The Role of Moisture–Convection Feedbacks in Simulating the Madden–Julian Oscillation

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“ Sensitivity of the MJO simulation
in NCAR CAM3.1 to variations of
moisture sensitivity parameters”

outline

- Methods
  - model description and setup
  - Observations and data processing
- Model sensitivity analysis
  - Minimum entrainment rate
  - Minimum entrainment composite analysis
  - rain evaporation fraction
  - mean state comparison
- Process-oriented diagnosis: Moisture-convection feedbacks
- Summary

Model description

- NCAR CAM(Community Atmospheric Model) v3.1
  - Keep Hack (1994) scheme to simulate shallow convection
  - To improve the model's tropical intra-seasonal variability
    - [deleted] Zhang and McFarlane (1995) scheme
    - [added] RAS convective parameterization of Moorthi and Suarez (1992)
- RAS
  - Simplified Arakawa–Schubert scheme
    - more computationally economical
    - allowed unrealistically low entrainment rates buffer these clouds from the effects of dry free tropospheric environments

2 Moisture sensitivity parameters

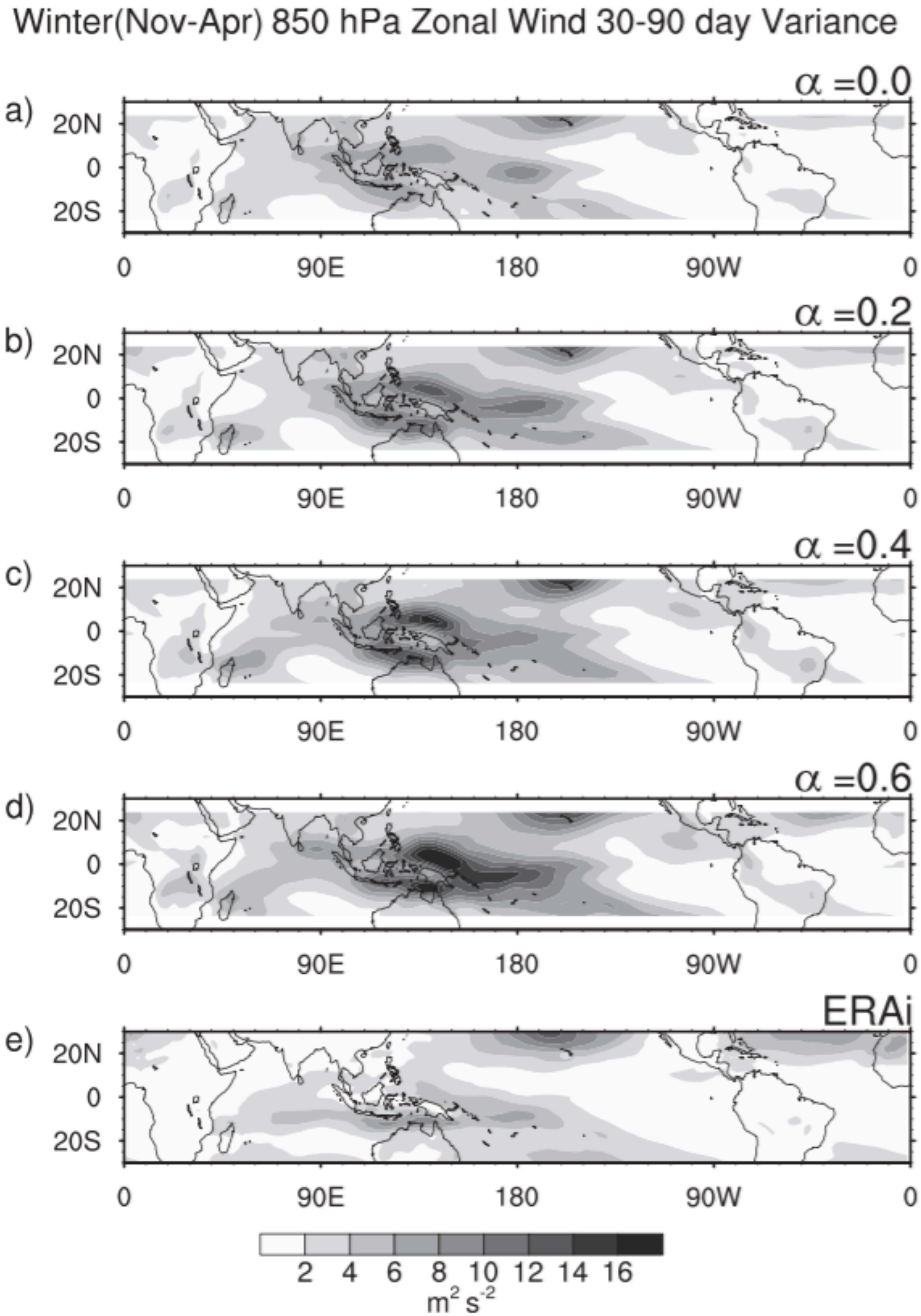
- Minimum entrainment rate (μ_{min})
  - Using this method resulted in an enhanced MJO signal in the model. (Tokioka et al.1988)
  - $\mu_{min} = \alpha / D$
    - α : dimensionless constant
    - D : depth of the boundary layer (=2000m in all models)
- Rain evaporation fraction (ε)
  - simulated MJO is sensitive to changes of this parameter (Grabowski and Moncrieff 2004; Maloney 2009)
  - specified fraction of convective precipitation to be exposed to the environment and evaporate depending on the environmental humidity as well as microphysical assumptions such as droplet size distribution and fall velocities

