A Unified Moisture Mode Theory for the MJO and the BSISO

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Madden Julian Oscillation vs
Boreal Summer Intraseasonal Oscillation

MJO

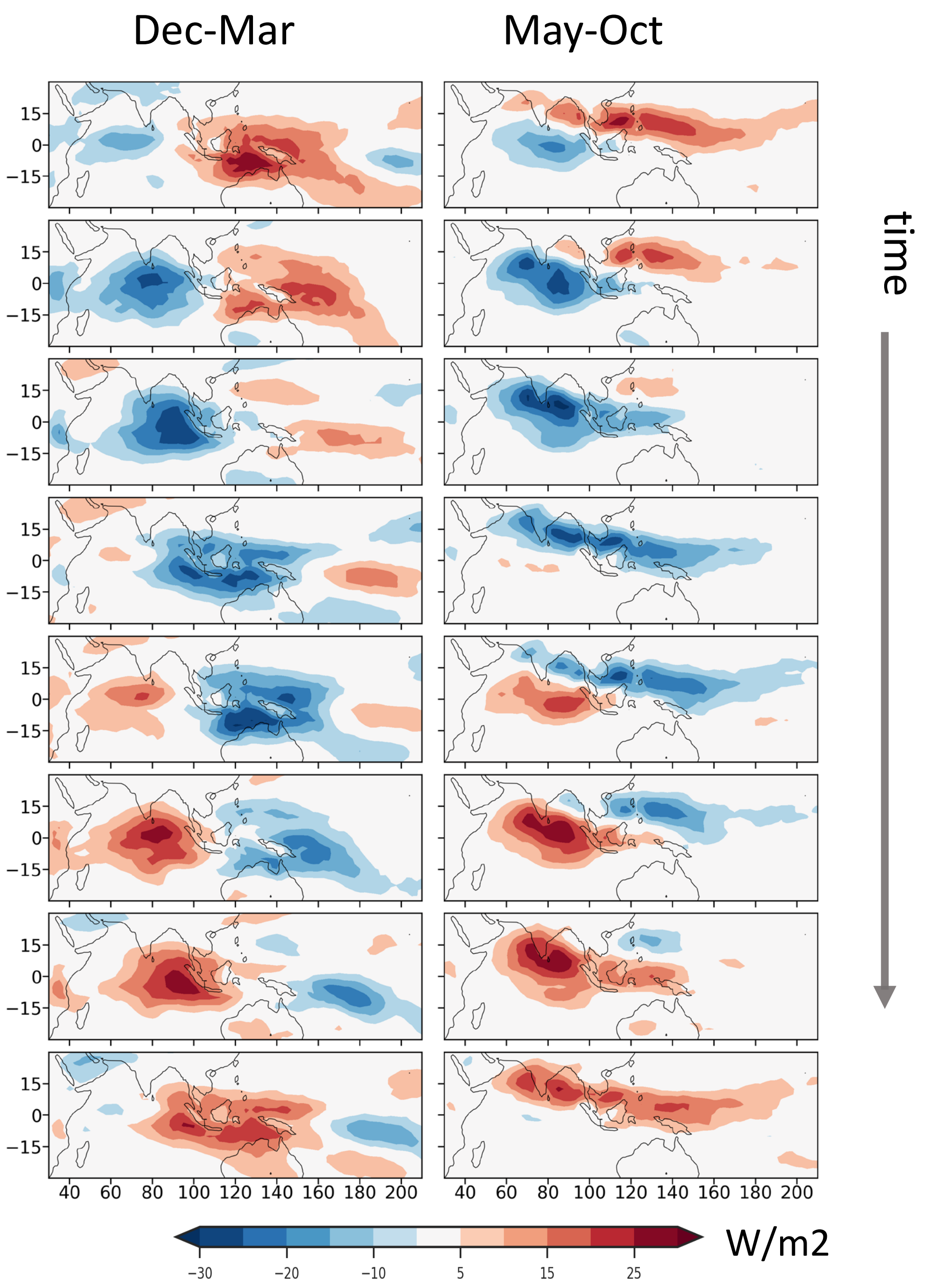
- northern winter
- eastward propagation
- Mostly the equator, biased toward SH

BSISO

- northern summer
- northwest-Southeast tilted rain bands
- significant poleward propagation + eastward propagation

Similarities:

- Grow in the Indian Ocean
- Intraseasonal time scales
- Eastward propagation



OLR Composites (Multivariate ISO Index, Wang et al. 2022, JGR; same with OMI, Kiladis et al 2014)

