The Tropical Madden-Julian Oscillations

As An Asymptotically-Nondivergent Nonlinear Rossby Wave

by **Jun-Ichi Yano, Meteo Frnace**

With Thnaks to:

Piotr Smolarkiewicz (SW Code),

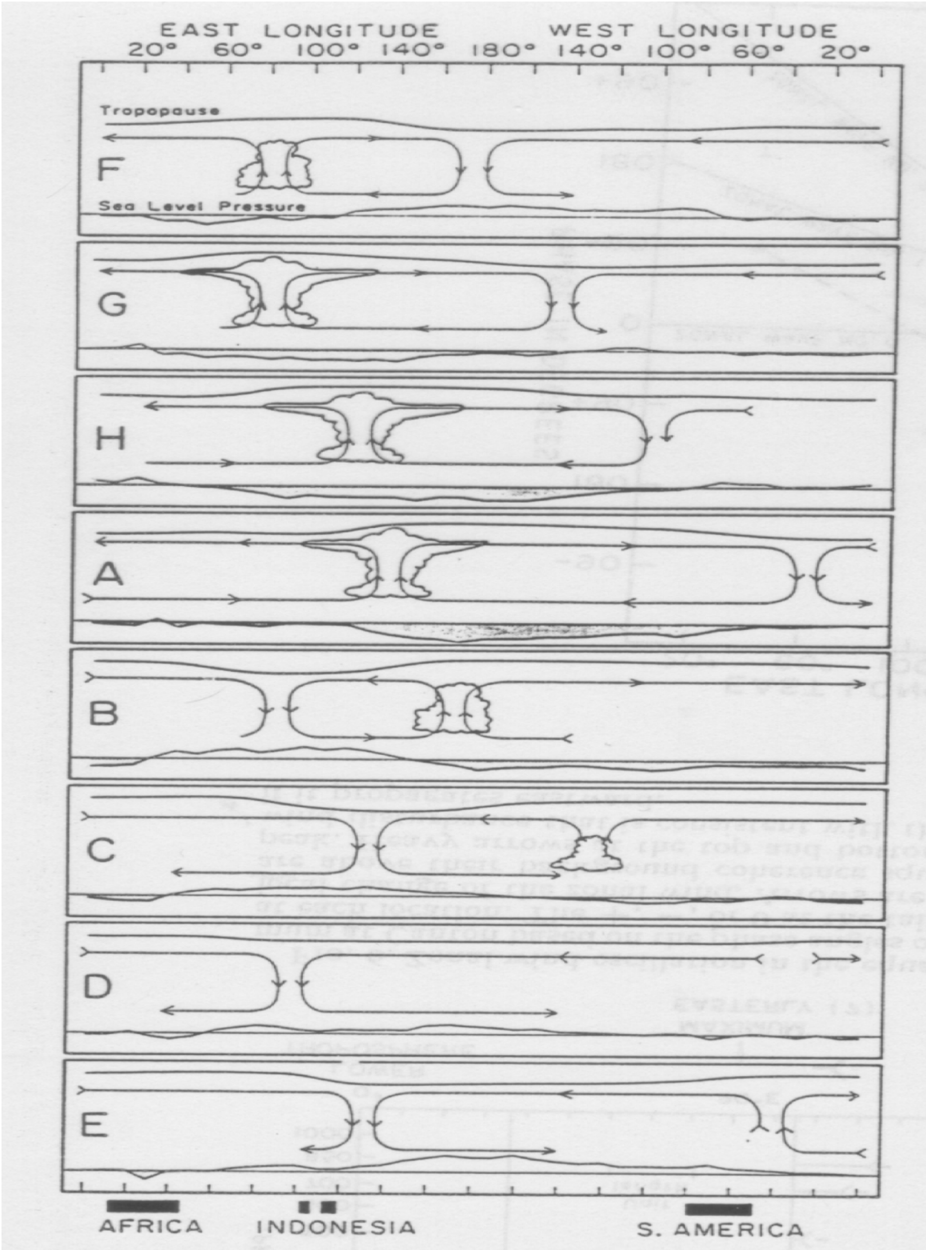
Wim Verkely (Modon Soluton)

What is MJO: Madden-Julian Oscillation?

:Madden & Julian (1972)

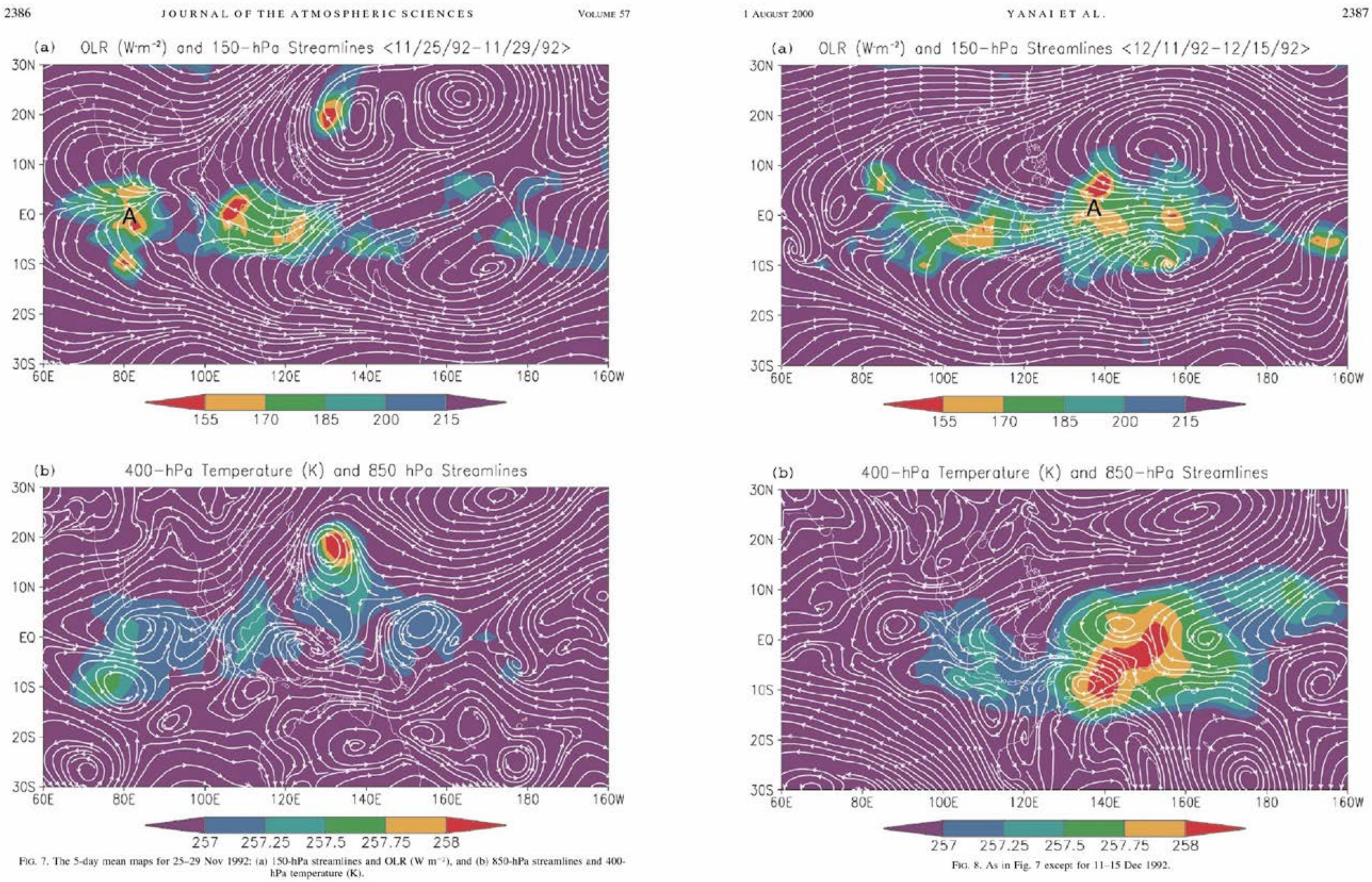
30-60 day-period eastward-propagating atmospheric eauqtorial Wave:

Mechanism?



MJO as a Vorticity Dynamics?

(e.g., Yanai et al., 2000)

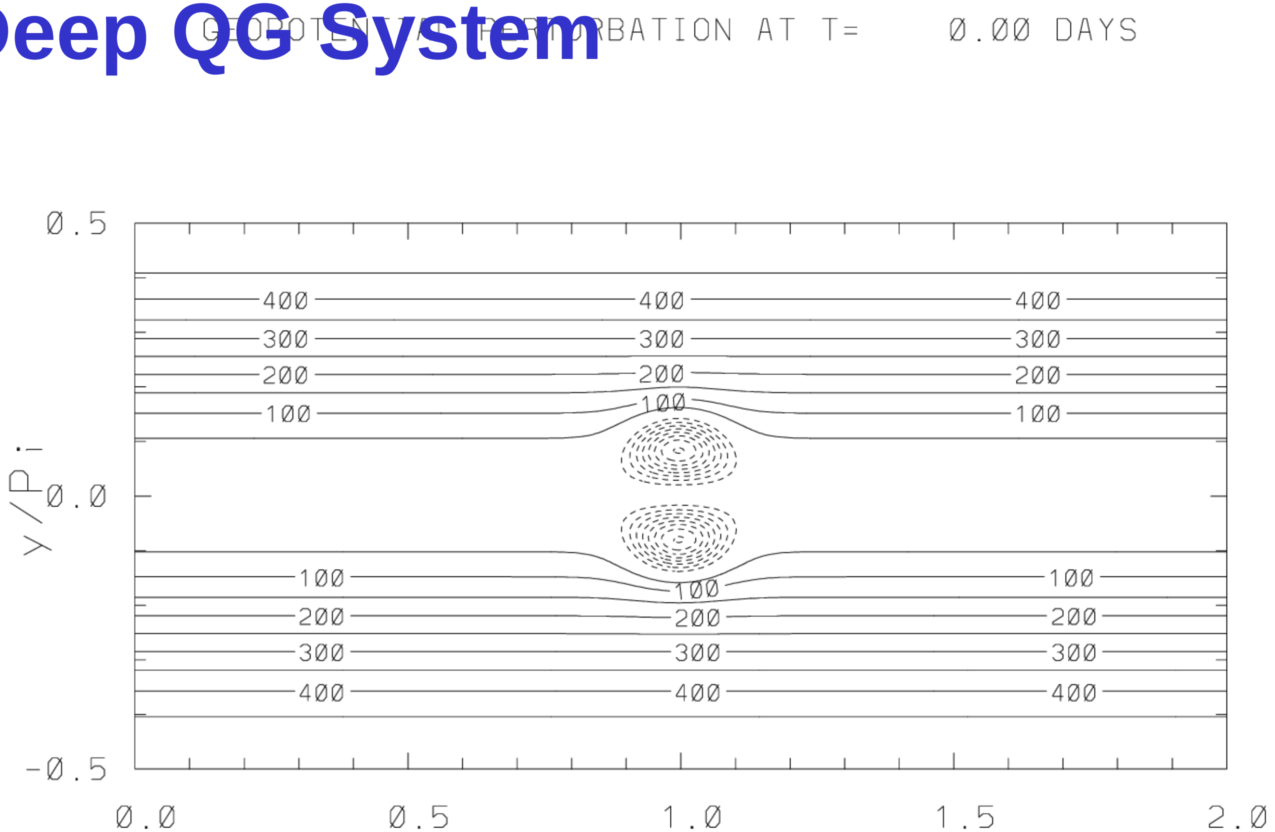


Main Conclusion: Preliminary Result:

MJO:

