Realistic MJO Dynamics And Initiation In An Aquaplanet Coarse Resolution GCM

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OUTLINE

- Motivation
- The multicloud model parametrization
- Model set up
- Role of circumnavigating dry Kelvin waves in MJO initiation (in the model)
- Characteristic dynamical features of simulated MJO
- Sensitivity to SST slow variability (mimicking ENSO, Monsoon, etc.): Northward propagation and warm pool confinement
- Conclusion

Motivation

- Despite continued effort and enormous progress in climate modelling capabilities, MJO remains major problem: poorly simulated by coarse resolution GCMs
- Search for convective parameterization that better mimic organized convection and new strategies for MJO simulations is major focus for improving climate models
- Widely recognized that large scale moisture/convective coupling plays key role
- Multicloud model (K. and Majda 2006, 2008,...) relies on the building block trimodal paradigm of organized tropical convection (Johnson et al. 1999)
- In Multicloud Model successfully represents CC waves as a natural synoptic scale instability

Motivation (cntd)

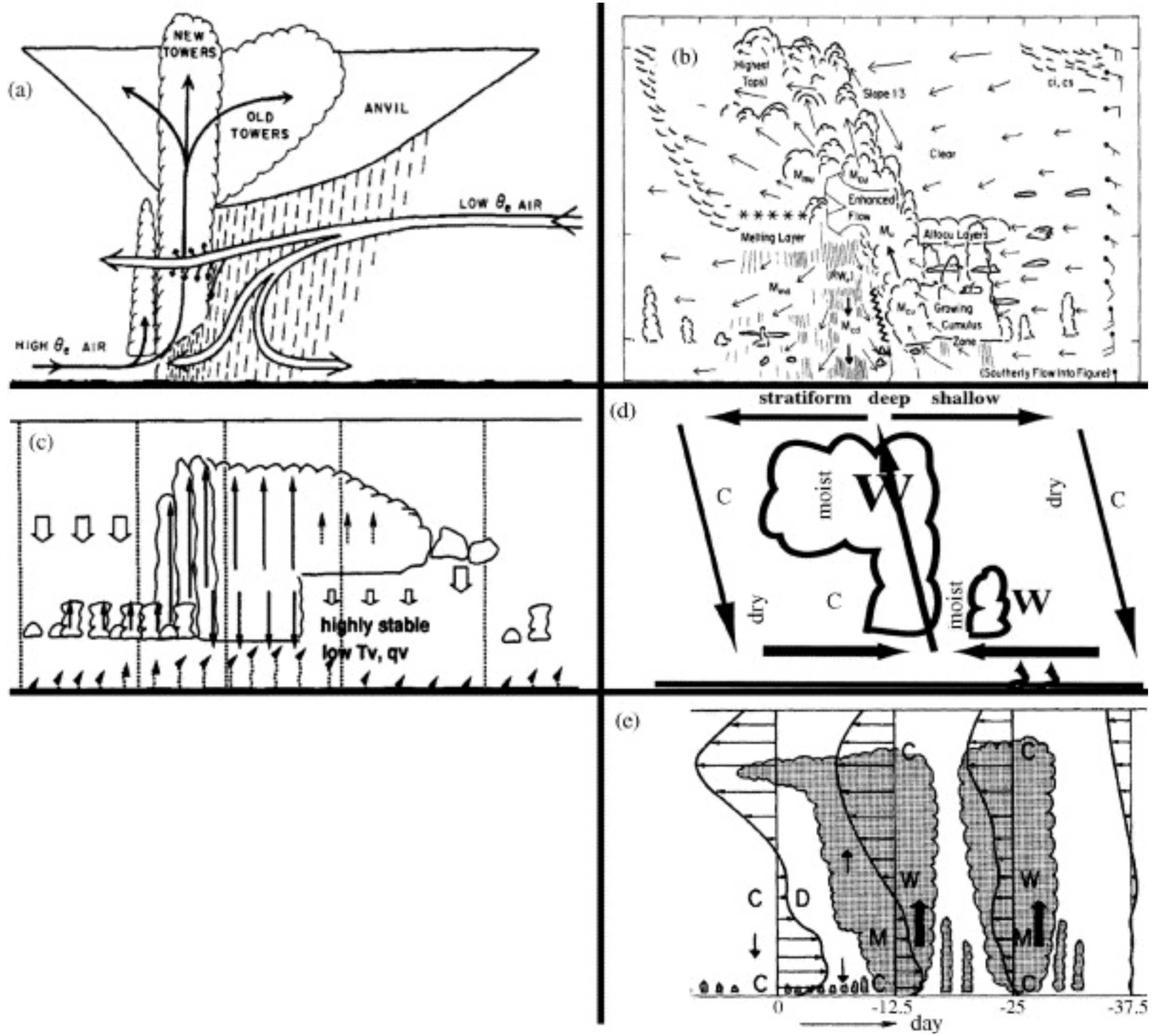
- Multicloud Model used as a parameterization in aquaplanet GCM (new NCAR spectral elements HOMME model as a dyn. core) proved successful in simulating MJO and convectively coupled waves
- Very realistic MJO features (propagation speed 5 m/s, vertical tilt, quadruple vortex structure, etc.)
- Multicloud-HOMME model is used as a virtual lab to understand MJO dynamics and climate variability
- HERE: Introduce warm pool forcing to learn more about MJO dynamics and initiation
- Influence of slow variation in SST-- El Nino/La Nina, Seasonal migration of ITCZ, warm pool width, etc.

