

Moisture and the Madden-Julian Oscillation

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August 04, 2015

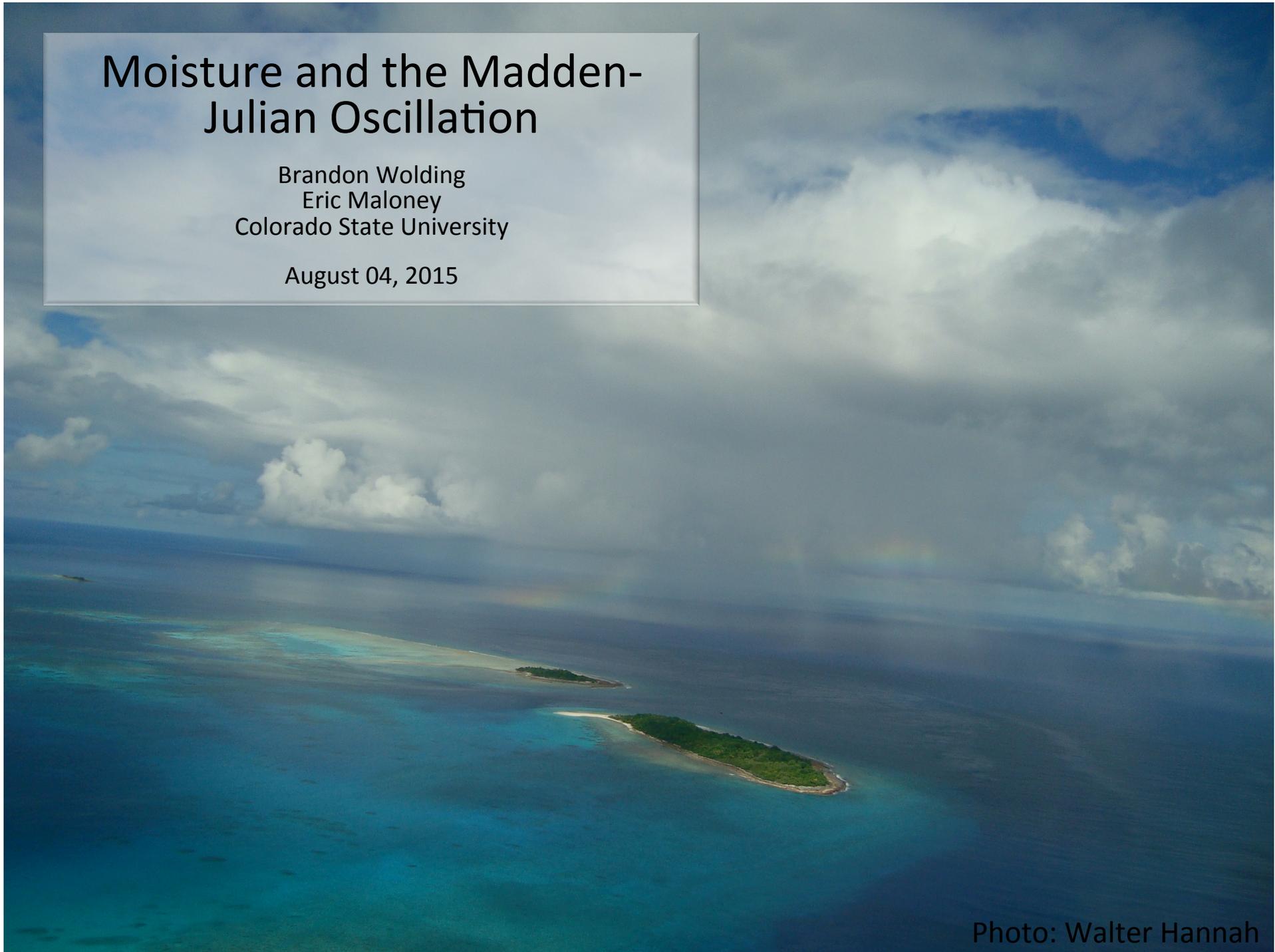