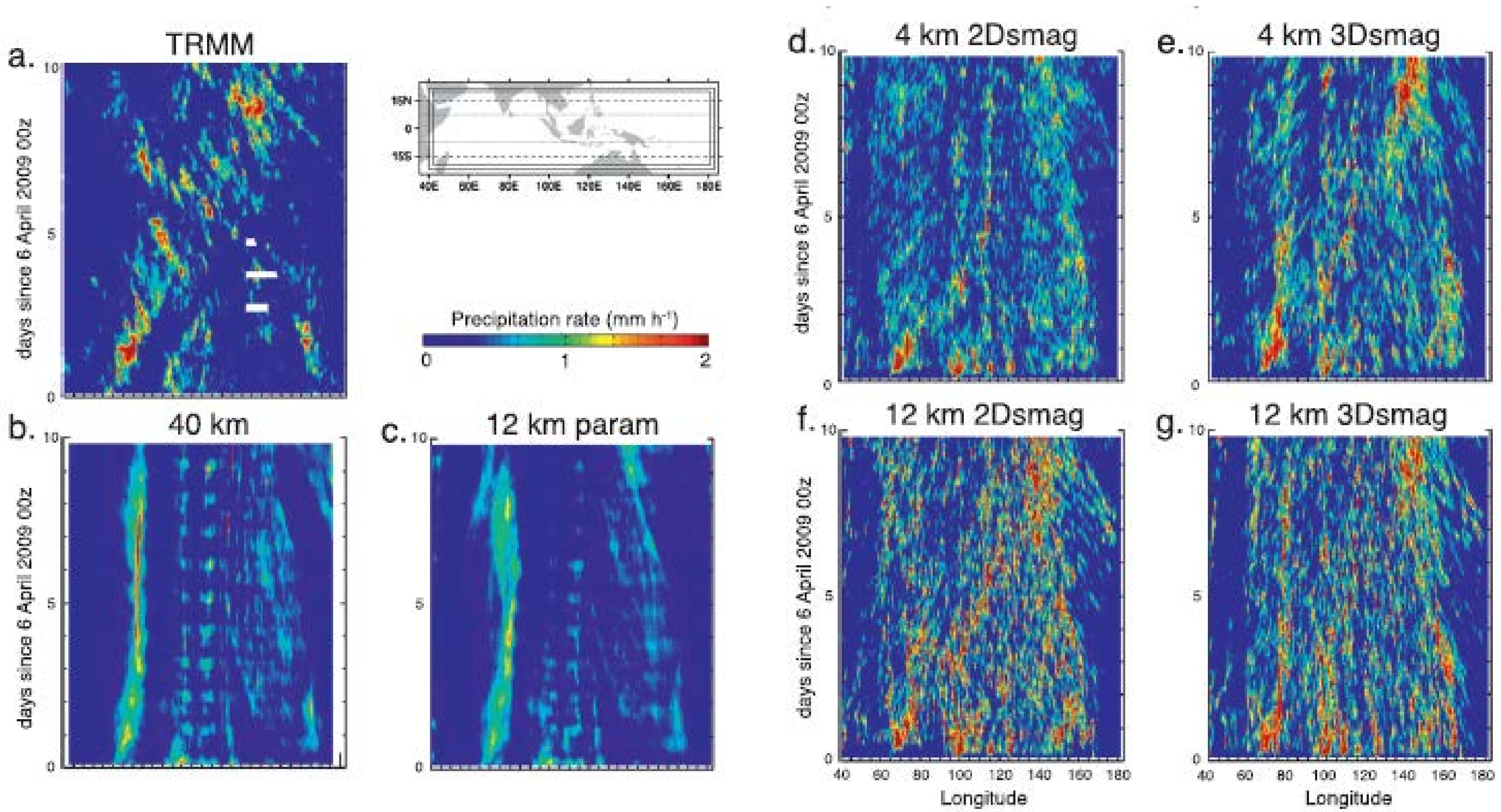
Simulated by a 1-km Deep Global Shallow-Water Model:

Initialized by: Equivalent-Barotropic Modon for 250m-Deep QG System



How the Global Models Simutate It?

(e.g., Holloway et al., 2013, UK UM):

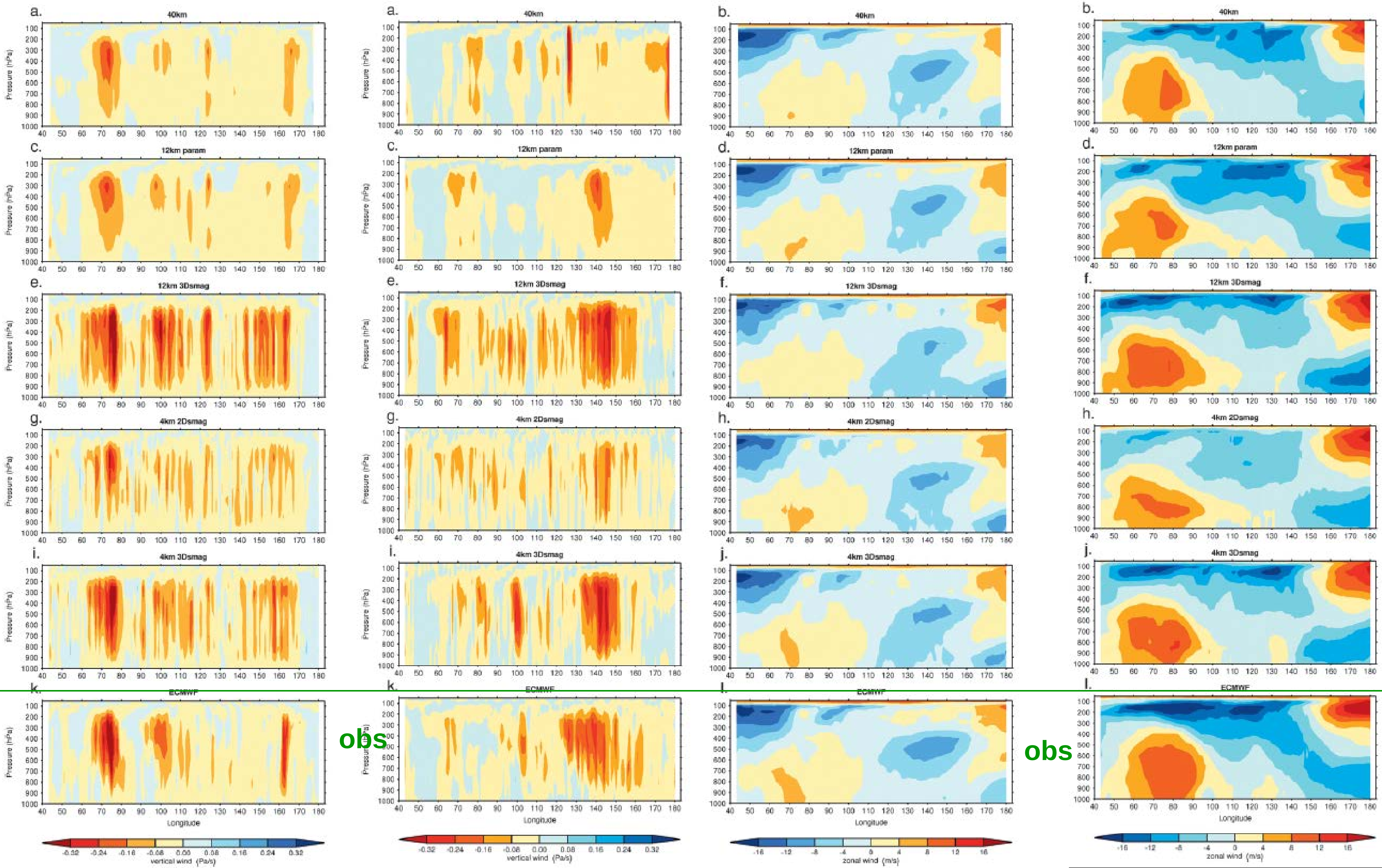


Precipitation Field

How the Global Models Simutate It?

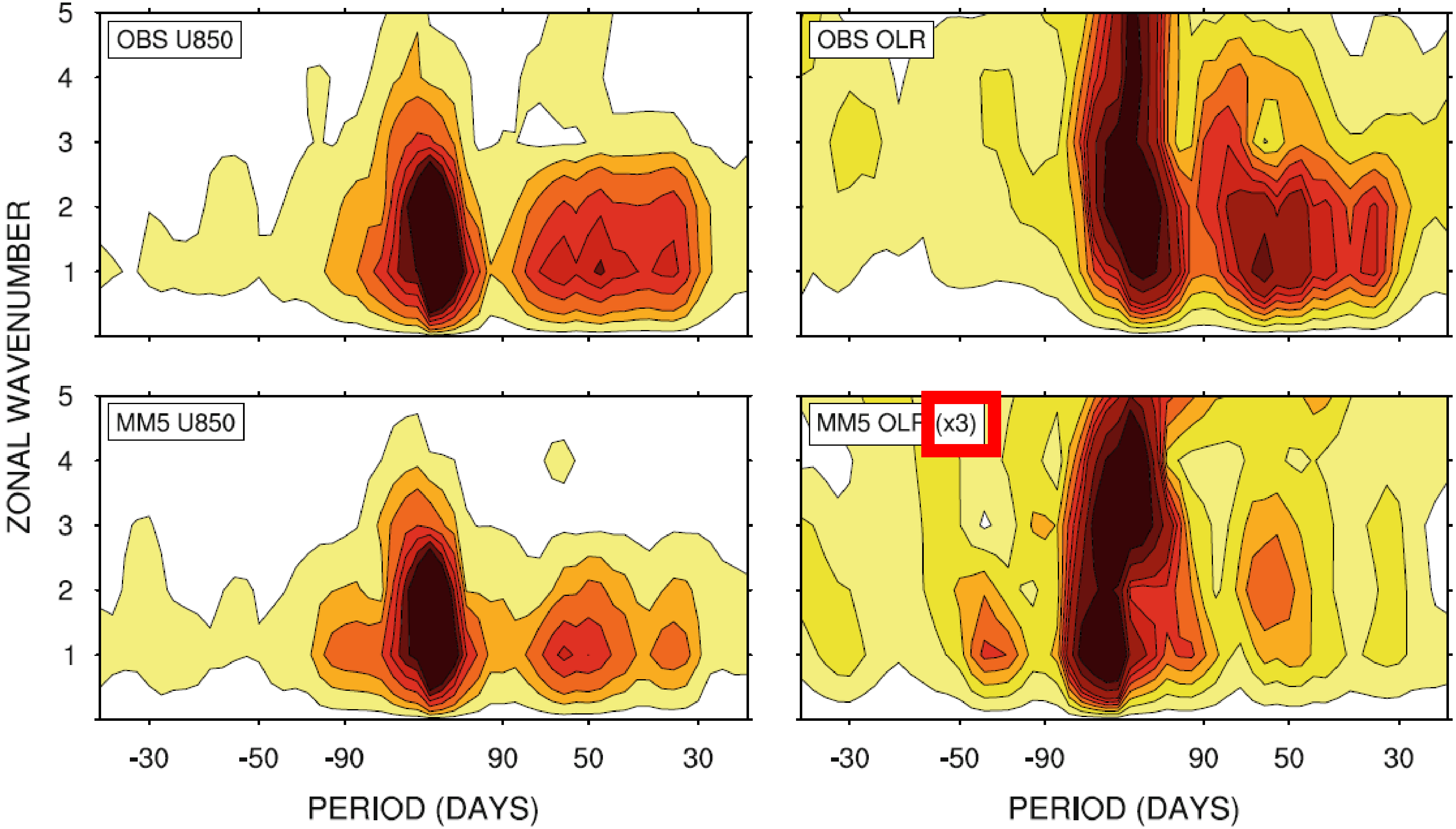
(e.g., Holloway et al., 2013, UK UM):

Vertical Velocity: 7 Apr 2009 **15 Apr 2009** **Zonal Velocity: 7 Apr 2009** **15 Apr 2009**



How the Global Models Simutate It?

(e.g., Monier et al., 2010, MM5):



How the Global Models Simutate It?:

Difficulties in
simulating Convection (& precipitation),
but
the Large-Scale Circulations (e.g., zonal winds) are often correct.