Moist linear shallow water equation set

$$\frac{\partial u}{\partial t} - yv = -\frac{\partial \Phi}{\partial x} - \alpha_u u$$

Rayleigh friction

$$\frac{\partial v}{\partial t} + yu = -\frac{\partial \Phi}{\partial y}$$

cloud-radiative feedback

Newtonian damping

$$\frac{\partial \Phi}{\partial t} + \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right) = -(\alpha + \varepsilon)q - \alpha_\Phi \Phi$$

precipitation/latent heating

$$\frac{\partial q}{\partial t} - (\Gamma - 1)\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right) = \Lambda u - \alpha q - u\frac{\partial Q_o}{\partial x} - v\frac{\partial Q_o}{\partial y}$$

meridional moisture advection

Gross moist stability

WISHE

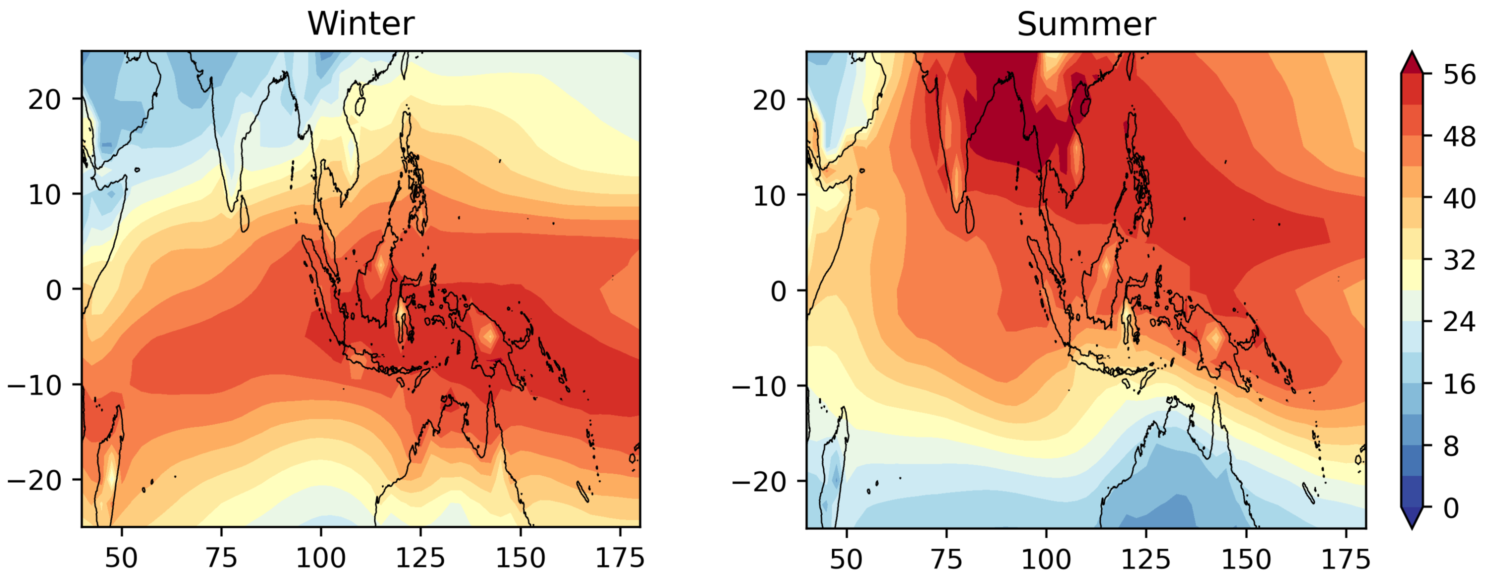
zonal moisture advection

- First baroclinic mode vertical structure
- Simple quasi-equilibrium convection parameterization: P is proportional to moisture
- 8 parameters for physical processes, 5/8 in the moisture equation:
    - zonal and meridional advection, WISHE, precipitation
- Ahmed (2021) studied the same system

Key model parameters

We estimate key parameters considering basic state in the Indian Ocean: low-level westerlies and moisture increasing with longitude

- meridional moisture gradient in the Indian Ocean sector
  - NH winter: moisture decrease poleward
  - NH summer: moisture gradient small, or increases poleward