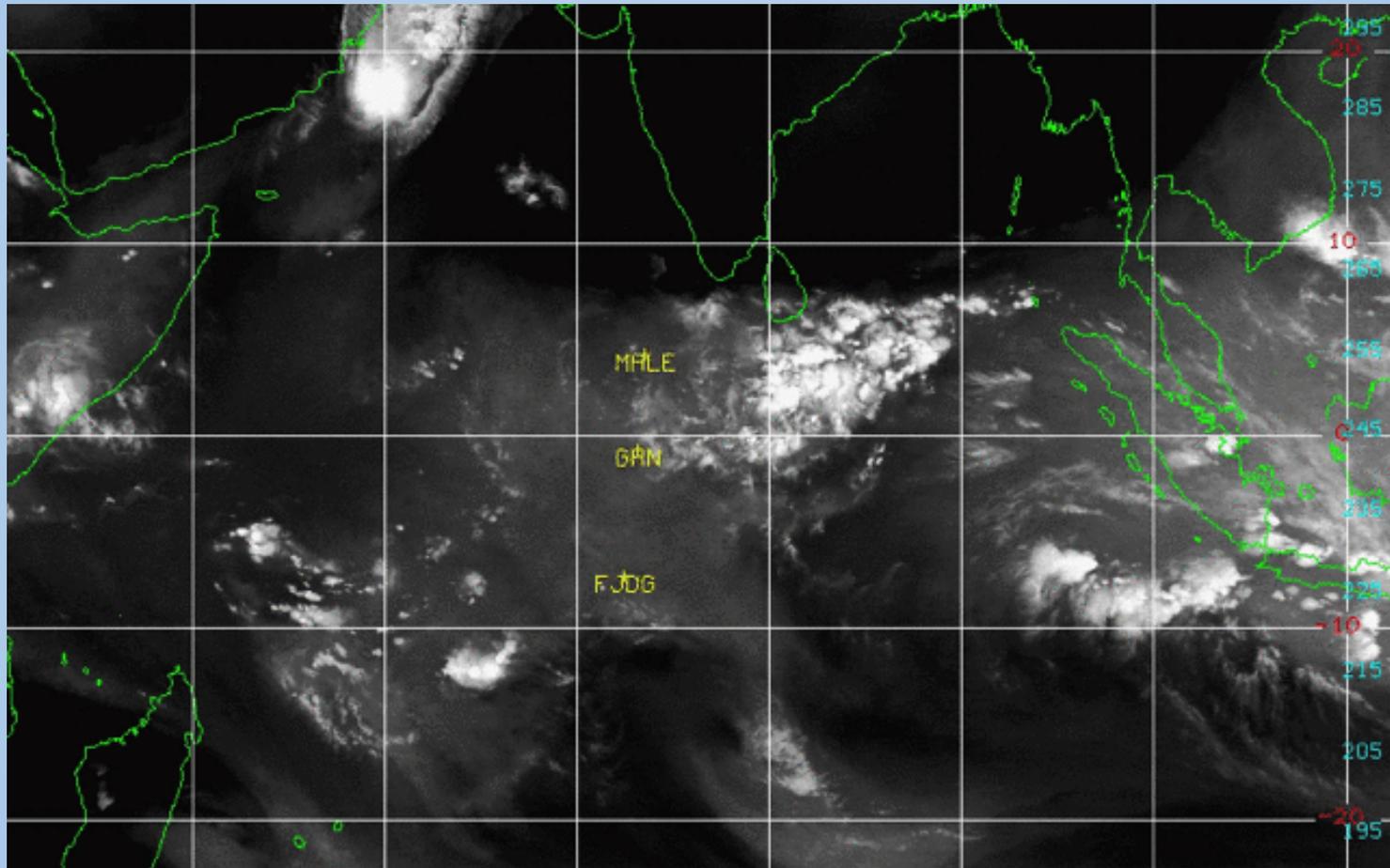
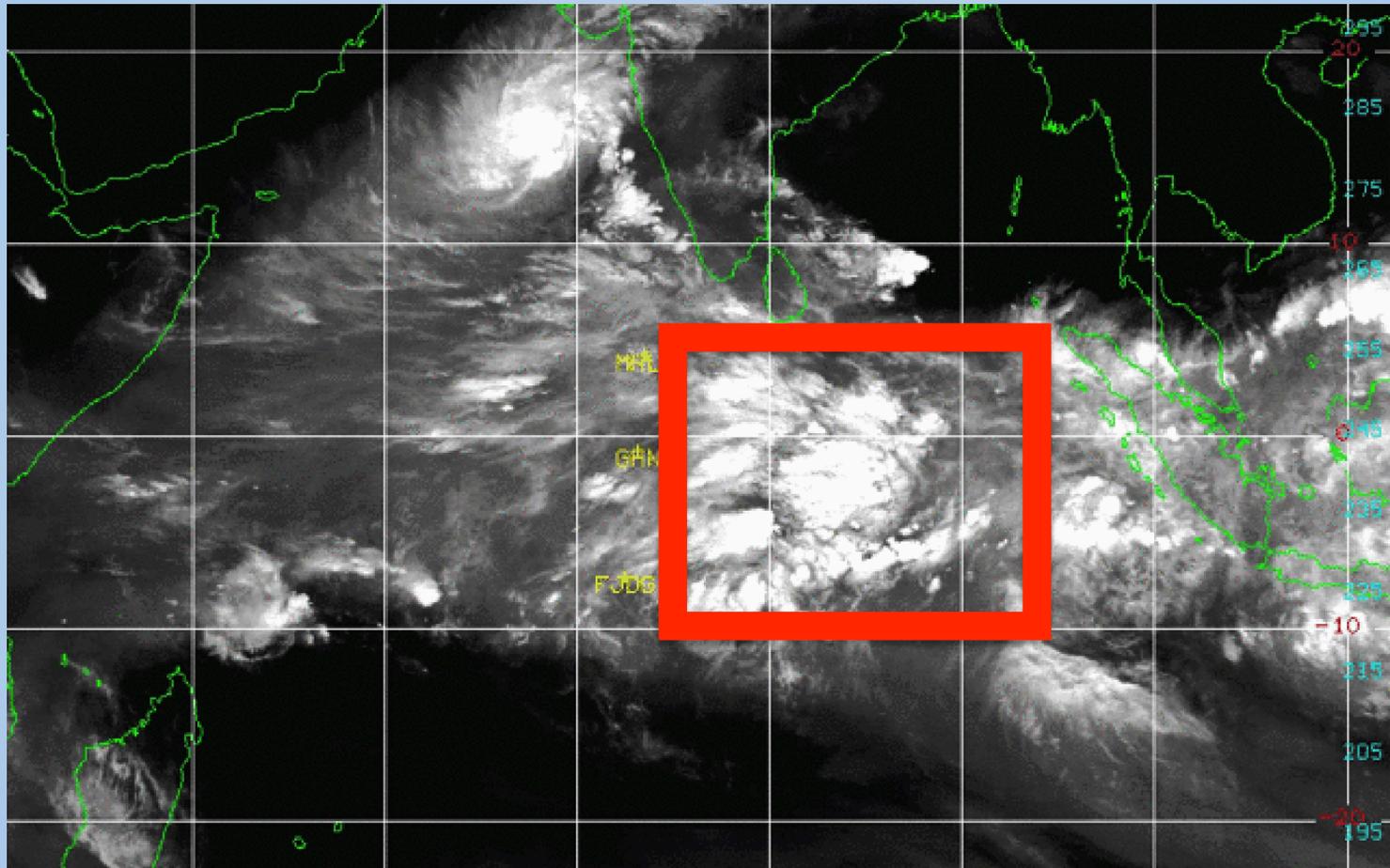
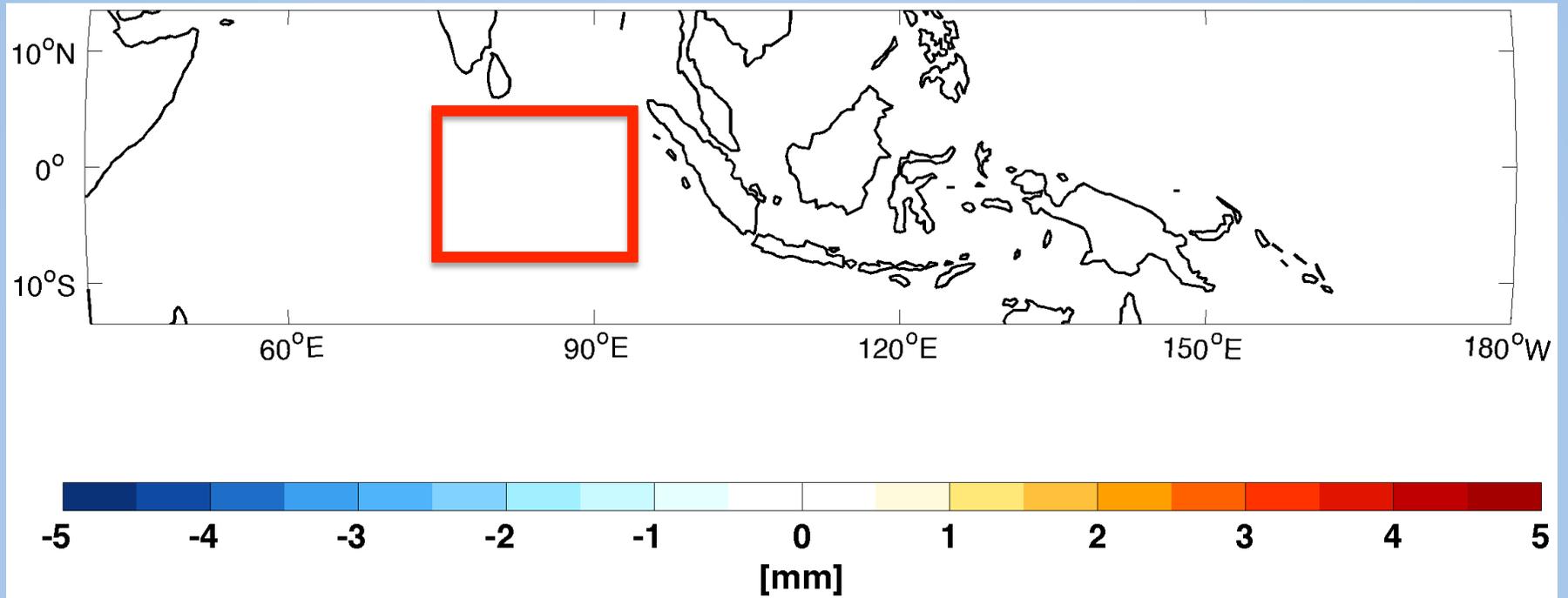