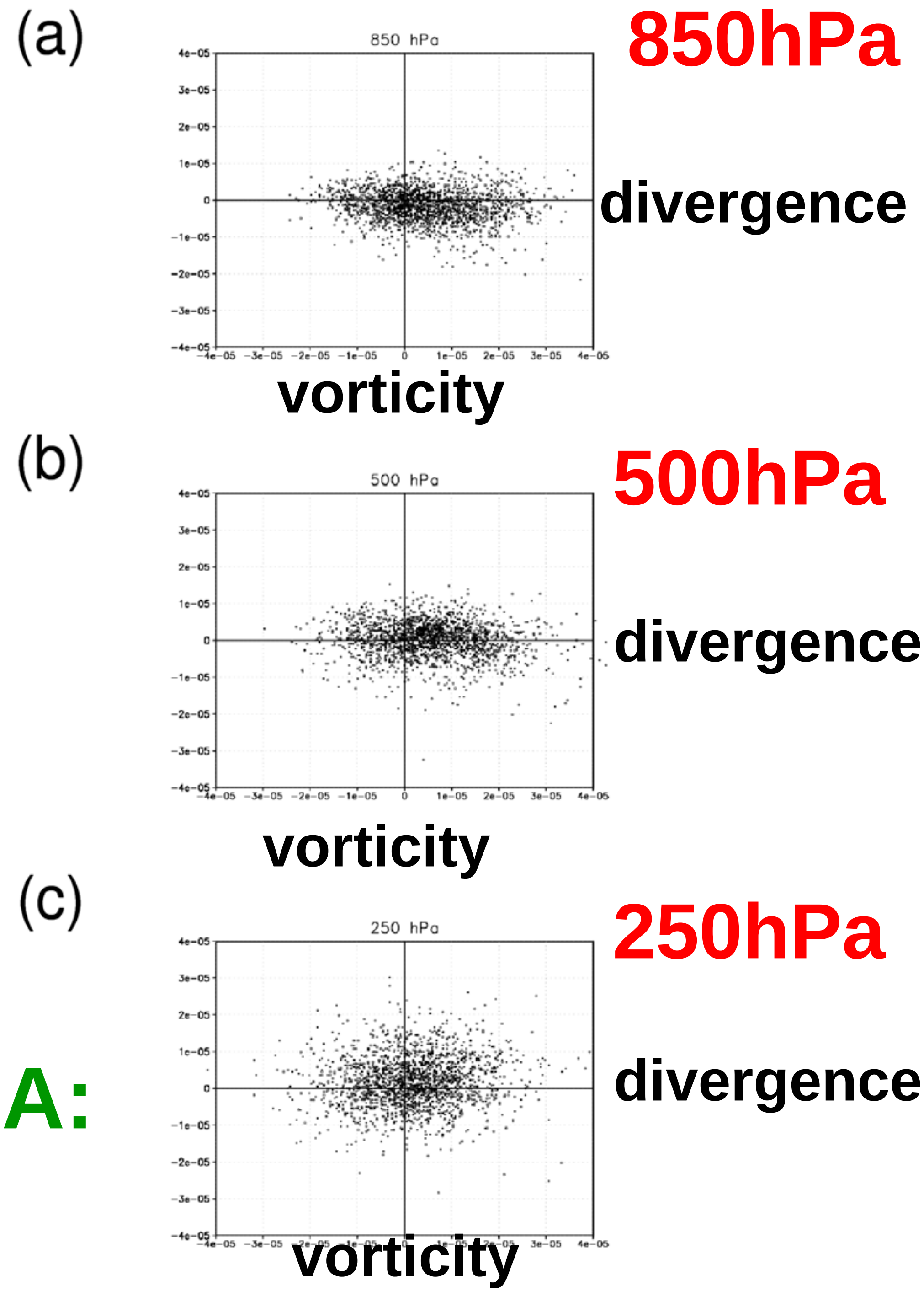
i.e.,
The Dynamical Component of MJO can be well simulated without Convection

Dry MJO?

[convection is likely working as damping in simulations]

Asymptotic-Nondivergence of the Large-Scale Tropical Circulations

Scatter Plots between Vorticity and Divergence (TOGA-COARE LSA: Yano et al., 2009)



<u>Asymptotic- Nondivergence</u>

or Quasi-Nondivergence

- **Leading-Order Dynamics is purely Rotational (<u>Vortex</u>-Dominant)**

- **<u>No</u> Leading-Order Role of <u>Convection</u>**

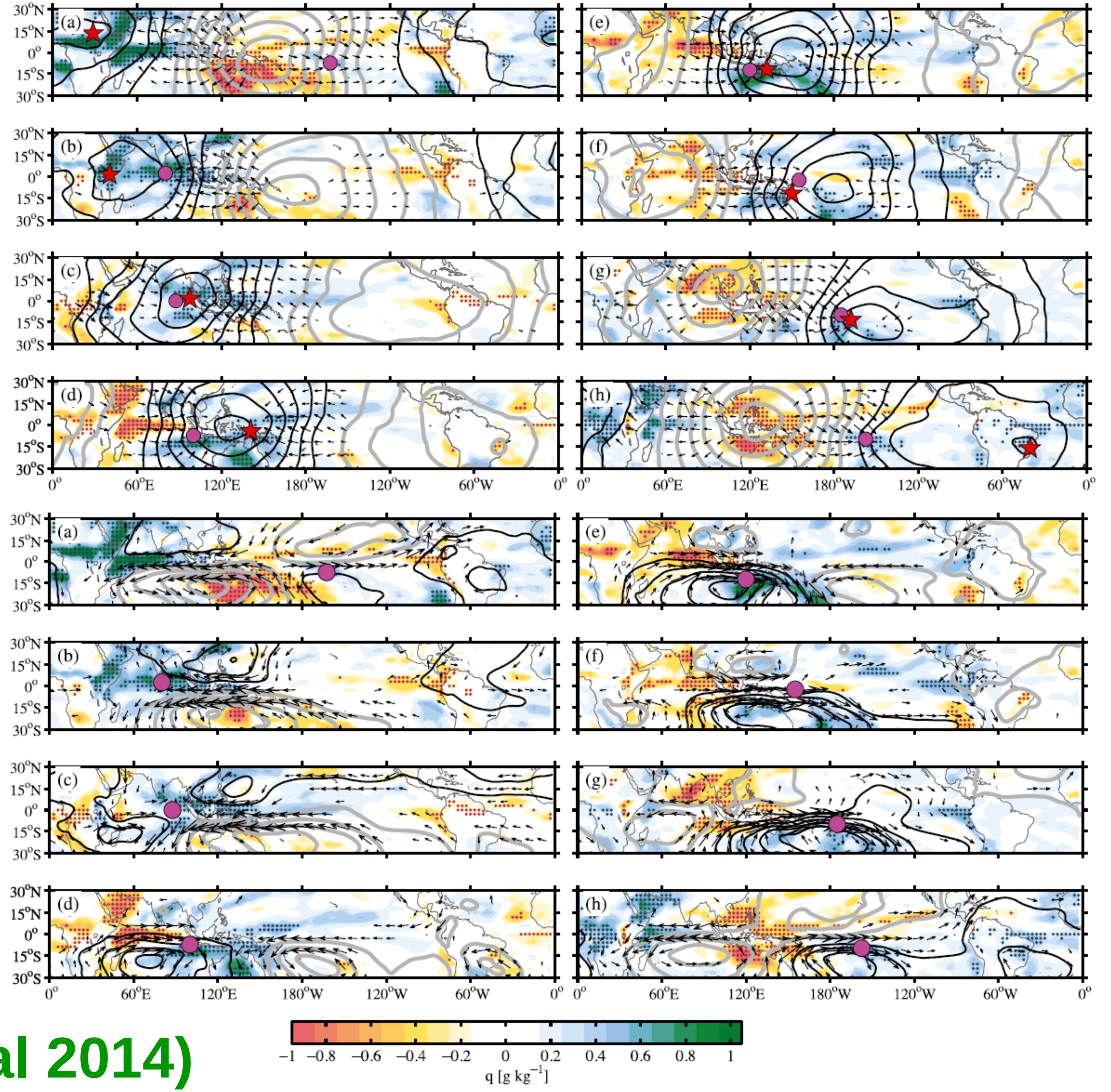
Dry Leading-Order Dynamics

Asymptotic-Nondivergence of MJO ?

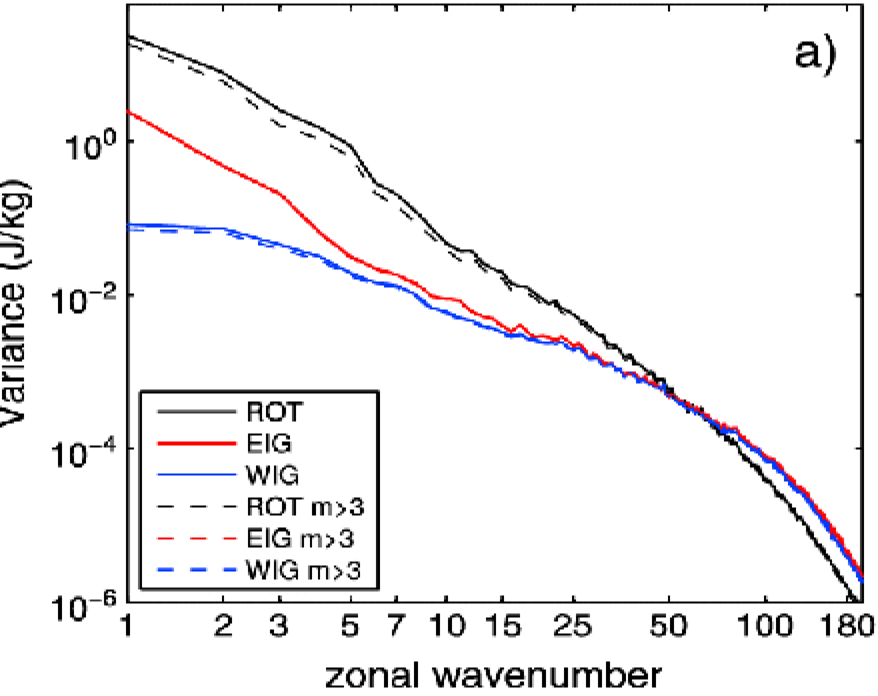
Asymptotic-Nondivergence of MJO

Divergent Wind

Rotational Wind

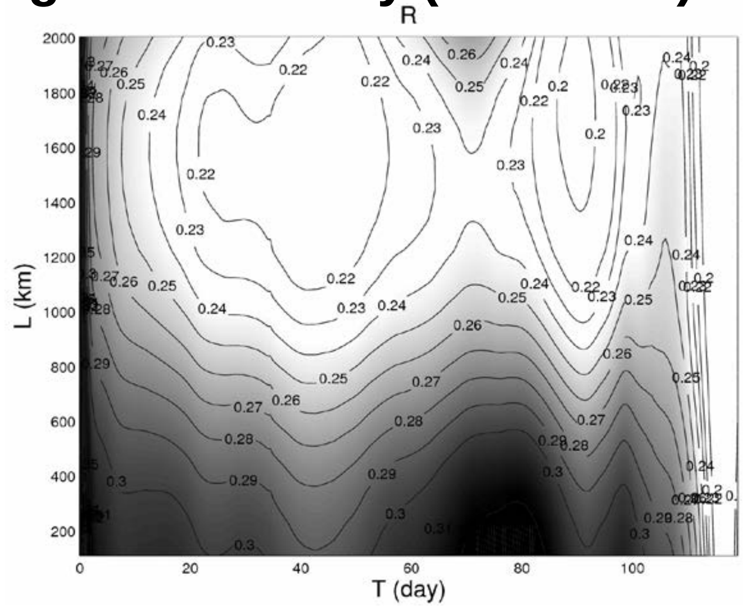


(Adames et al 2014)



Divergence/Vorticity (Transient)

horizontal scale (km)



Time scale (days)

(Zagar and Franzke 2015)

(Yano et al., 2009)

Asymptotic-Nondivergence of MJO :

Dry Wave Dynamics?:

Two Slowest Equatorial Waves:

- **Kelvin Wave: Nondispersive (Not Slow Enough)**
- **Rossby Wave: ?**

Linear Rossby-Wave Dispersion:

$c_p = -\beta L_p^2, \quad 1/L_p^2 = k^2 + l^2 + (1/L_R)^2$

for MJO: $c_p = 5\ m/s$

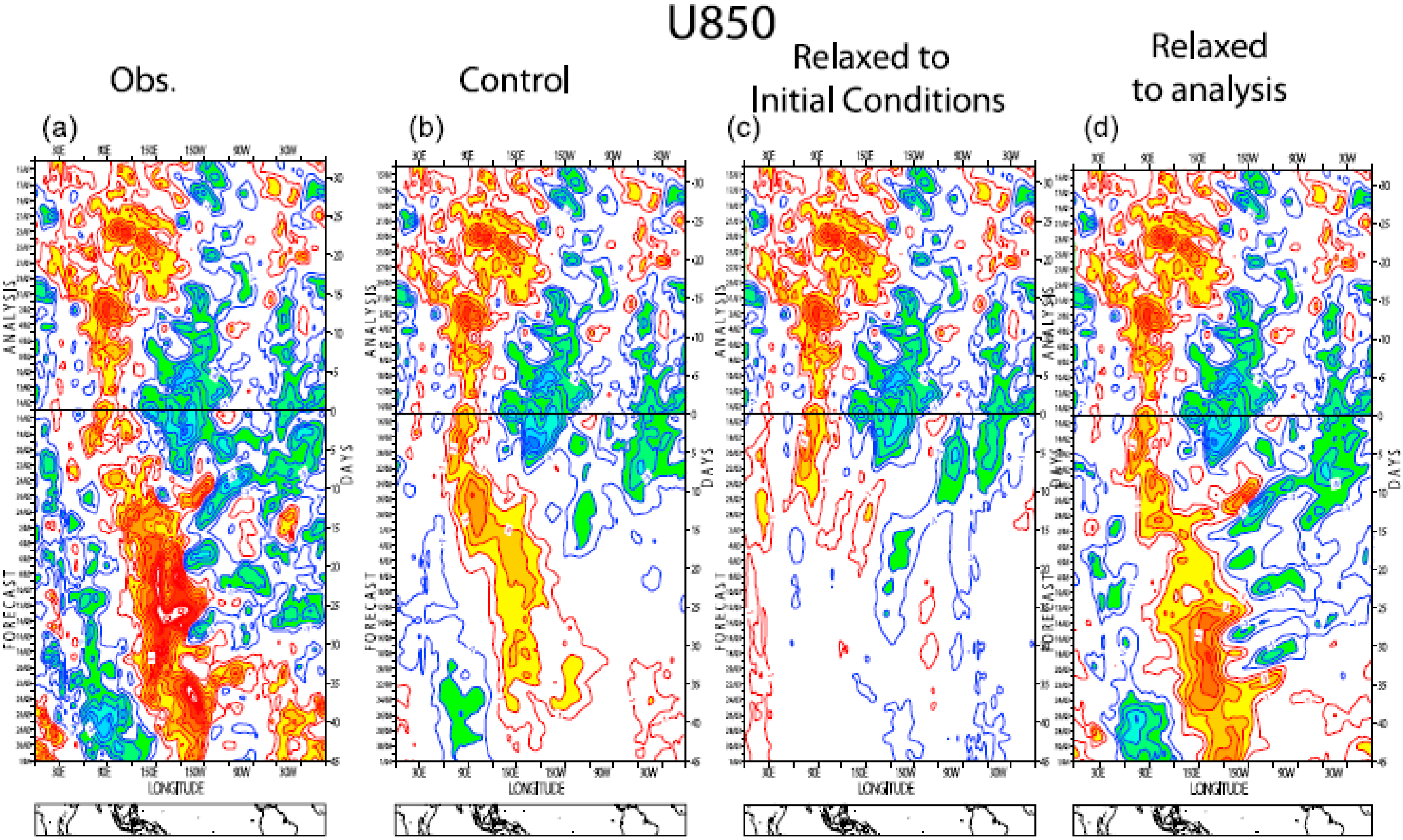
for $|\phi| < 30°$, $\beta \sim 2 \times 10^{-11}$ 1/s/m

