Propagating vs. Non-propagating Madden-Julian Oscillation Events

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What is this?

- That has been studied more than 40 years but still poorly understood
- “a ‘holy grail’ in the quest to understand tropical atmospheric dynamics” (Raymond 2001)

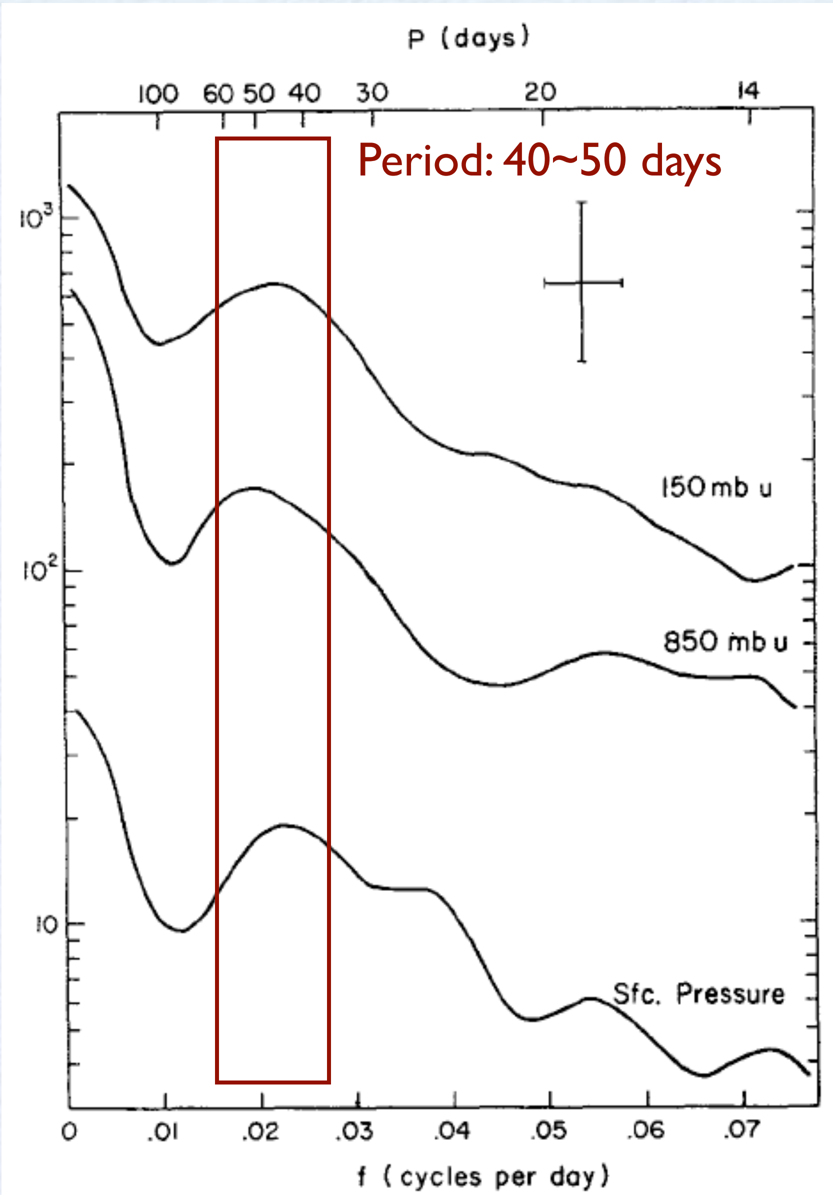
Madden-Julian Oscillation (MJO)

Dr. Paul Julian

Dr. Roland Madden

Picture: Courtesy of Dr. Duane Waliser

What Madden and Julian were looking at



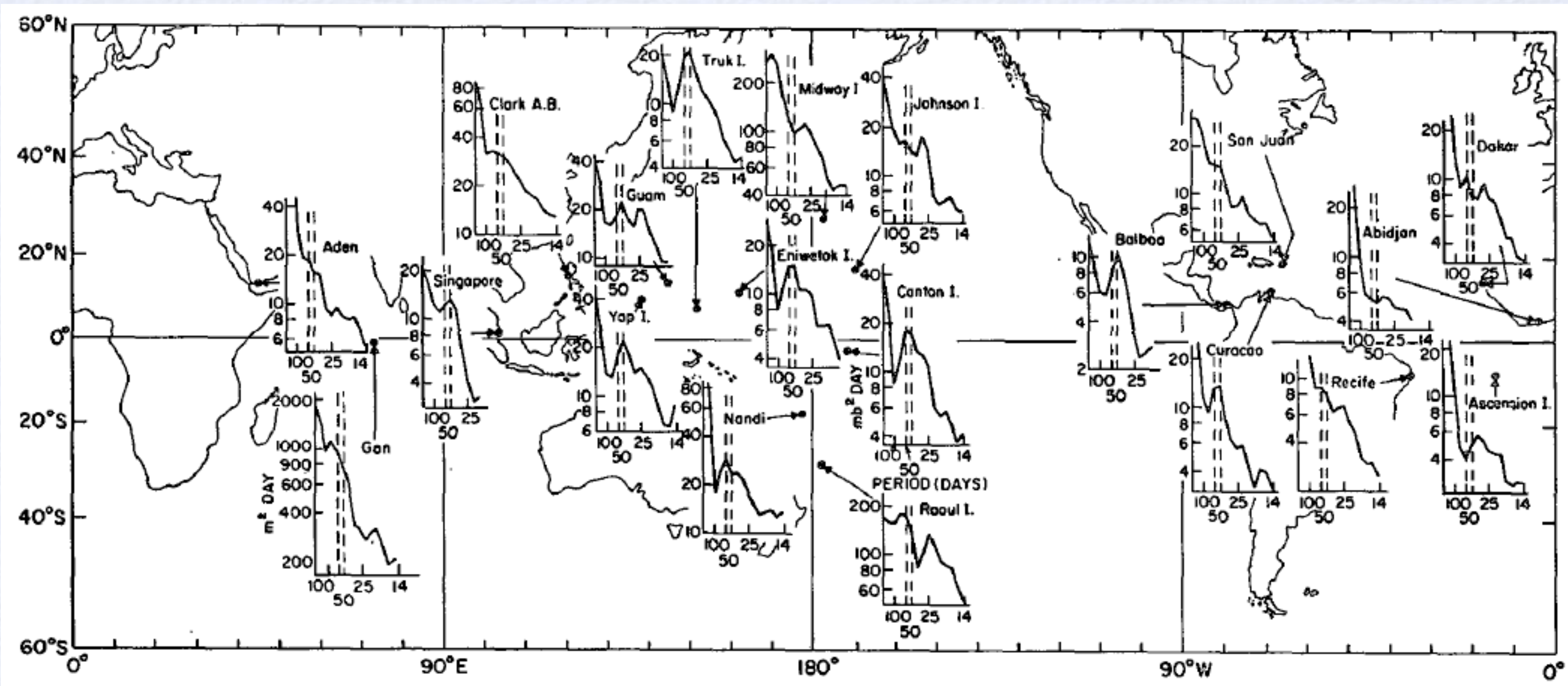
Power spectrum of zonal wind and surface pressure

at Canton Island (3°S, 172°W)
~ 10 years daily rawinsonde data

Madden and Julian (1971)

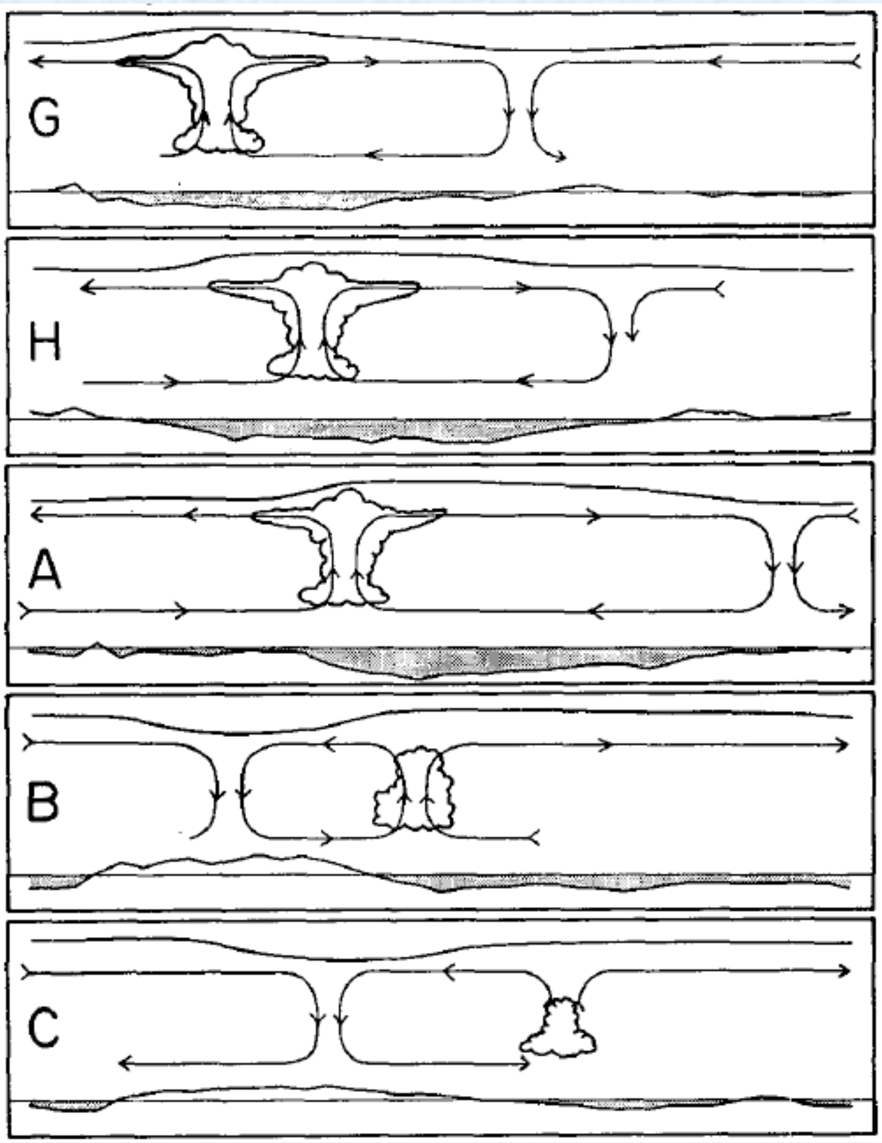
What Madden and Julian were looking at

Power spectrum of surface pressure at 20 stations



Madden and Julian (1972)

What they thought what it was



Madden and Julian in 1972

- Eastward propagating large-scale convection with 40-50 days period in the tropics