Experiment setup

- Four 16-yr simulations of CAM with the RAS convective scheme
  - sensitivity to the minimum entrainment parameter
    - $\varepsilon = 0.3$ and $\alpha = 0.0, 0.2, 0.4$, and 0.6.
  - sensitivity to rain evaporation fraction
    - $\alpha = 0.2$ and $\varepsilon = 0.05$ and 0.6
- spectral dynamical core at T42 resolution (2.8 x 2.8 grid resolution) with climatological seasonal cycles of SST and insolation applied
- 26 vertical levels
- Time step: 20 min

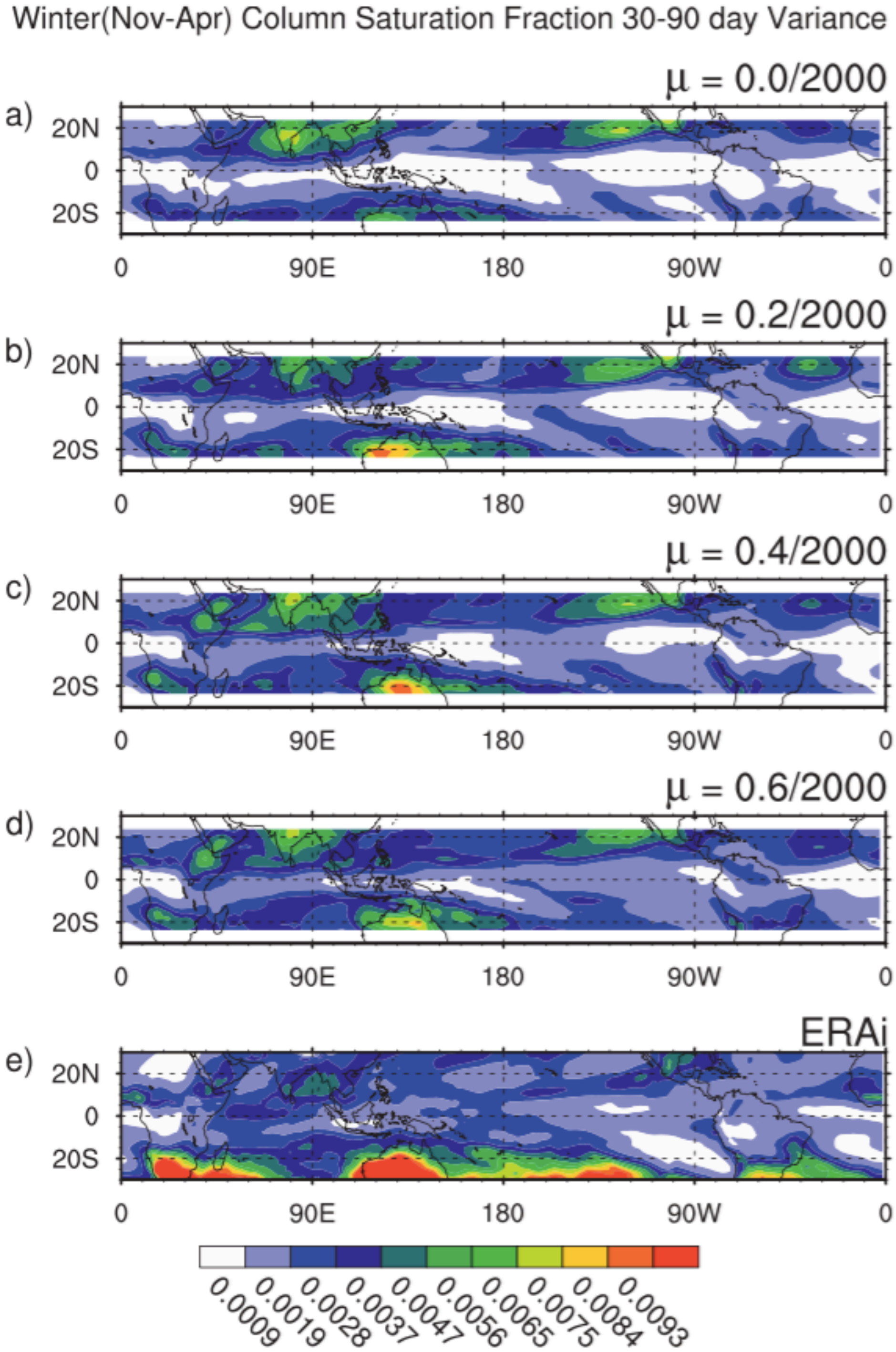
Observations and data processing

- ERAi 1.5 x 1.5 degree