Column moisture

Normal mode solution

- Assume wave solutions: v(x,y,t) ~ *V*(y) exp[i(kx-ωt)],
- A single equation for *V* (as long as $v \neq 0$):

moist *v* equation

$$a_0 \frac{d^2V}{dy^2} + a_1 y \frac{dV}{dy} + (d_0 + d_2 y^2)V = 0$$

dry *v* equation

$$\frac{\partial^2 \hat{v}}{\partial y^2} + \left[\left(\frac{\nu^2}{gh_e} - k^2 - \frac{k}{\nu}\beta\right) - \frac{\beta^2 y^2}{gh_e}\right]\hat{v} = 0$$

(Matsuno 1966)

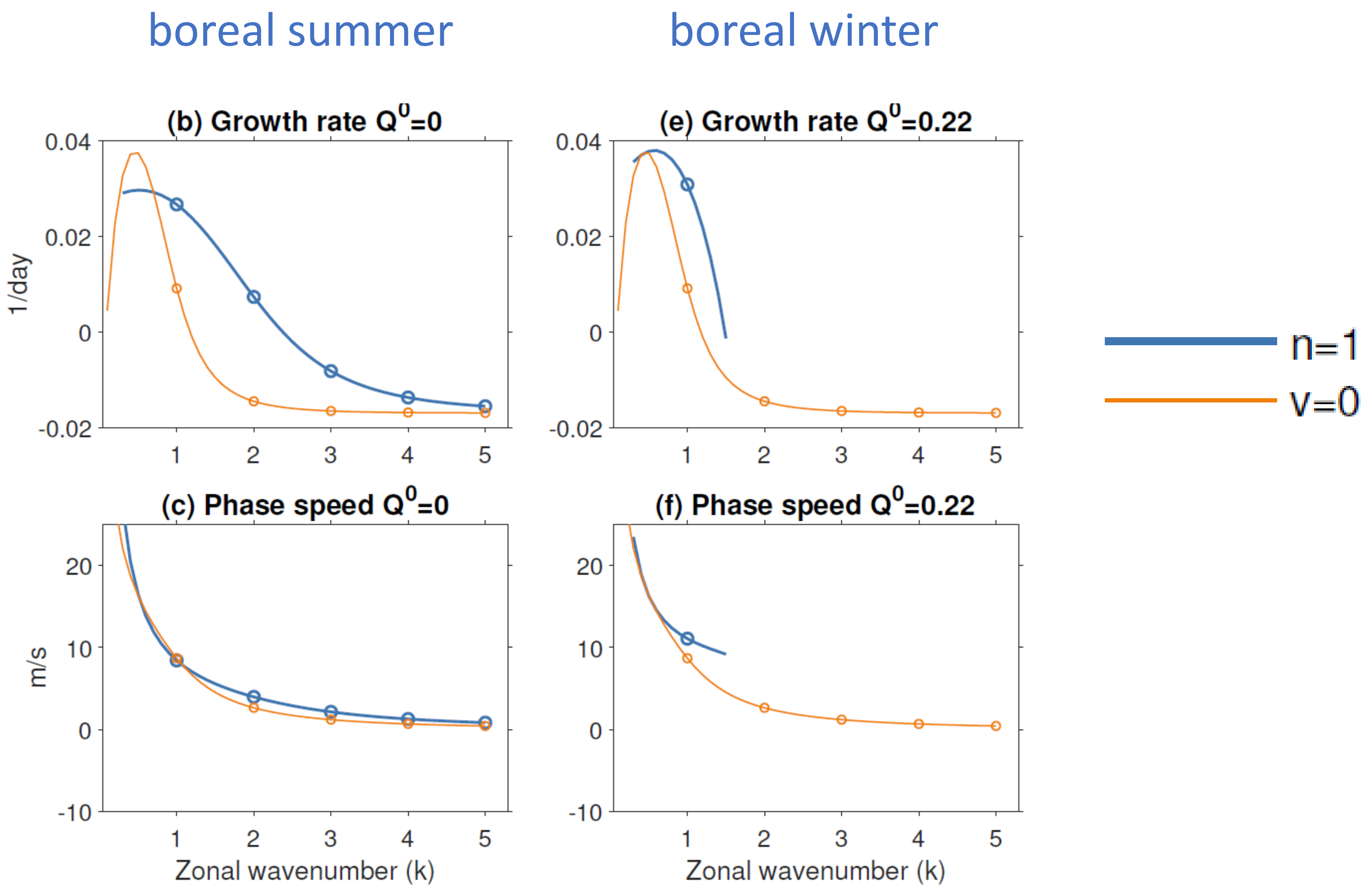
- The coefficients, a_0, a_1 , d_0 d_2 are functions of wave parameters (ω, k) and model parameters

cf. Fuchs and Raymond (2005, 2017); Ahmed (2021)

