Convection, Tropical Waves, and Double ITCZs

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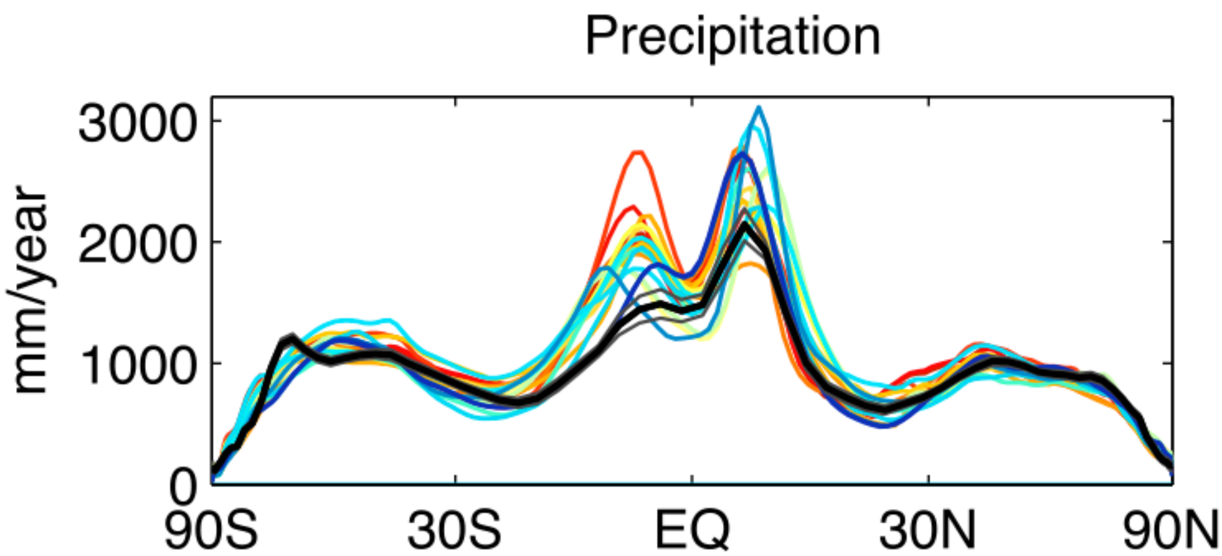
Thanks to John Chiang (UC Berkeley)
Mike Pritchard (UC Irvine)
Zhihong Tan (Caltech)

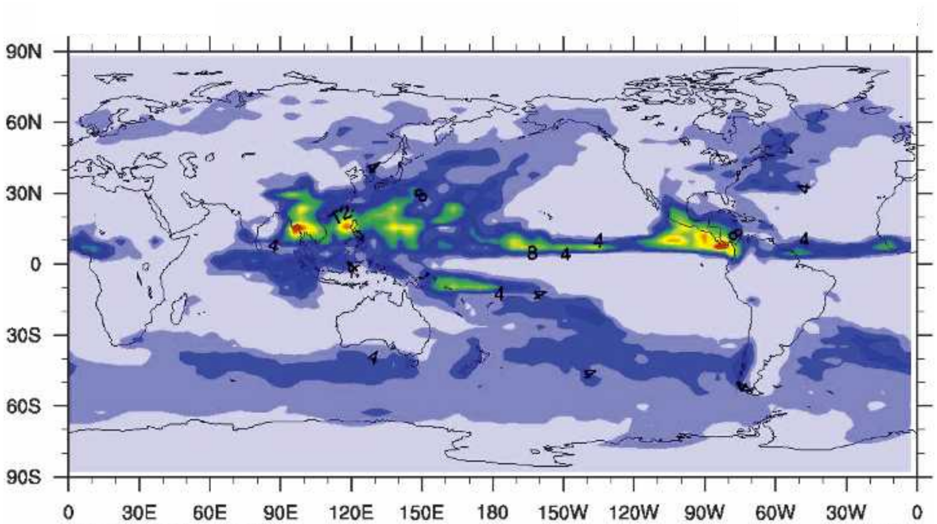
Double Inter-tropical Convergence Zones (ITCZs)



Black: Observation
Others: CMIP simulation results

Hwang & Frierson, 2013

Double ITCZs are simulated by the SPCAM



Khairoutdinov et al. 2005

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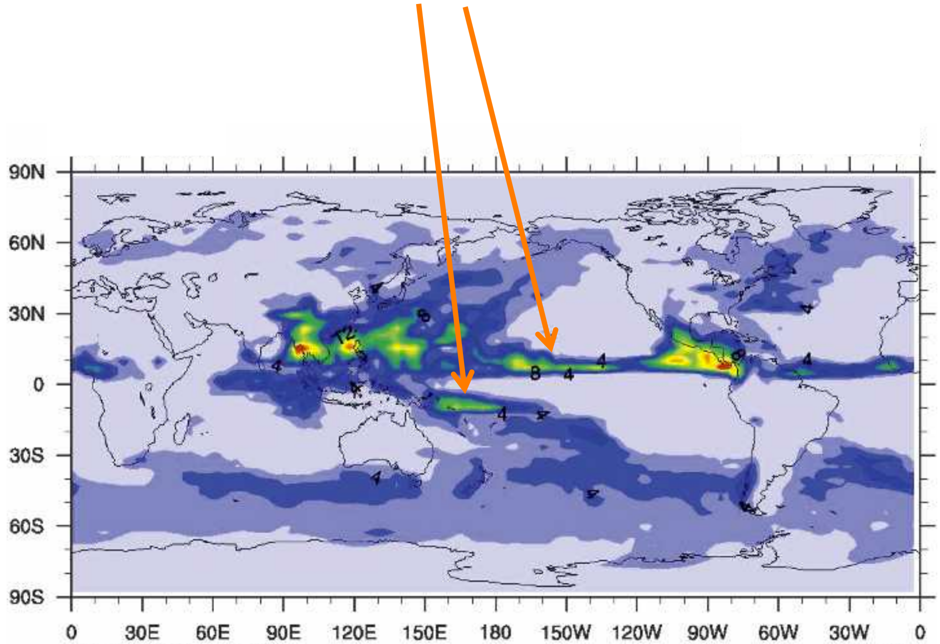

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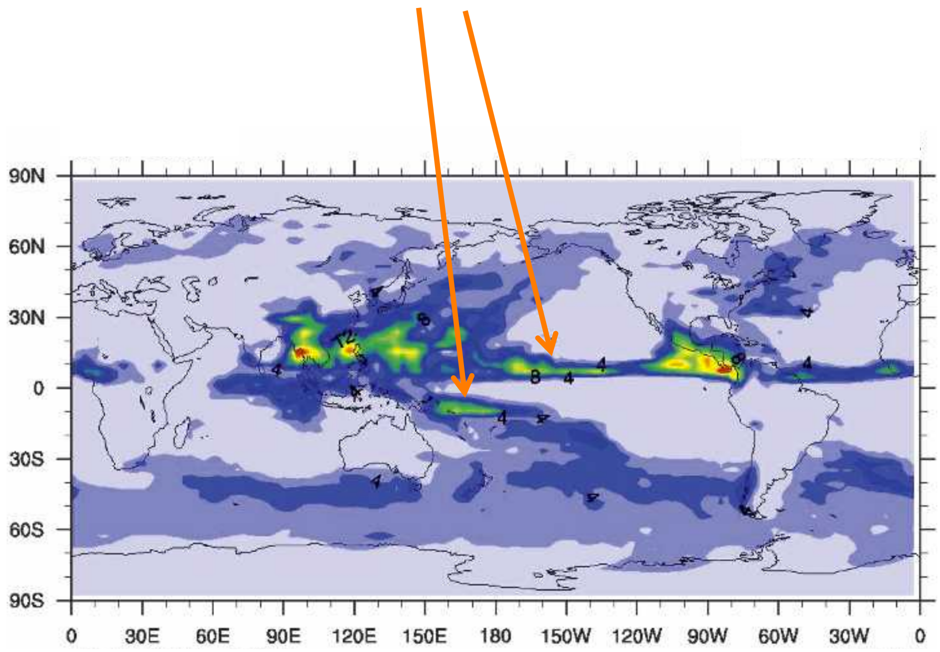