  - 13 vertical levels from 975 to 100 hPa
  - latitudes between 15N and 15S,
  - all longitudes
  - 1990–2004
- Intraseasonal anomalies in all fields are calculated by applying a linear nonrecursive digital band-pass filter with half-power points at 30- and 90-day periods.
- Significant MJO events were defined on the basis of maxima in the anomalous zonal wind having amplitudes greater than one standard deviation.



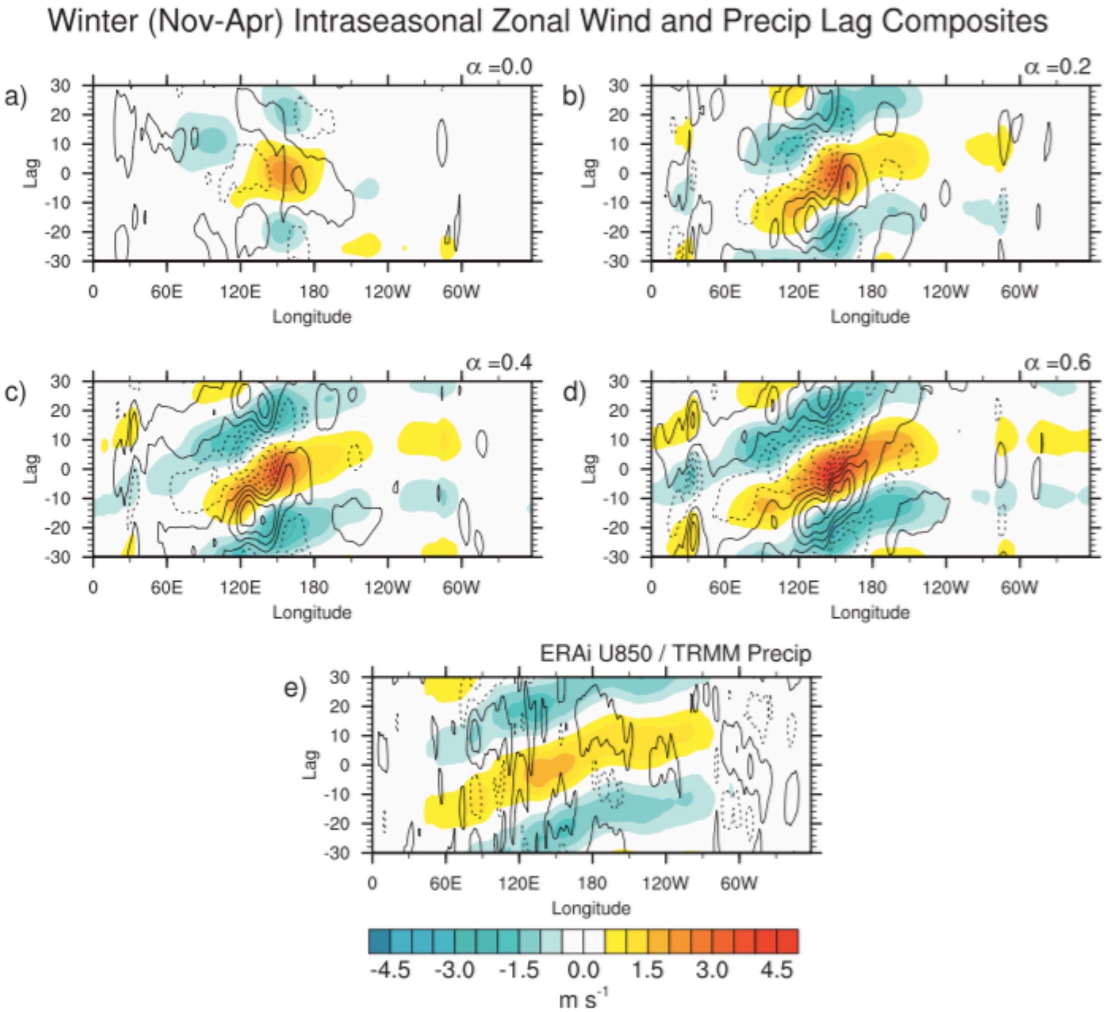
Boreal winter mean 850-hPa zonal wind for model runs α = 0.0, 0.2, 0.4, and 0.6 and ERAi data.