- Two kinds of solutions (as in the dry problem)

$v(x,y,t) \sim H_n(y/\eta_n) \exp[\xi_n y^2] \exp[i(kx-\omega t)]$ or $v = 0$

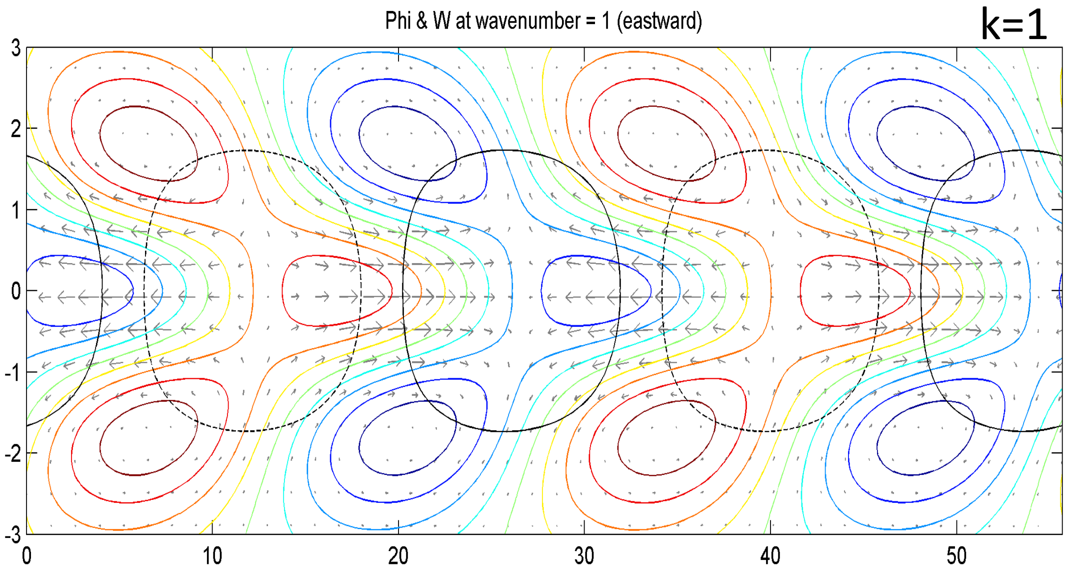
Linear instability: growth rate and phase speed



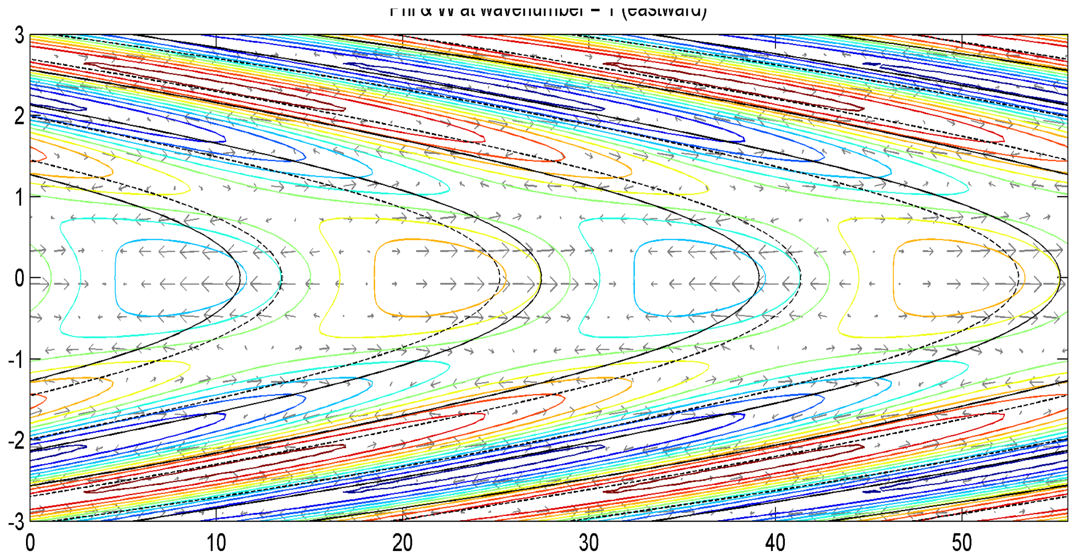
Maximum growth rates for large horizontal scale eastward-propagating modes.