Multiscale self-similar convective systems often embedded in each other like Russian dolls.

Squall lines

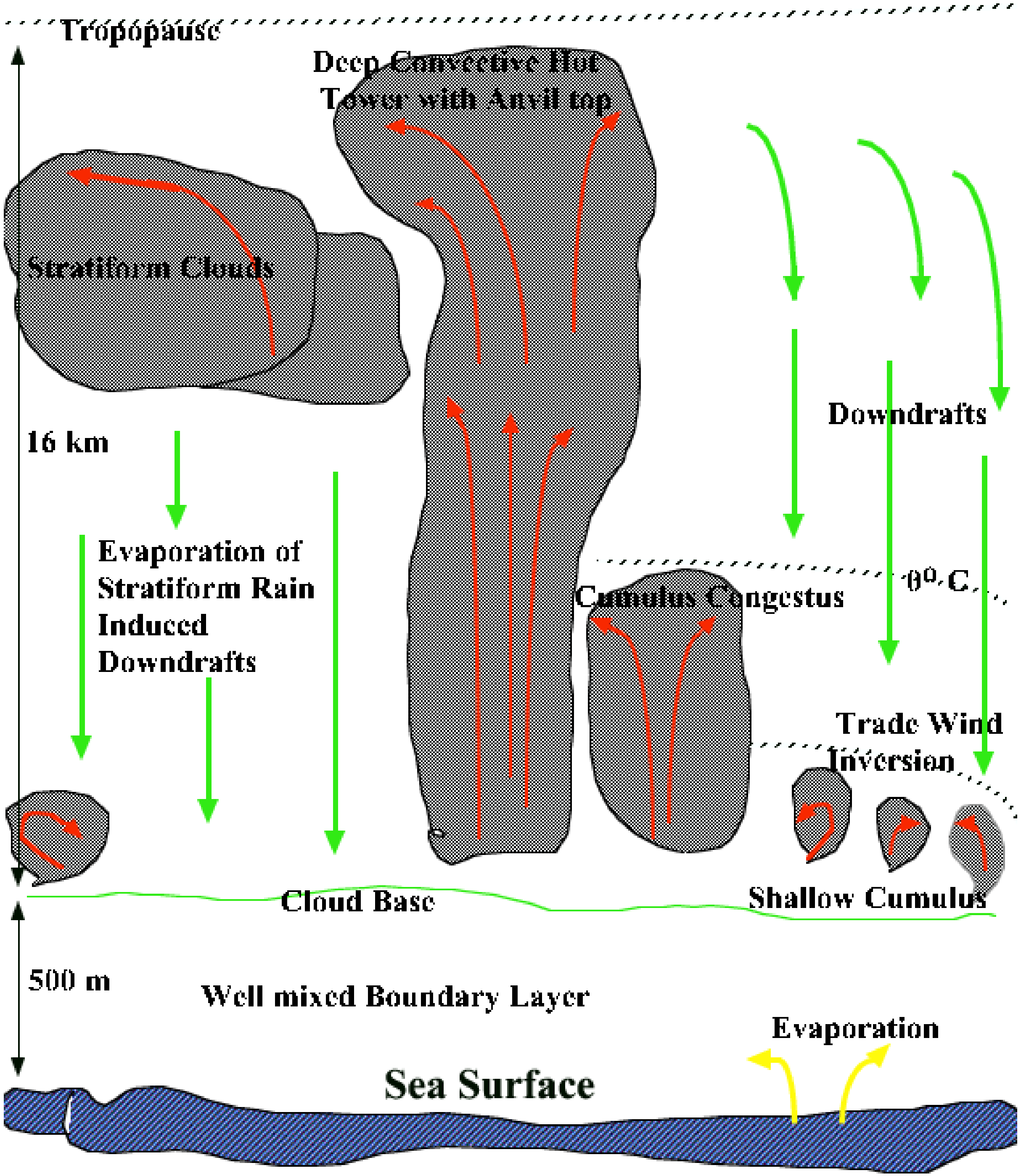
C.C.W.