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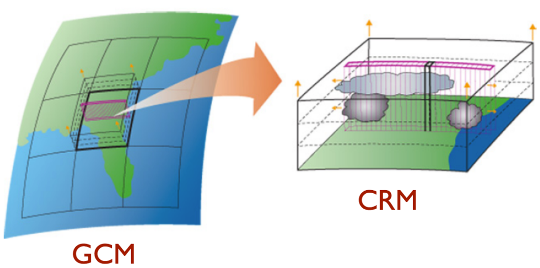

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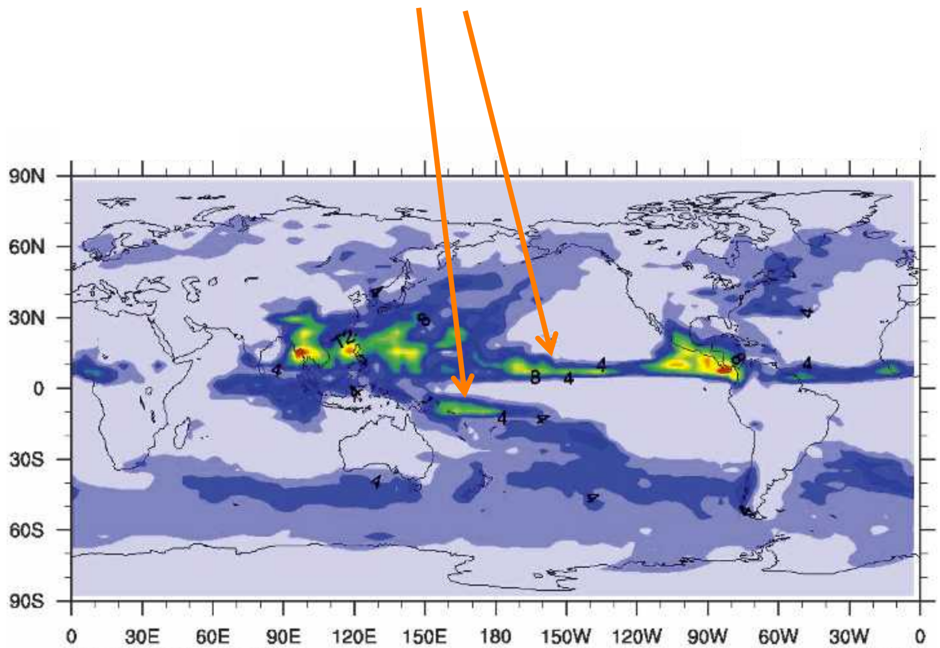

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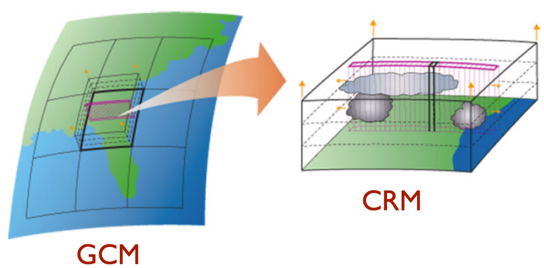
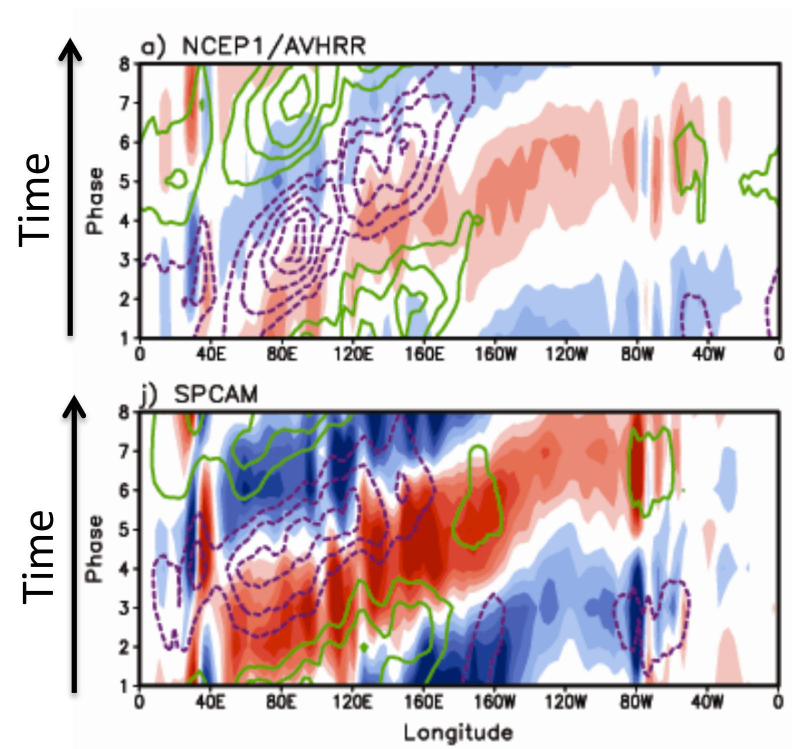
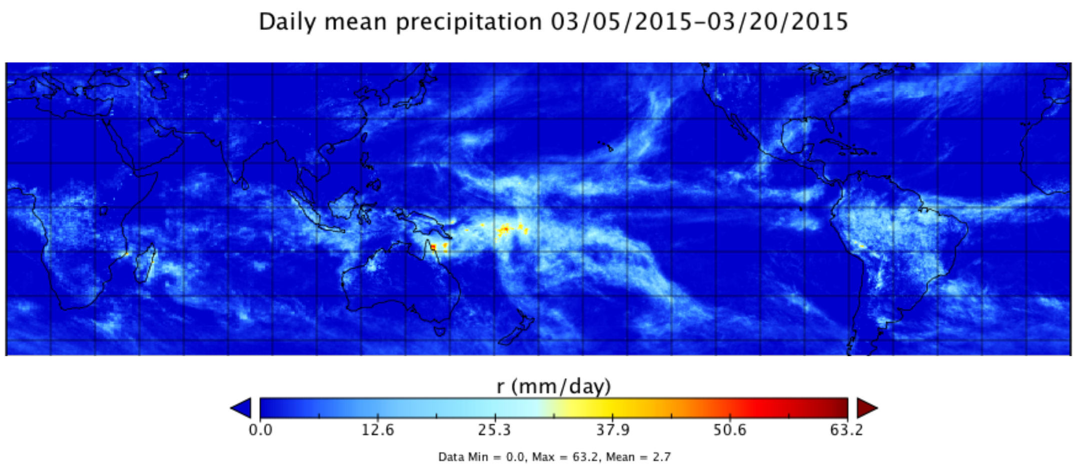


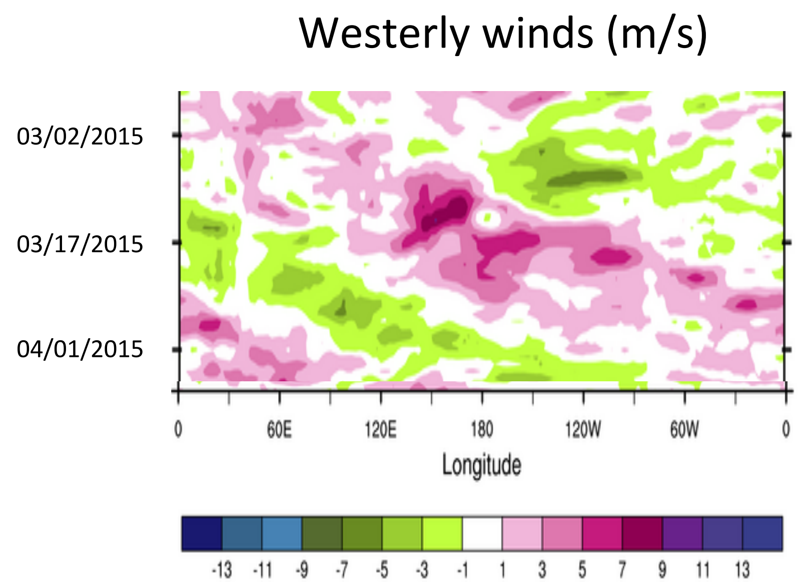
SPCAM simulates even stronger MJOs then observation.