Change in structure with moisture gradient

Idealized MJO
$Q_y = 0.22$
(like northern winter)



Idealized BSISO
$Q_y = 0$
(like northern summer)



Color: geopotential Black: vertical velocity horizontal wind vectors

Change in structure with moisture gradient

Idealized MJO
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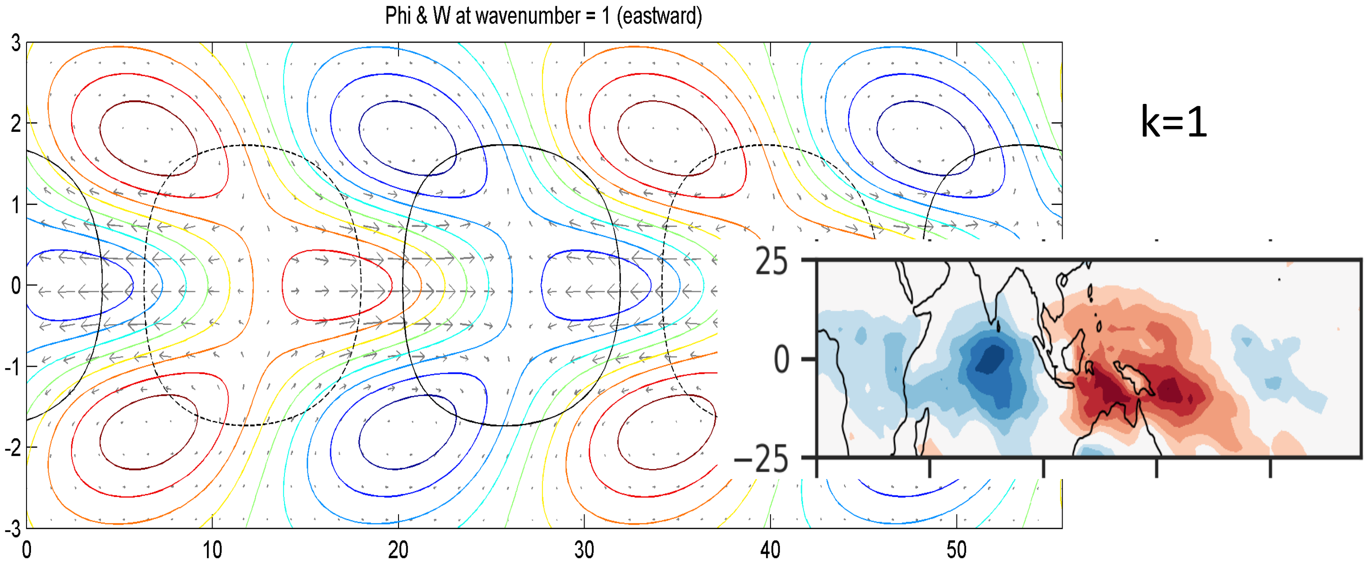
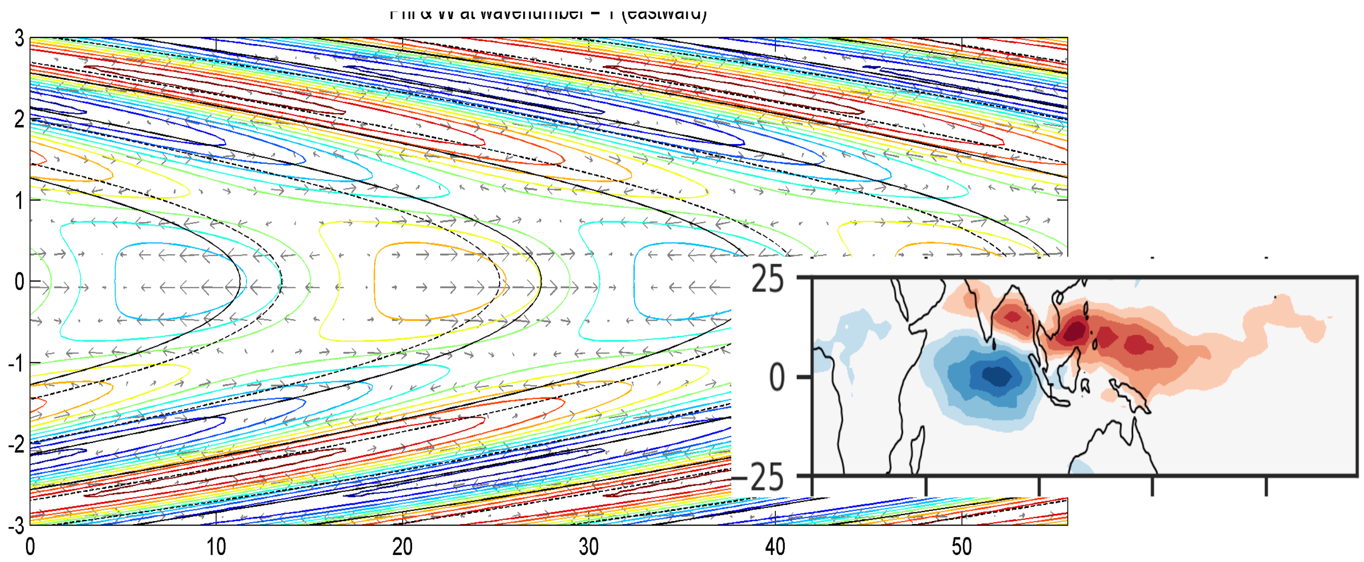