- MJO propagation may be strongly regulated by zonal moisture advection.
- Accurate low-level wind distribution was important for producing realistic MJO propagation in a GCM.
  - Inness et al. (2003) and Inness and Slingo (2003)
- MJO in the simulations is weaker than observed over the Indian Ocean, consistent with a lack of mean westerlies there.



Boreal winter 30–90-day saturation fraction variance for model runs α =0.0, 0.2, 0.4, and 0.6 and ERAi data.

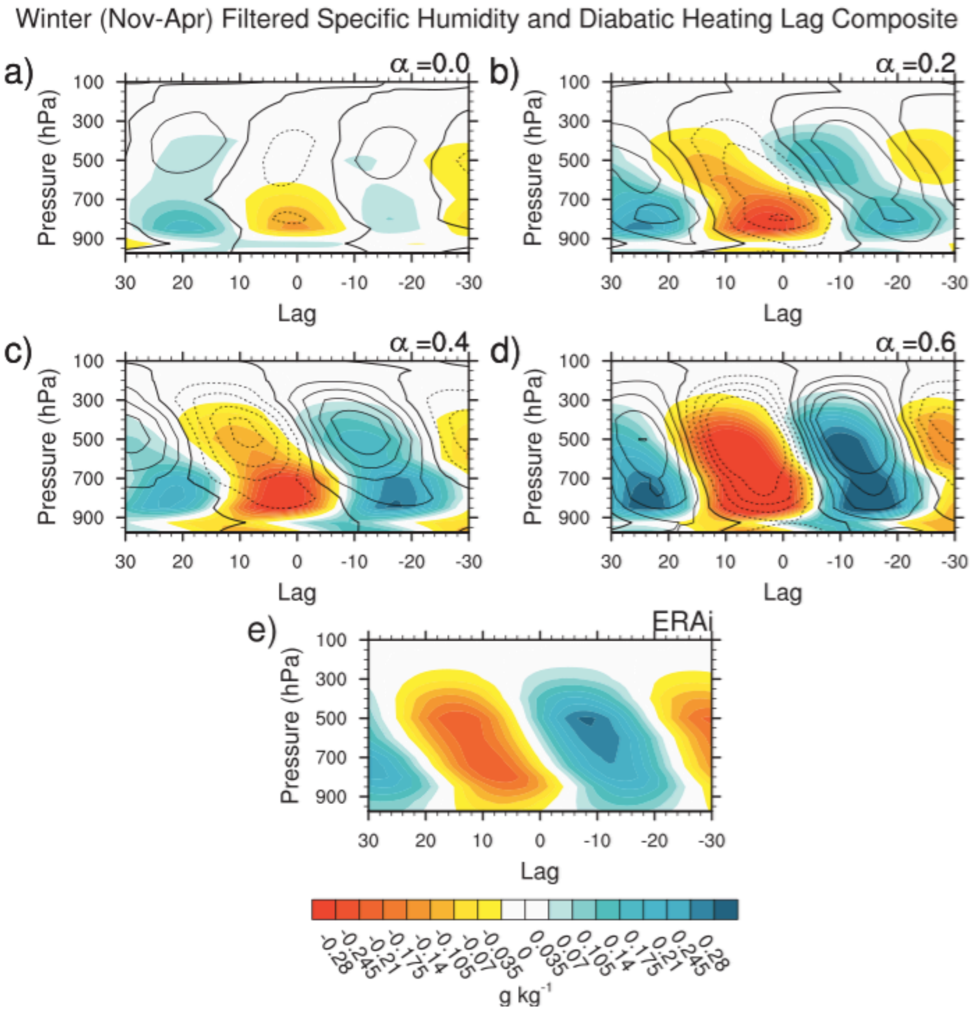
- If the model's intraseasonal variability is related to moisture–convection feedbacks, then there should be a detectable change in the intraseasonal variability of column moisture.
- Intraseasonal variance of the model:
  - Overestimated:
    - zonal wind
    - precipitation
  - Underestimated:
    - saturation fraction variance in the Indo-Pacific warm-pool region