M.J.O.



Compiled by Mapes et al. DAO. 2006

THE MULTICLOUD BUILDING BLOCK

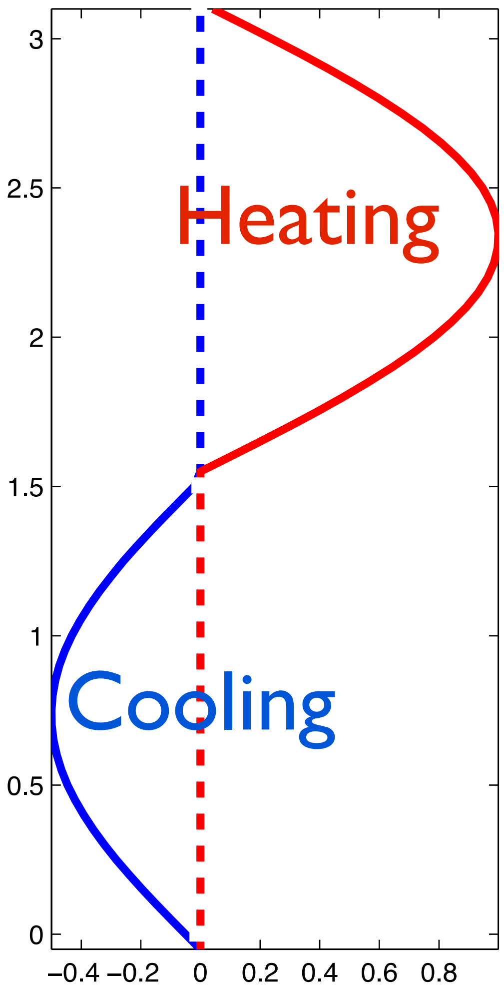


The multicloud model dynamics

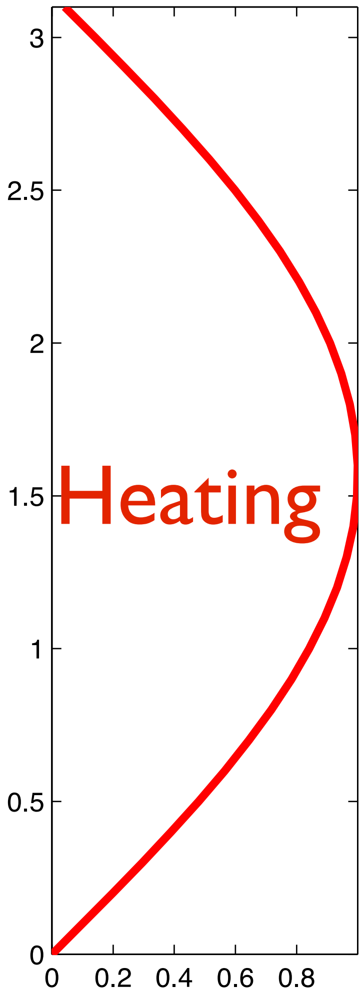
- Based on three cloud types, congestus, deep, and stratiform
- Moisture Switch: Dry mid-troposphere favours congestus clouds while moist lower troposphere favours deep convection
- Stratiform clouds lag deep convection
- Associated heating profiles force the first two baroclinic modes of vertical structure
- MC Model is coupled to the boundary layer and to a vertically averaged moisture equation through downdrafts and precipitation