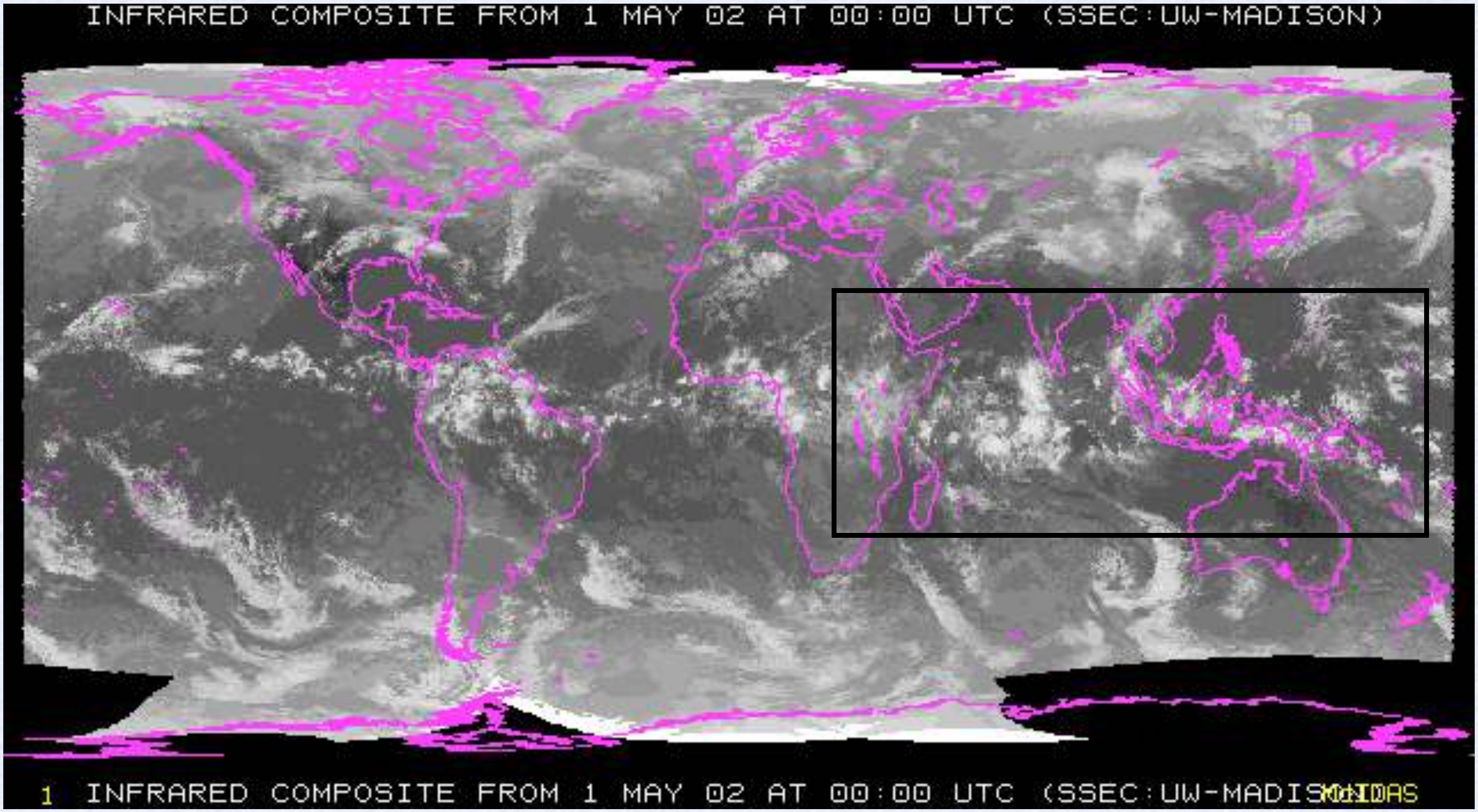
Today's definition of the MJO

- Eastward propagating planetary-scale convection with 30-60 days period in the tropics

Madden and Julian (1972)

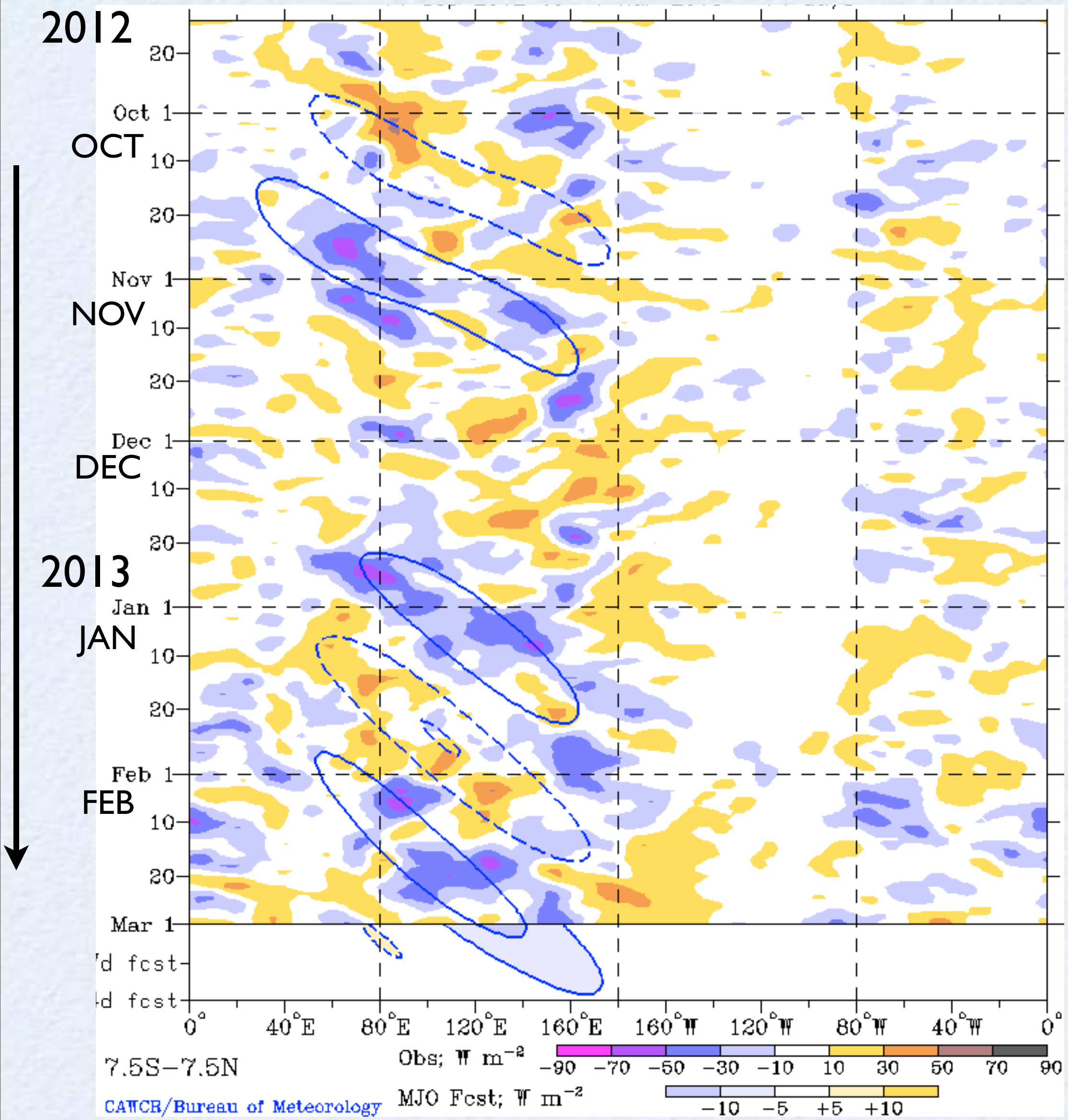
Today, it's much easier to find it

IR satellite image during 1-13 May 2002



http://weather.is.kochi-u.ac.jp/sat/globe/

What is the MJO?



7.5°S-7.5°N OLR anomaly

- Shaded: deviation from seasonal cycle
- Contour: MJO-filtered
  - Wavenumber: 1-5
  - Period: 30-96 days
  - Eastward propagation

"Satellite data can be used to confirm if, and to learn exactly how, convection is associated with the disturbance."
(Madden and Julian 1972)