Photo: Walter Hannah



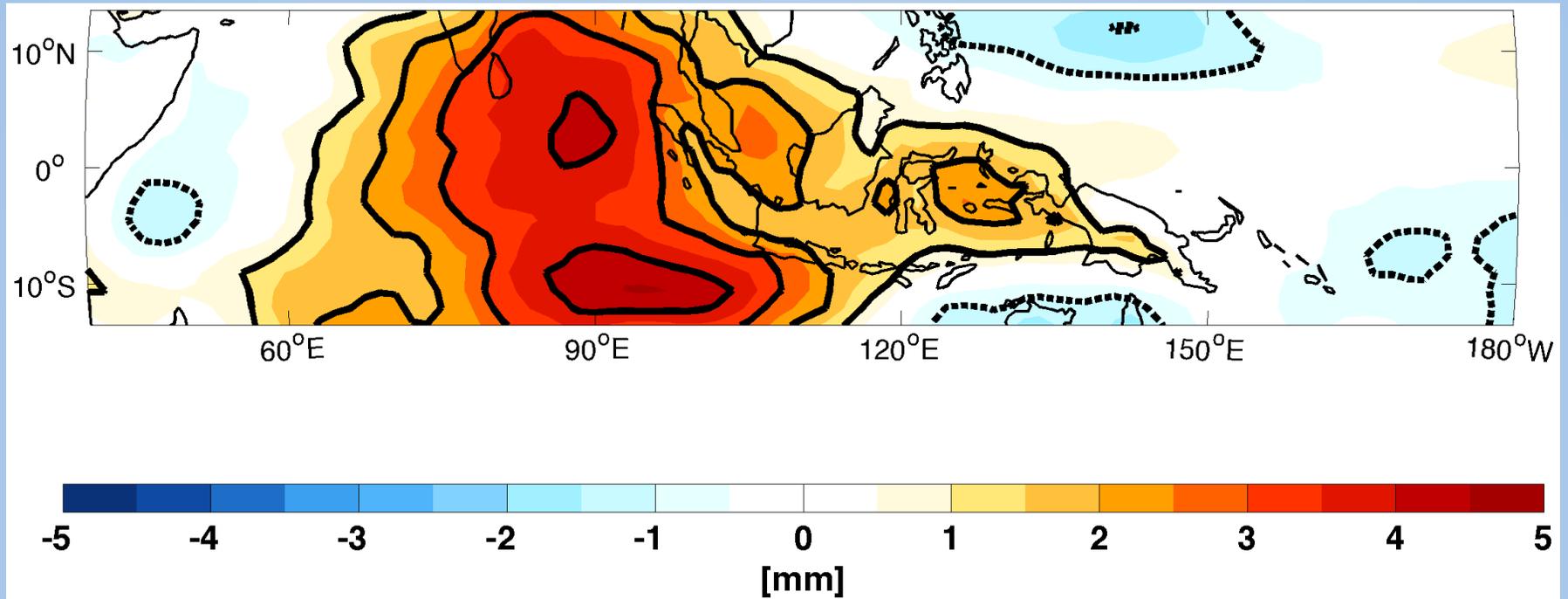


ERA-Interim



ERA-Interim

$\langle q \rangle$

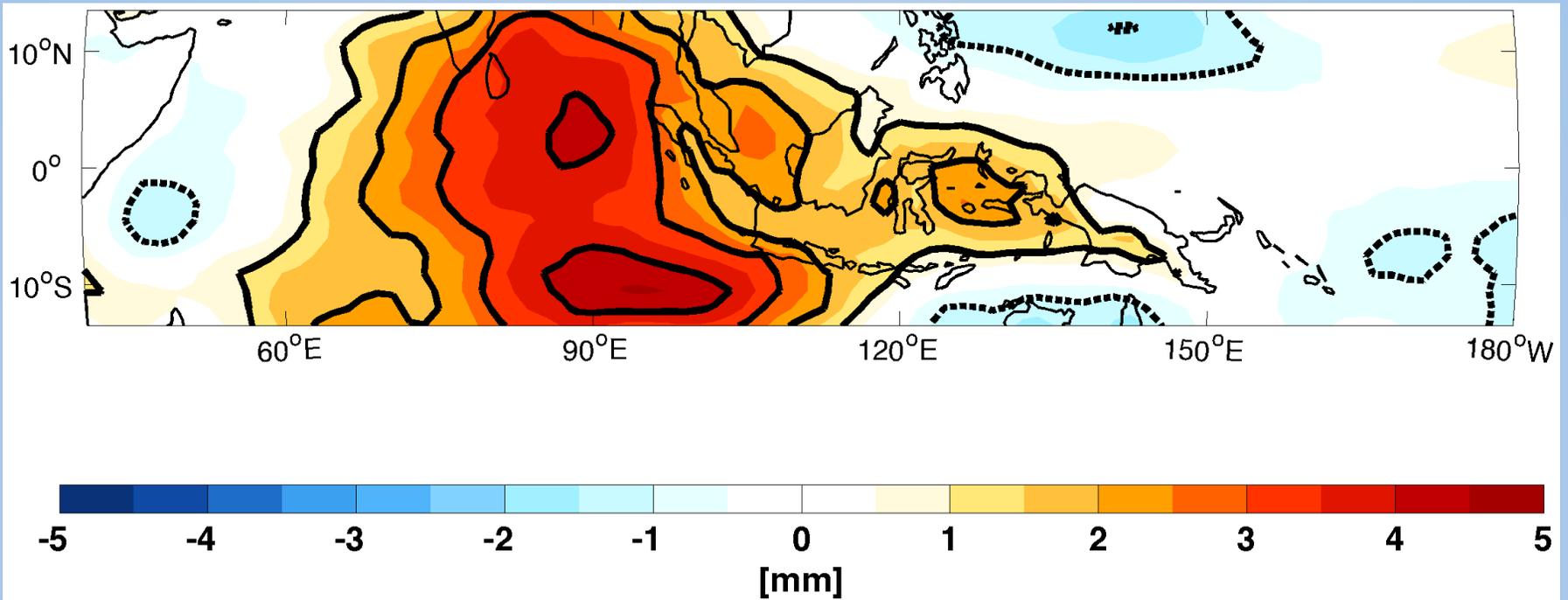


Moisture:

- 1.) Has a strong influence on tropical convection
- 2.) Varies systematically with the MJO
- 3.) Is central to recent theories of the MJO

ERA-Interim

$\langle q \rangle$



What drives these moisture variations?