Boreal winter 30–90-day-filtered 850-hPa zonal wind and precipitation composites as a function of lag based on peak-filtered zonal wind.

Shading: Zonal wind anomalies
Contour: precipitation anomolies (interval = 0.75 mm/day).
Time period used for observations: 1997–2003.
Data were averaged from 10ºS to 10ºN before compositing.

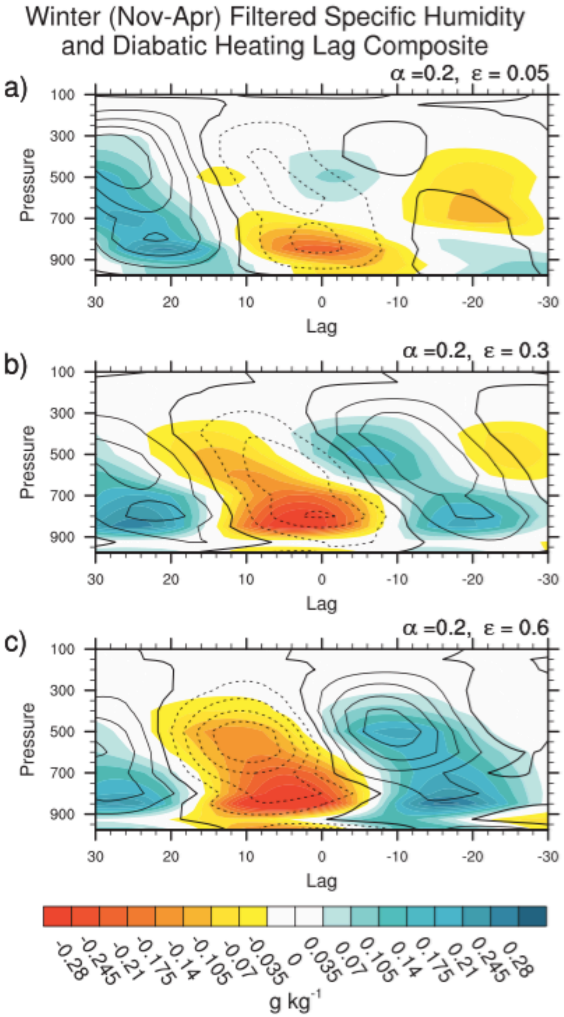
- Phase relationship between zonal wind and precipitation anomalies displays a similar quadrature relationship to the results of previous observational studies (Hendon and Salby 1994).
- Zonal wind anomalies for nonzero minimum entrainment rates are stronger than observations, but precipitation anomalies are comparable in amplitude except over the Indian Ocean.