The multicloud model

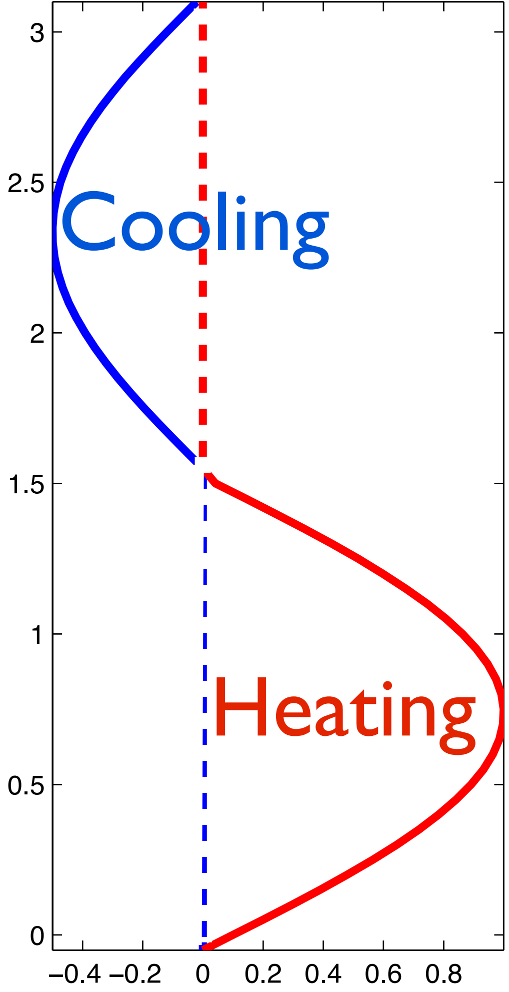
Stratiform



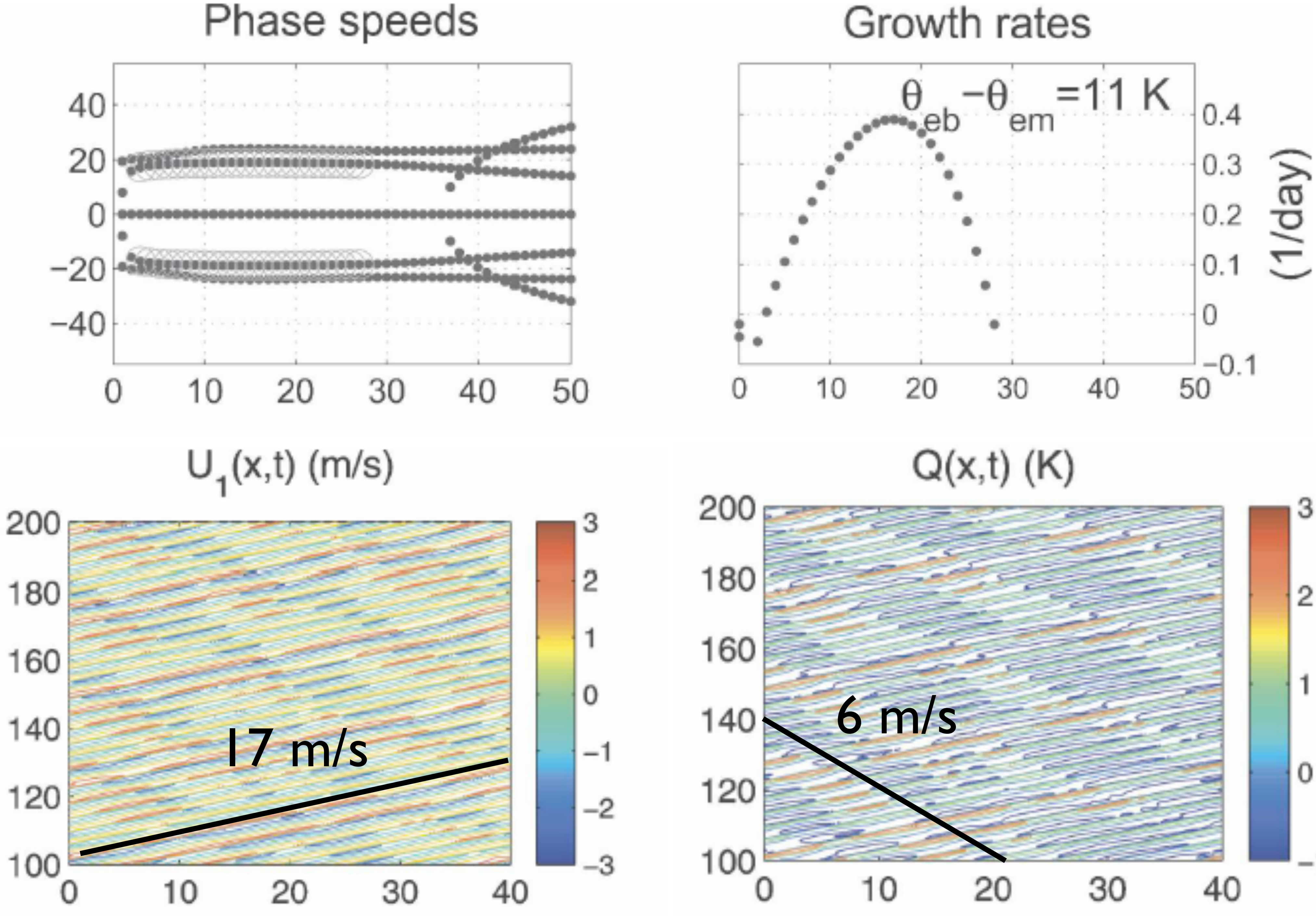
Deep



Congestus



Waves in MCM: Flow over the equator



Phase speeds

Growth rates

$U_1(x,t)$ (m/s)