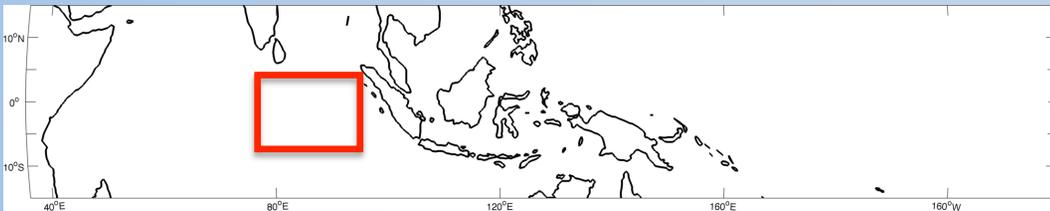
Moisture Variation:

$$\left\langle \frac{\partial q}{\partial t} \right\rangle =$$

Mean state:

$$0 =$$

[mm/day]



Moisture Variation:

$$\left\langle \frac{\partial q}{\partial t} \right\rangle =$$

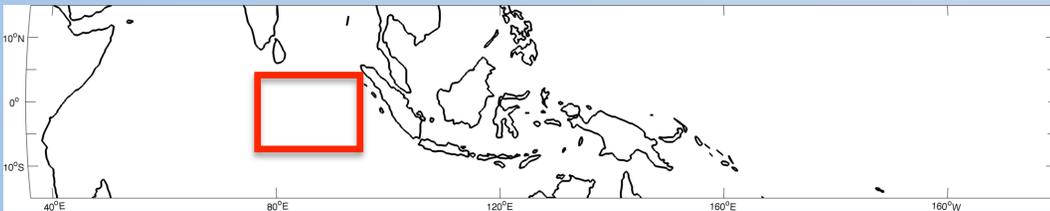
$+SLHF$

Mean state:

$$0 =$$

5.5

[mm/day]



Moisture Variation:

$$\left\langle \frac{\partial q}{\partial t} \right\rangle =$$

$$-P \quad +SLHF$$

Mean state:

$$0 =$$

-7

5.5

[mm/day]

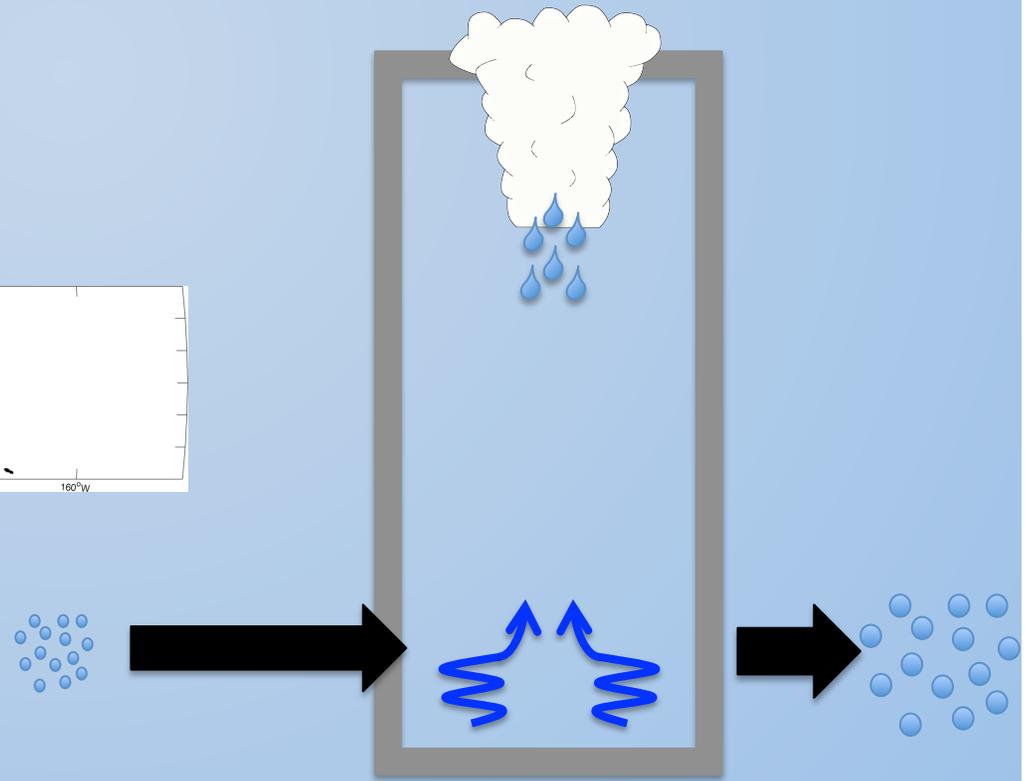


Moisture Variation:

$$\left\langle \frac{\partial q}{\partial t} \right\rangle = -\left\langle \vec{V}_h \cdot \nabla q \right\rangle$$

$$-P \quad +SLHF$$

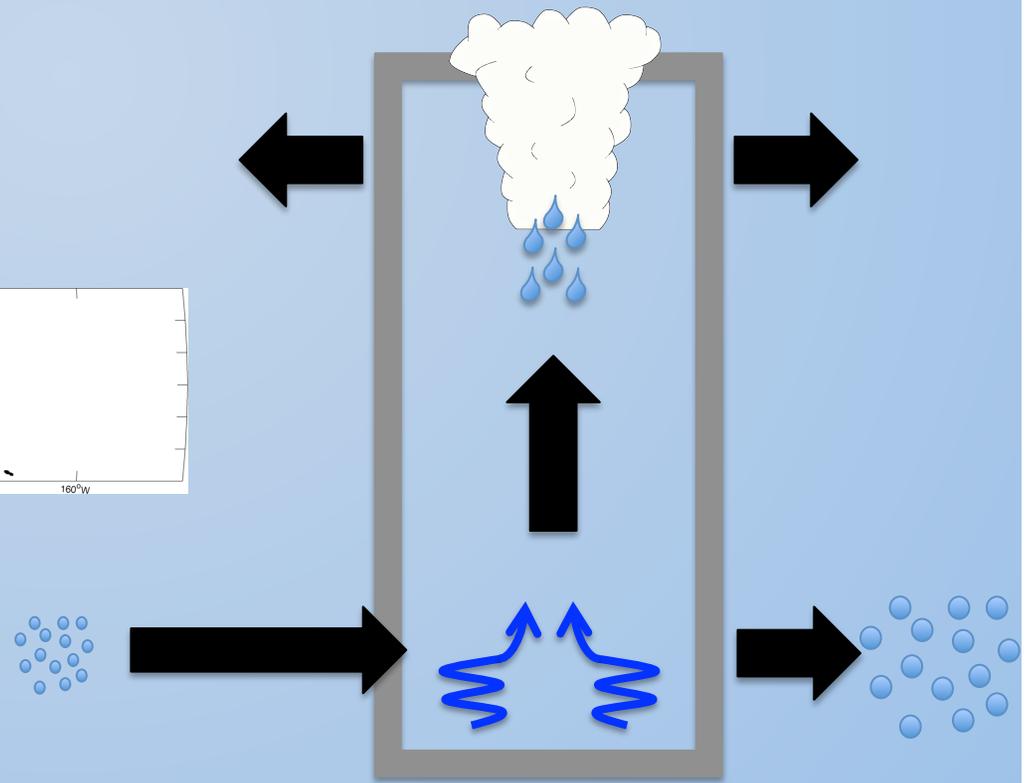
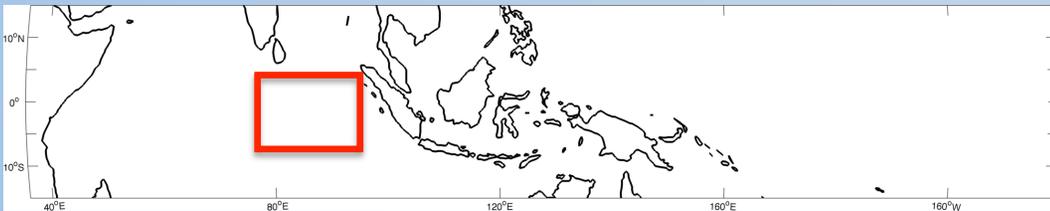
Mean state: 0 = -2 -7 5.5 [mm/day]