$iL_p = (c_p/L_p)^{1/2} \sim 500\ km \sim L_R \sim 10^3\ km$

i.e.,

only the evanescent wave solution can explain MJO under linear Rossy-wave dynamics

Just Laterally-Forced? (Vitart and Jung 2010)



IFS GCM

IFS with $\phi > 35°N$ nudging

Just Laterally-Forced? : Linear Thoery :

with zonal wavenumber : $n_x = 1 - 3$

$k^{-1} \sim 10^4$ km $>> L_R \sim |L_p|$

latitudinal scale: $l^2 \sim 1/L_p^{\,2} - [k^2 + 1/L_R^{\,2}]$

$\sim 1/L_p^{\,2} - 1/L_R^{\,2}$

$\sim -1/L_R^{\,2}$

$(il)^{-1} \sim L_R \sim 10^3$ km : Influence Scale of the lateral forcing

i.e.,

the effect of the lateral forcing is confined to $L_R \sim 10^3$ km with no Effect seen at the Equator

→ **Nonlinear Response** (Nontrivial Problem)

Nonlinear Response (Nontrivial Problem):

Nonlinear Solitary Rossby-Wave: Theory for MJO:

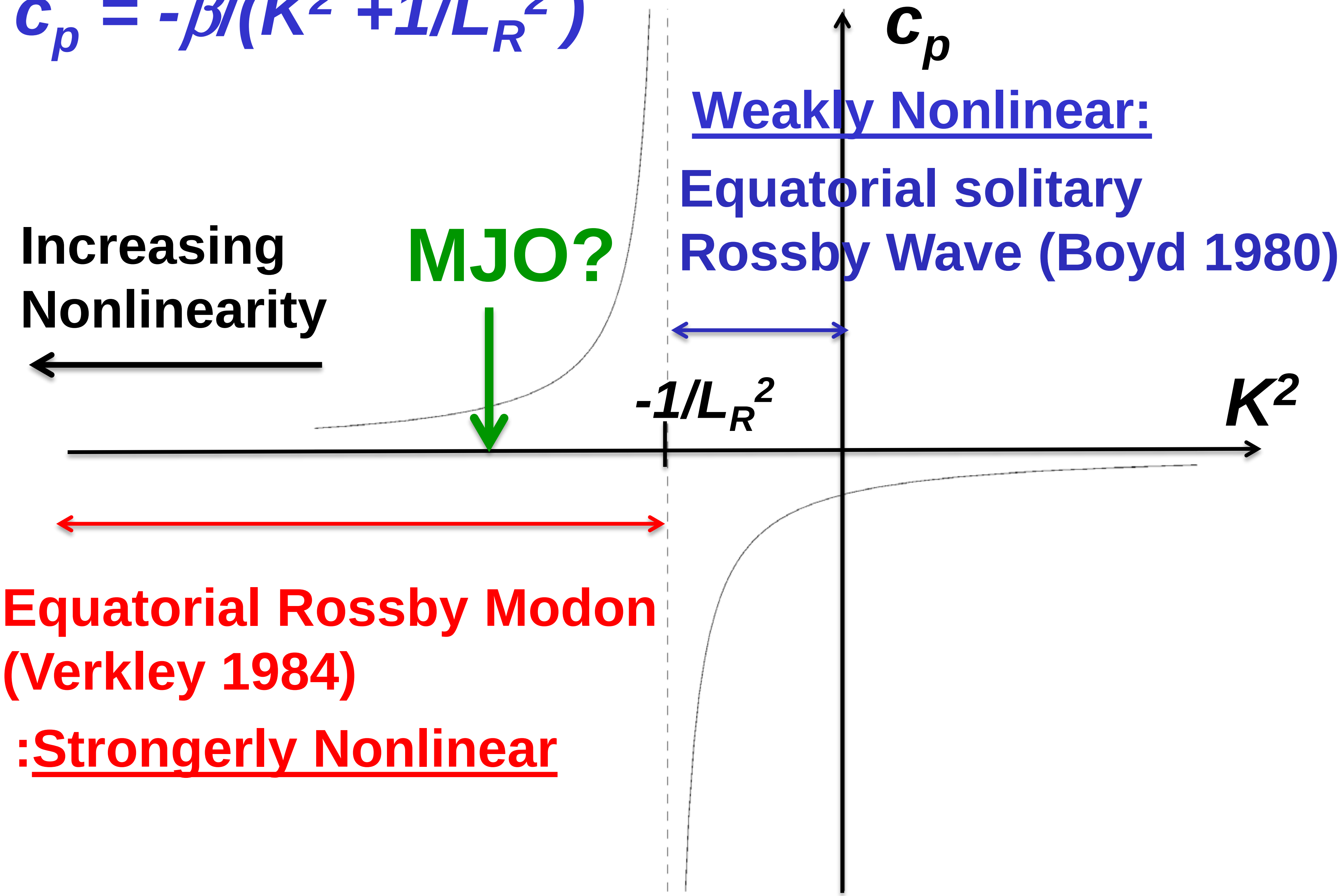
with prescribed latitudinal scale $l < 1/L_R$:

Why It Propagates Easwards?:

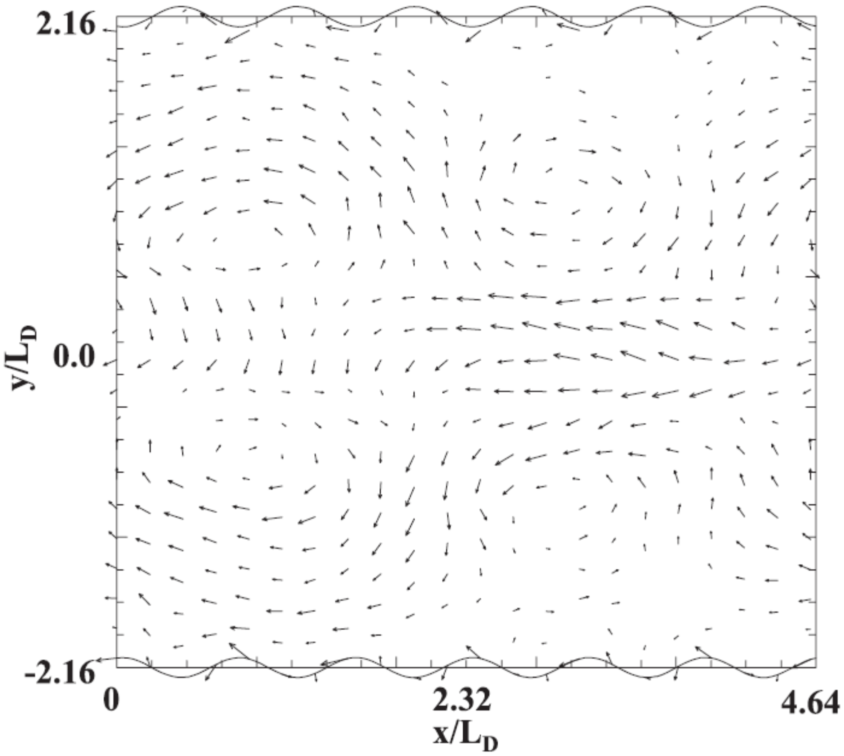
Because the tail-part is linear and evanescent with the scale : $(ik)^{-1} \sim L_R \sim 10^3$ km

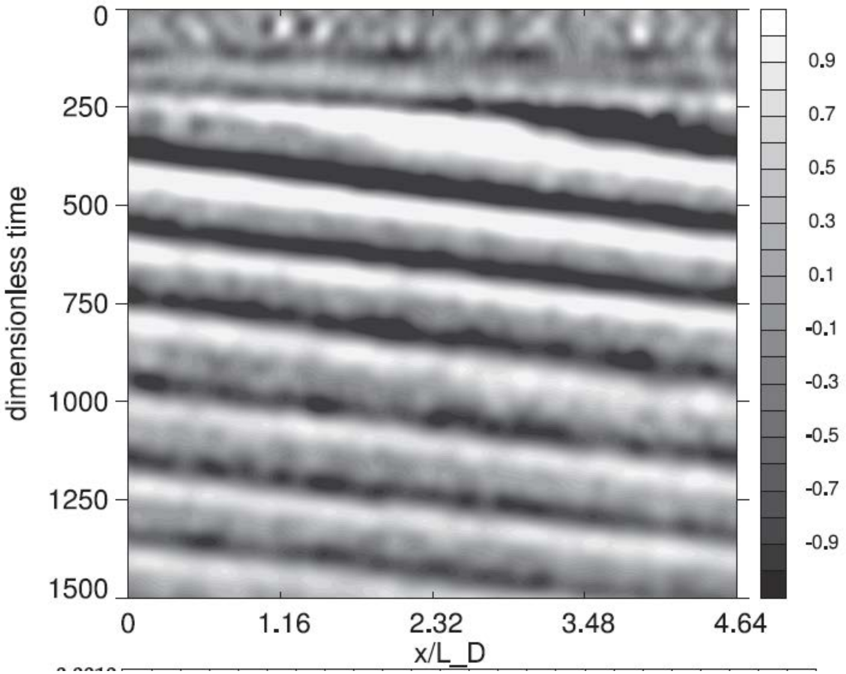
Rossby Wave Dispersion (Summary):

