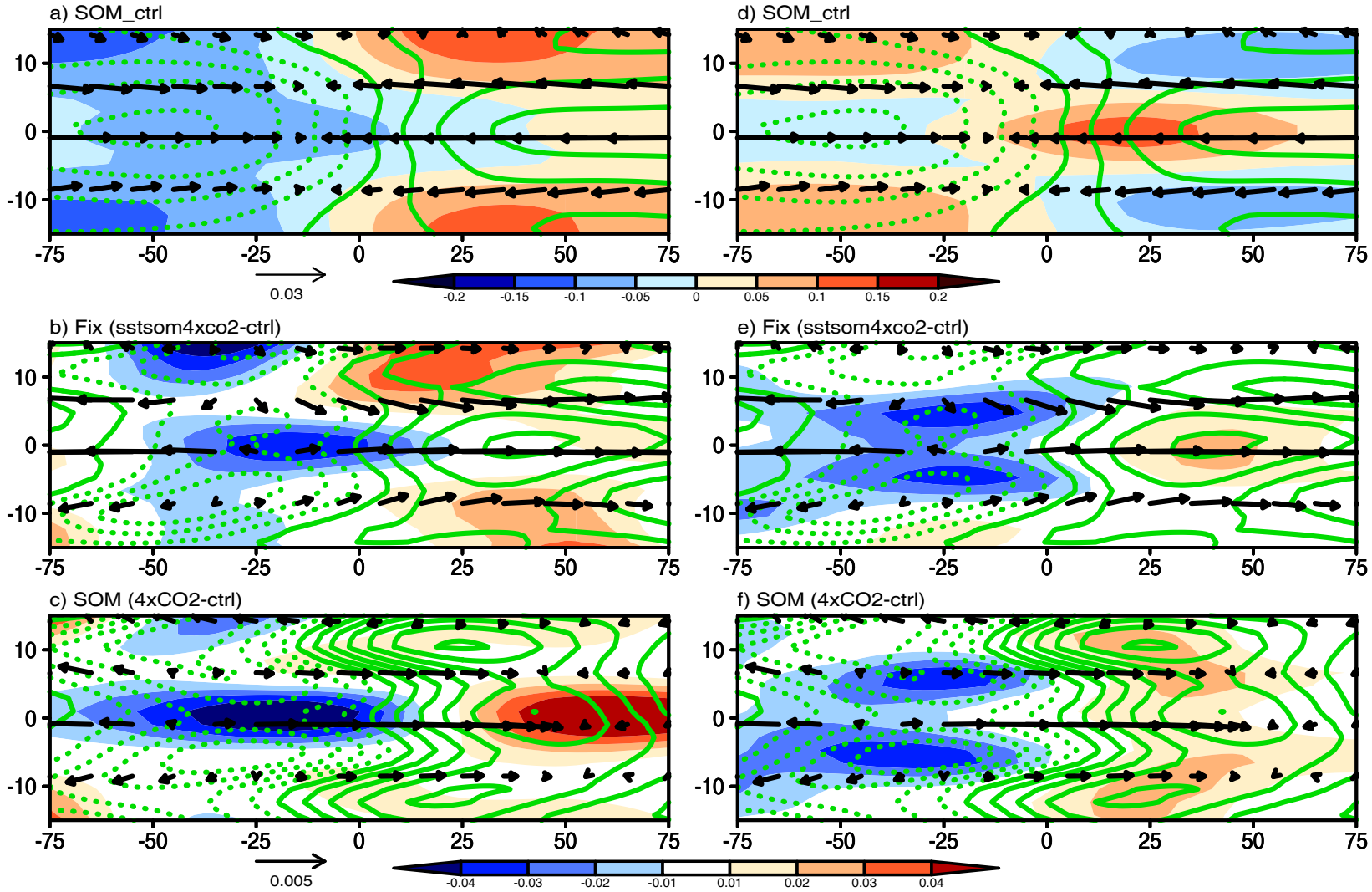
SOM_ctrl

Fix (sstsom4xCO$_2$-ctrl)