Moisture Variation:

$$\left\langle \frac{\partial q}{\partial t} \right\rangle = -\left\langle \vec{V}_h \cdot \nabla q \right\rangle - \left\langle \omega \frac{\partial q}{\partial p} \right\rangle - P + SLHF$$

Mean state: 0 = -2 3.5 -7 5.5 [mm/day]



Moisture Variation:

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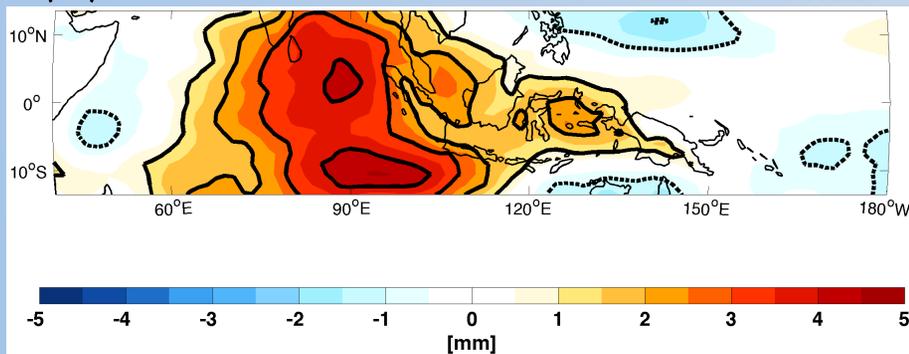
Mean state: 0 = -2 3.5 -7 5.5 [mm/day]

+

Mature phase:
(anomalies) = -7 [mm/day]

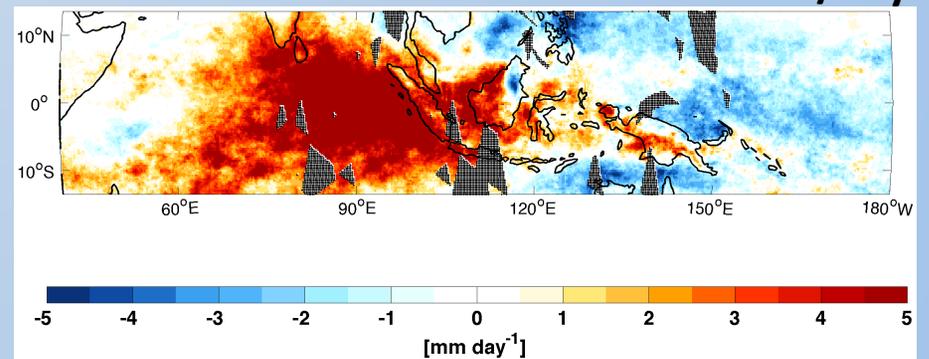
$\langle q \rangle$

~ 4 mm



P : TRMM

~ 7 mm/day



Moisture Variation:

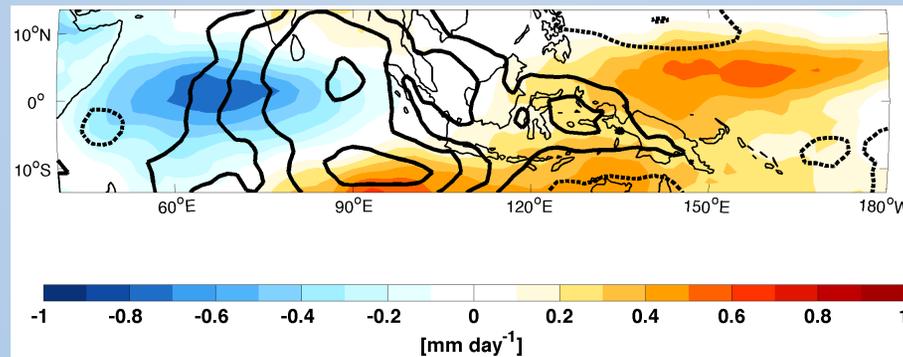
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Mean state: 0 = -2 3.5 -7 5.5 [mm/day]

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Mature phase:
(anomalies) 0 = -7 [mm/day]

$$\left\langle \frac{\partial q}{\partial t} \right\rangle$$



Moisture Variation:

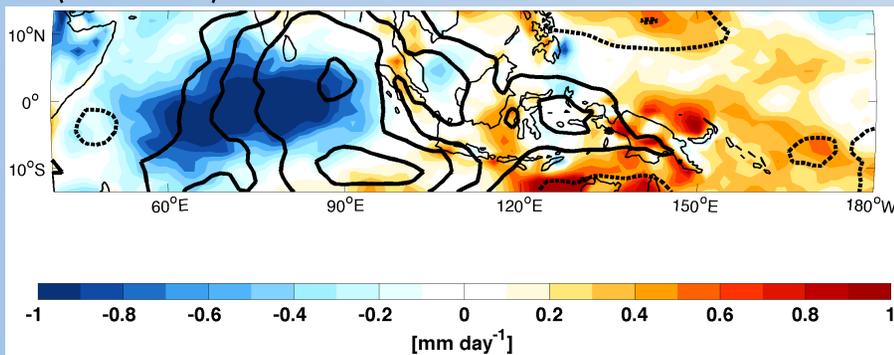
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Mean state: 0 = -2 3.5 -7 5.5 [mm/day]

+

Mature phase:
(anomalies) 0 = -0.7 -7 [mm/day]

$$-\left\langle \vec{V}_h \cdot \nabla q \right\rangle$$



Moisture Variation:

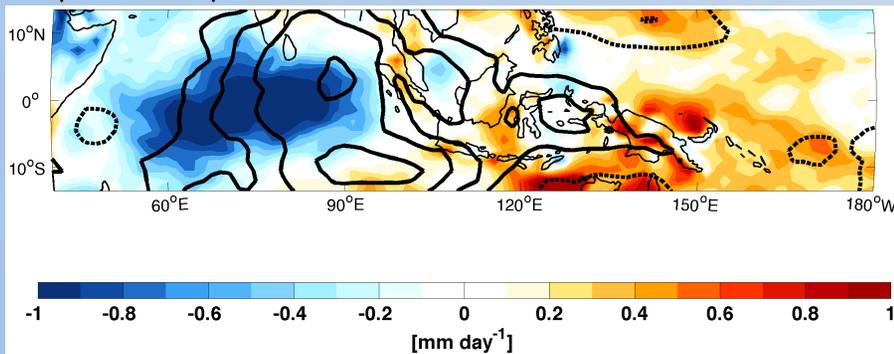
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Mean state: 0 = -2 3.5 -7 5.5 [mm/day]