$c_p = -\beta/(K^2 + 1/L_R^2)$



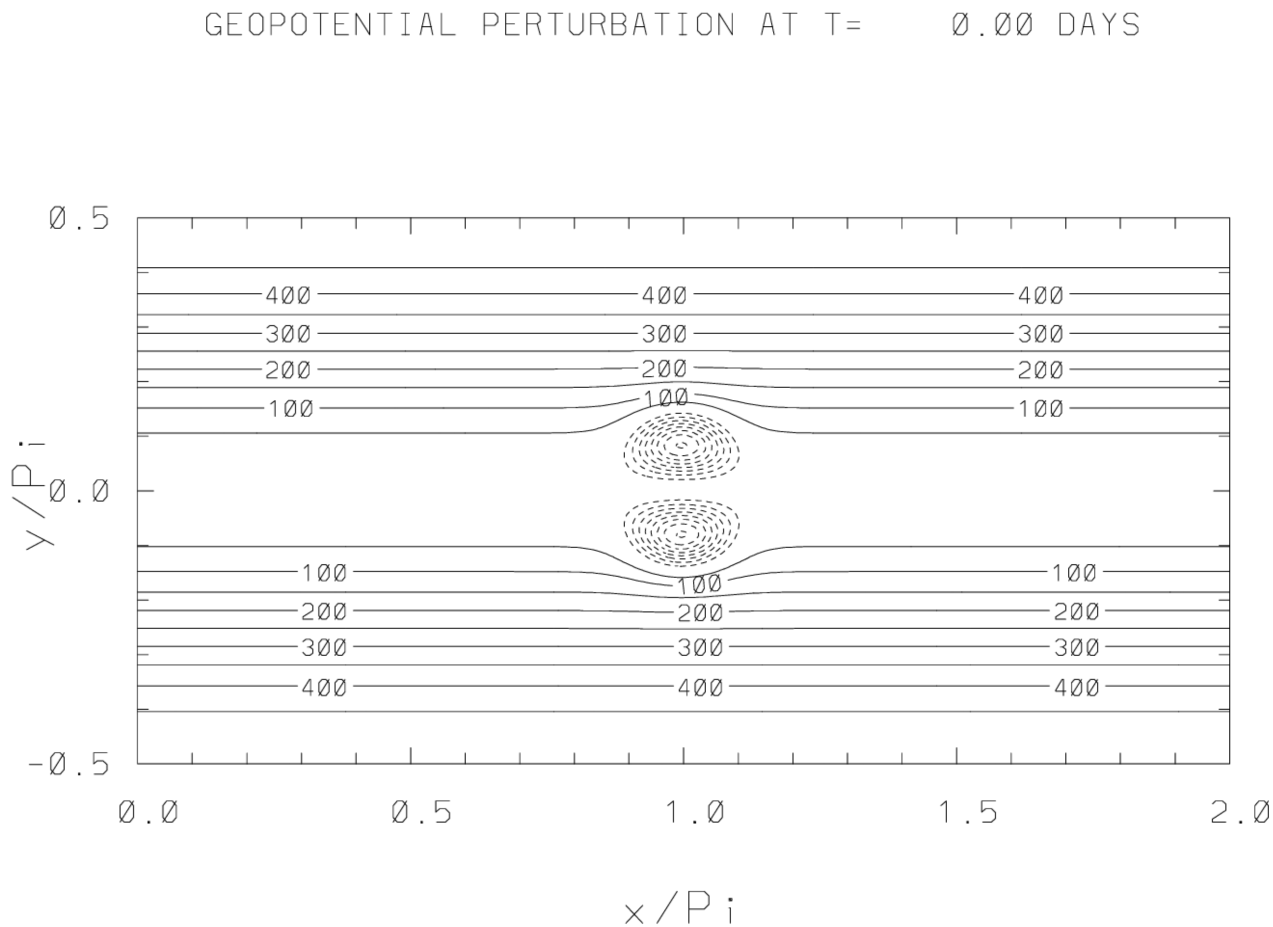
Nonlinear Solitary Rossby-Wave Simulation: MJO:





(Wedi and Smolarkiewicz 2010)

Main Conclusion: Preliminary Result:



MJO:

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MJO Problem:

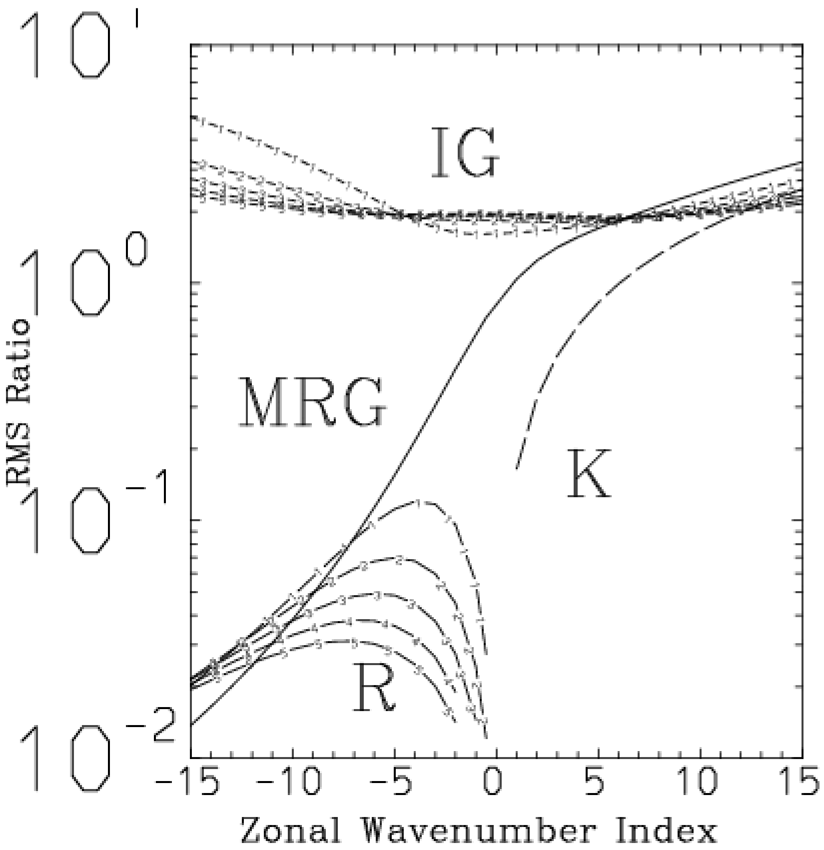
Analogy with Midlatitude Synoptic Storm Problem

	Midlatitude Synoptic Storm	MJO
Old Dominant Theory	Controlled by Rain Formation (Sir John Mason, F. H. Ludlam)	Driven by Convection (Y. Hayashi, R. S. Lindzen, ….)
Modern Theory	Baroclinic Instabilities (Eady, Charney)	Nonlinear Solitary Rossby Wave (Yano, Wedi, Smolarkiewicz)

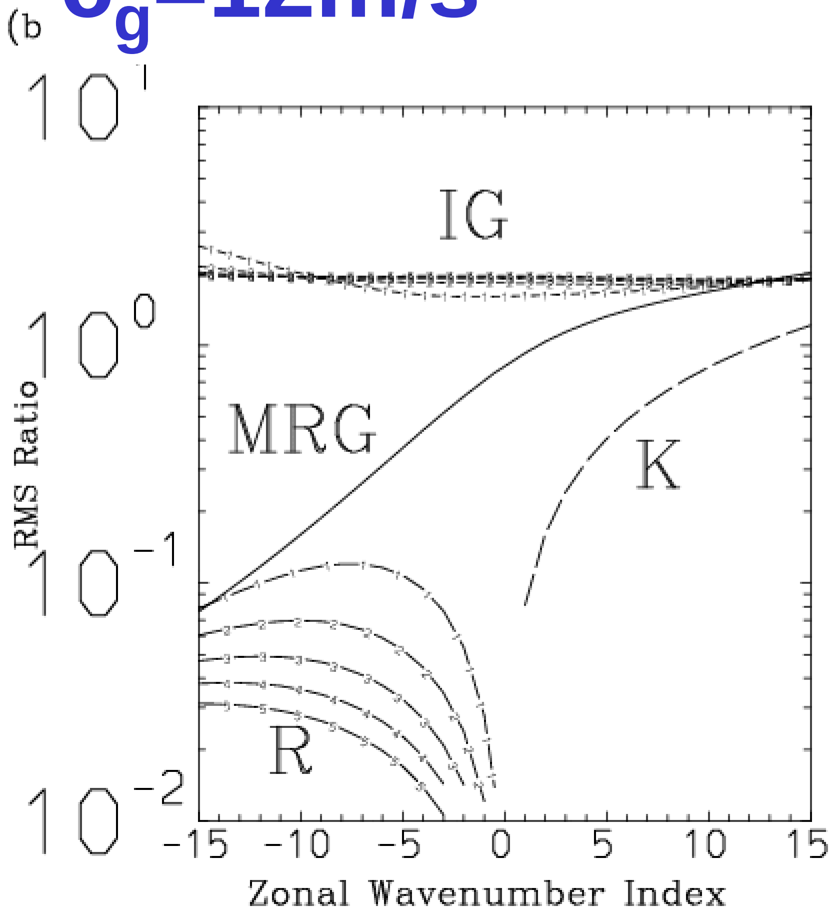
Further Materials for Questions and Discussions

Linear Free Wave Solutions:
RMS of divergence/vorticity

c_g=50m/s



c_g=12m/s



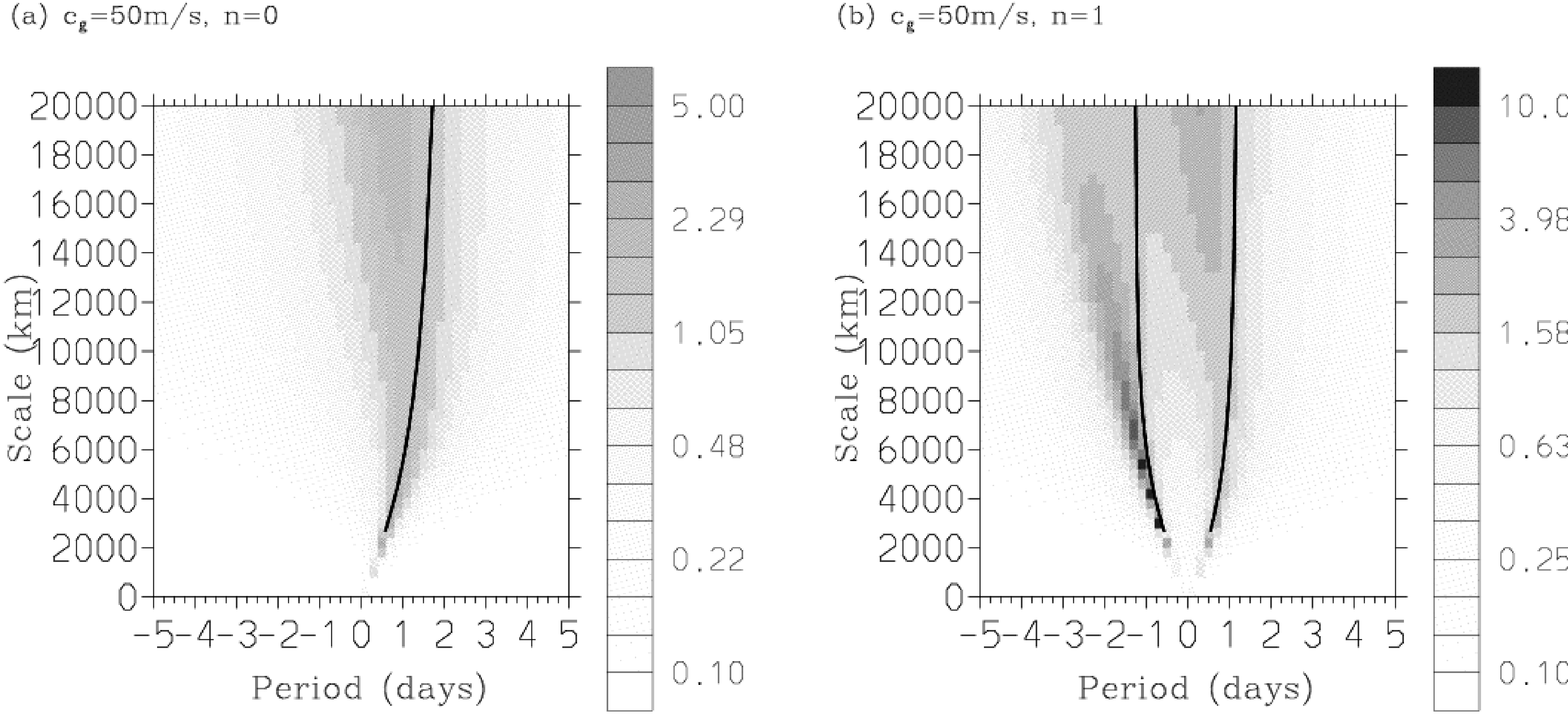
Forced Problem

$$\frac{\partial^2 \tilde{v}}{\partial y^2} + [(\frac{\nu^2}{gh_e} - k^2 - \frac{k}{\nu}\beta) - \frac{\beta^2 y^2}{gh_e}]\tilde{v} = H_n(\xi)\exp(-\xi^2/2 - i\nu t)$$

Linear Forced Wave Solutions(c_g=50m/s):