$Q(x,t)$ (K)

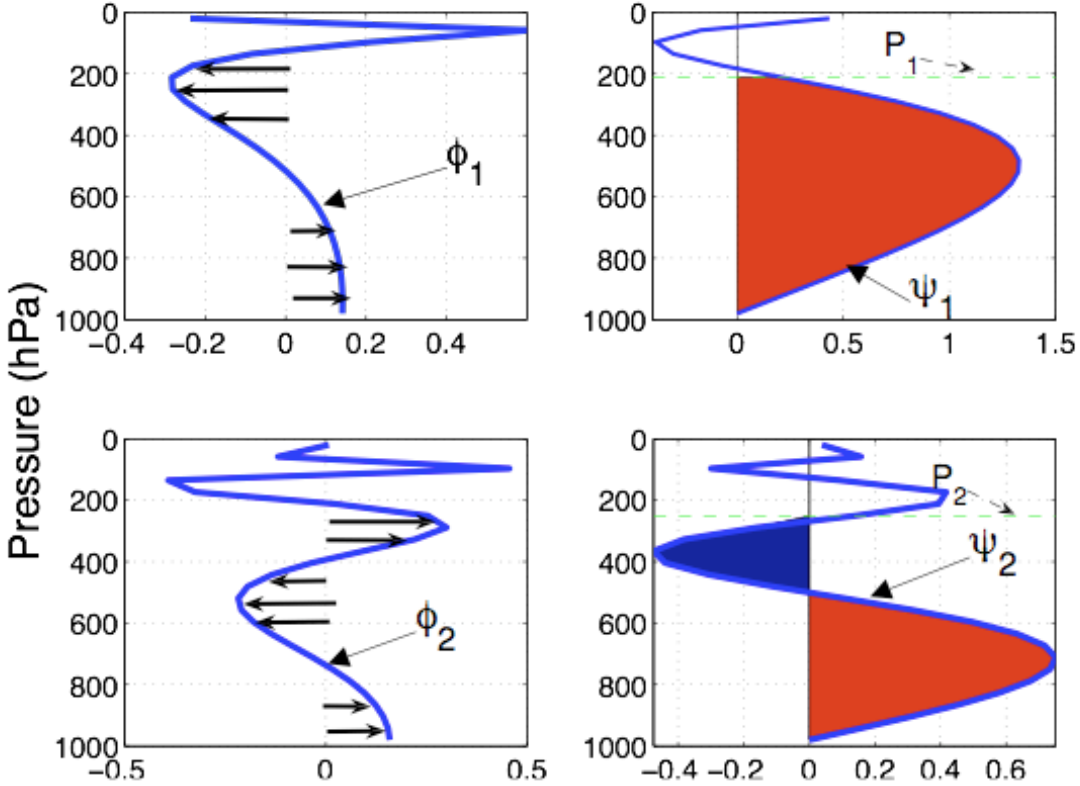
17 m/s

6 m/s

Multicloud in Aquaplanet GCM (HOMME)