Kim et al. 2009

Double ITCZs emerged during a strong Madden-Julian Oscillation event in March 2015

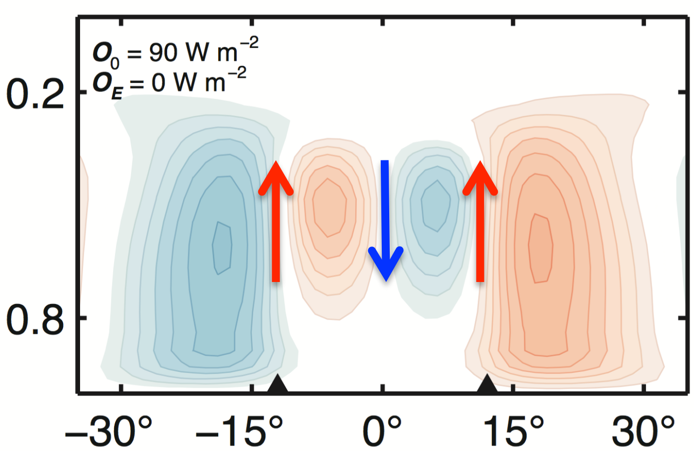




http://www.bom.gov.au/climate/mjo/#tabs=Weekly-note

Why double ITCZs?

Anomalous anti-Hadley circulations



Arguments about ITCZ location:

A1: SST distribution: *e.g.*, Lindzen and Nigam 1987; Neelin 1989; Wang and Li 1993; Chiang et al. 2001

A2: Quasi-equilibrium: *e.g.*, Emanuel 1995; Prive and Plumb 2007; Boos and Kuang 2010

A3: Energy transport: *e.g*, Kang et al. 2008, 2009; Frierson and Hwang 2012; Donohoe et al. 2013; Bischoff and Schneider 2015

Bischoff and Schneider 2015

A thought experiment

- Imagine …
  - Aquaplanet
  - Forced by uniformly distributed sea surface temperatures

    (No baroclinic waves)
  - No Sunlight (only longwave radiation)

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  - Are there still tropical rainfall peaks?
  - Where are they?

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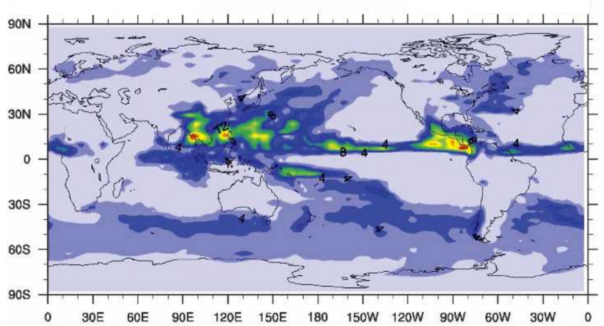
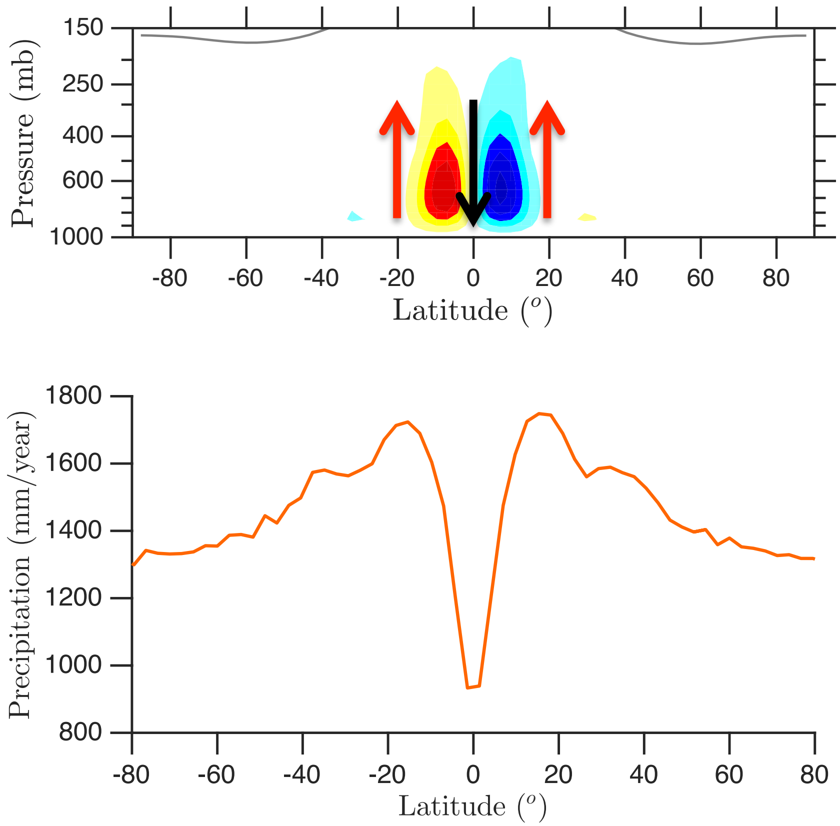
SPCAM



Double ITCZs emerge over uniform SSTs



This result suggests:

- Thermodynamic constraints cannot predict this behavior.
- We need other constraints.

Proposed mechanism:

Tropical waves can drive double ITCZs by transporting angular momentum

At steady state, when $R_o << 1$,

$$f\overline{v} \approx S.$$

eddy momentum flux divergence

Schneider 2006; Bordoni and Schneider 2008; Shaw 2014;

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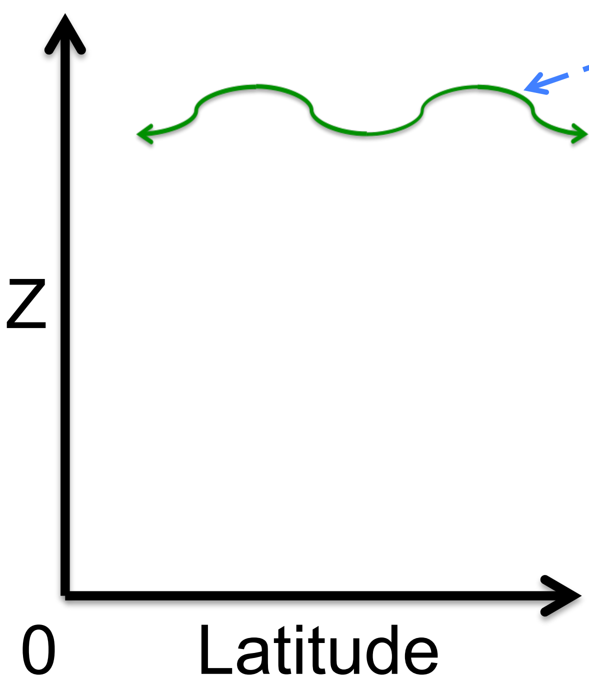

Tropical waves converge angular momentum, *i.e.*, $S < 0$,

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$\Leftrightarrow$ Equatorward flow

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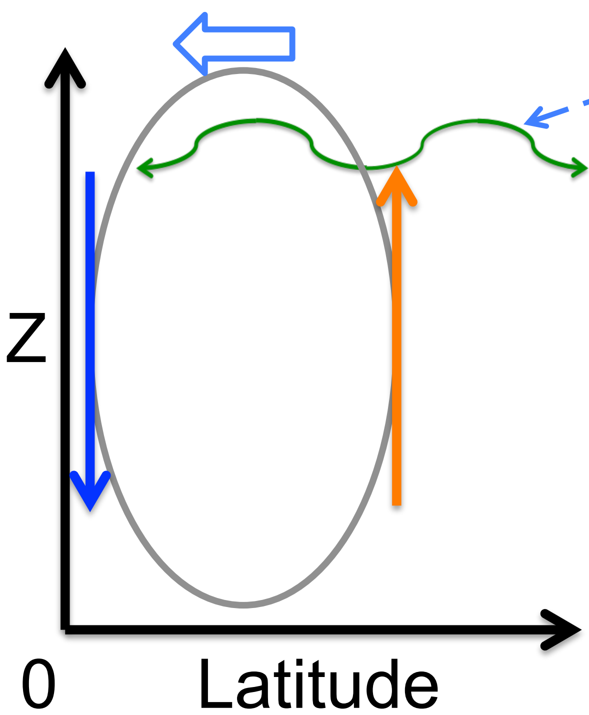