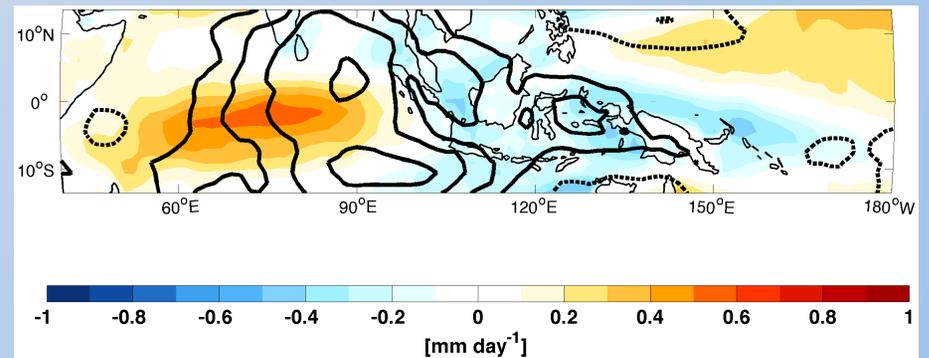
+

Mature phase:
(anomalies) 0 = -0.7 -7 0.7 [mm/day]

$$-\left\langle \vec{V}_h \cdot \nabla q \right\rangle$$



$$SLHF$$



Moisture Variation:

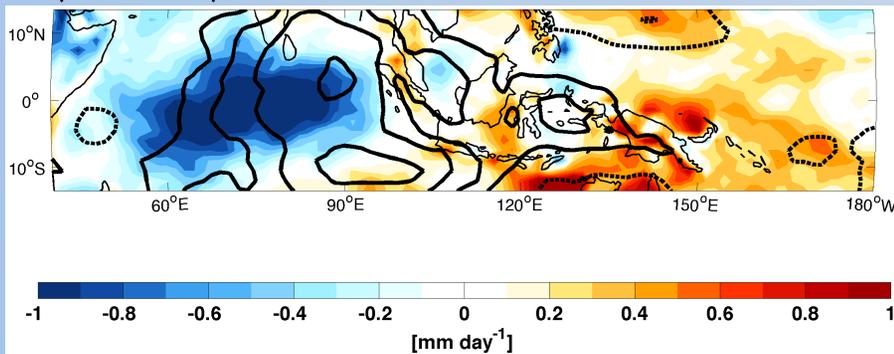
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Mean state: 0 = -2 3.5 -7 5.5 [mm/day]

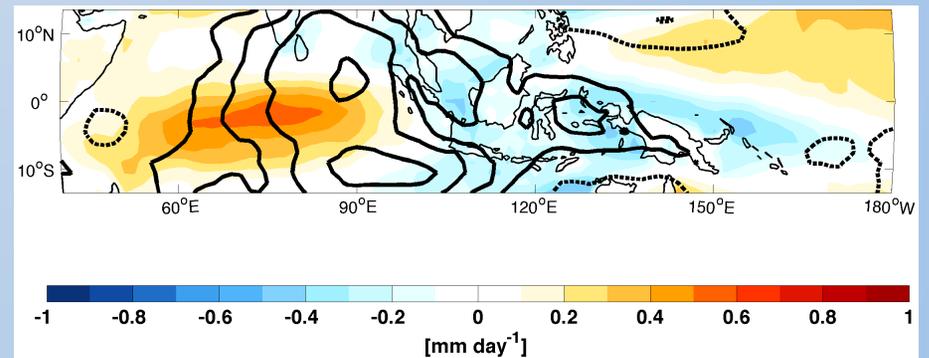
+

Mature phase:
(anomalies) 0 = -0.7 7 -7 0.7 [mm/day]

$$-\left\langle \vec{V}_h \cdot \nabla q \right\rangle$$



$$SLHF$$



Moisture Variation:

$$\left\langle \frac{\partial q}{\partial t} \right\rangle = -\left\langle \vec{V}_h \cdot \nabla q \right\rangle - \left\langle \omega \frac{\partial q}{\partial p} \right\rangle - P + SLHF$$

Mean state:	0	=	-2	3.5	-7	5.5	[mm/day]
+							
Mature phase: (anomalies)	0	=	-0.7	7	-7	0.7	[mm/day]
=							
Mature phase: (total)	0	=	-2.7	10.5	-14	6.2	[mm/day]



Understanding these changes is of primary importance!

**How can we gain an understanding of
these changes in large-scale vertical
moisture advection?**

Sherwood 1999

Grabowski and Moncrieff 2004

Chikira 2014



Use WTG balance!

WTG balance to the rescue!

$$\bar{\omega} = \frac{\bar{Q}_s - \frac{\partial \bar{\omega}'s'}{\partial p}}{\frac{\partial \bar{s}}{\partial p}}$$

Large-scale vertical motion can be diagnosed from apparent heating

Apparent heating processes include:

Radiative heating

Net condensation

Net freezing

Net deposition

Sub-grid scale vertical eddy fluxes of DSE

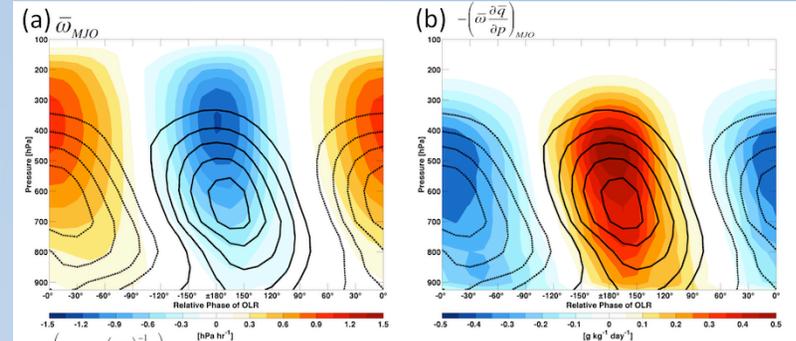
SP-CCSM 3.0

Vertical

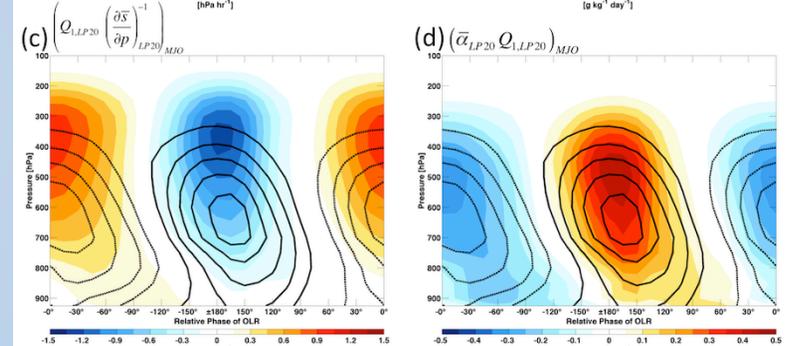
Moisture Advection

Omega

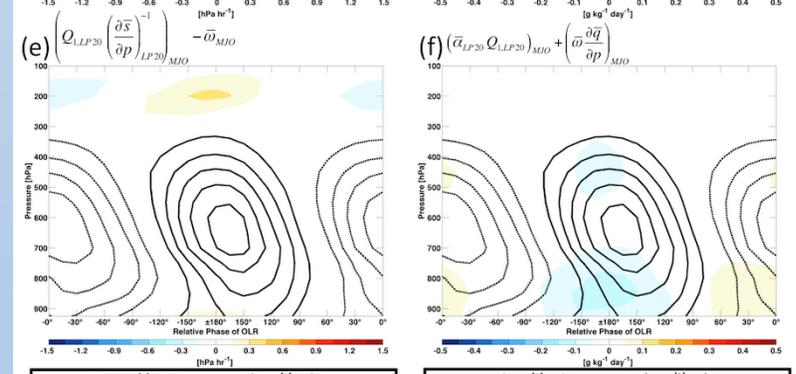
Actual



Diagnosed



Difference (error)