SOM (4xCO$_2$-ctrl)

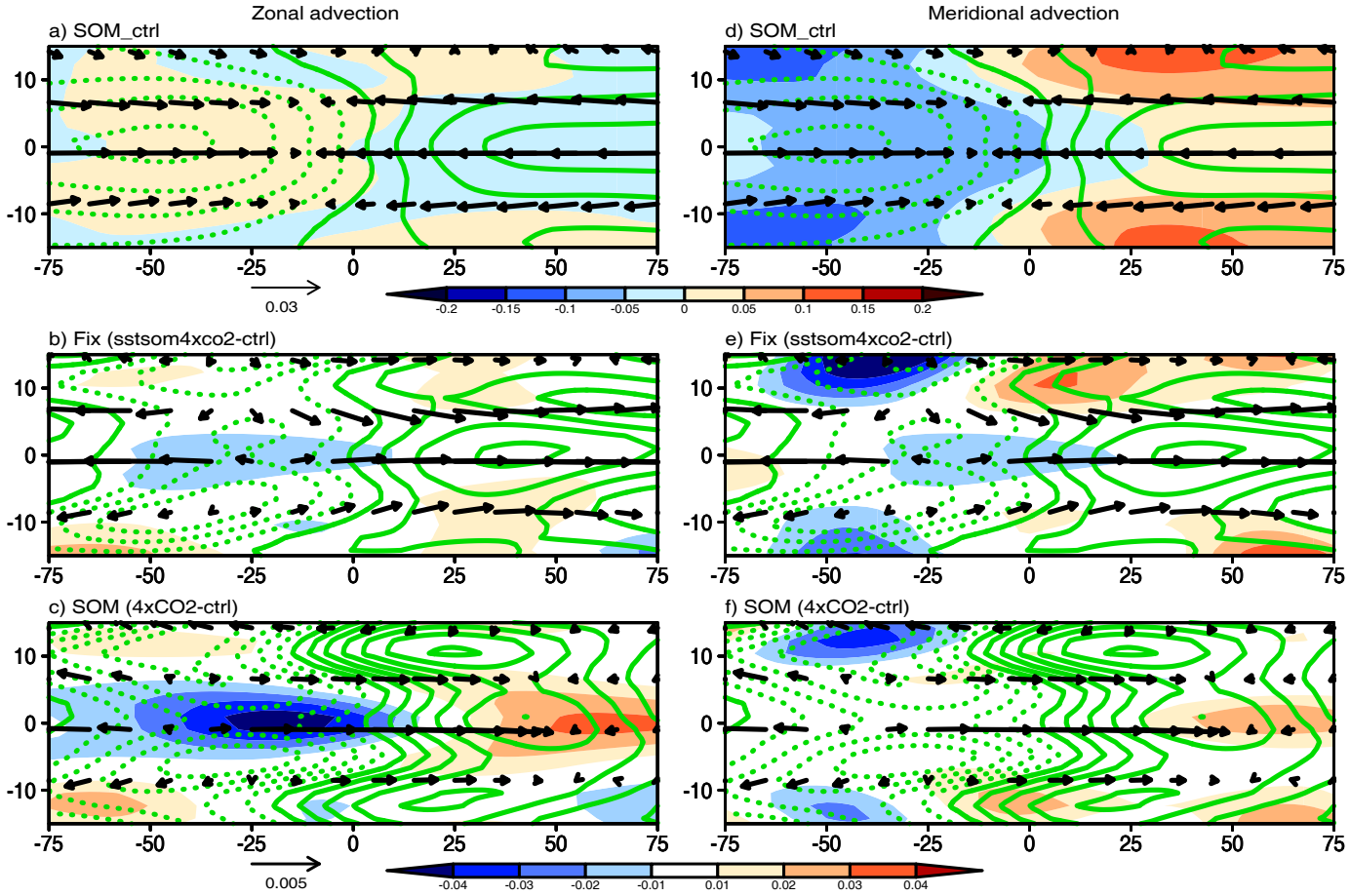
Horizontal advection

Vertical advection + LW + SW



- Horizontal advection is important!