Boreal winter 30–90-day-filtered specific humidity and diabatic heating composites as a function of lag based on peak-filtered zonal wind.

Shading: Specific humidity anomalies
Contour: diabatic heating anomalies (interval = 2.5x10-6 K/s).
Data were averaged from 5°S to 5°N before compositing.

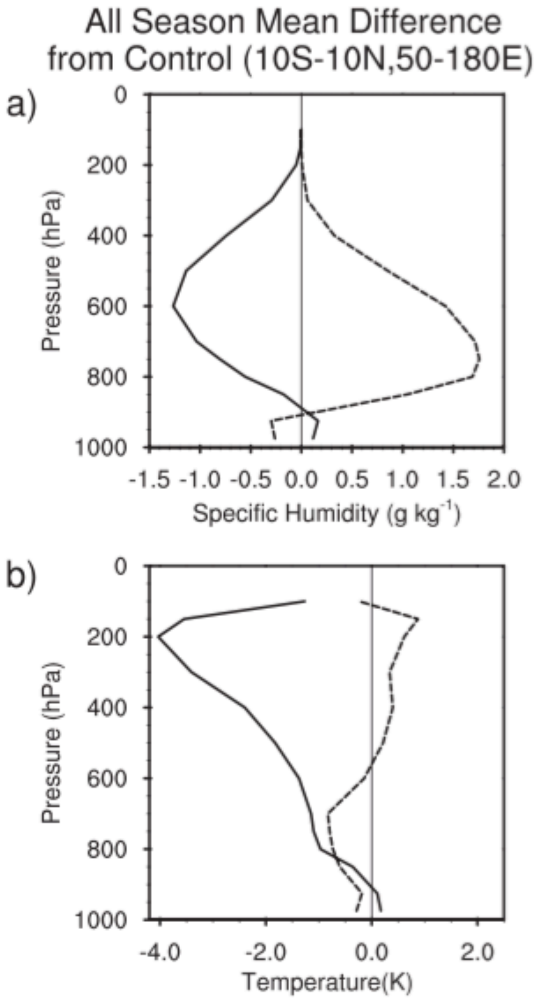
- The westward tilt with height is an essential feature of the MJO remains an open question…
- Sensitivity: minimum entrainment rate
- Anomaly magnitudes in the models with higher minimum entrainment rates are overestimated compared to observations.
- The westward tilt with height, this tilt appears to diminish slightly as the minimum entrainment rate is increased.


Winter (Nov-Apr) Filtered Specific Humidity and Diabatic Heating Lag Composite

Boreal winter 30–90-day-filtered specific humidity and diabatic heating composites as a function of lag based on peak-filtered zonal wind.

Shading: Specific humidity anomalies
Contour: diabatic heating anomalies (interval = 2.5x10-6 K/s).
Data were averaged from 5ºS to 5ºN before compositing.