suppressed transition to suppressed enhanced transition to enhanced suppressed

suppressed transition to suppressed enhanced transition to enhanced suppressed

SP-CCSM 3.0

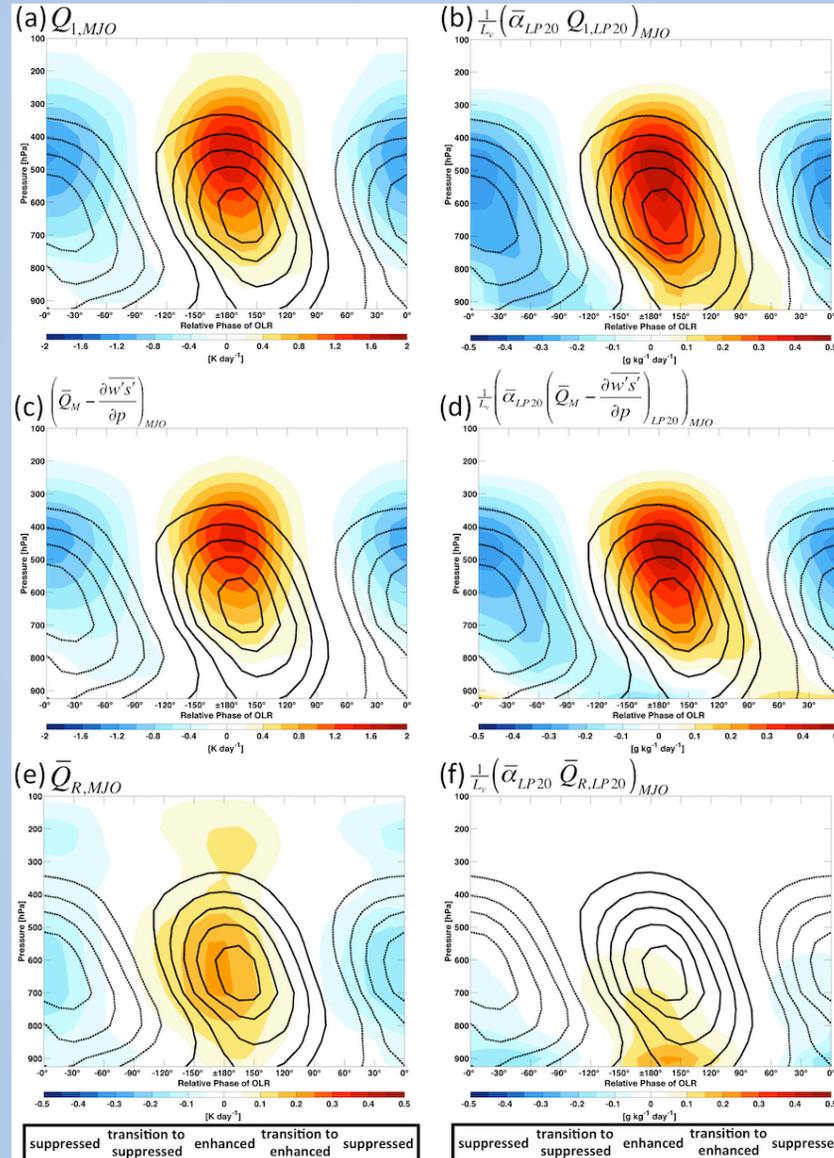
Heating

Moistening

Total
Apparent
Heating

Latent Heating
and SGS Eddy
Fluxes

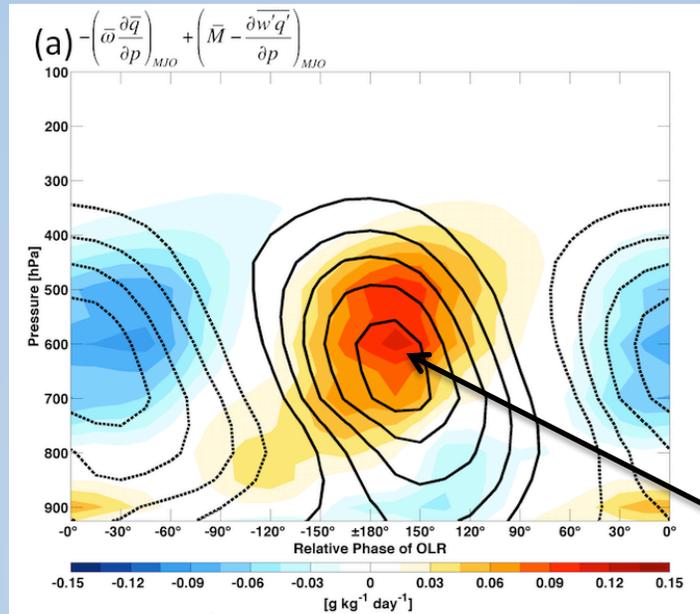
Radiative
Heating



What role do radiative heating anomalies play in destabilizing the MJO?

SP-CCSM 3.0 Moistening

“Column Process”
Vertical moisture advection
+
CRM q tendency
(i.e. microphysics + SGS
vertical eddy fluxes)