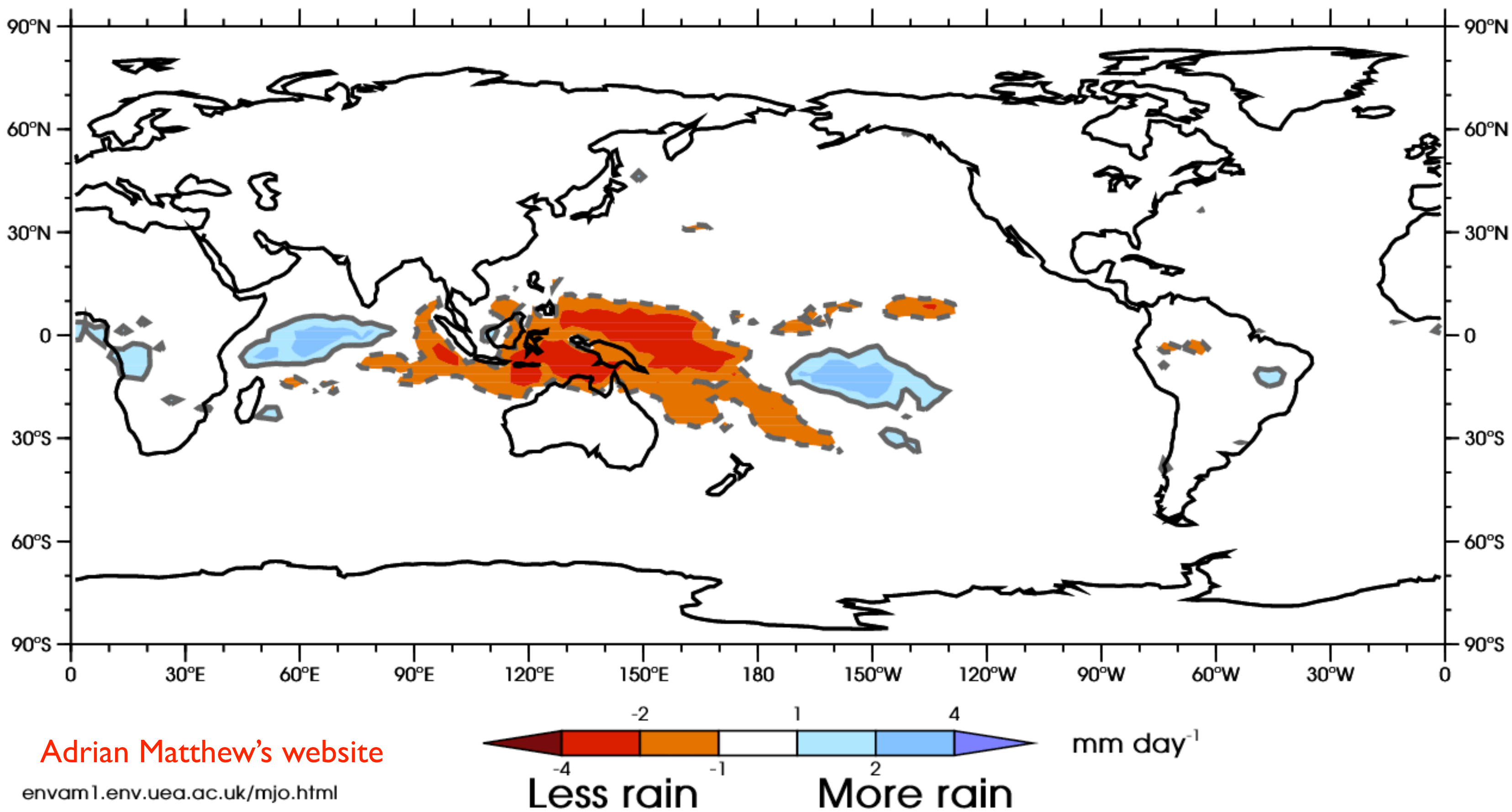
*OLR: outgoing longwave radiation

http://cawcr.gov.au/staff/mwheeler/maproom/OLR_modes/index.htm

'Typical' MJO cycle

MJO convection

• Explains half of total intraseasonal (20-100 days) variability



Adrian Matthew's website

envam1.env.uea.ac.uk/mjo.html

To go, or not to go: that is the question

1985

1986

15°S-15°N OLR anomaly

- Shaded: 20-100 day filtered
- Contour: MJO-filtered

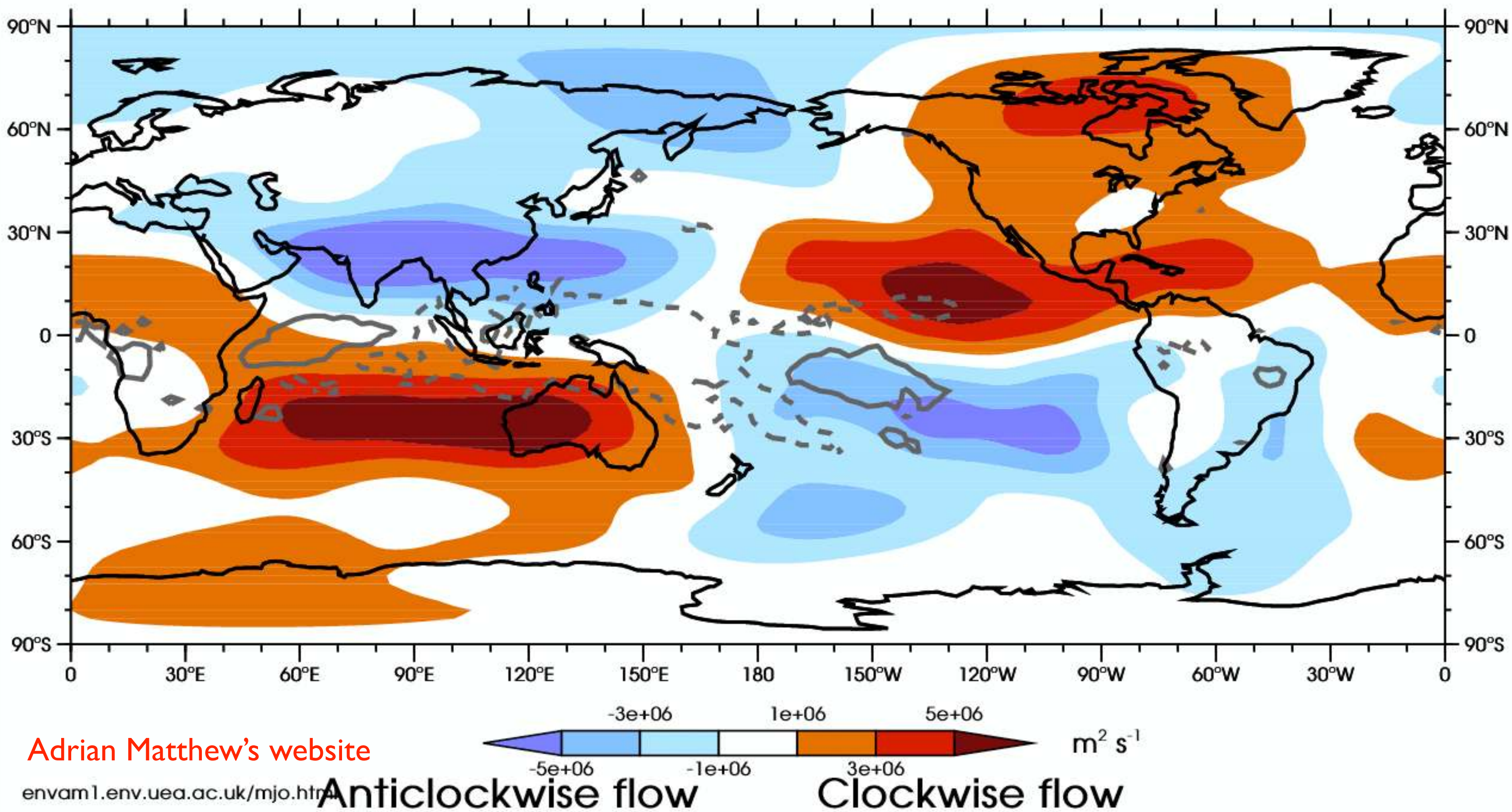
W m^{-2}

Kim et al. (2013, JC, in review)

'Typical' MJO cycle

MJO convection

- Tightly coupled to tropical circulation
- Affects global circulation anomalies



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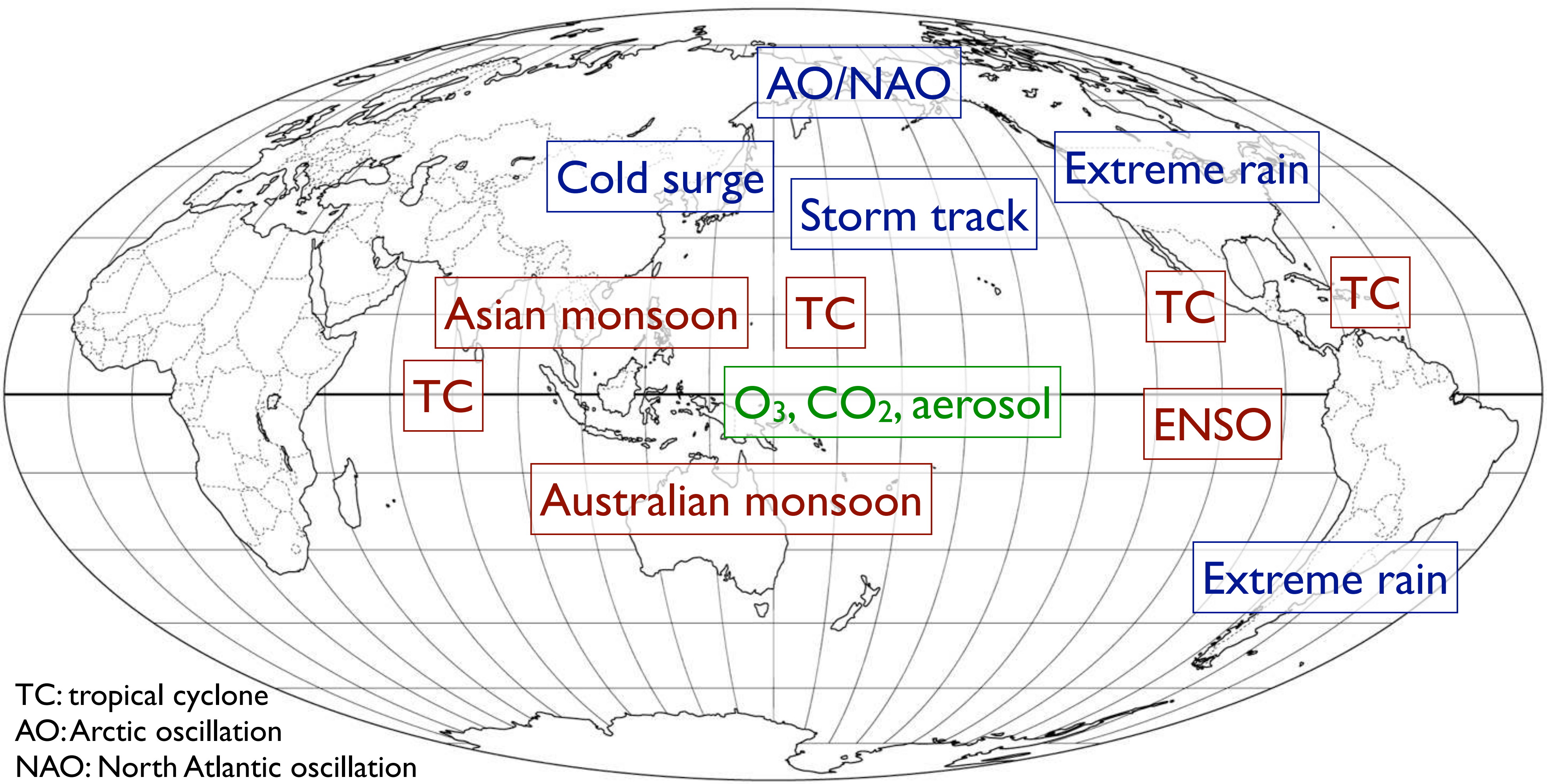
Impacts of the MJO

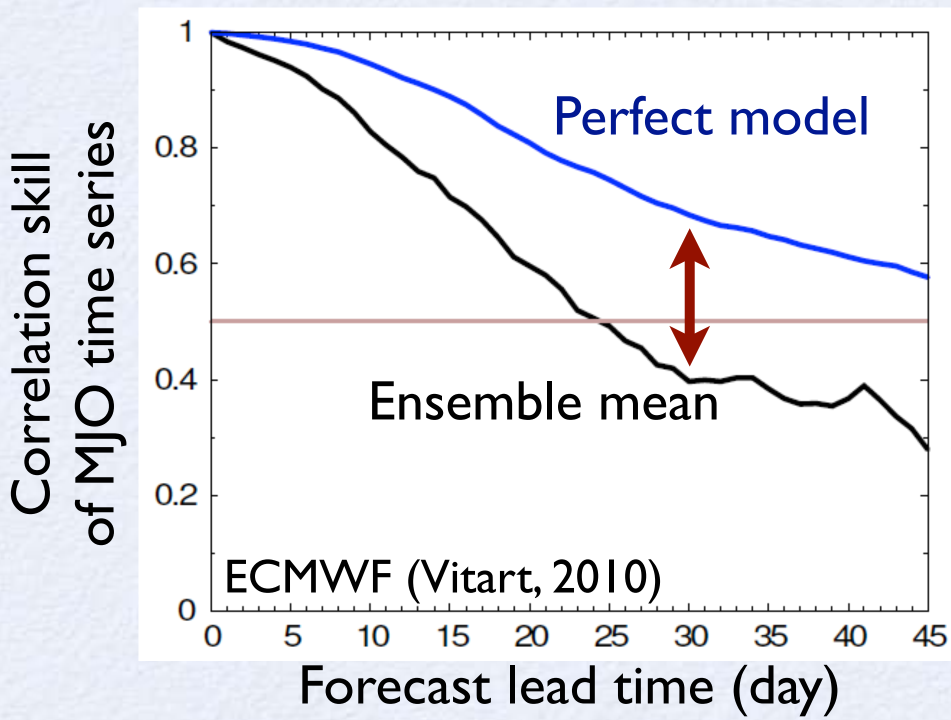
Components of the Earth's climate system that are affected by the MJO



TC: tropical cyclone
AO: Arctic oscillation
NAO: North Atlantic oscillation

Status of our capability

- MJO Forecast
  - Useful prediction up to ~25 days vs. Potential predictability >45 days (ECMWF, Vitart 2010)



Status of our capability

- MJO simulation using GCMs
  - Strengthening moisture sensitivity of parameterized convection can enhance MJO variability
    (e.g. Maloney and Hartmann 2001; Lin et al. 2008; Kim and Kang 2012; Kim et al. 2012)
  - GCM intercomparison studies: weak variability/propagation
    (e.g. Slingo et al. 1996; Lin et al. 2006; Kim et al. 2009; Hung et al. 2013)
  - MJO-mean state tradeoff (Kim et al. 2011)
  - The lack of the MJO in GCM simulations represents the lack of our understanding of the MJO.
- Why is it so hard to understand/simulate/forecast the MJO? What is special about the MJO?

What is special about the MJO?