RMS of divergence/vorticity

n=0 n=1

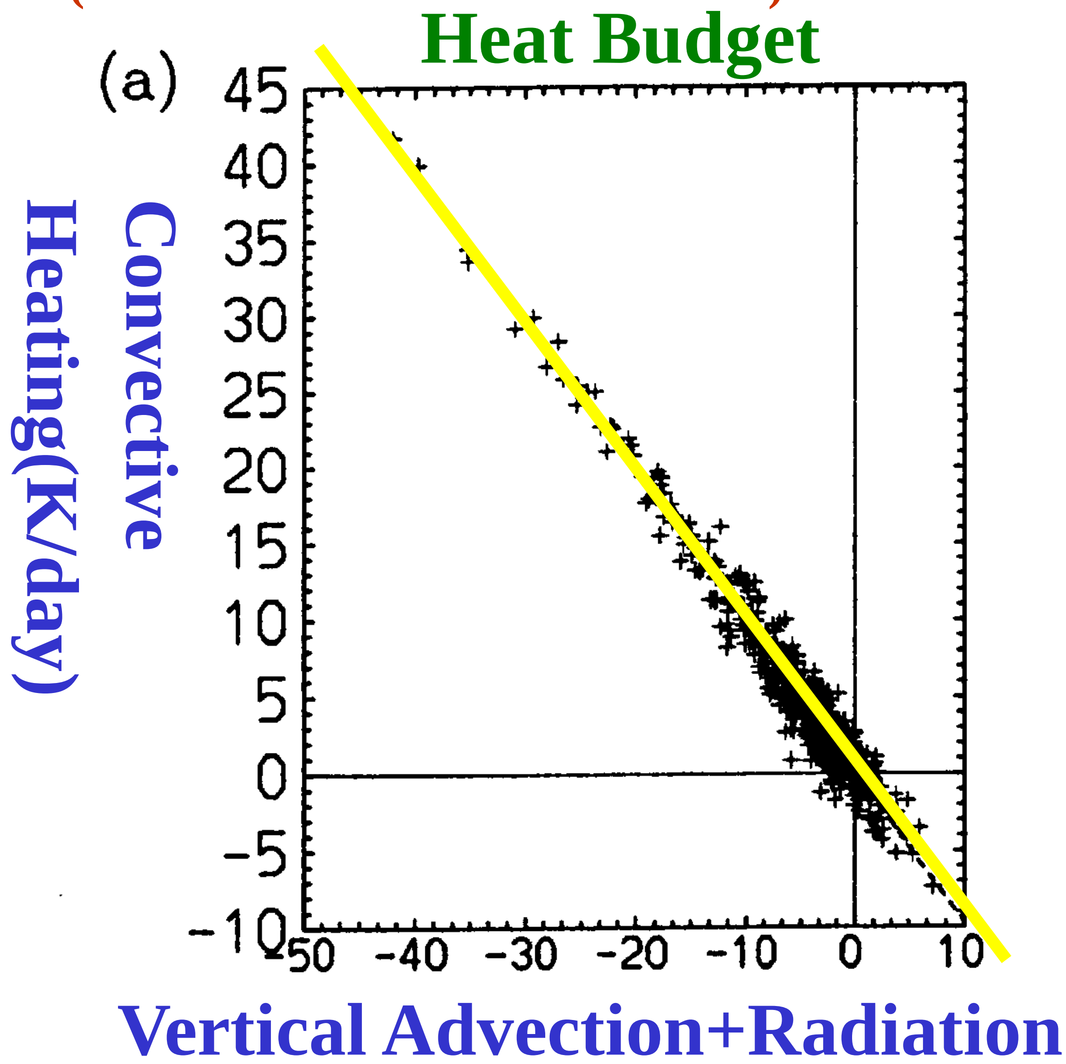


Balanced?

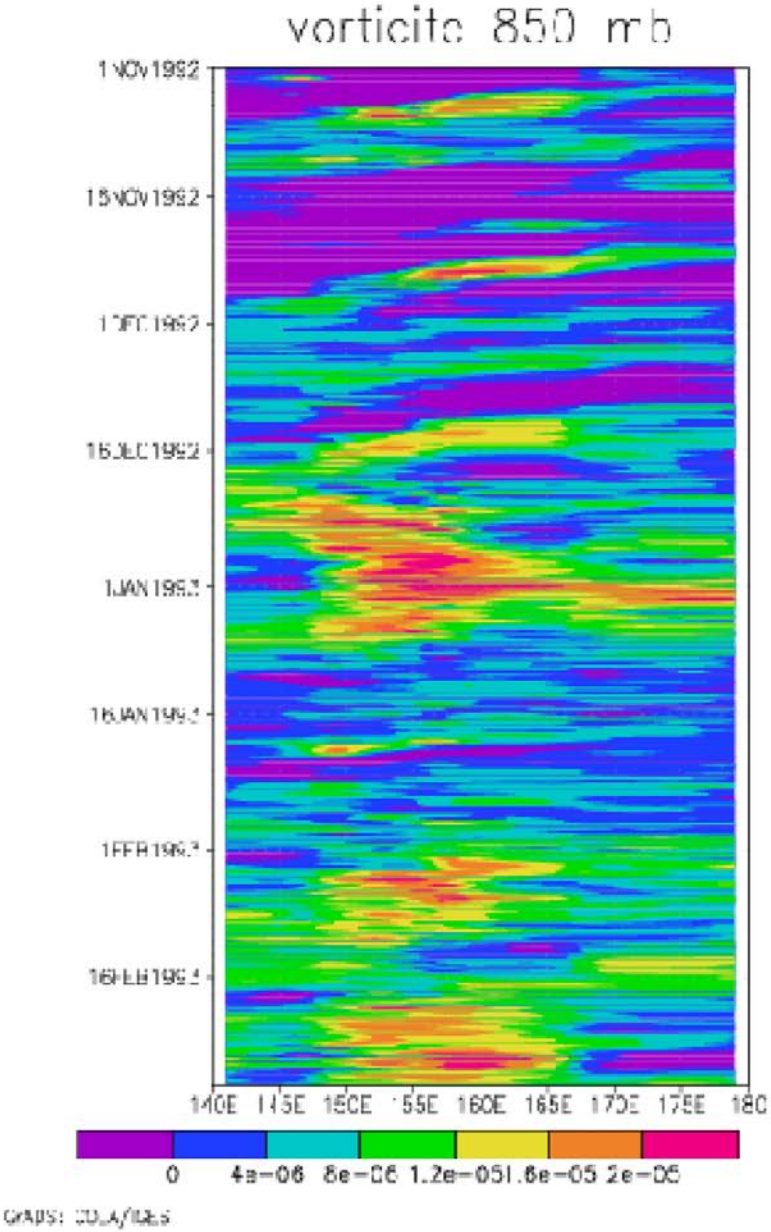
(Free-Ride, Fraedrich & McBride 1989):

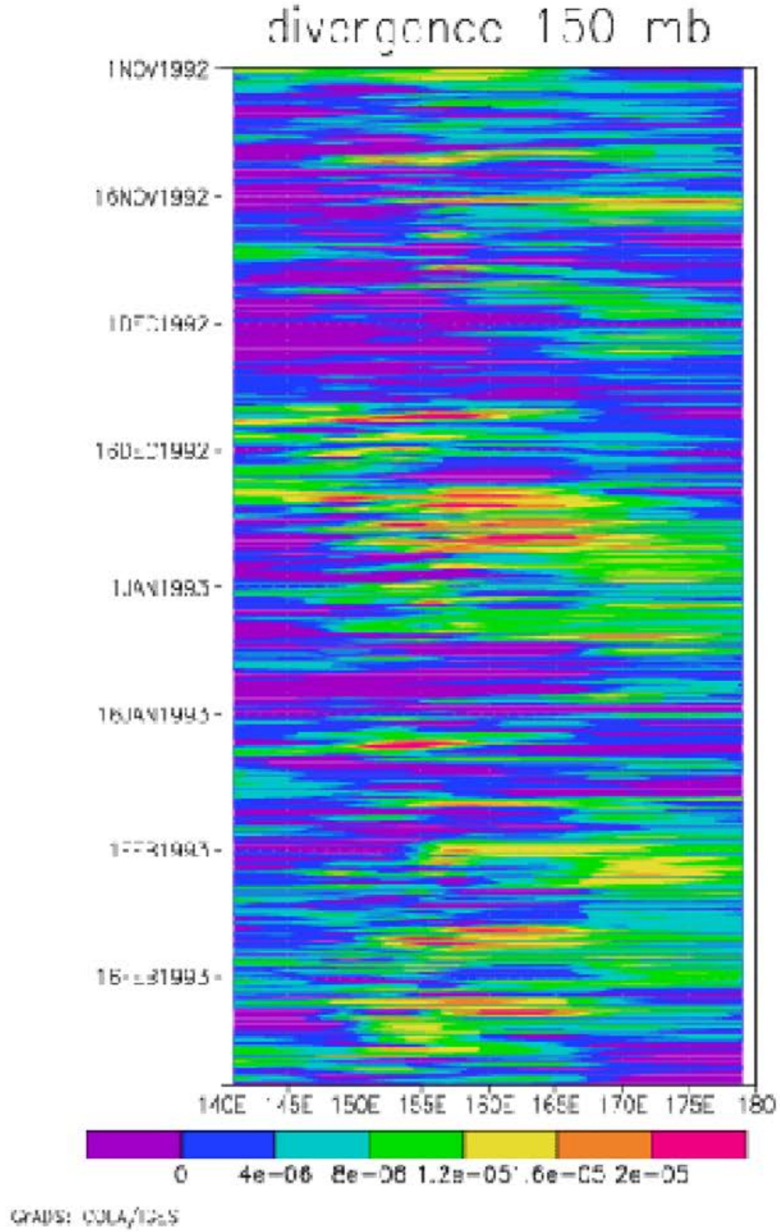
Vertical Advection =Diabatic Heating

(TOGA-COARE IFA Observation)



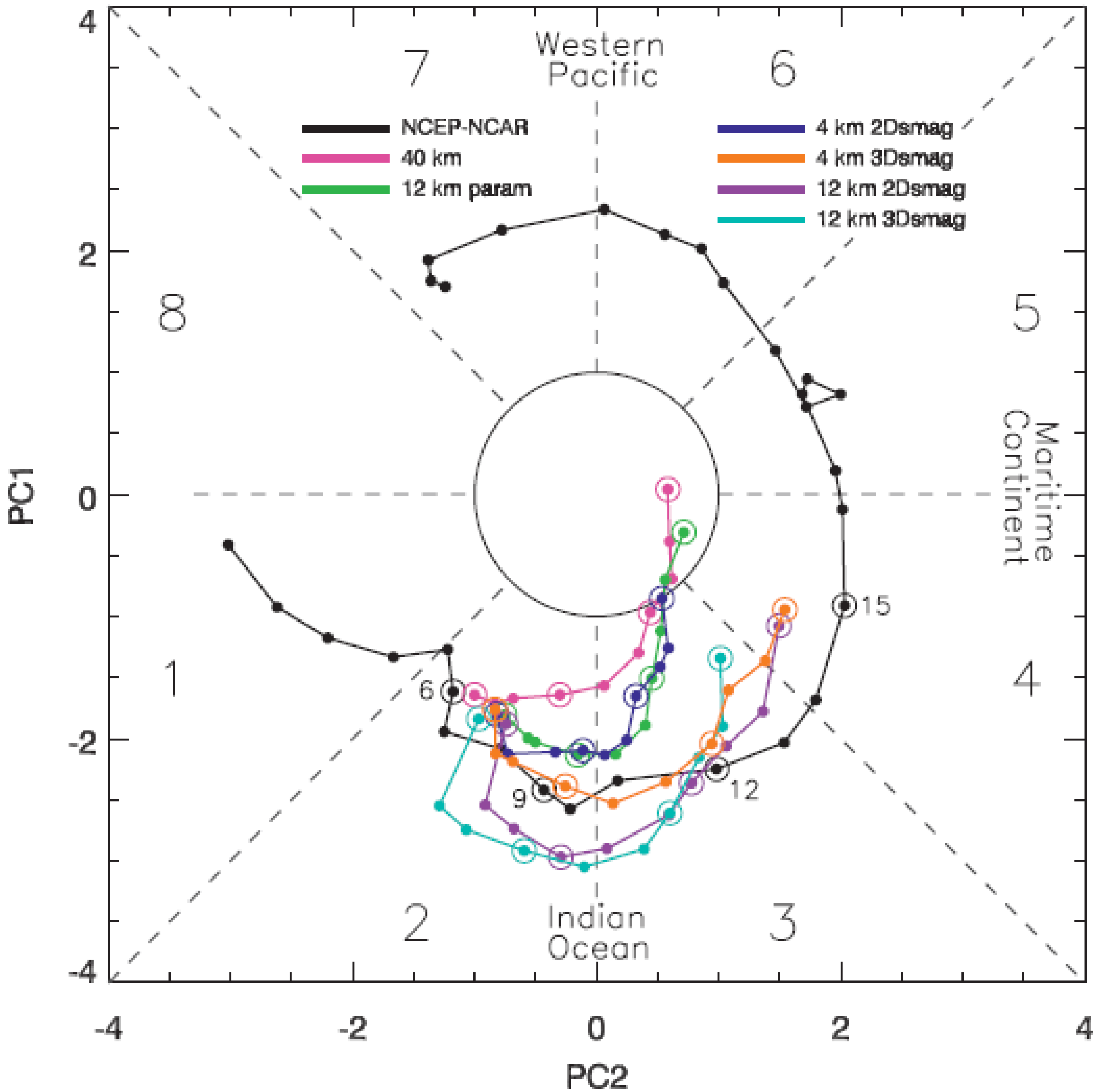
Vorticity >> Divergence with MJO:





How the Global Models Simutate It?