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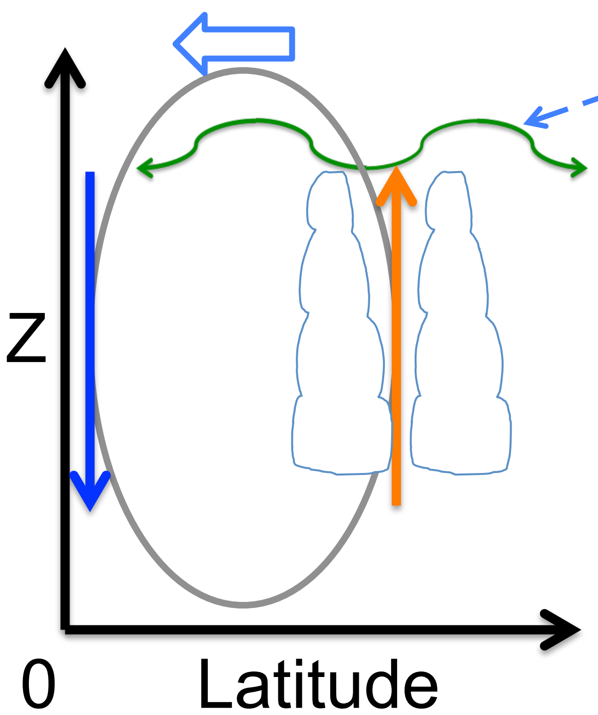

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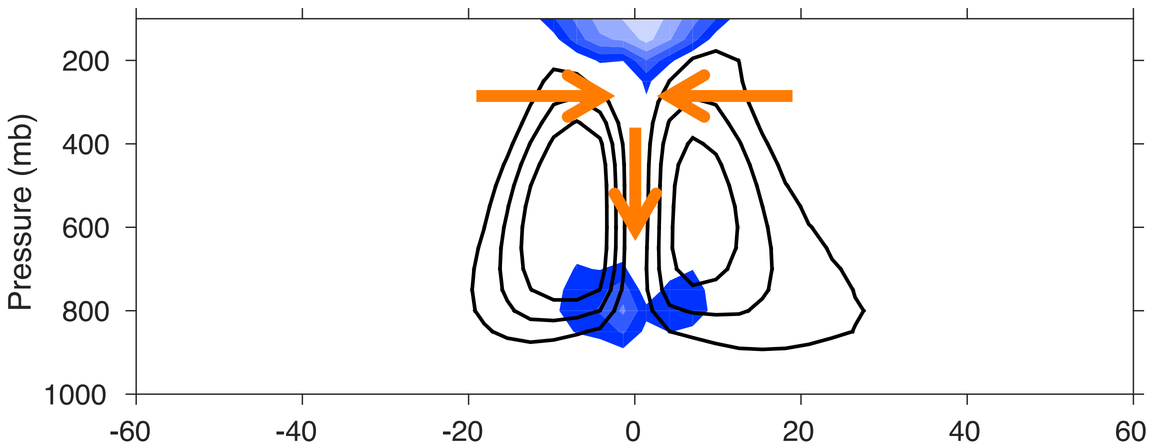
Angular momentum argument should work



color shading: $R_o > 0.2$

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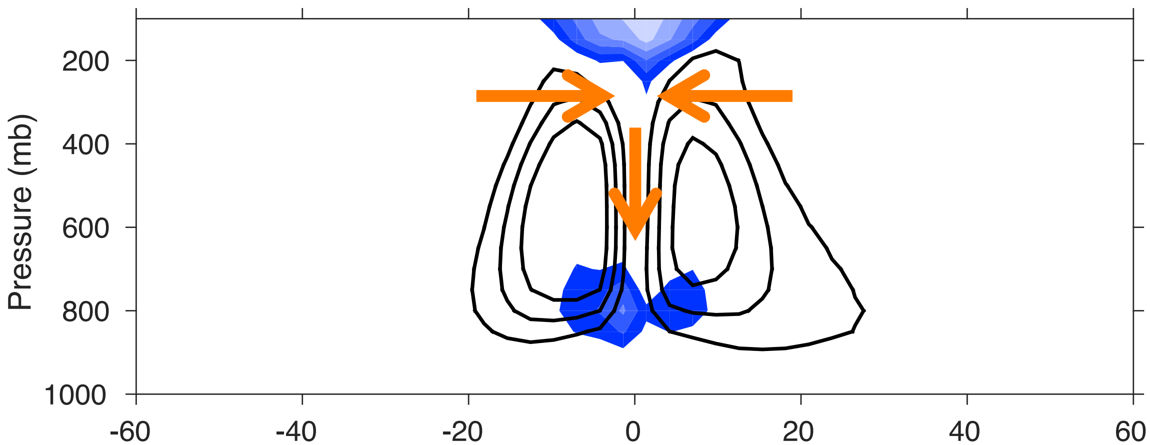

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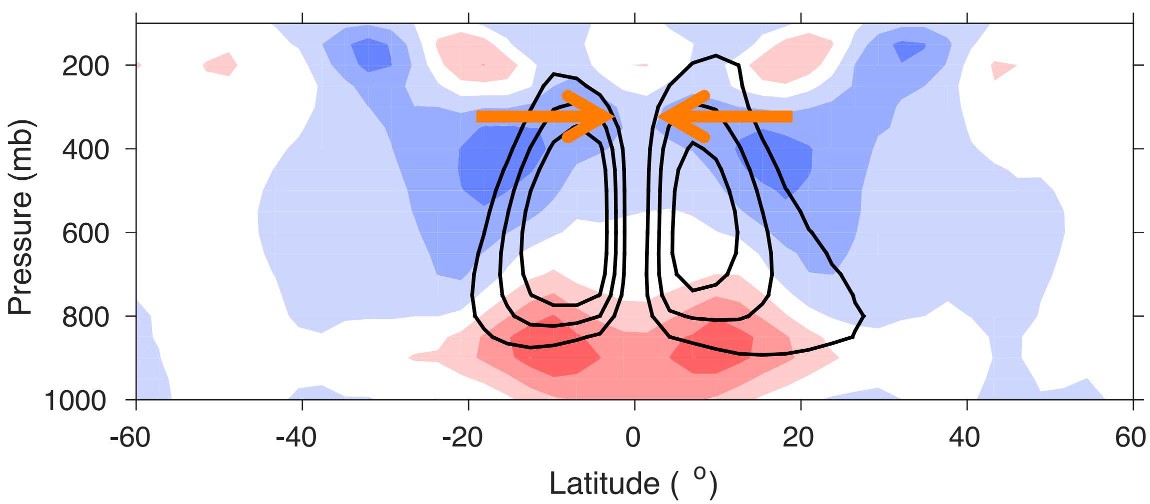
AM flux convergence requires equatorward flow



color shading: S

Blue: convergence, $S < 0$
Red: divergence, $S > 0$

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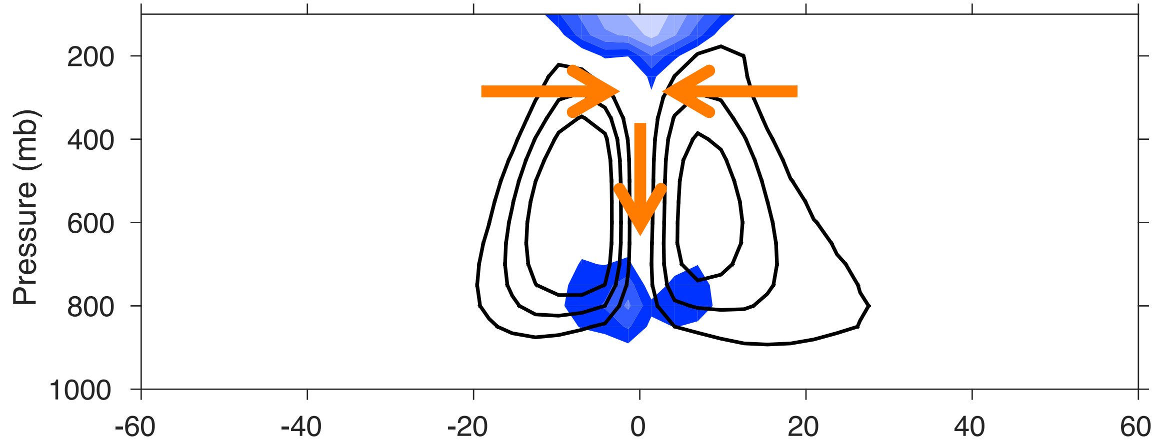
Where is this from?