We can further decompose the horizontal advection to zonal and meridional components



Total horizontal advection = zonal + meridional

$$-\langle \mathbf{v} \cdot \nabla m \rangle_{MJO} = -\langle u \frac{\partial m}{\partial x} \rangle_{MJO} - \langle v \frac{\partial m}{\partial y} \rangle_{MJO}$$

- Dry effect of zonal advection to the east of convective center
- More change occurs the coupled run

Time decomposition …

Previous slide $$-\langle \mathbf{v}\cdot\nabla m\rangle_{MJO} = -\langle u\frac{\partial m}{\partial x}\rangle_{MJO} - \langle v\frac{\partial m}{\partial y}\rangle_{MJO}$$

$$u = \bar{u} + u'$$
$$v = \bar{v} + v'$$

deviation from the mean

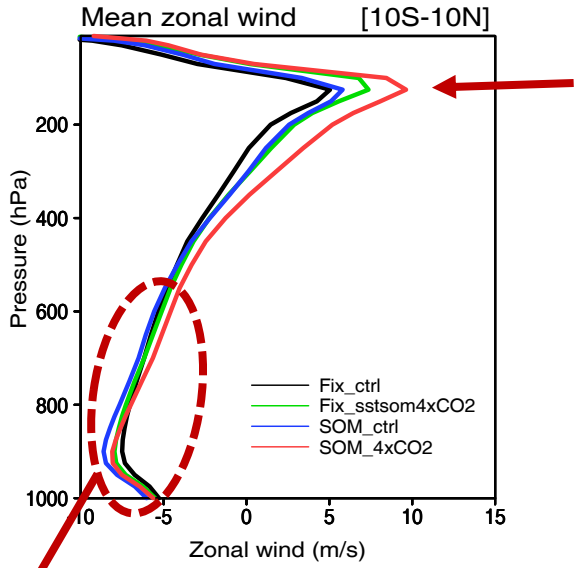
climatological mean

$$\langle u\frac{\partial m}{\partial x}\rangle_{MJO} \approx \langle u'\frac{\partial \bar{m}}{\partial x}\rangle_{MJO} + \langle \bar{u}\frac{\partial m'}{\partial x}\rangle_{MJO} + \langle u'\frac{\partial m'}{\partial x}\rangle_{MJO}$$

$$\langle v\frac{\partial m}{\partial y}\rangle_{MJO} \approx \langle v'\frac{\partial \bar{m}}{\partial y}\rangle_{MJO} + \langle \bar{v}\frac{\partial m'}{\partial y}\rangle_{MJO} + \langle v'\frac{\partial m'}{\partial y}\rangle_{MJO}$$

eddies

➢ Weakening of the lower tropospheric easterly mean zonal wind (super-rotation)



Wind becomes more westerly with coupling

We have examined …

Temperature vs. CO_2?

- ✓ **4xCO_2**: small and insignificant impact
- ✓ **Temperature**: substantial impacts
  - ➢ increase in MJO precipitation variability
  - ➢ slower increase in MJO circulation variability
  - ➢ faster MJO eastward propagation

Coupled vs. uncoupled?

- ✓ **Ocean coupling** → greater increases in MJO propagation speed even for the same mean SST climatology.
- ✓ Increased super rotation

Bui, H. X., Maloney, E. D. (2020). Changes to the Madden-Julian Oscillation in coupled and uncoupled aquaplanet simulations with 4xCO2. *Journal of Advances in Modeling Earth Systems*, 12, e2020MS002179. https://doi.org/10.1029/2020MS002179.

Thank you!