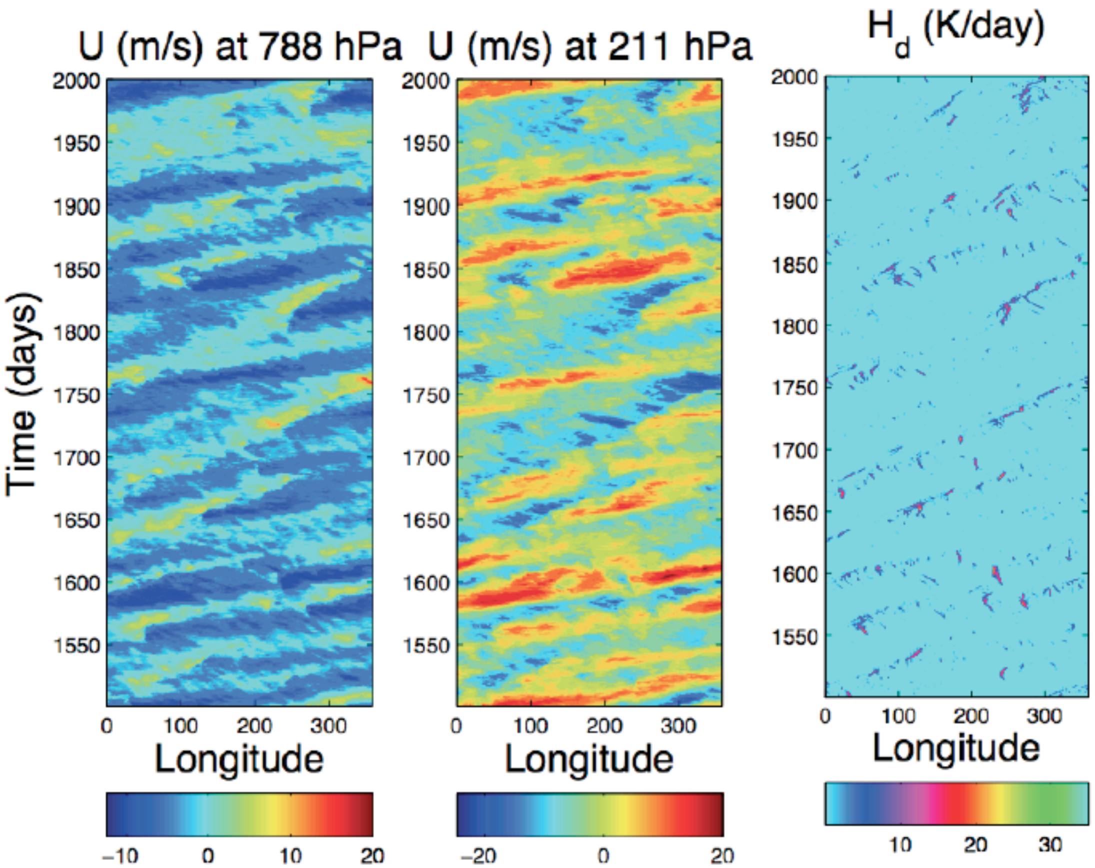
$$\mathcal{H}^{tot} = \mathcal{H}_d \tilde{\psi}_1(p) + (\mathcal{H}_c - \mathcal{H}_s)\tilde{\psi}_2(p).$$

$$\psi_j(p) = -\int_{p_T}^{p} \phi_j(p')dp'$$



Imposed Heating and Moisture background profiles: Based on GATE sounding (Grabowski et al. 2001)

MJO in MC-GCM (HOMME): Uniform SST



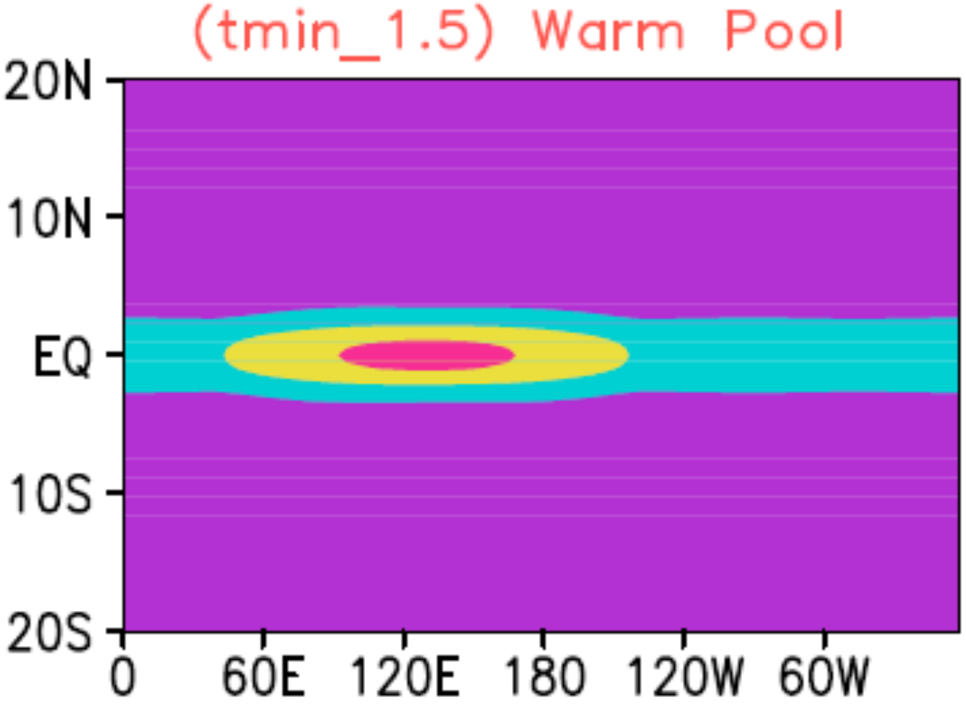
MJO key features:

- 5 m/s prop. speed
- Baroclinic structure with westerly wind lagging convection
- Quadruple vortex striding the equator
- Progressive moistening prior to convection
- Boundary layer moisture lead

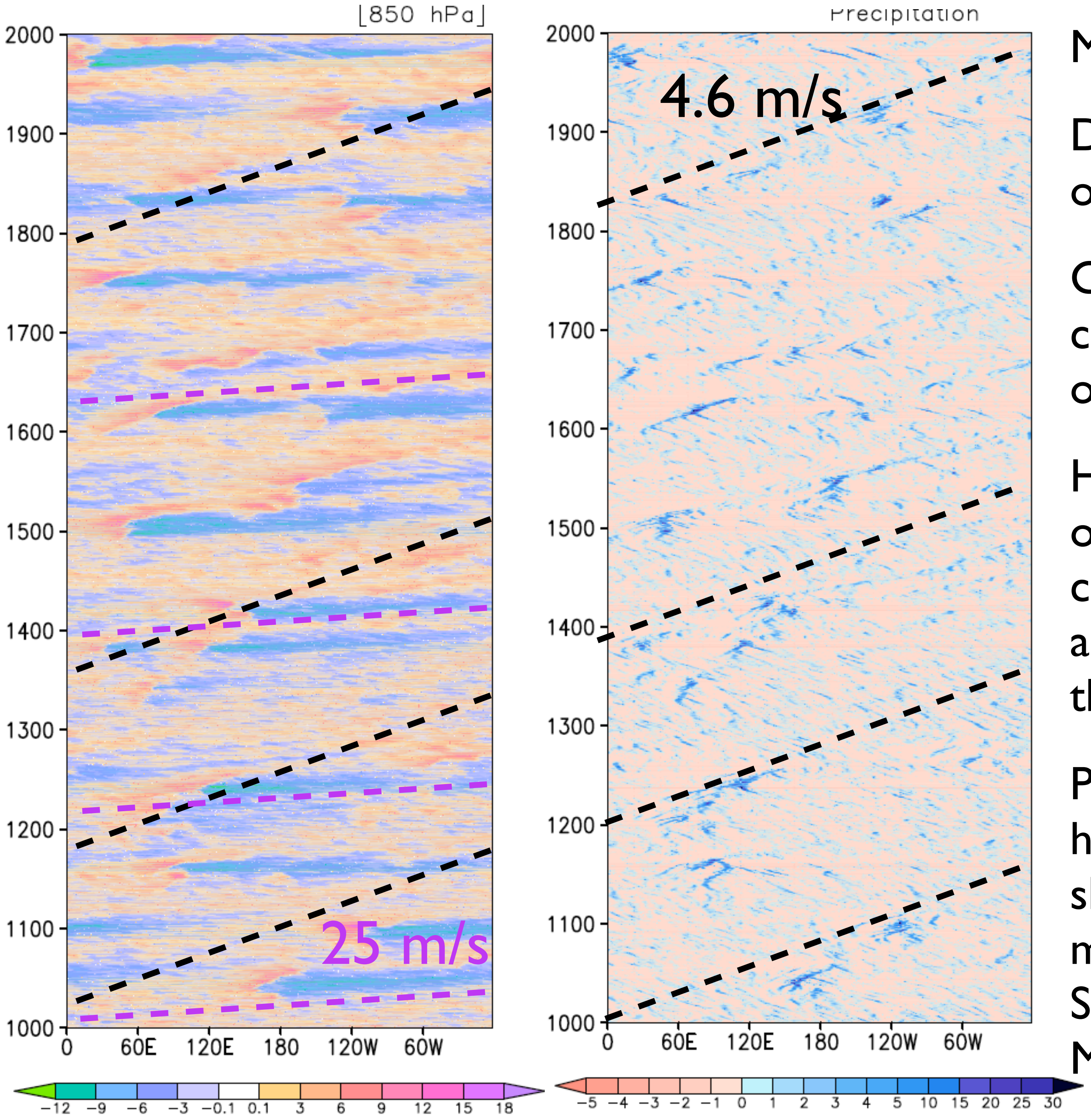
K., St-Cyr, Majda, Tribbia (2011)