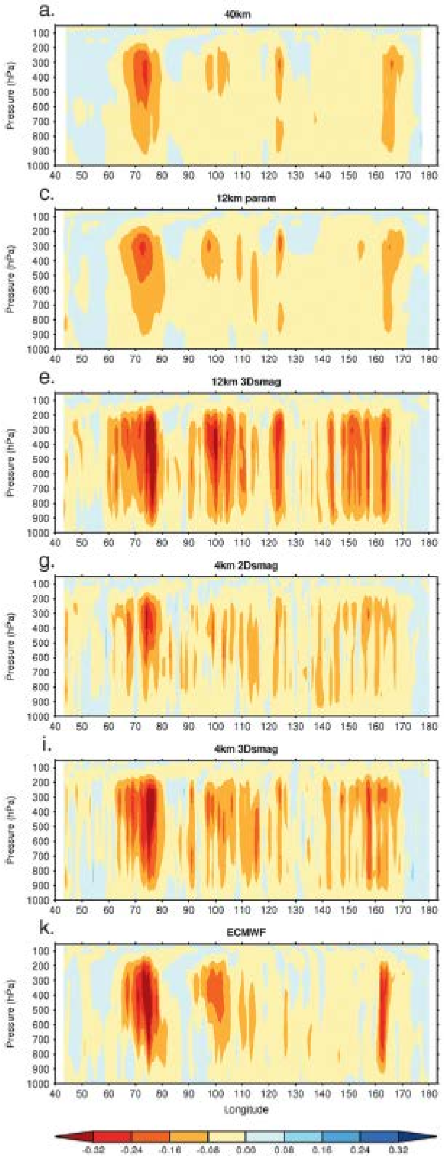
(e.g., Holloway et al., 2013, UK UM):



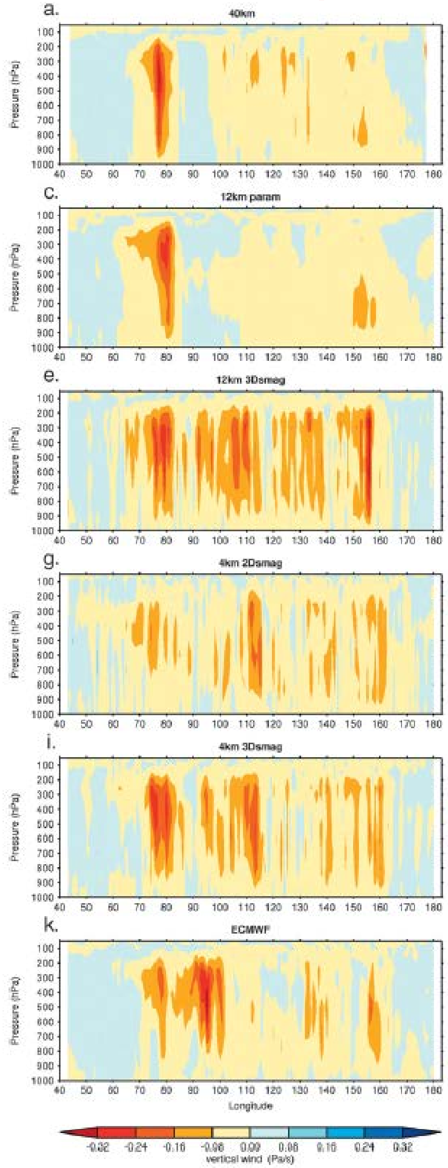
How the Global Models Simutate It?

(e.g., Holloway et al., 2013, UK UM):

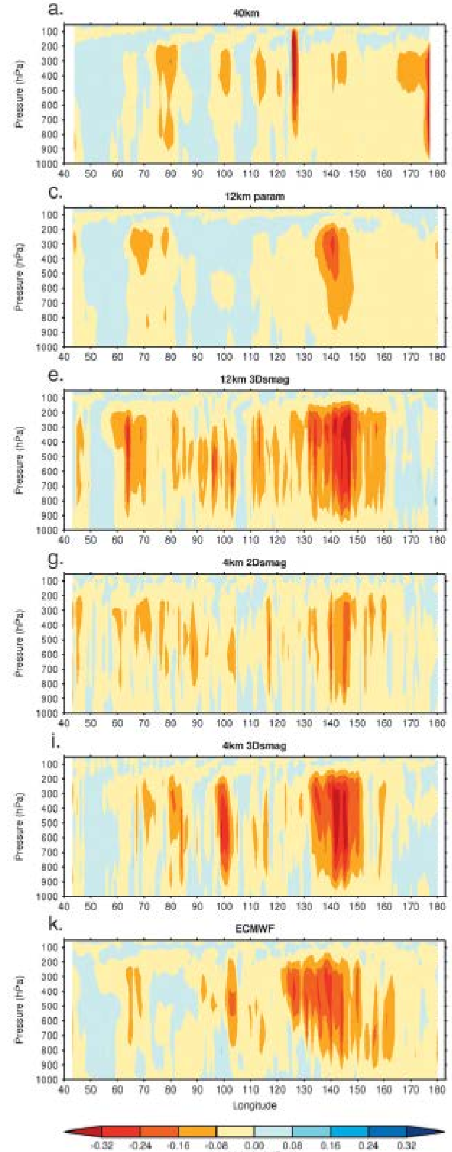
Vertical Velocity: 7 Apr 2009



10 Apr 2009



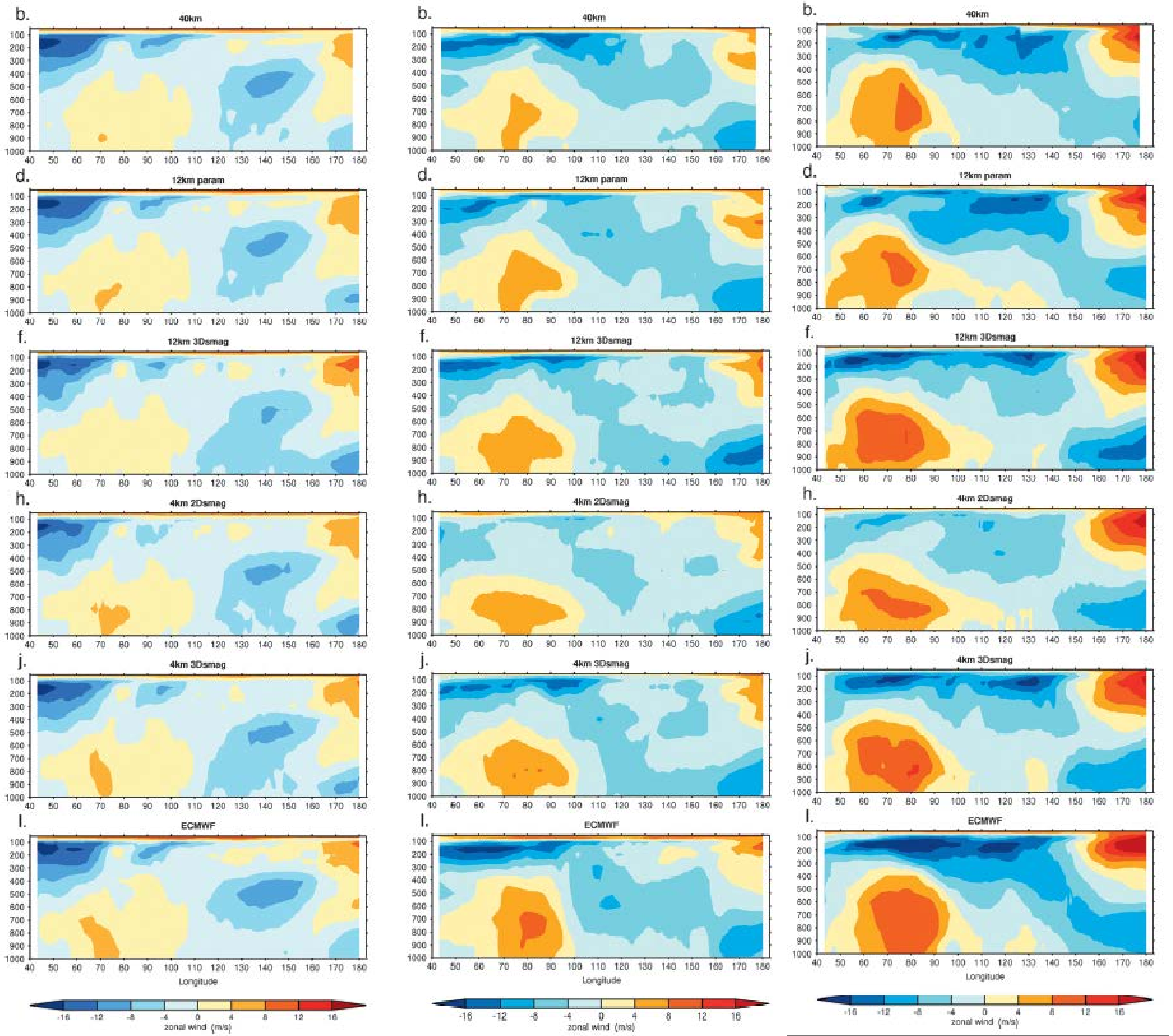
15 Apr 2009



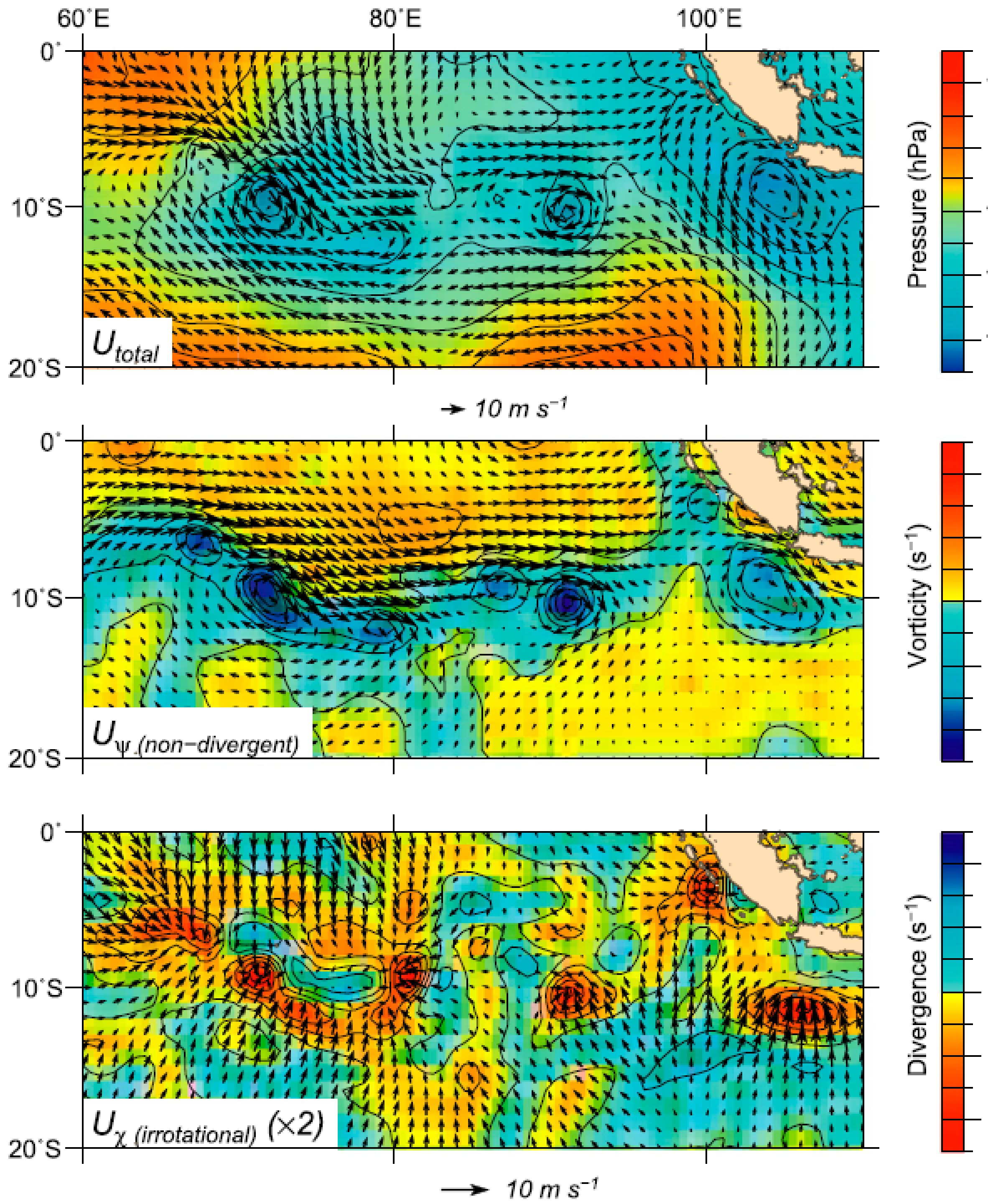
How the Global Models Simutate It?