All processes except
horizontal advection

Further moisten regions
that are anomalously
moist

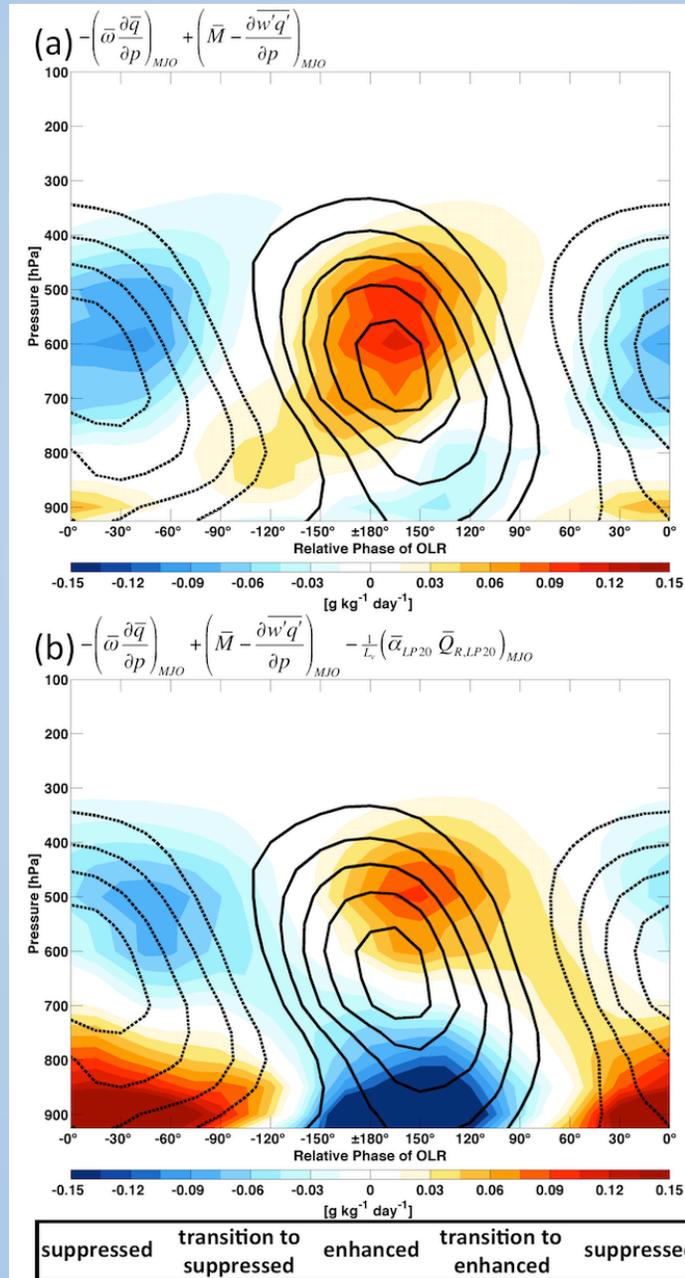
suppressed transition to enhanced transition to suppressed

SP-CCSM 3.0 Moistening

“Column Process”
Vertical moisture advection
+
CRM q tendency
(i.e. microphysics + SGS vertical eddy fluxes)

“Column Process”
-
Vertical moisture advection
associated with radiative heating

All processes except horizontal advection



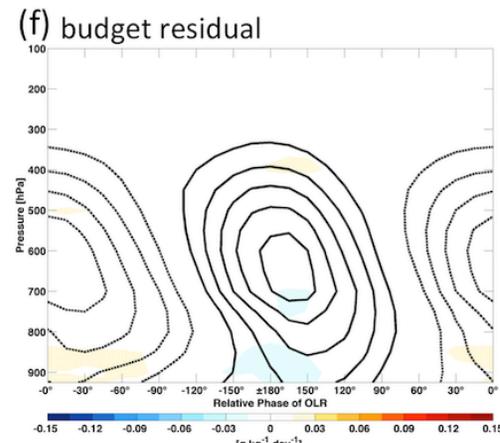
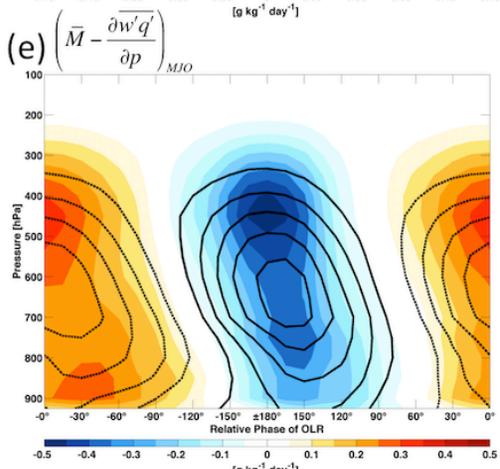
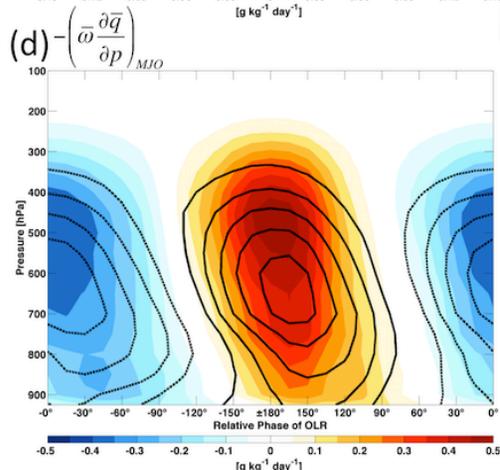
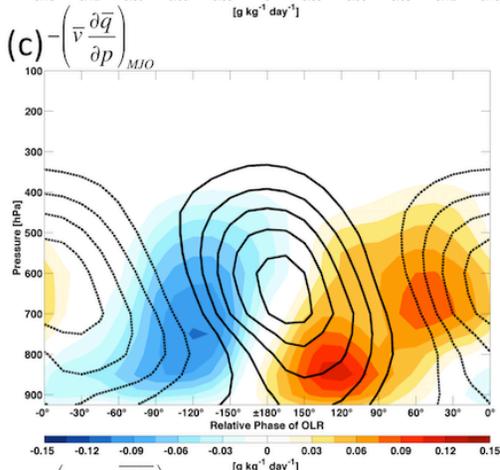
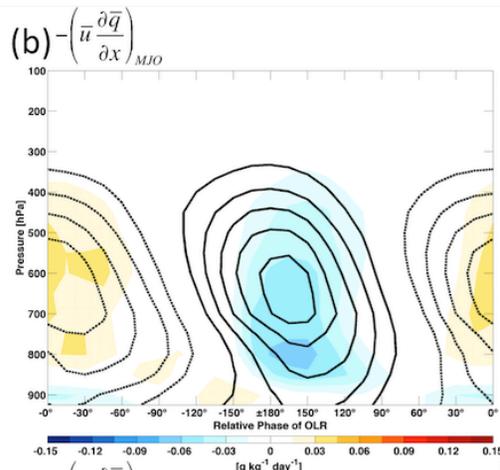
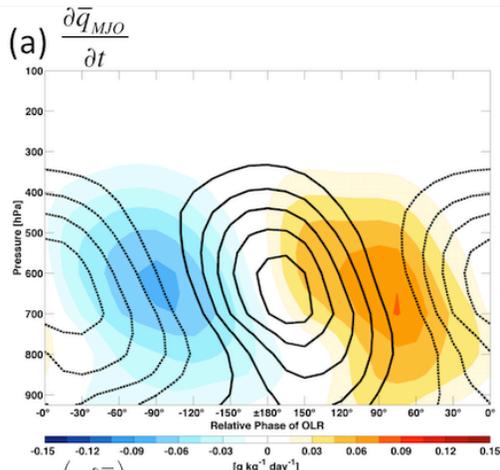
Summary

The increase in vertical moisture advection during the mature phase of the MJO is essential for maintaining precipitation anomalies

Weak temperature gradient balance provides a framework for understanding intraseasonal changes in large scale vertical moisture advection

Radiative feedbacks appear to play an important role in maintaining lower free tropospheric moisture anomalies associated with the MJO

Questions ?



suppressed transition to suppressed enhanced transition to enhanced suppressed

suppressed transition to suppressed enhanced transition to enhanced suppressed

$\langle q \rangle$ anomaly is ~ 5 mm

P anomaly is ~ 7 mm/day

Precipitation anomalies must be supported by anomalous moisture sources

0.5 vs 0.15 g/kg/day