Angular momentum argument should work



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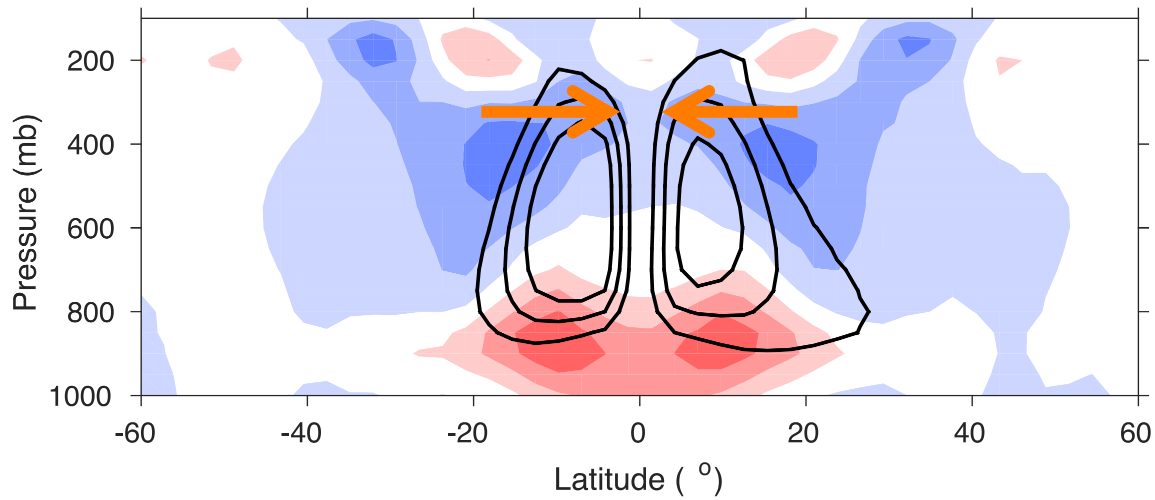

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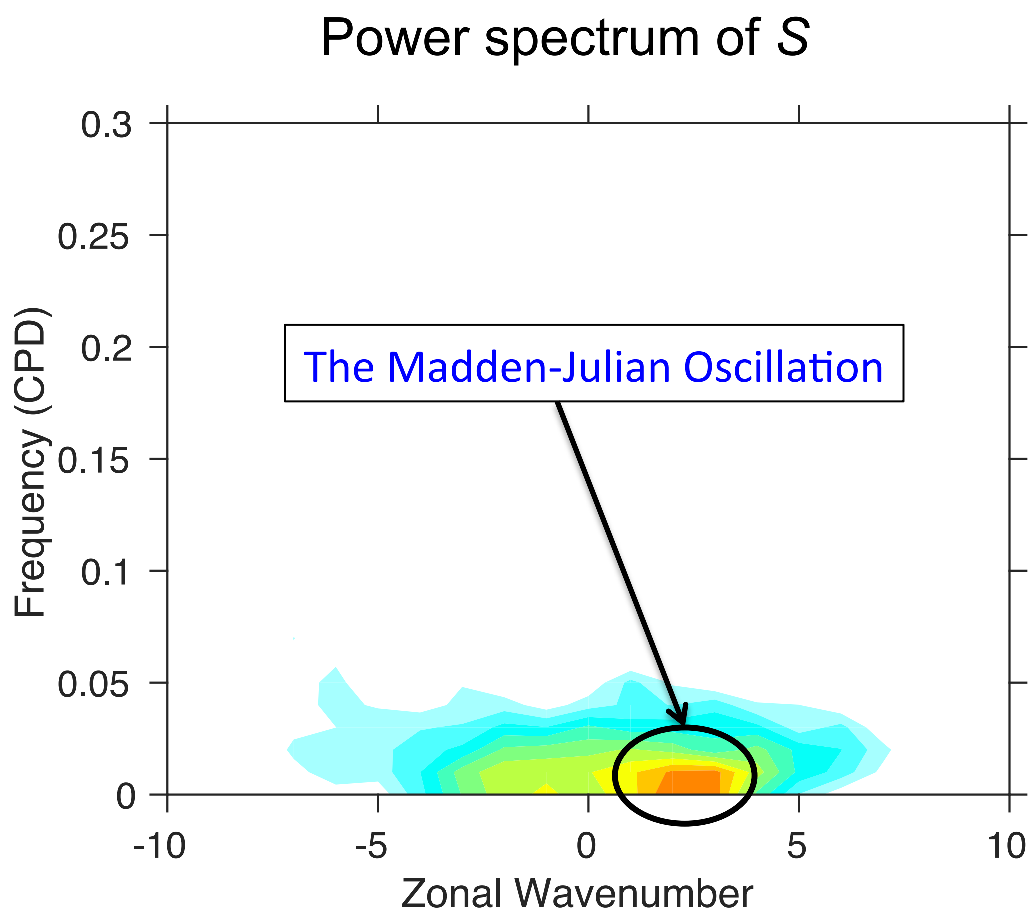
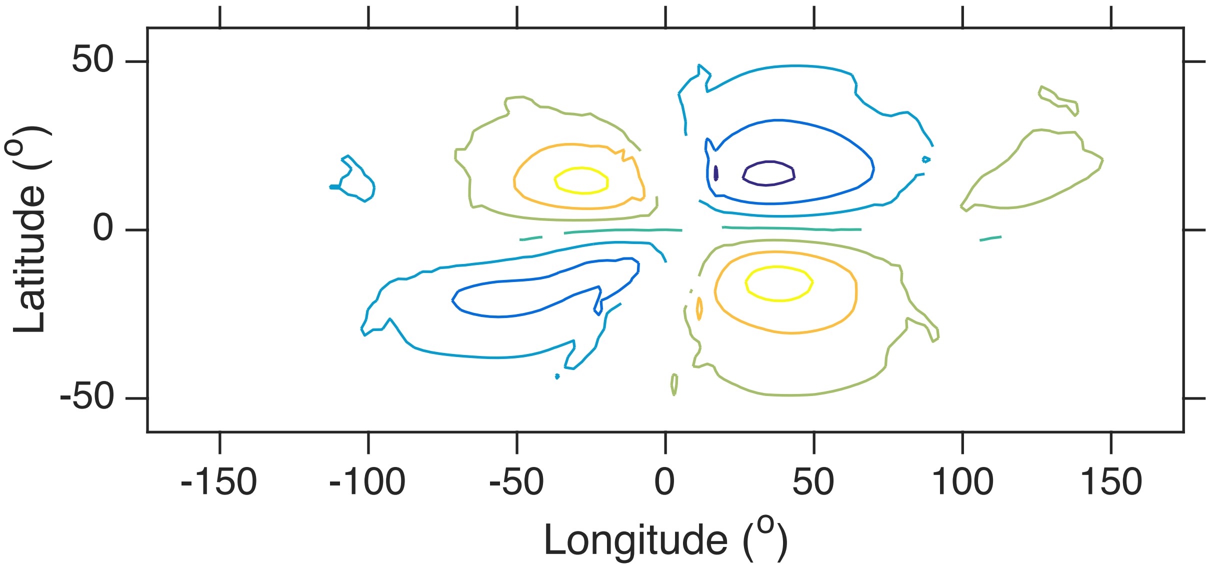
The Madden-Julian Oscillation dominates the momentum transport.