Shallow water equation in the equatorial beta-plane

Zonal wind

$$\frac{\partial u}{\partial t} - yv + \frac{\partial \phi}{\partial x} = 0$$

Meridional wind

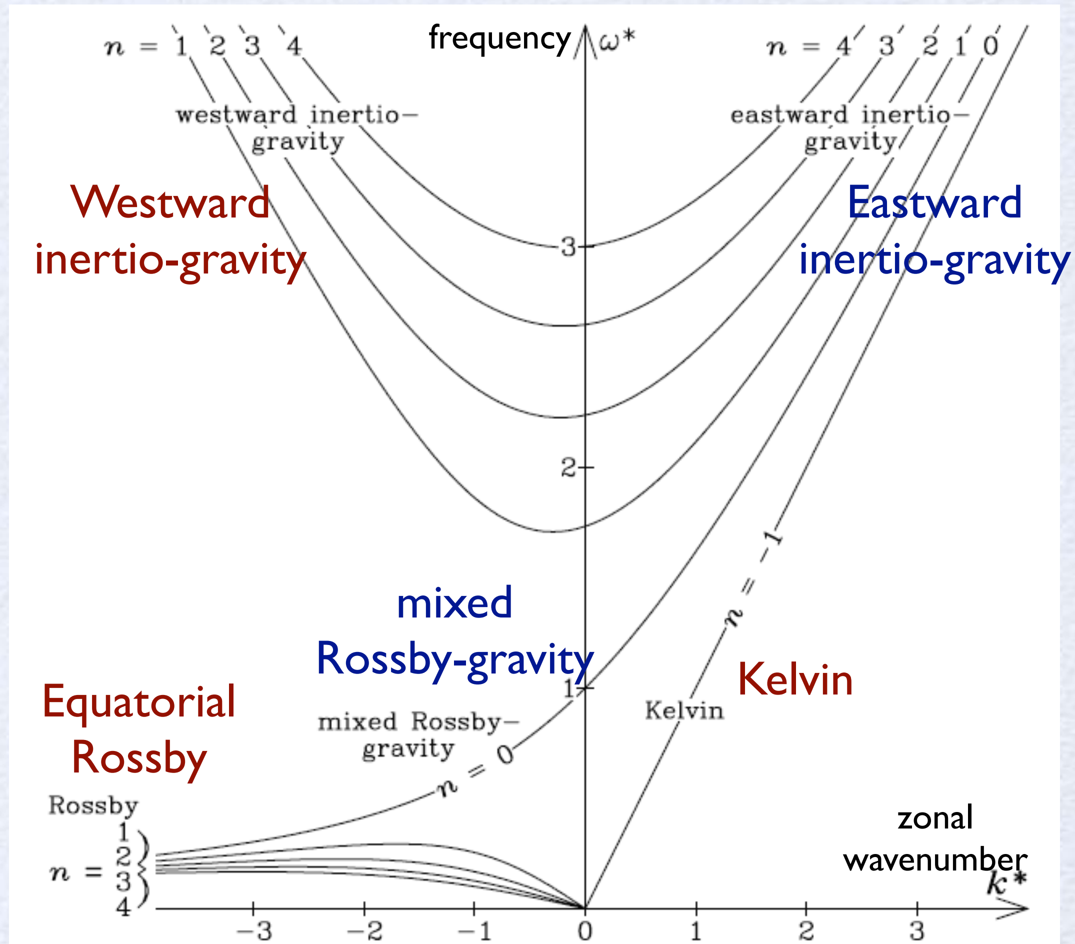
$$\frac{\partial v}{\partial t} + yu + \frac{\partial \phi}{\partial y} = 0$$

Geopotential height

$$\frac{\partial \phi}{\partial t} + \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0$$

Matsuno (1966)

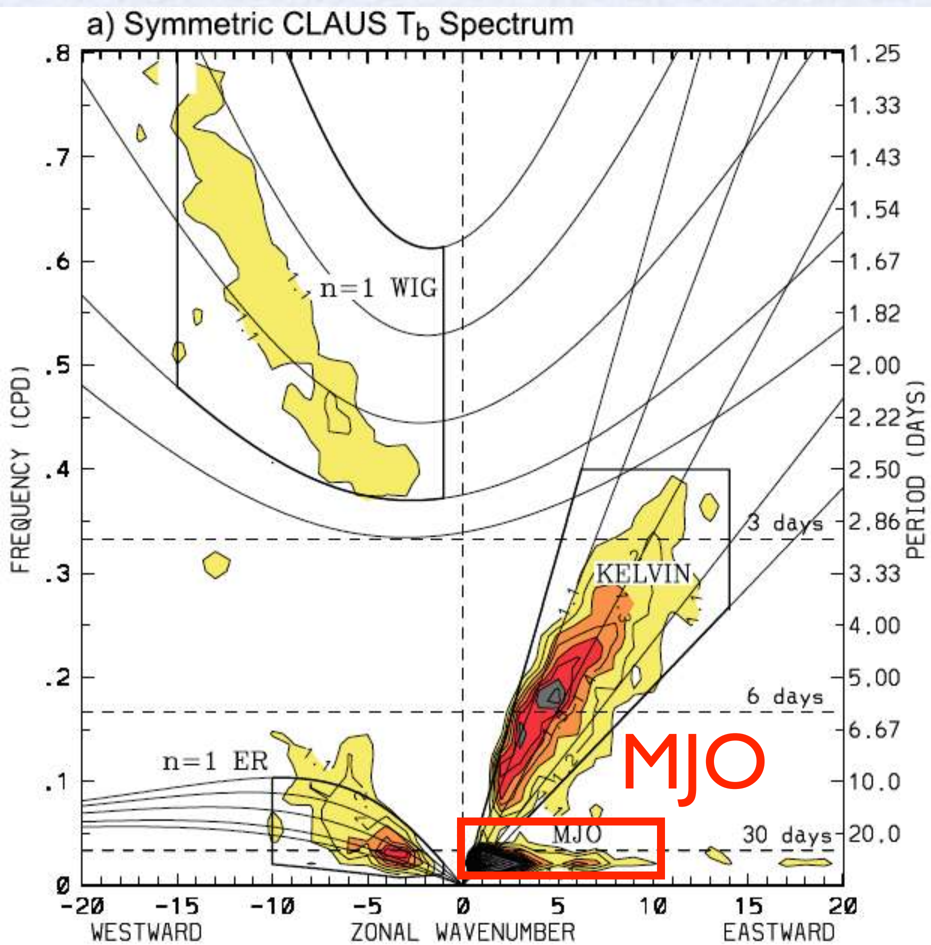
Solutions



Kiladis et al. (2009)

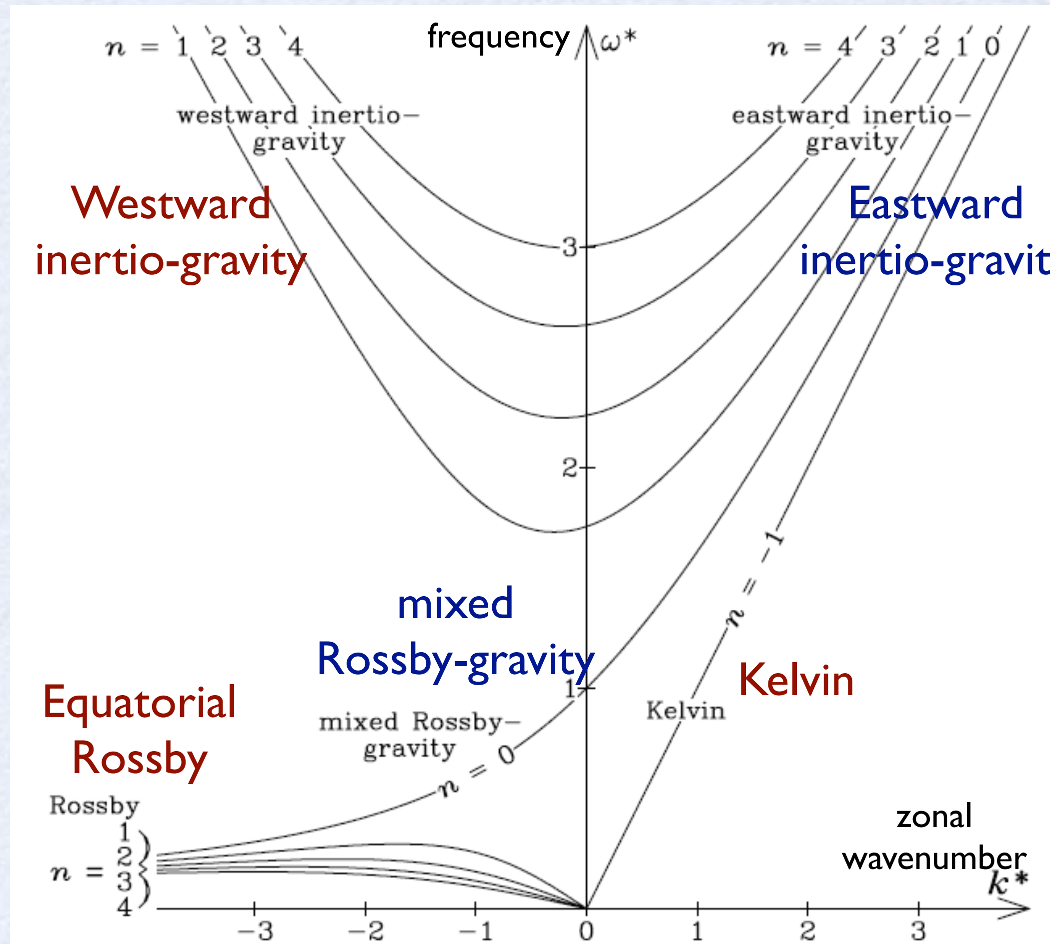
What is special about the MJO?

Space-time power spectrum of brightness temperature



Wheeler and Kiladis (1999)
Kiladis et al. (2009)

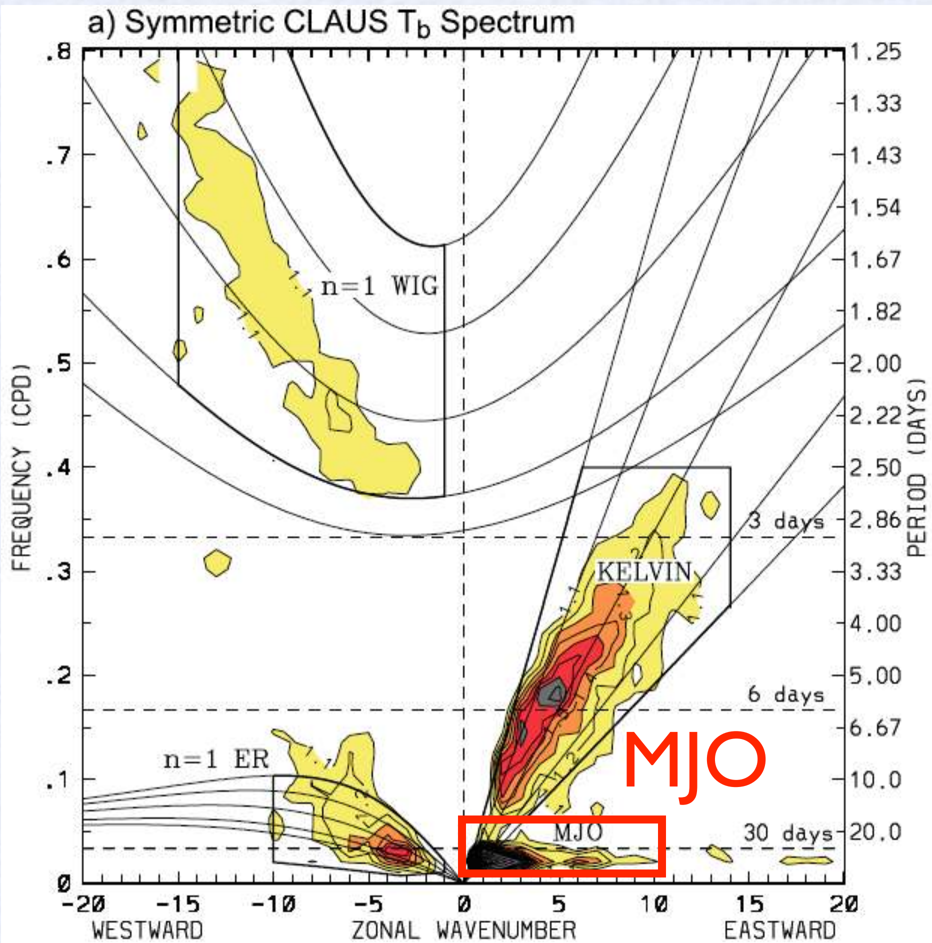
Solutions to shallow water equation



Kiladis et al. (2009)

What is special about the MJO?