(e.g., Holloway et al., 2013, UK UM):

Zonal Velocity: 7 Apr 2009 **10 Apr 2009** **15 Apr 2009**

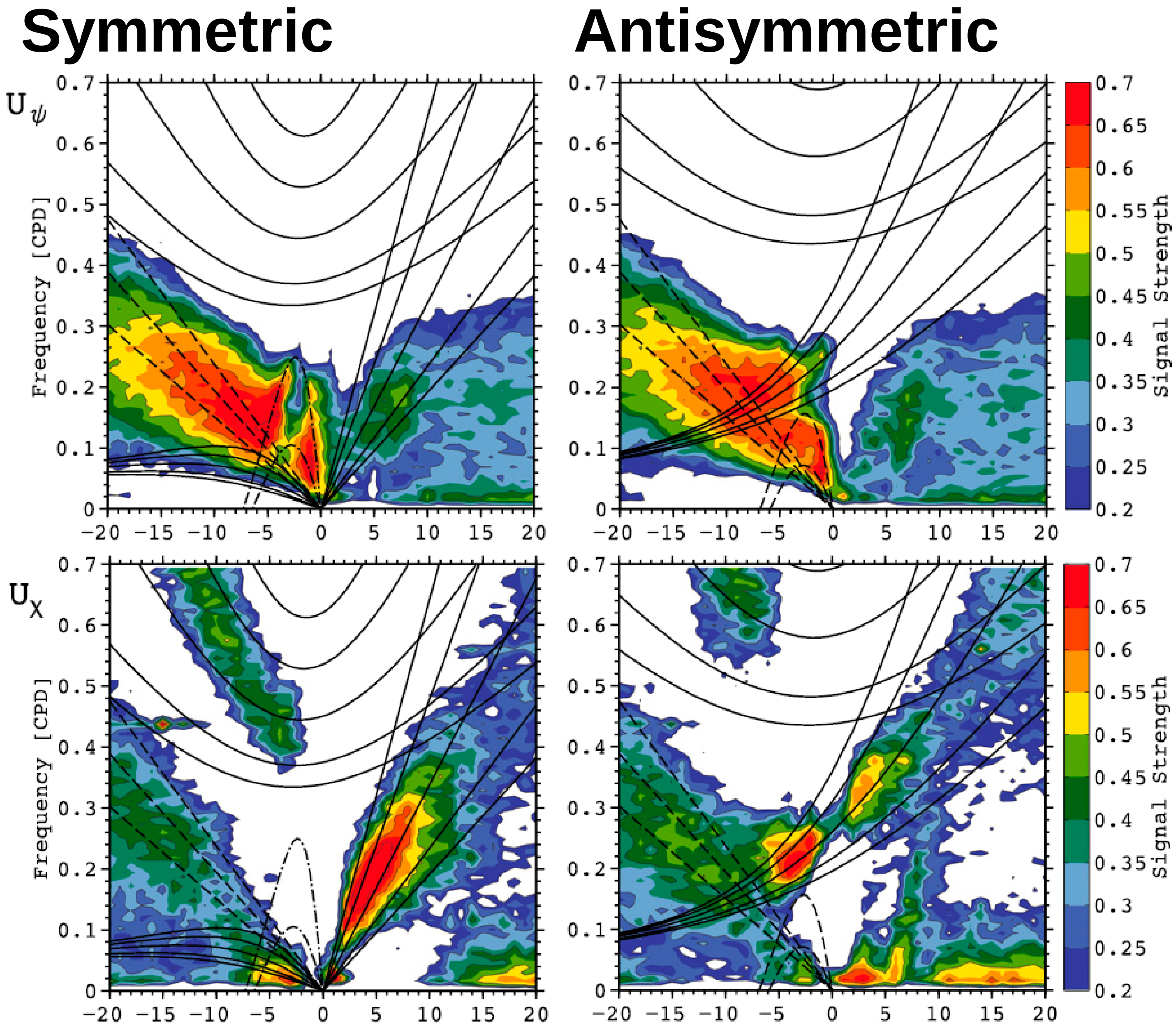


Asymptotic-Nondivergence of the Large-Scale Tropical Circulations



(Adames et al 2014)

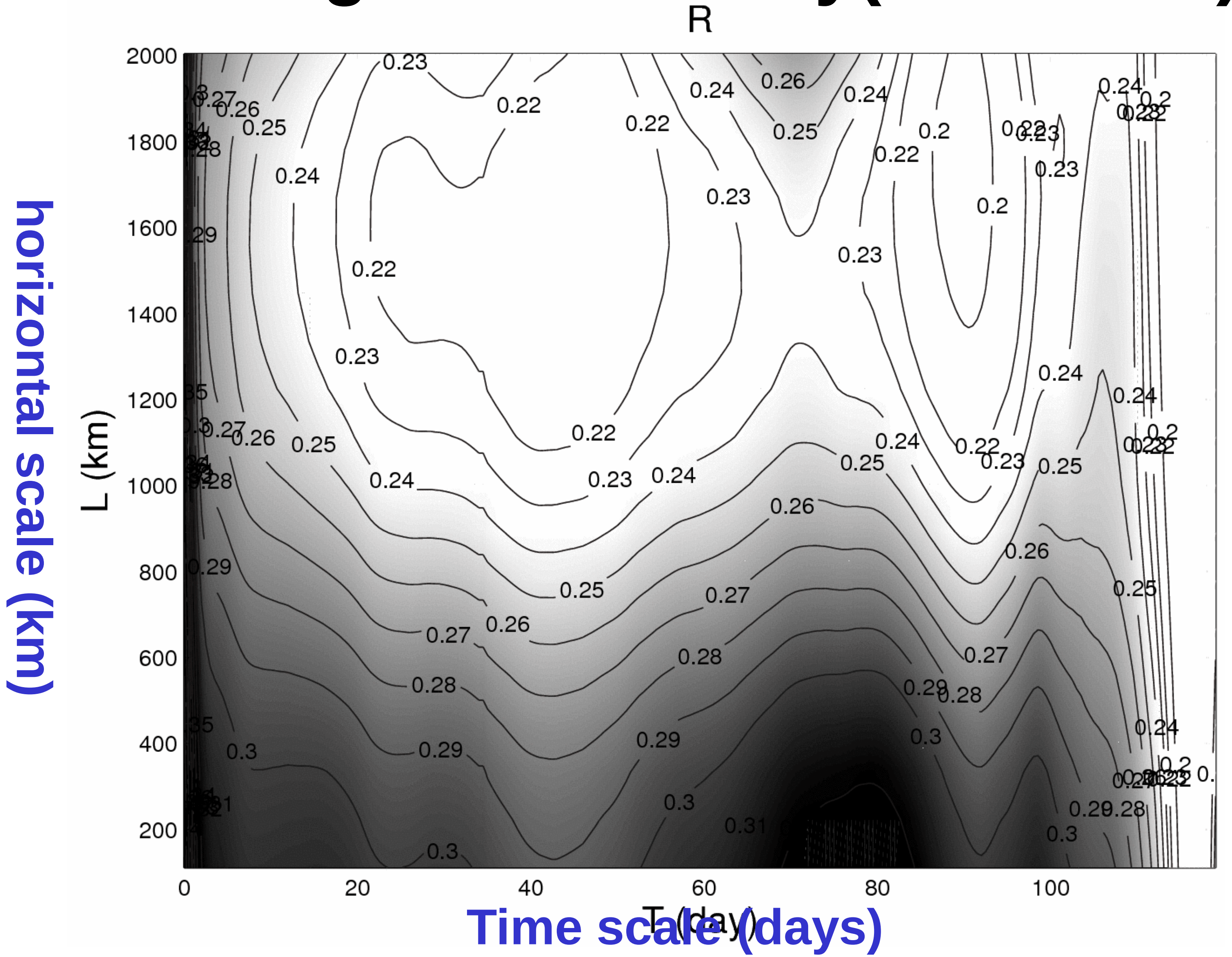
Asymptotic-Nondivergence of MJO



(Adames et al 2014)

Asymptotic Tendency for Non-Divergence:

Divergence/Vorticity(Transient)



Weakly-Nonlinear Theory Does Not Explain MJO:

Rossby Wave Dispersion: $\omega = -\beta k/(k^2+l^2+F)$

Weakly-Nonlinear Approximation:

Longwave Limit:

$$\omega \simeq -\beta k/(l^2+F)[1 - k^2/(l^2+F)]$$

or

$$c_p \simeq -\beta k/(l^2+F)[1 - k^2/(l^2+F)] < 0 \quad \textbf{always!}$$

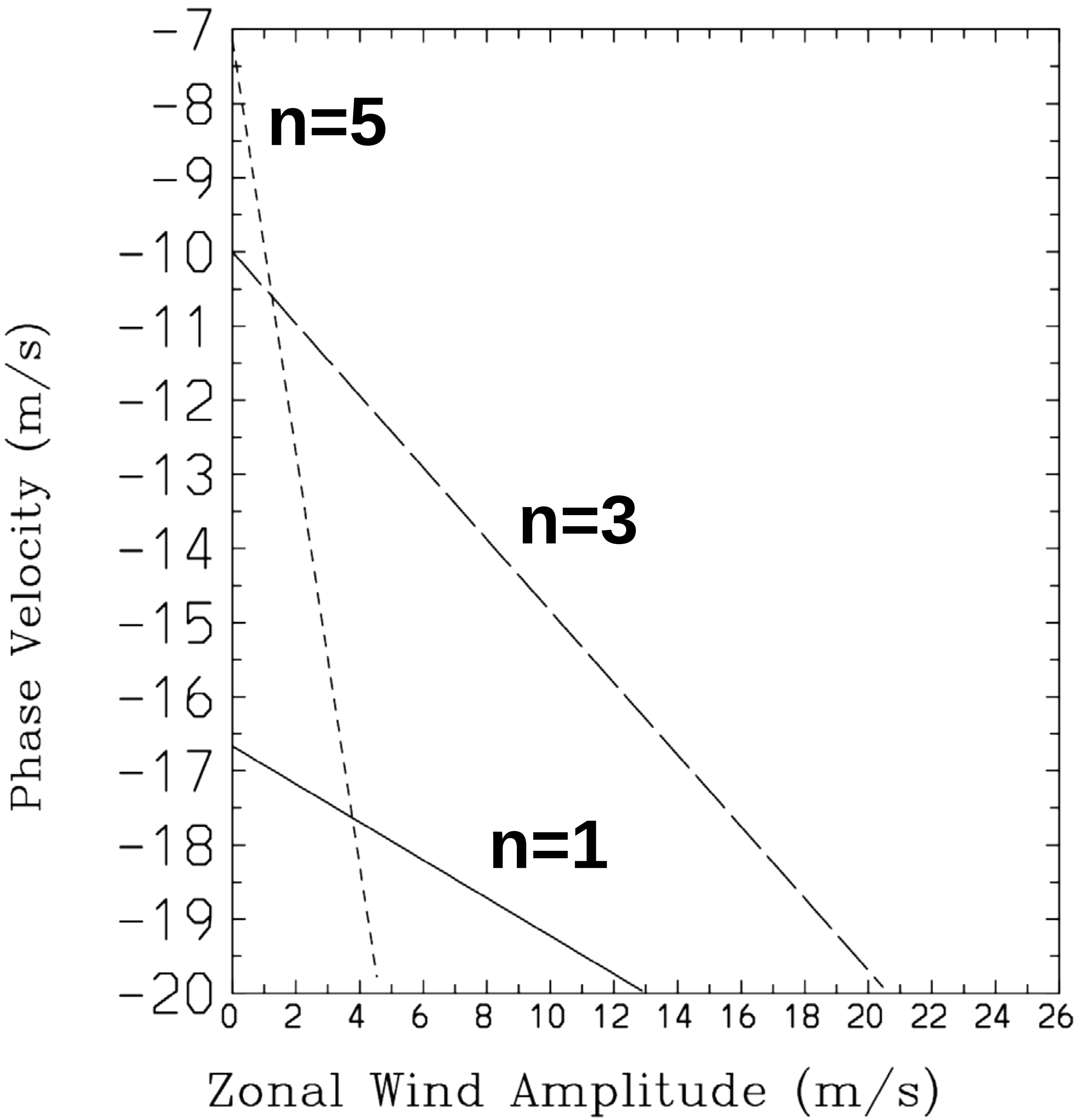
or

$$-d/dt = -\beta/(l^2+F)(d/dx)[1 + 1/(l^2+F)(d^2/dx^2)]$$

***cf.,* KdV Equation:**

$$u_t + uu_x + u_{xxx} = 0$$

Equatorial-Rossy Solition Dispersion (Boyd 1980)



MJO phase speed