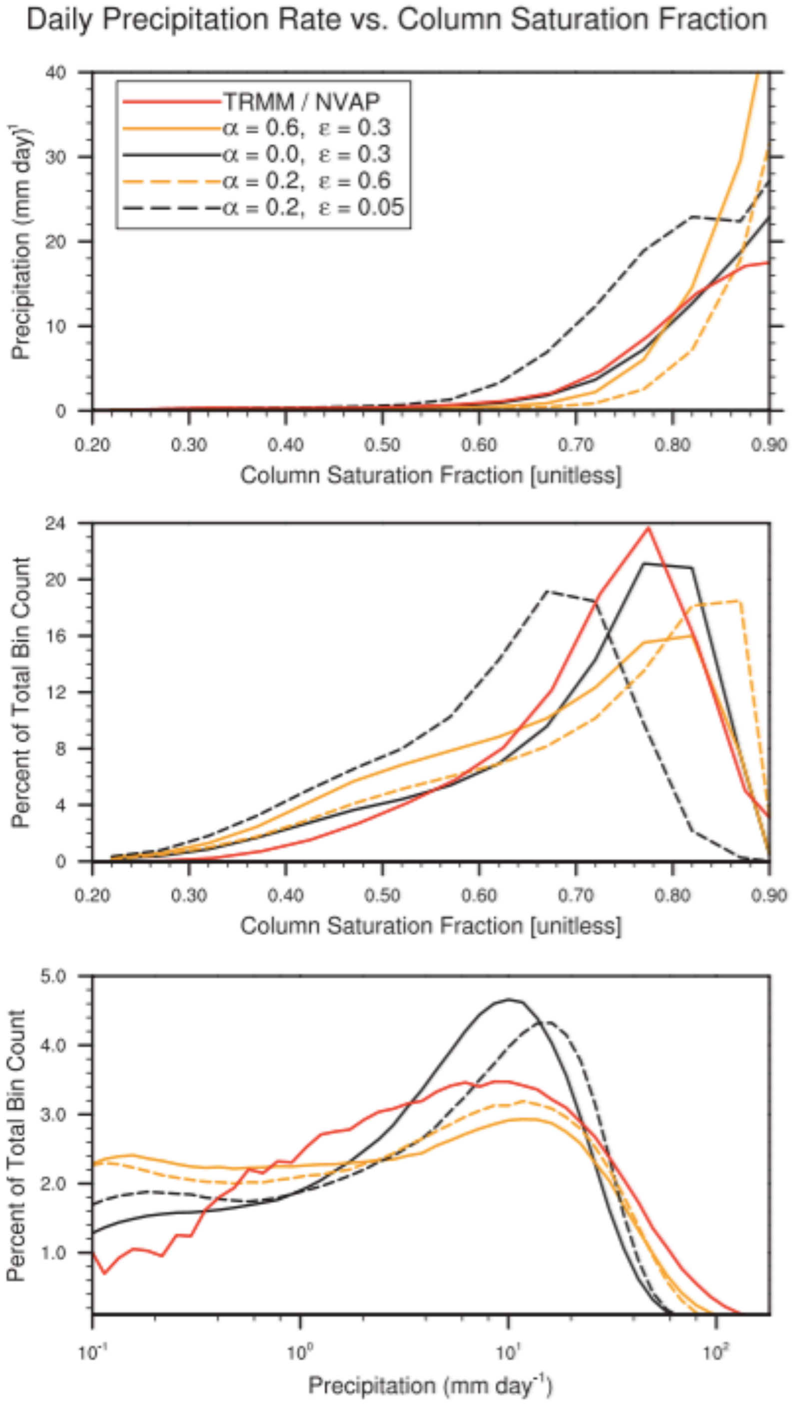
- MJO was enhanced in a GCM with a variant of RAS when ε was increased. (Maloney 2009)
- Sensitivity : rain evaporation fraction
- When ε is larger, a tilted structure is apparent.
- The dominant period of the oscillation associated with ε = 0.6 is longer than that produced with increased minimum entrainment, and moisture and diabatic heating anomalies are not as strong.



All-season mean specific humidity and temperature difference between the model run region 10°S–10°N, 50°E–180°.

Solid: minimum entrainment rate = 0.6 and 0.0
Dash: rain evaporation fraction = 0.6 and 0.05
Data were averaged from 10°S to 10°N, 50°E to 180°E

- Several results show that by increasing the strength of a moisture trigger, the MJO signal is improved and the time mean humidity in the tropics increases.
  - Tokioka et al. 1988; Maloney and Hartmann 2001; Maloney 2009
- Li et al (2008) show several cases in which moisture trigger strength does not produce increased time mean total precipitable water, although intraseasonal variability increases.



Daily Precipitation Rate vs. Column Saturation Fraction

Top:
Mean daily average precipitation rate binned by column saturation fraction.