Space-time power spectrum of brightness temperature



Wheeler and Kiladis (1999)
Kiladis et al. (2009)

Shallow water equation in the equatorial beta-plane

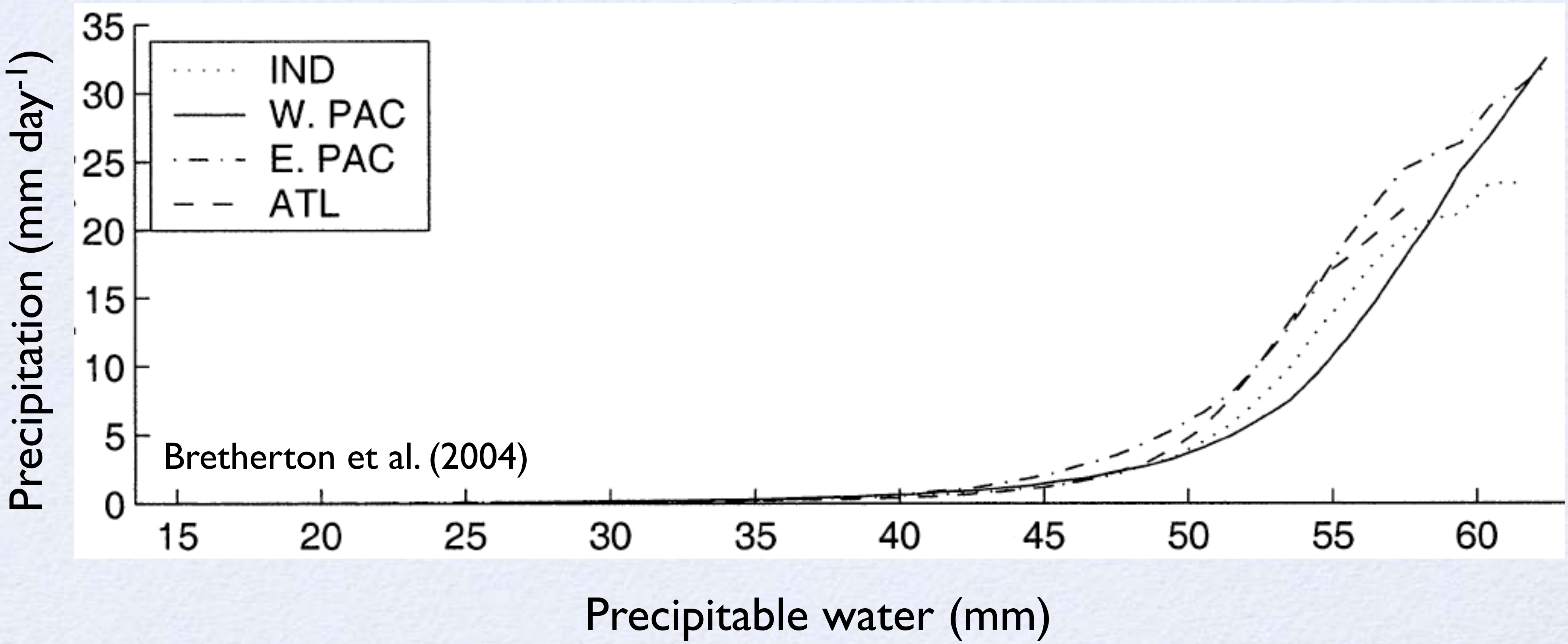
- **Linear**
  "it seems quite unlikely that linear wave propagation theory will be able to contribute to an understanding of the oscillation" (Madden and Julian 1971)

- **Dry**
  - Interaction of moisture with other circulation anomalies and convection is ignored

Matsuno (1966)

Moisture-convection coupling

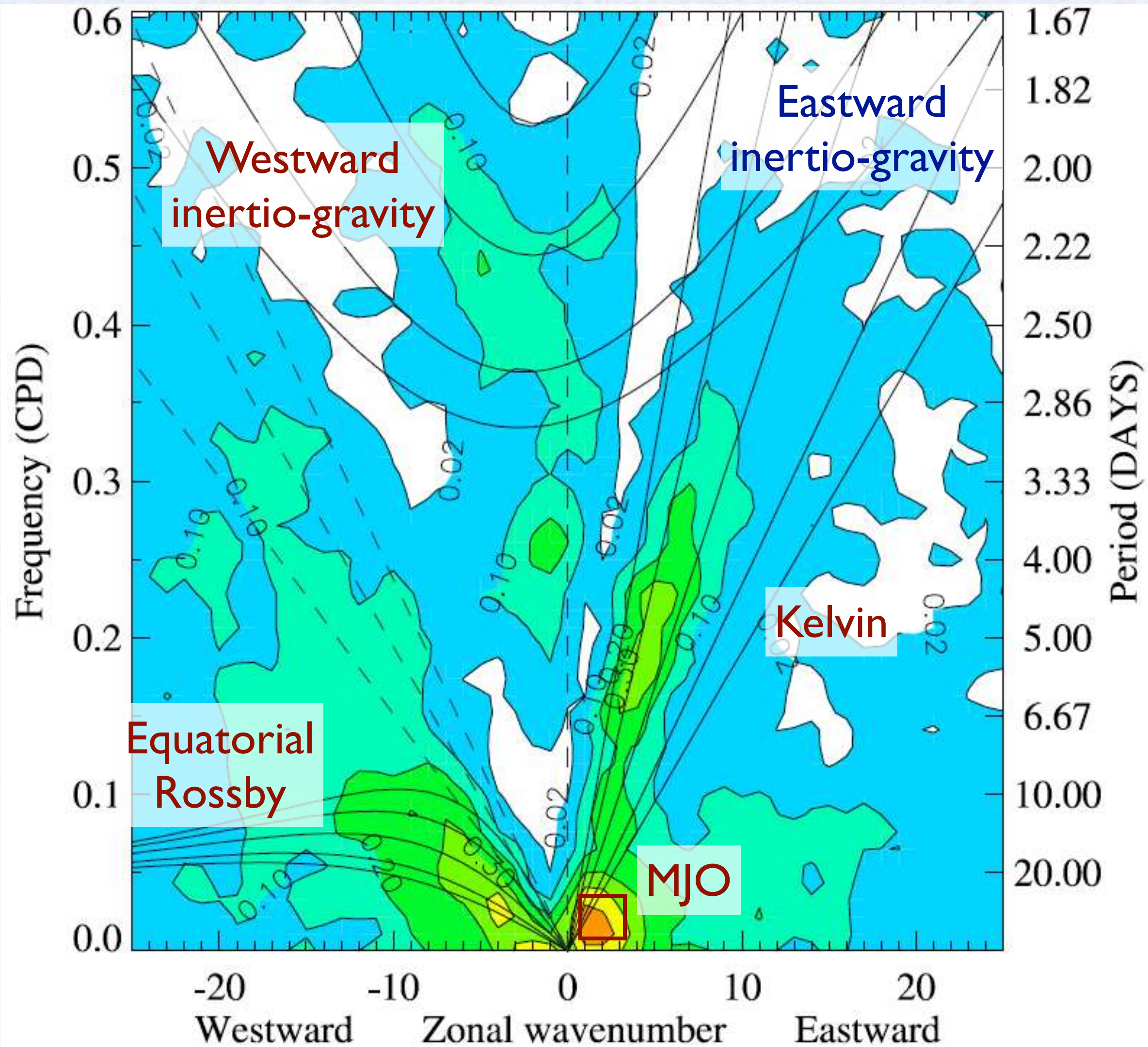
Mean daily precipitation in 1mm bin PW (SSM/I)



Tropical convection is strongly coupled to tropospheric water vapor

MJO Moisture-convection coupling

Space-time coherence spectrum (Precipitation & PW)

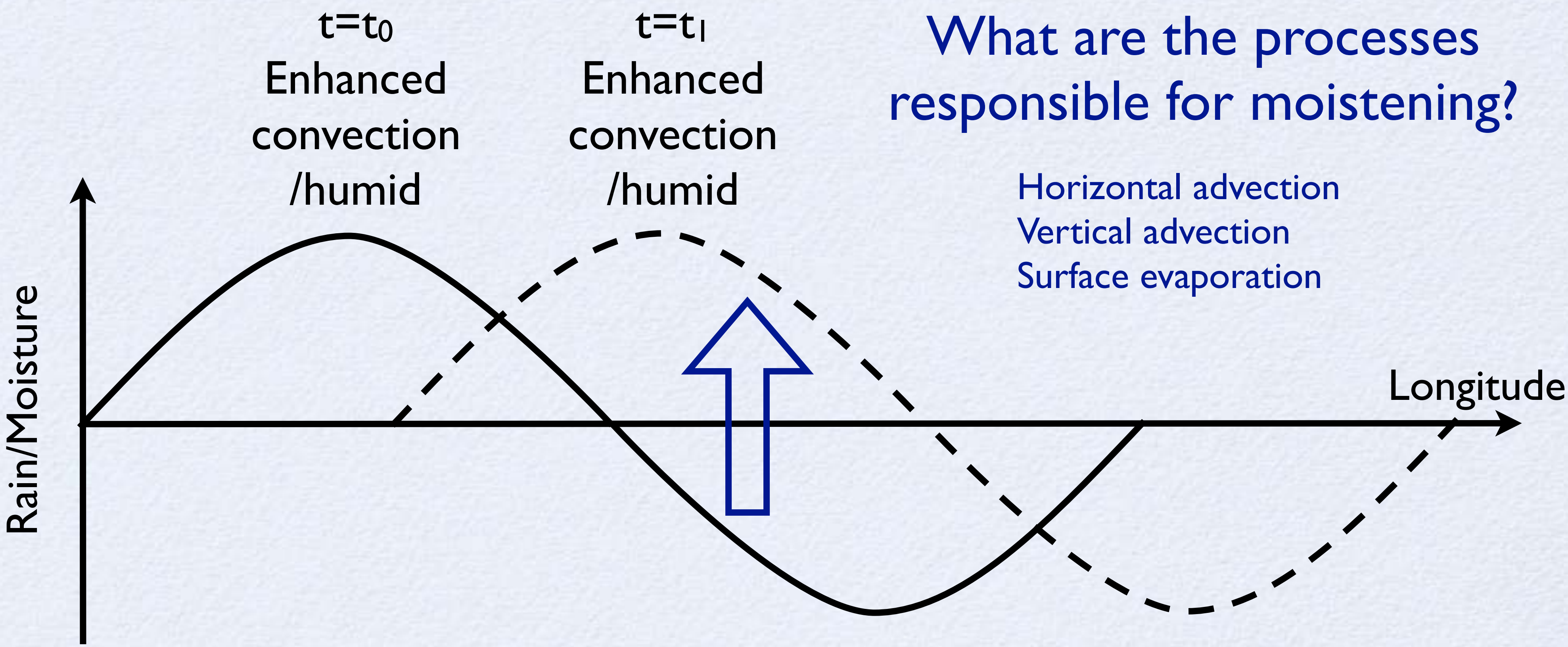


MJO is distinguished from other waves by the strong coupling between moisture and convection anomalies

Can we use this knowledge to better understand the mechanism of the MJO?

Yasunaga and Mapes (2012)

Propagation mechanism of the MJO



What are the processes responsible for moistening?