Consistent with studies under more realistic setup,
e.g., Lee 1999, Caballero and Huber 2010, Arnold et al. 2012

Momentum transport by the MJO



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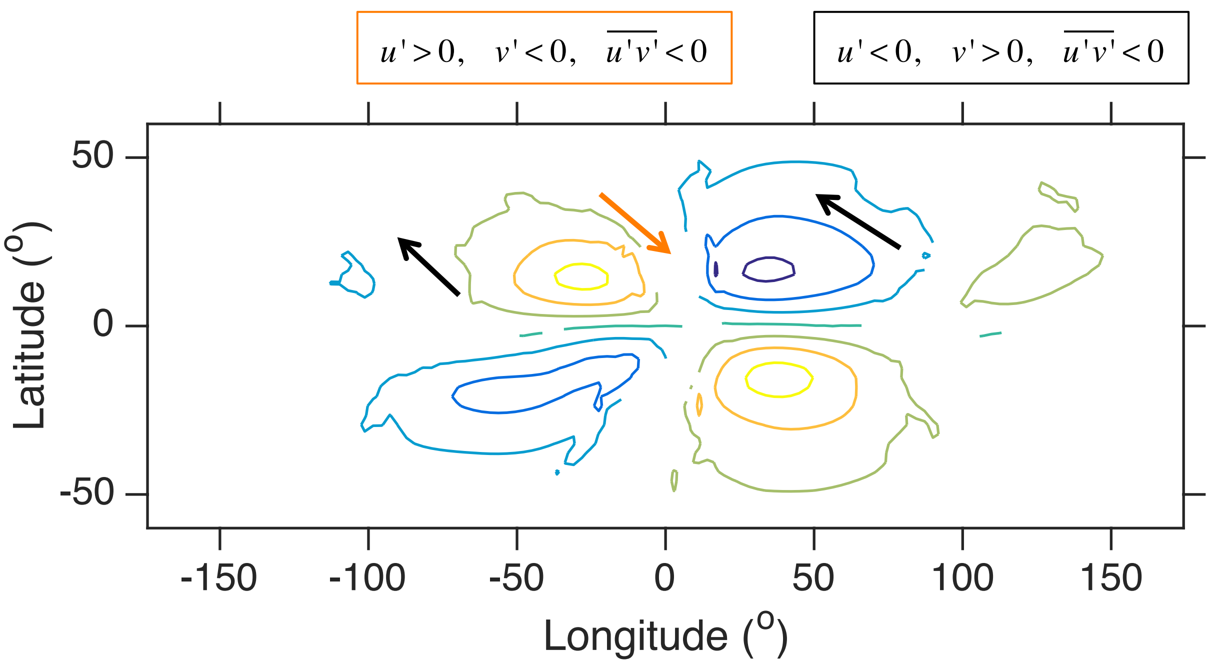

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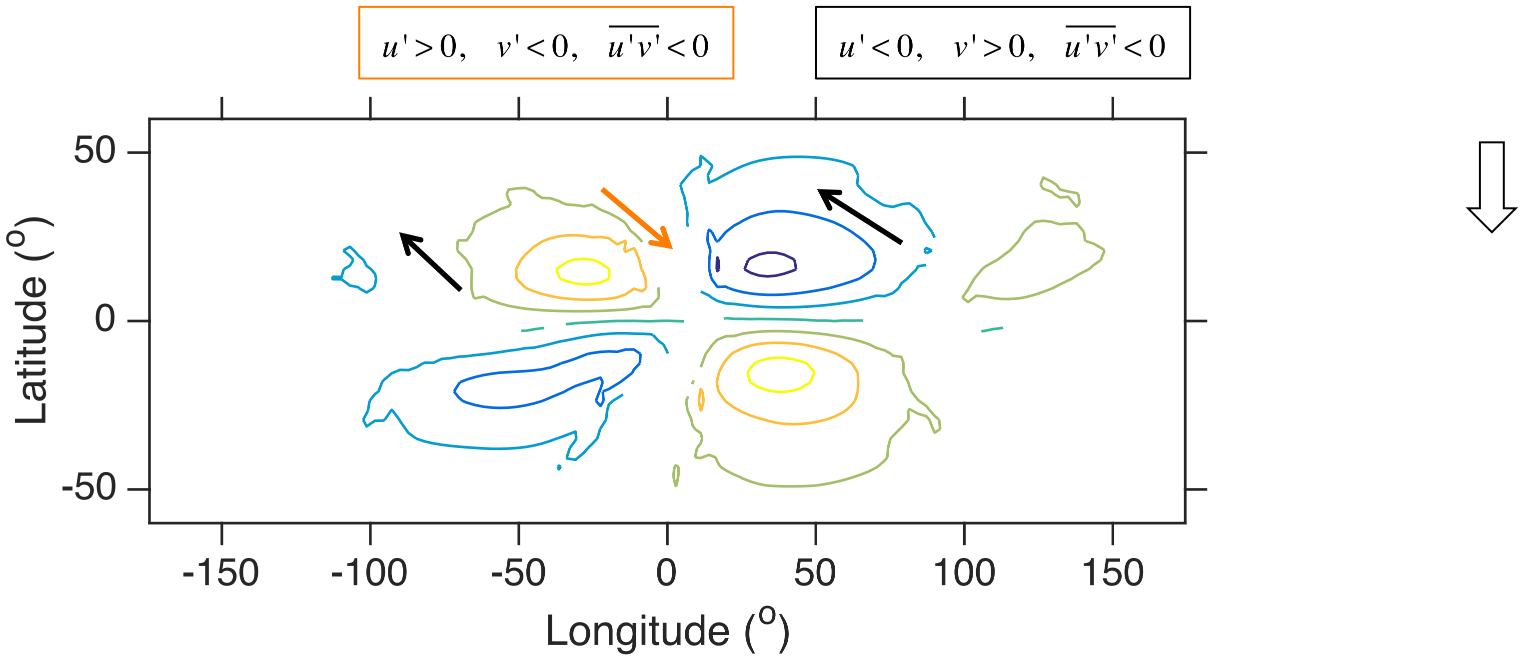

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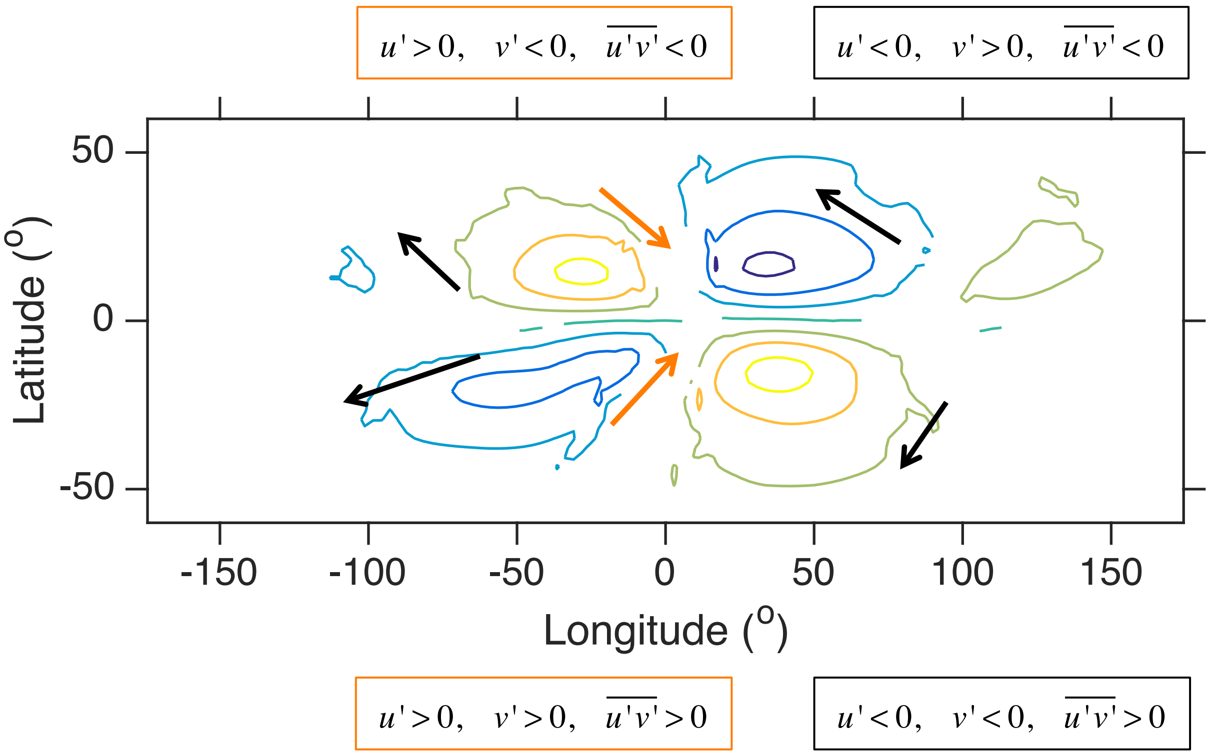