k=1

Idealized BSISO
$Q_y = 0$
(like northern summer)



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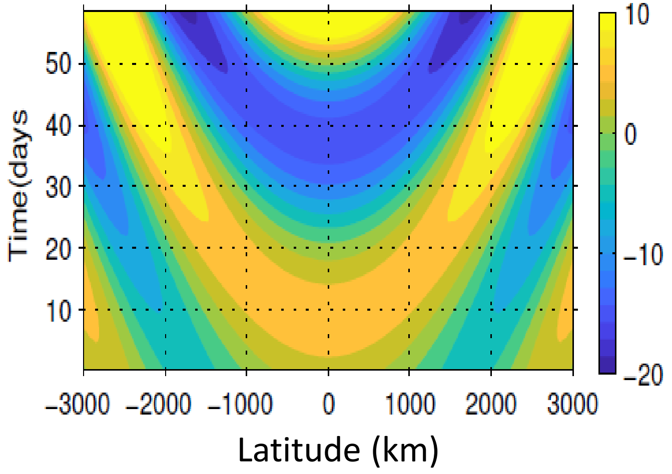
Poleward propagation

Idealized BSISO shows poleward propagation



Observed BSISO

(Waliser et al. 2009)

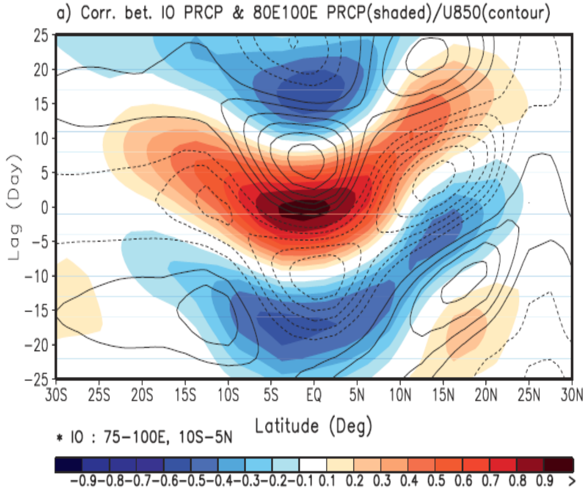


FIG. 6. May–October lag–latitude diagram of 80°–100°E-averaged intraseasonal precipitation anomalies (colors) and intraseasonal 850-hPa zonal wind anomalies (contours) correlated against intraseasonal precipitation at the Indian Ocean reference point at the equator. Contours and colors are plotted every 0.1. The zero line is not shown.

Idealized BSISO vs observed BSISO

- Poleward propagation
- Zonal advection and surface fluxes are key to propagation as in observation (Jiang et al 2018)
- Moisture gradient: increases poleward
- Planetary scale

Difference: idealized BSISO is symmetric; observed BSISO is not

Conclusions

- The theory unifies the MJO and BSISO as different manifestations of the "moisture mode" over the Indian Ocean, where both modes grow
- The different structures are a result of different seasonal states of climatological moisture field
- Horizontal advection of moisture – both zonal and meridional – is essential

Wang, S., A.H. Sobel. 2022: A unified moisture mode theory for the Madden Julian Oscillation and the Boreal Summer Intraseasonal Oscillation. J. Climate. 35(4), 1267-1291. https://doi.org/10.1175/JCLI-D-21-0361.1