Horizontal advection
Vertical advection
Surface evaporation

Moisture budget

Column integrated moisture budget

$$\left\langle \frac{\partial q}{\partial t} \right\rangle = -\left\langle \vec{v}\nabla \cdot q \right\rangle - \left\langle w \frac{\partial q}{\partial z} \right\rangle - P + Evap$$

Tendency — Horizontal advection — Vertical advection — Precipitation — Surface evaporation

Vertical advection: **+**

Precipitation: **-**

Condensation
=> Precipitation

Vertical advection
of moisture

Convection:
upward motion

Moisture budget is not adequate to investigate moistening processes

Moist static energy budget

Moist static energy $m = C_p T + gz + Lq$

Dry static energy $s = C_p T + gz$

Column integrated dry static energy budget

$$\left\langle \frac{\partial s}{\partial t} \right\rangle = -\left\langle \vec{v}\nabla \cdot s \right\rangle - \left\langle w \frac{\partial s}{\partial z} \right\rangle + LP + Sens + \left\langle LW \right\rangle + \left\langle SW \right\rangle$$

$$+ \text{L x} \left\langle \frac{\partial q}{\partial t} \right\rangle = -\left\langle \vec{v}\nabla \cdot q \right\rangle - \left\langle w \frac{\partial q}{\partial z} \right\rangle - P + Evap$$

Column integrated moist static energy budget

$$\left\langle \frac{\partial m}{\partial t} \right\rangle = -\left\langle \vec{v}\nabla \cdot m \right\rangle - \left\langle w \frac{\partial m}{\partial z} \right\rangle + L \cdot Evap + Sens + \left\langle LW \right\rangle + \left\langle SW \right\rangle$$

Tendency | Horizontal advection | Vertical advection | Surface turbulent fluxes | Radiative fluxes

To go, or not to go: that is the question

1985

15°S-15°N OLR anomaly

- Shaded: 20-100 day filtered
- Contour: MJO-filtered

1986

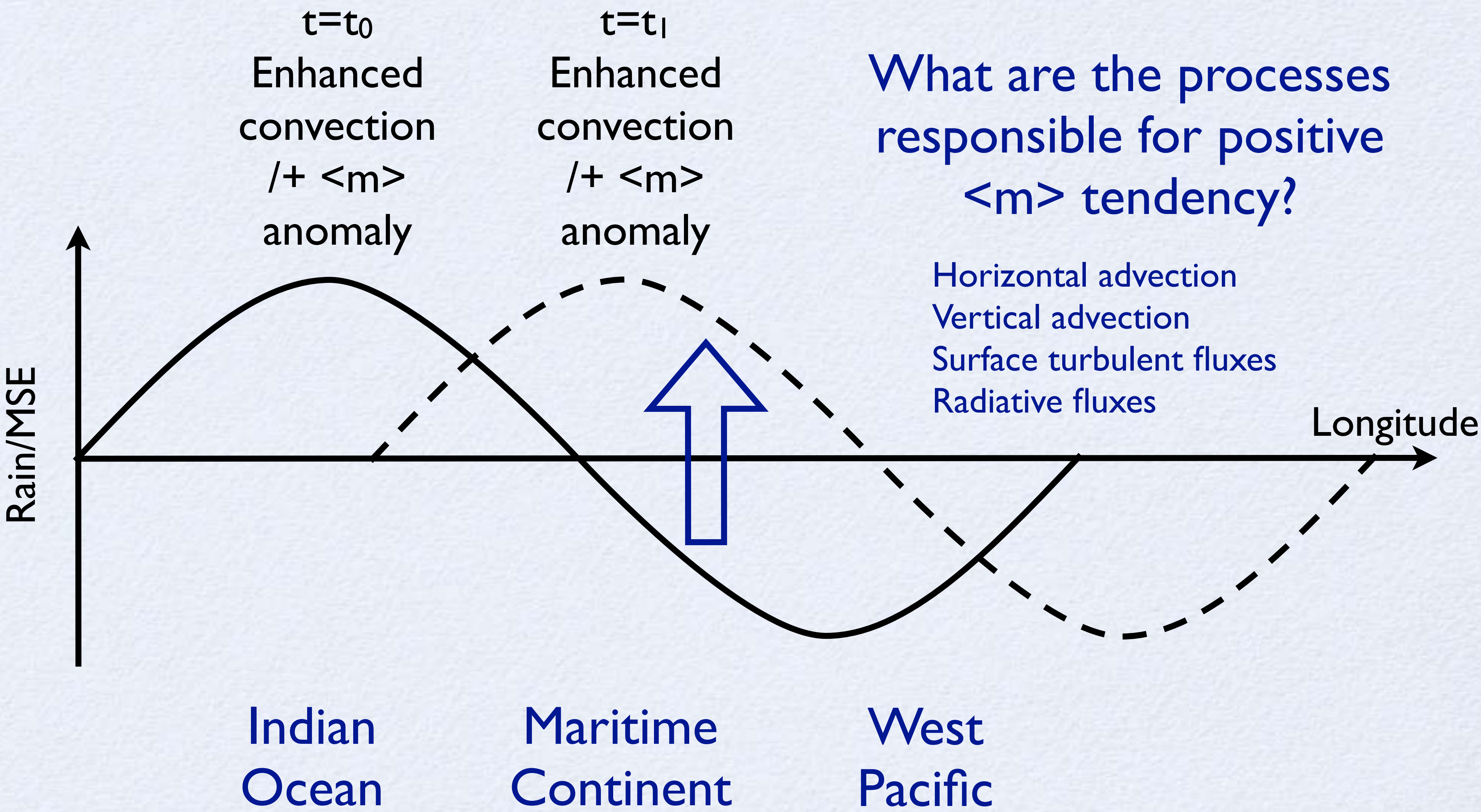
What is the role of the WP dry on the propagation of the IO convection through the MC?

What is its implication to MJO dynamics?

W m^{-2}

Kim et al. (2013, JC, in review)

Propagation mechanism of the MJO



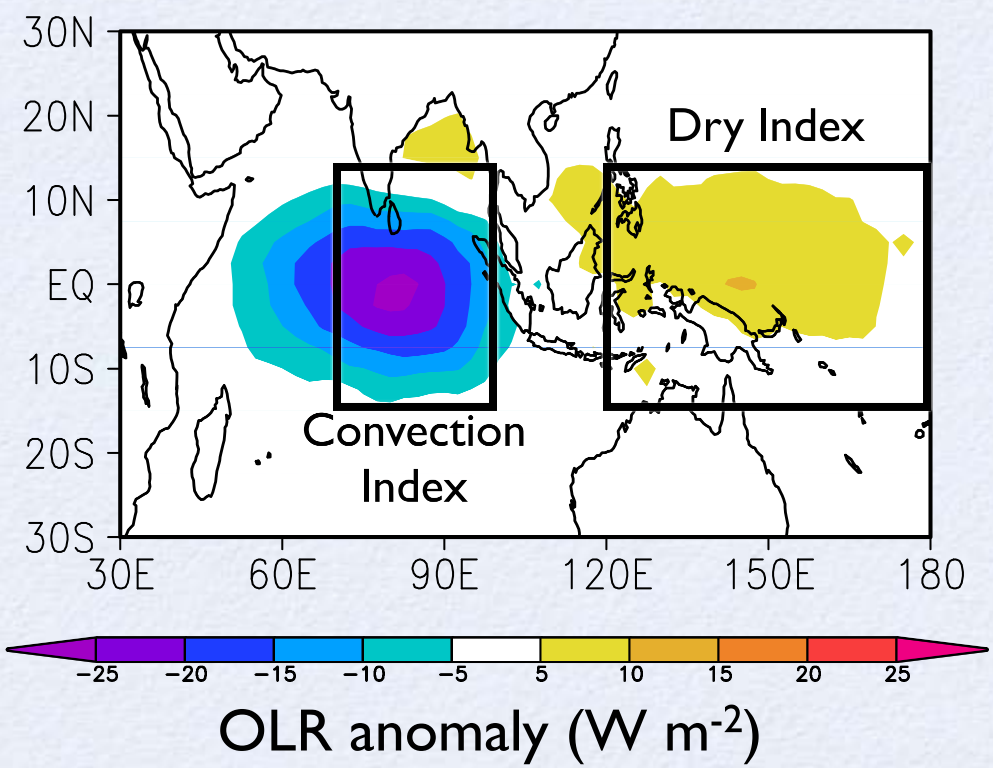
What are the processes responsible for positive <m> tendency?

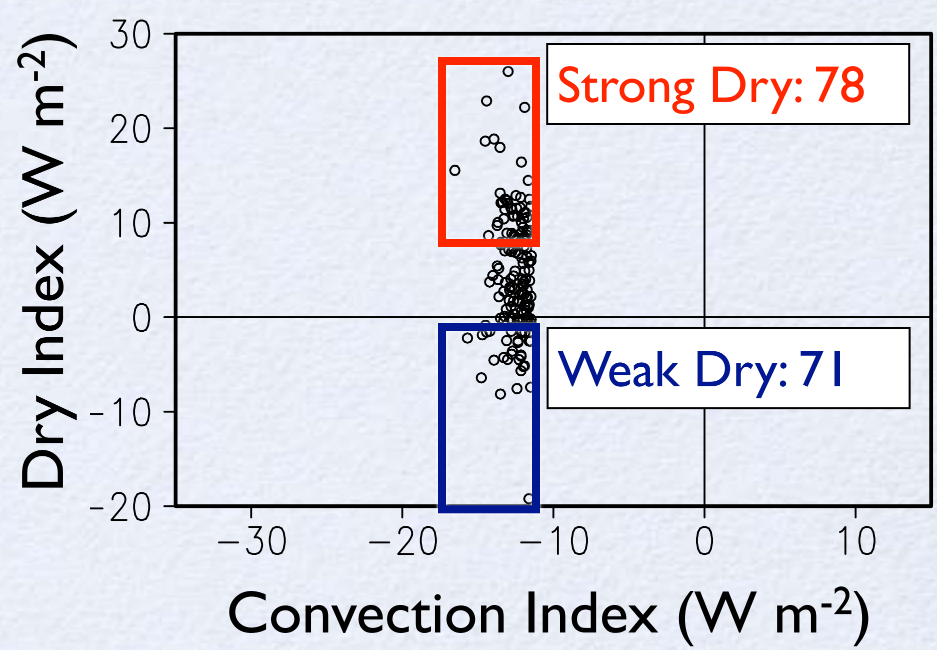
- Horizontal advection
- Vertical advection
- Surface turbulent fluxes
- Radiative fluxes

Onset detection

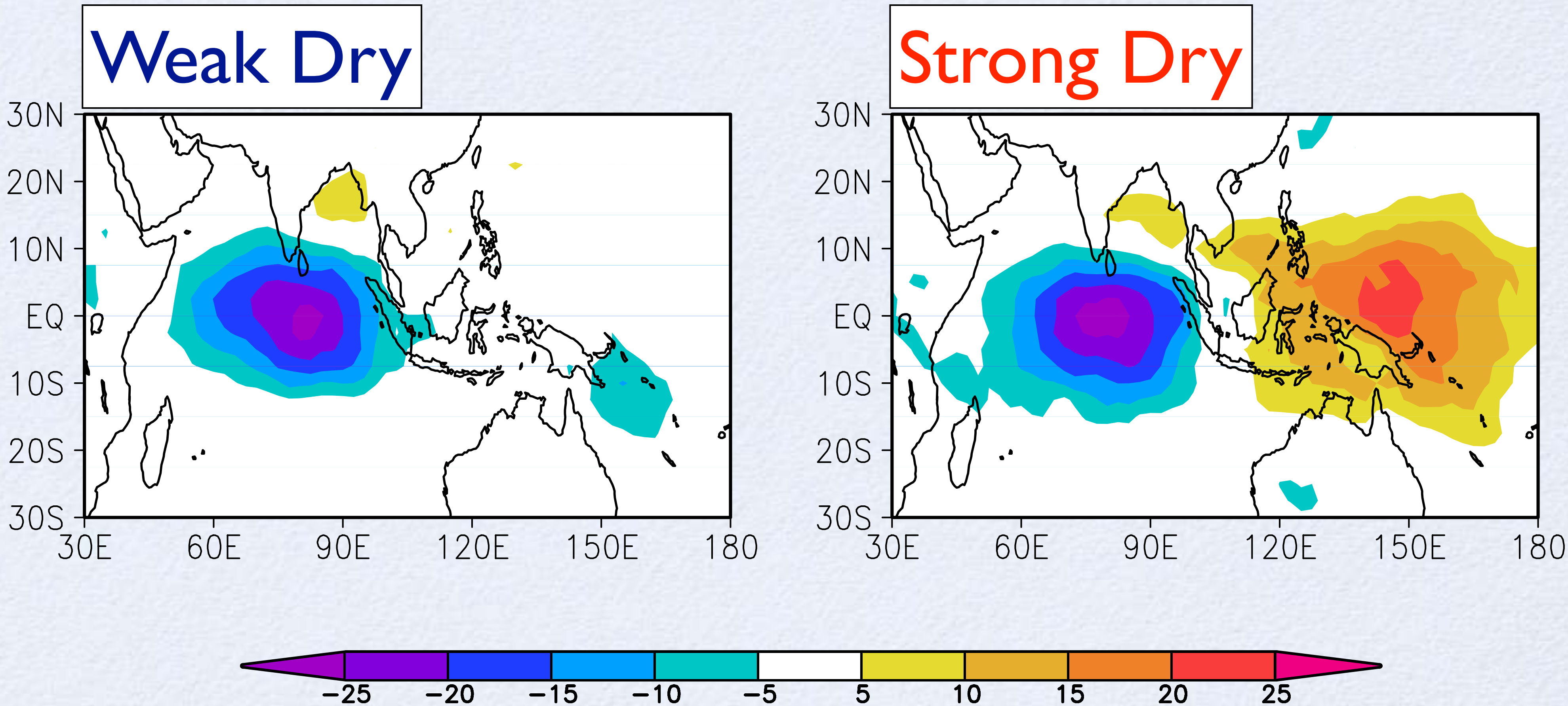
- Onset of convection over the Indian Ocean
  : 20-100 day bandpass filtered OLR anomaly (70-100°E, 15°S-15°N) becomes lower than its negative STD