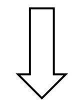

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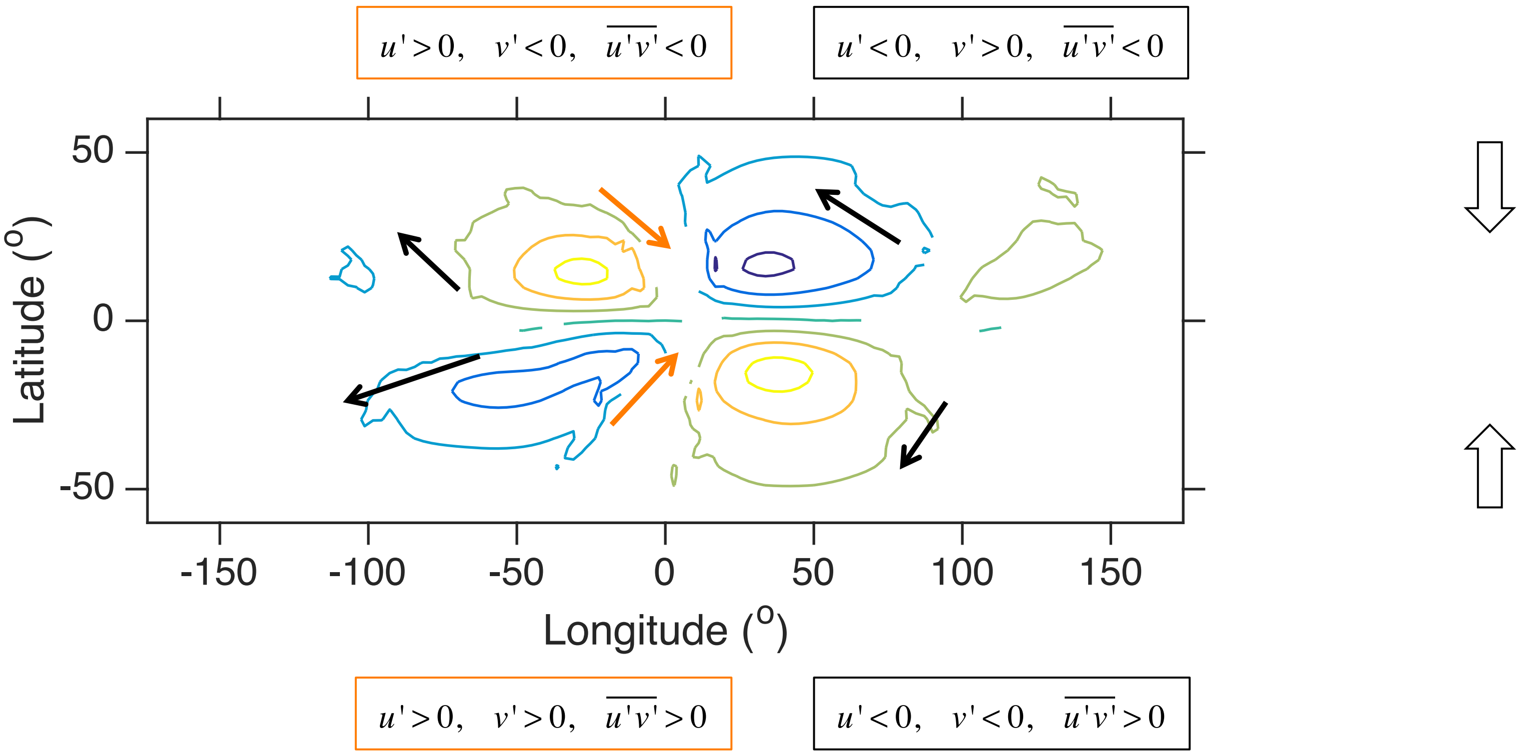

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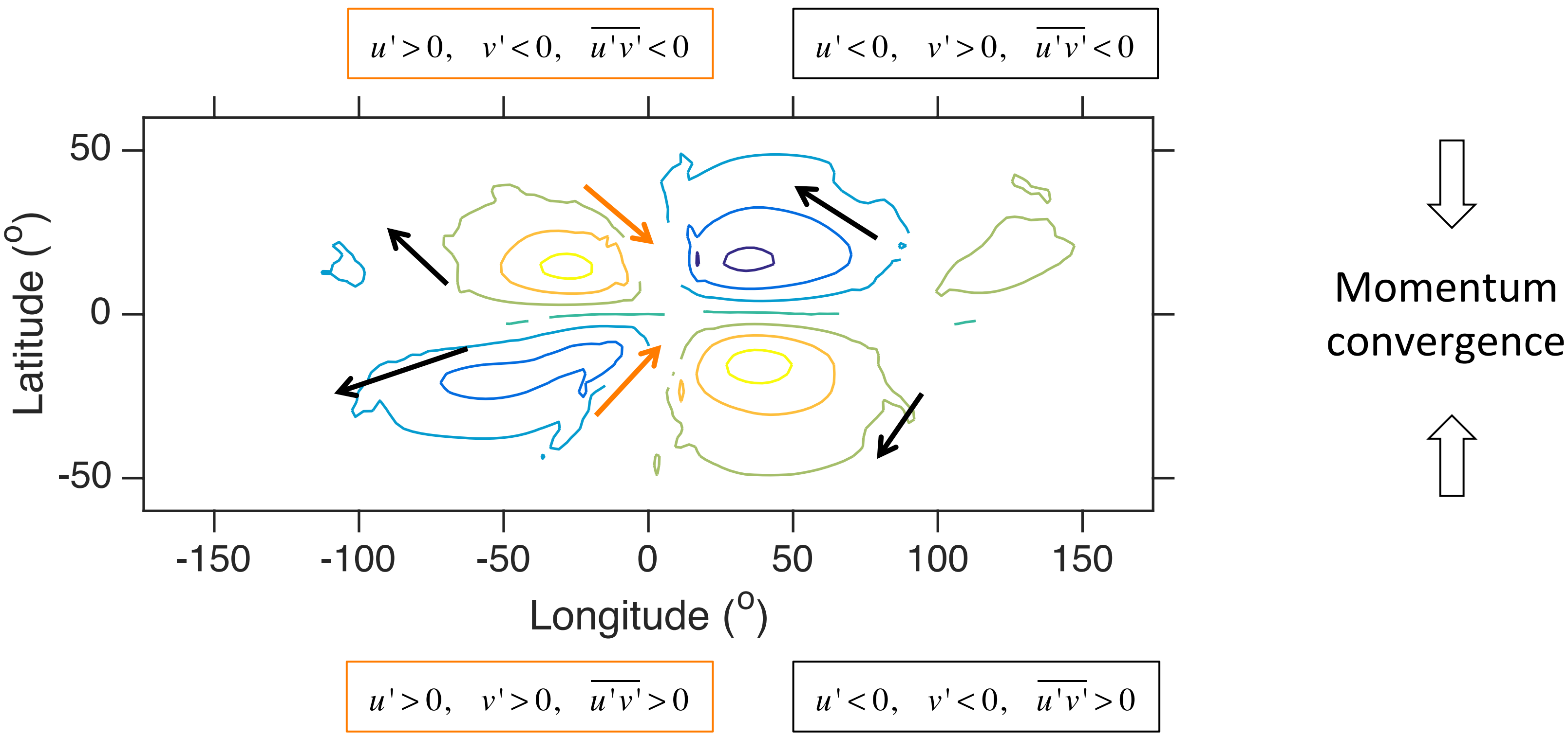
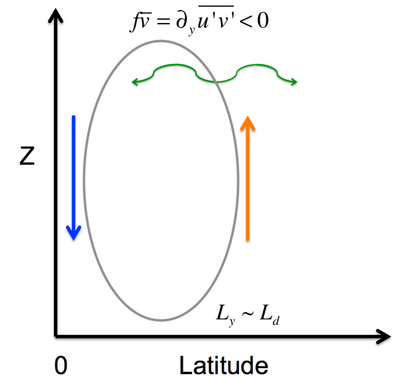