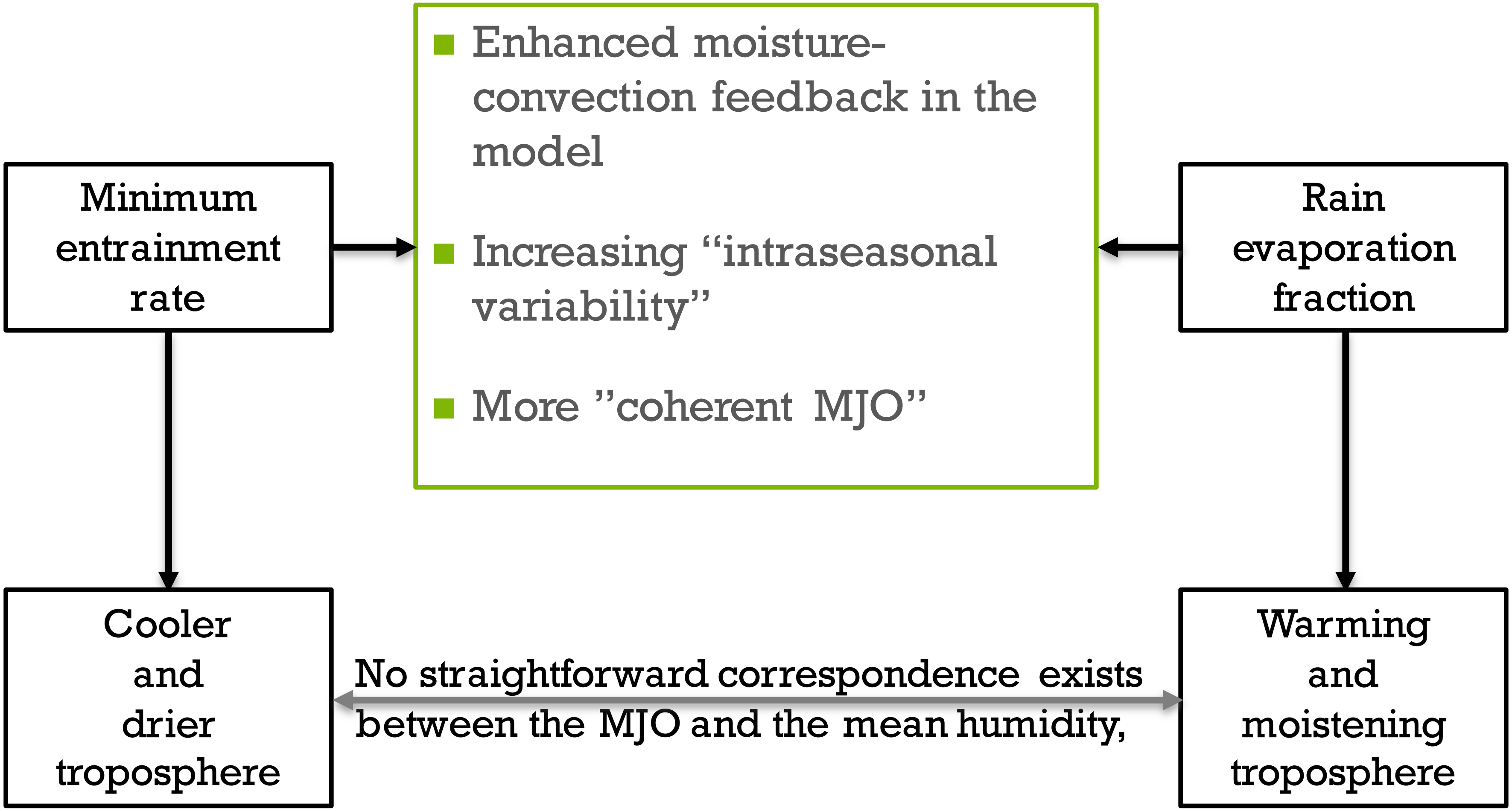
Middle:
Distributions of data are shown for saturation fraction

Bottom:
Distributions of data are shown for precipitation.

Solid: minimum entrainment rate = 0.6 and 0.0
Dash: rain evaporation fraction = 0.6 and 0.05

Precipitable water (Obs): NVAP
Precipitation (OBS): SSM/I
Temperature and surface pressure: ERAi

Data were averaged from 18ºS to 18ºN, 50ºE to 180ºE
1998-2001



Minimum entrainment rate

- Enhanced moisture-convection feedback in the model
- Increasing “intraseasonal variability”
- More ”coherent MJO”

Rain evaporation fraction

Cooler and drier troposphere

No straightforward correspondence exists between the MJO and the mean humidity,

Warming and moistening troposphere