Onset days (n=189)





Onset days



OLR anomaly (W m^{-2})

Propagation characteristics

10°S-10°N averaged OLR anomaly

Weak Dry

Strong Dry

(W m^{-2})

Propagation of <m>

<m> [6×10^{2} kJ m^{-2}]

d<m>/dt [W m^{-2}]

Strong Dry

Moistening processes

W m^{-2}

$\times 10^6$ J m^{-2}

<MSE> tendency

Day -5

Day +5

Day -5~+5

<MSE> anomaly

Column integrated dry static energy budget (20-100 day filtered)

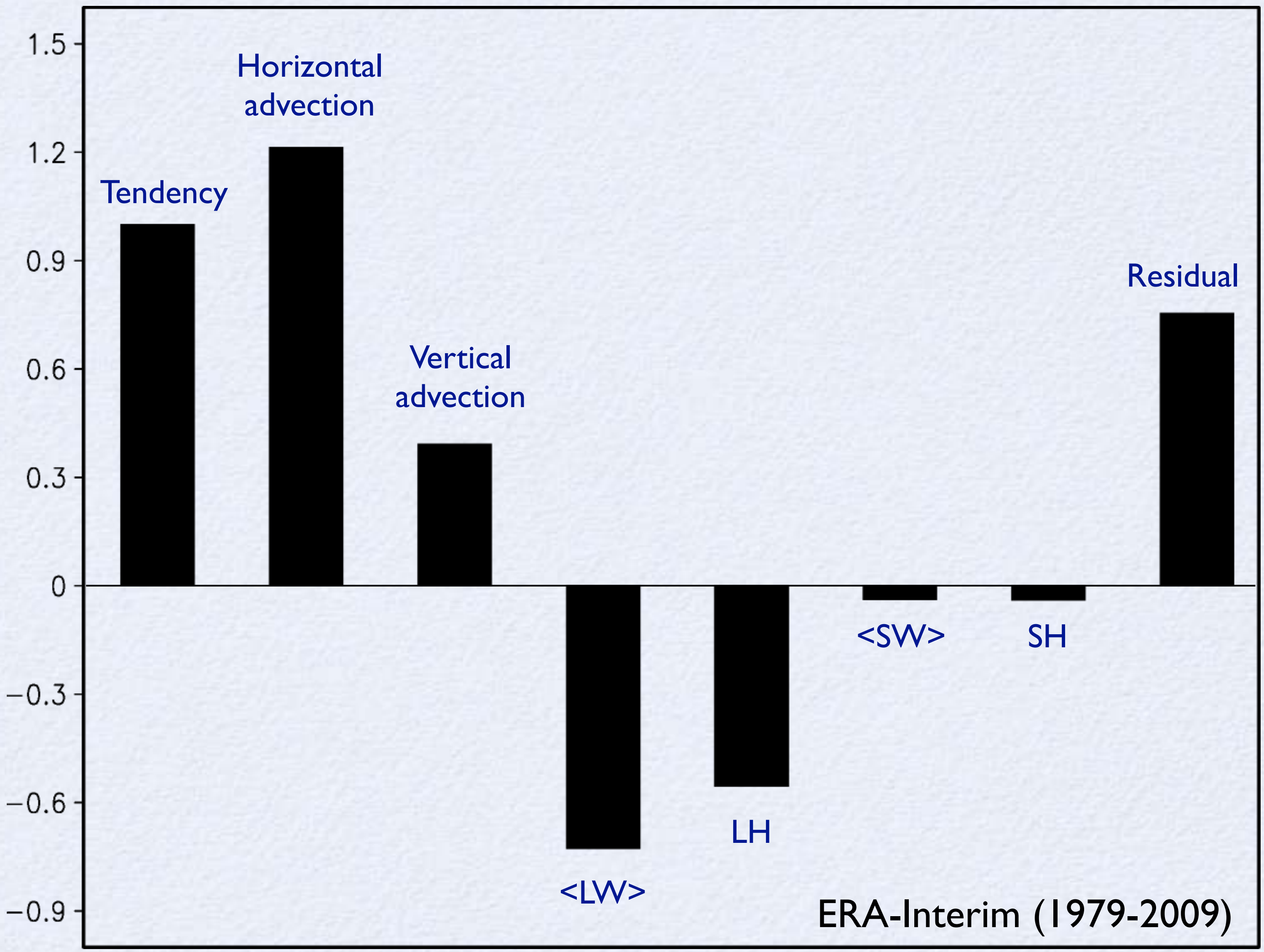
$$\left\langle \frac{\partial m}{\partial t} \right\rangle = -\left\langle \vec{v}\nabla \cdot m \right\rangle - \left\langle w\frac{\partial m}{\partial z} \right\rangle + L \cdot Evap + Sens + \left\langle LW \right\rangle + \left\langle SW \right\rangle$$

Tendency | Horizontal advection | Vertical advection | Surface turbulent fluxes | Radiative fluxes

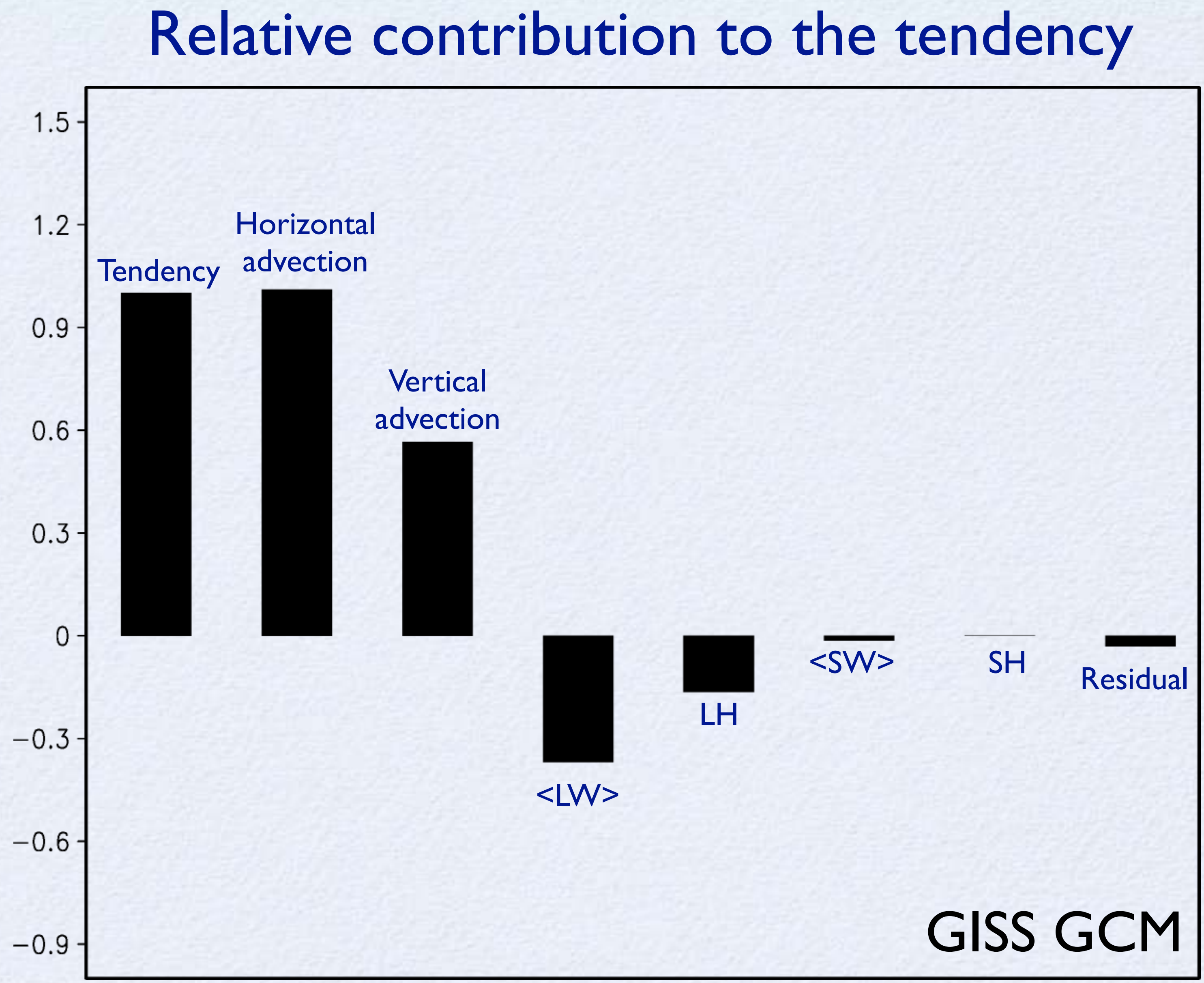
Which processes are responsible for the tendency?