Also see Lee 1999, Caballero and Huber 2010, Arnold et al. 2012

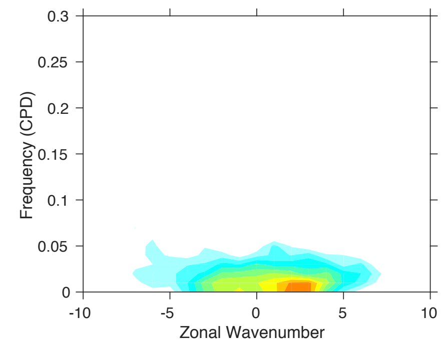
Summary

- Double ITCZs are simulated over uniform sea surface temperatures in SPCAM.
  - NOT expected from the thermodynamic arguments.

- The angular momentum argument can explain this result.

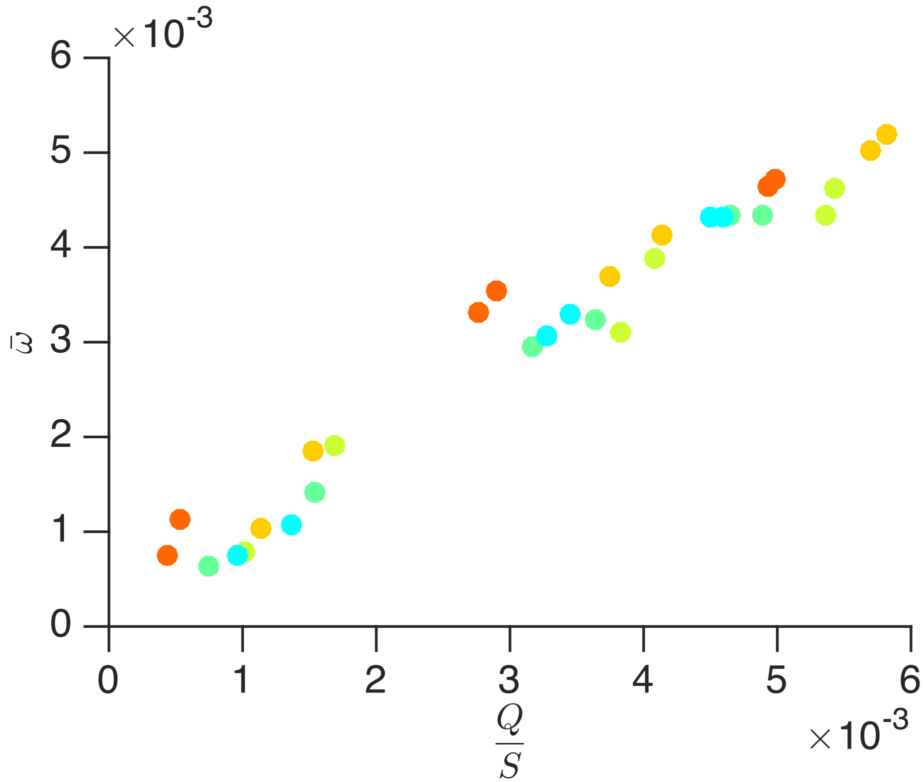


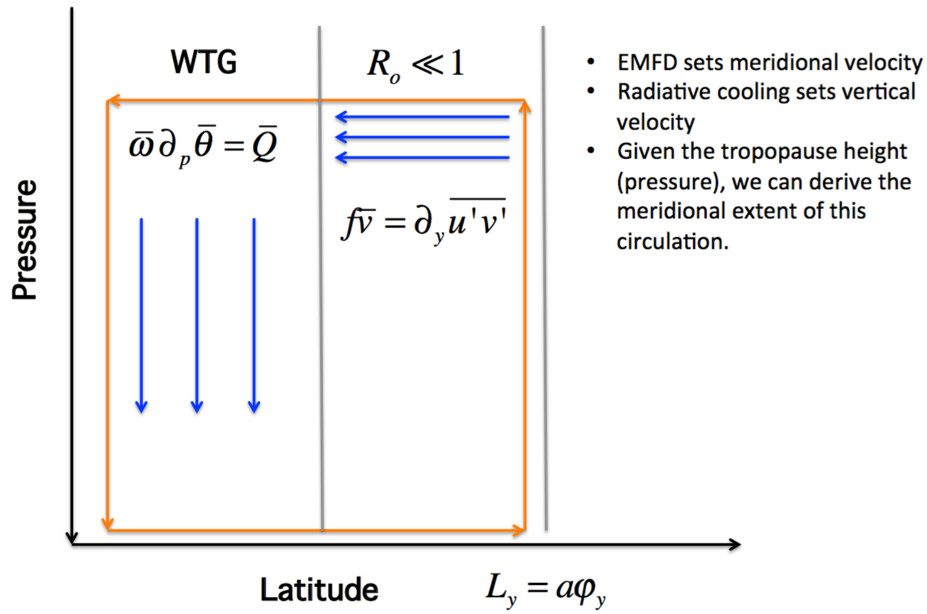
- The Madden-Julian Oscillation dominates the meridional eddy momentum transport.



- Double ITCZs in SPCAM might be due to strong MJO signals.
  - When the equatorial wave activity (e.g., the MJO and Rossby waves) is strong, this proposed mechanism can produce double ITCZs.

Weak temperature gradient approximation holds globally





$$L_y \sim \left(\frac{\Delta p \partial_p \bar{\theta} \partial_y \overline{u'v'}}{\beta \bar{Q}}\right)^{1/2}$$

Figure 1: Schematics of the proposed mechanism of the anti-Hadley circulation. The left and right boxes are connected by continuity.

$$f\bar{v} = \partial_y \overline{u'v'} \tag{2}$$

$$\bar{\omega}\partial_p\bar{\theta} = \bar{Q} \tag{3}$$

$$\partial_y \bar{v} + \partial_p \bar{\omega} = 0 \tag{4}$$

From (4), we know

$$\frac{|\omega|}{|v|} \sim \frac{\Delta p}{L_y} \tag{5}$$

Here L_y is the meridional extent of this tropic cell, and $\Delta p = p_s - p_t$. Combining (2) & (3), we get

$$\frac{\omega}{v} \sim \frac{fQ}{\partial_y \overline{u'v'} \partial_p \bar{\theta}} \sim \frac{2\Omega \sin\varphi_c \bar{Q}}{\partial_y \overline{u'v'} \partial_p \bar{\theta}} \sim \frac{2\Omega \varphi_c \bar{Q}}{\partial_y \overline{u'v'} \partial_p \bar{\theta}} \tag{6}$$

MJO in SAM
SST = 290 K, 1/3 of Earth's circumference