Moistening processes

Relative contribution to the tendency

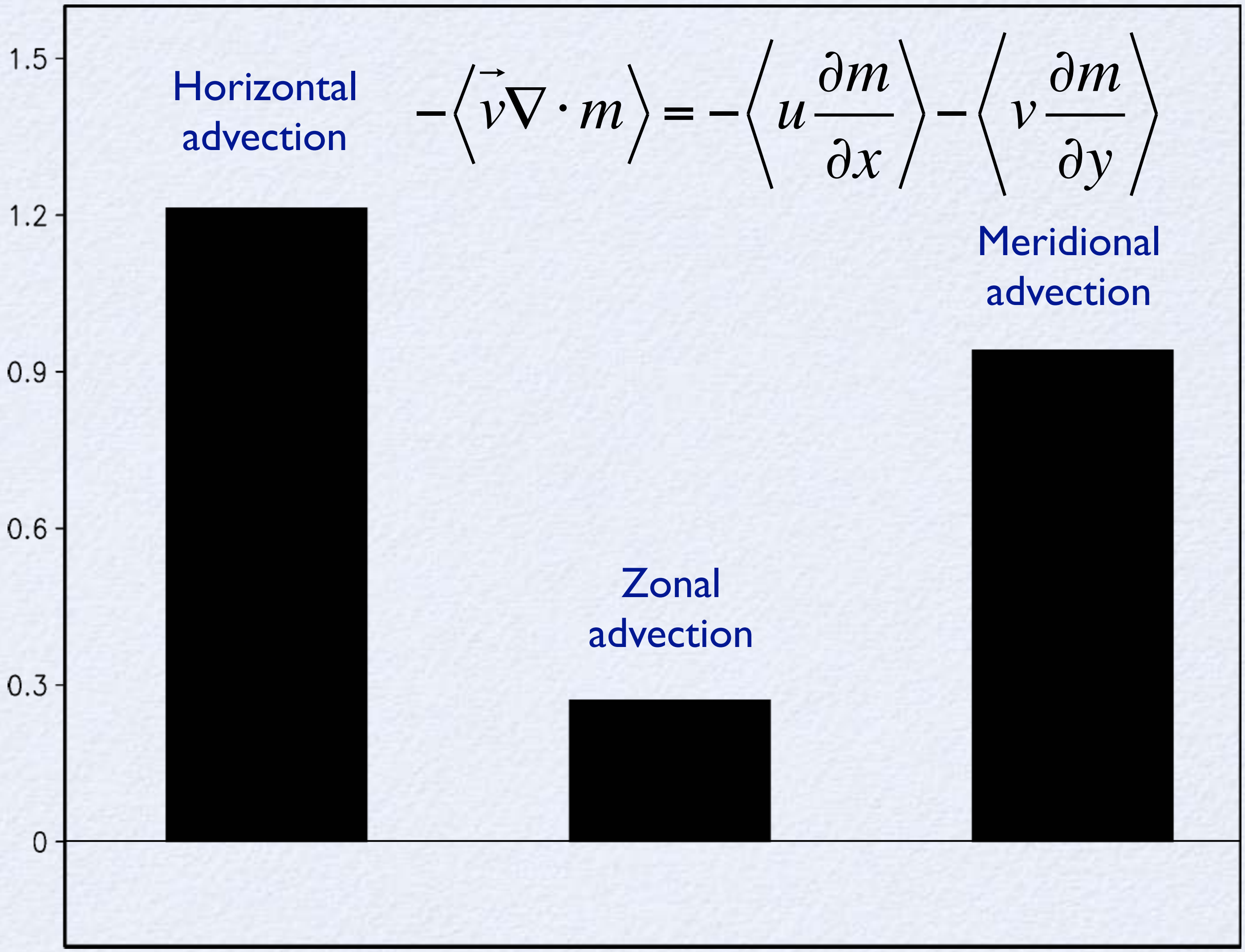


Moistening processes



Decomposition

Relative contribution to the tendency



$$-\left\langle \vec{v}\nabla \cdot m \right\rangle = -\left\langle u\frac{\partial m}{\partial x} \right\rangle - \left\langle v\frac{\partial m}{\partial y} \right\rangle$$

Decomposition

$$-\left\langle v\frac{\partial m}{\partial y}\right\rangle'_{FT}$$

free-tropospheric meridional advection

mean (seasonal cycle) — high-frequency (<20 day)

$$v = \overline{v} + v' + v'' + \varepsilon_v$$

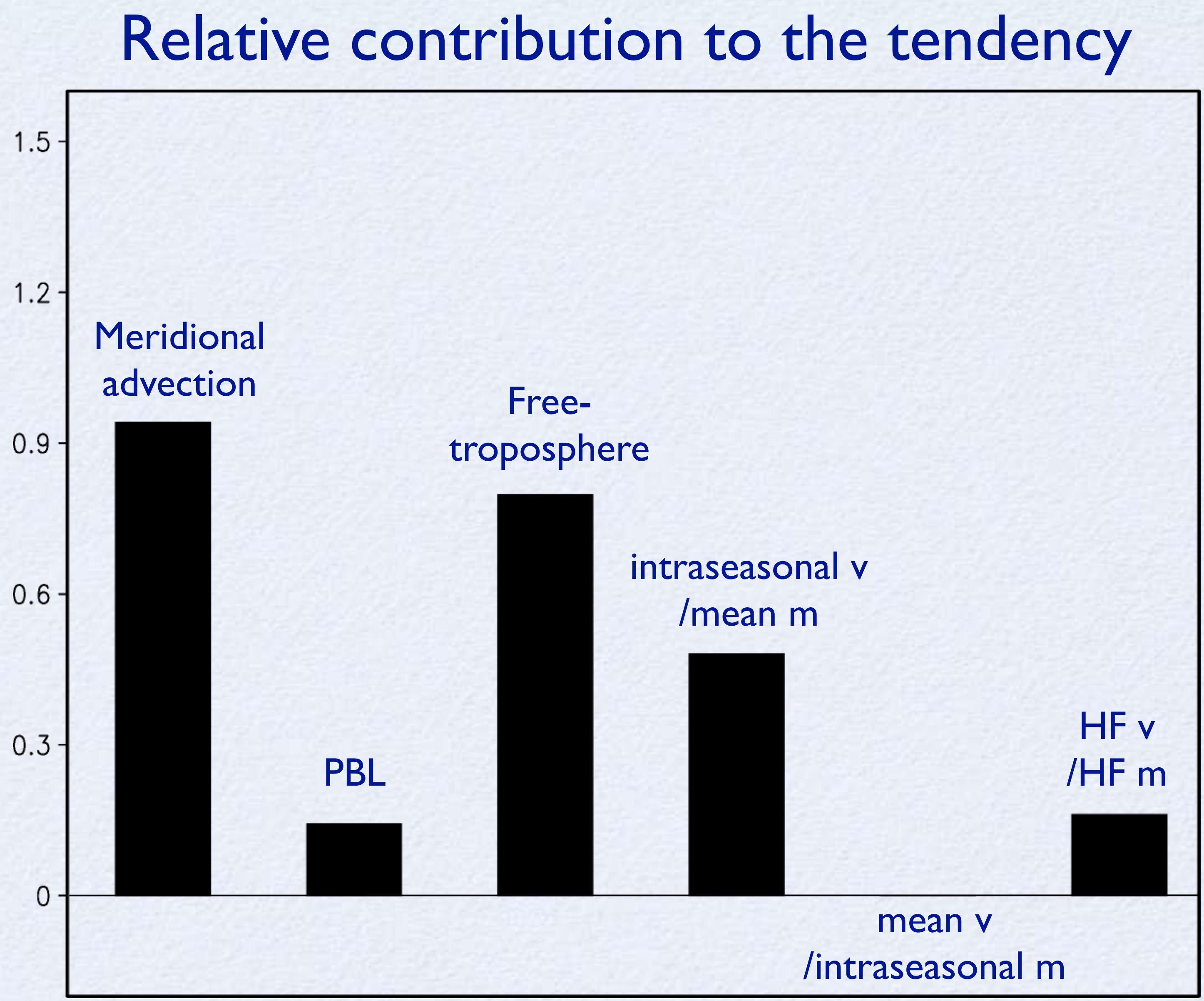
total — intraseasonal (20-100 day) — residual

$$m = \overline{m} + m' + m'' + \varepsilon_m$$

intraseasonal v /mean m — mean v /intraseasonal m — high-frequency v /high-frequency m

$$-\left\langle v\frac{\partial m}{\partial y}\right\rangle'_{FT} \approx -\left\langle v'\frac{\partial \overline{m}}{\partial y}\right\rangle'_{FT} -\left\langle \overline{v}\frac{\partial m'}{\partial y}\right\rangle'_{FT} -\left\langle v''\frac{\partial m''}{\partial y}\right\rangle'_{FT}$$

Moistening processes



Major moistening process

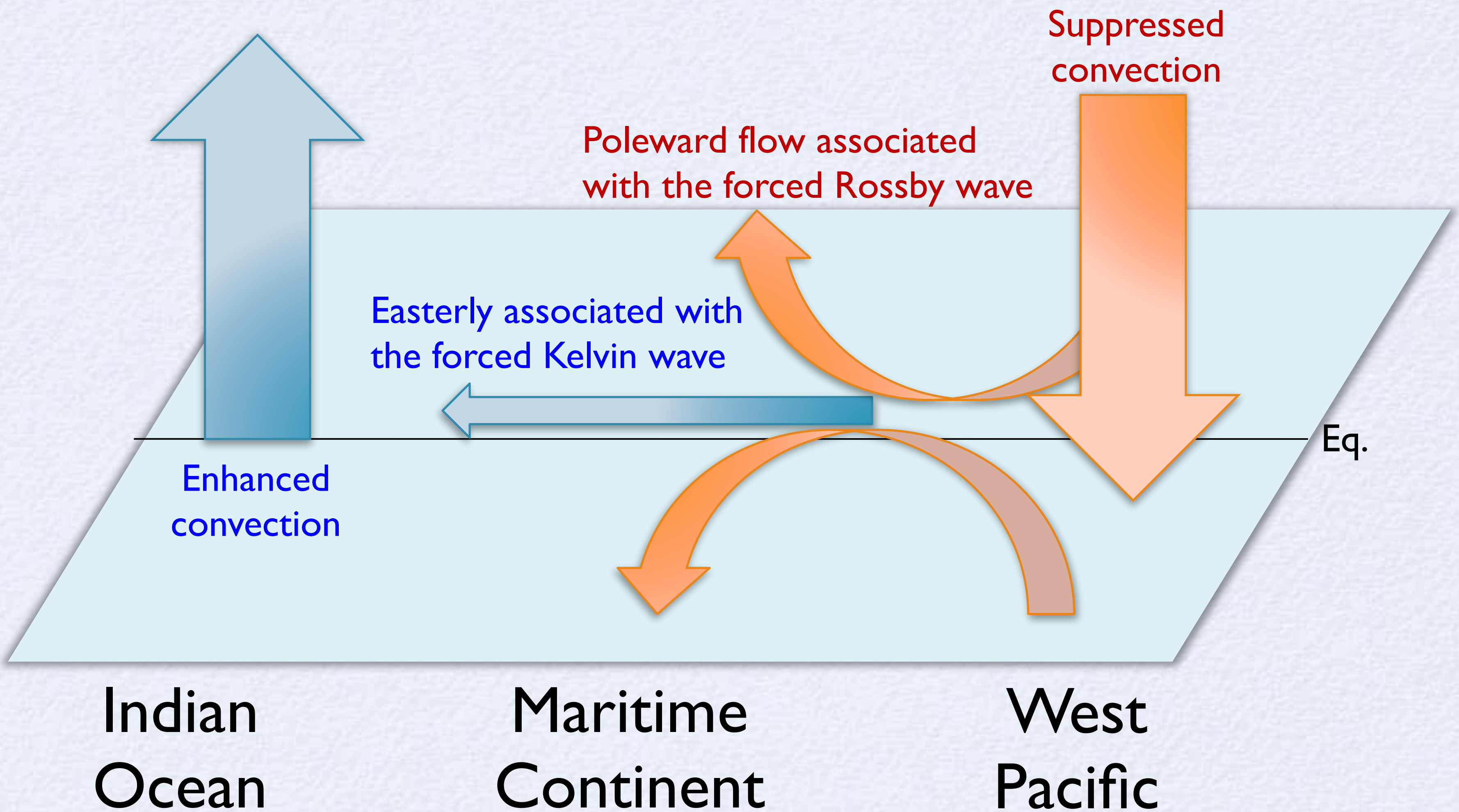
Day -5 ~ +5 average (750 hPa)

Shaded: intraseasonal v
Contour: mean m

$$-\left\langle v' \frac{\partial \overline{m}}{\partial y} \right\rangle'_{FT}$$

intraseasonal v
/mean m

Schematic view



Summary

- Basin-wide convective anomalies over the Indian Ocean (IO) associated with the Madden-Julian oscillation (MJO) sometimes propagate eastward and reach the west Pacific (WP), but sometimes do not.
- The IO convection anomaly preferentially makes propagation to the east and reaches the WP when the dry anomaly is stronger.
- Analysis of the column integrated moist static energy (MSE) budget shows that horizontal advection moistens the atmosphere to the east of the positive MSE anomaly associated with the active convection. A residual term, of smaller but comparable magnitude to the horizontal advection, also moistens the column to the east of the positive MSE anomaly.
- A dominant contribution is from free-tropospheric meridional advection by the instraseasonal time-scale wind anomalies. The positive meridional advection in between the convective and dry anomalies is induced by the anomalous poleward flow, which we interpret as part of the Rossby wave response to the dry anomaly, and the climatological MSE pattern, which peaks at the equator.

Kim et al. (2013, JC, in revision)