CCPM Set Up

- Coupled HOMME-Multicloud model (K. et al 2011)
- Aquaplanet with fixed Non-Uniform SST--mimicking Indian Ocean/Western Pacific warm pool



Key Parameters:
Strength, Width, Latitude



MJO in Warm Pool

Dry Kelvin Waves outside Kelvin Waves

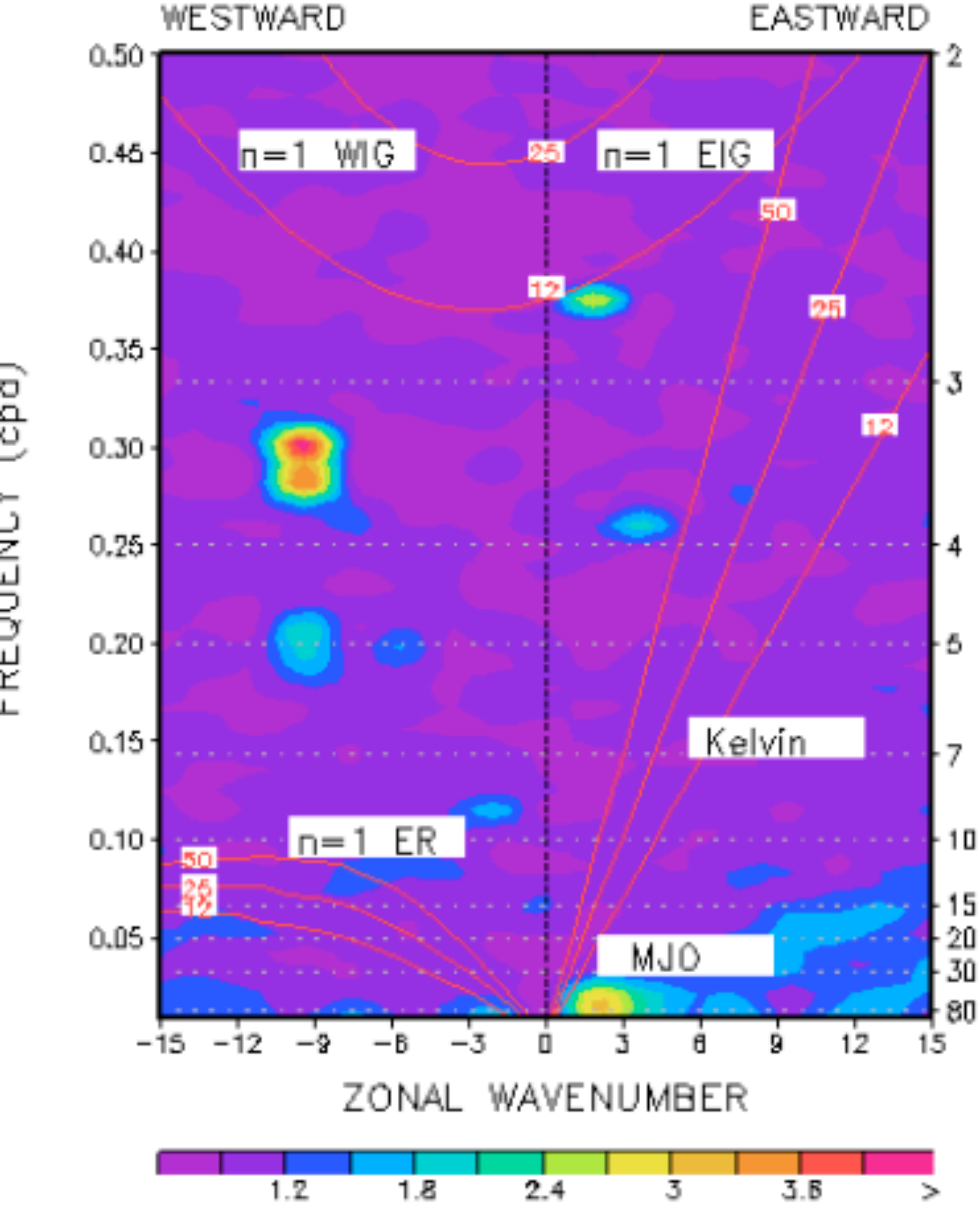
Circle the glob and coincide with initiation of succeeding MJO...

Helps organize otherwise chaotic convective mesoscale and synoptic waves on the planetary scale...

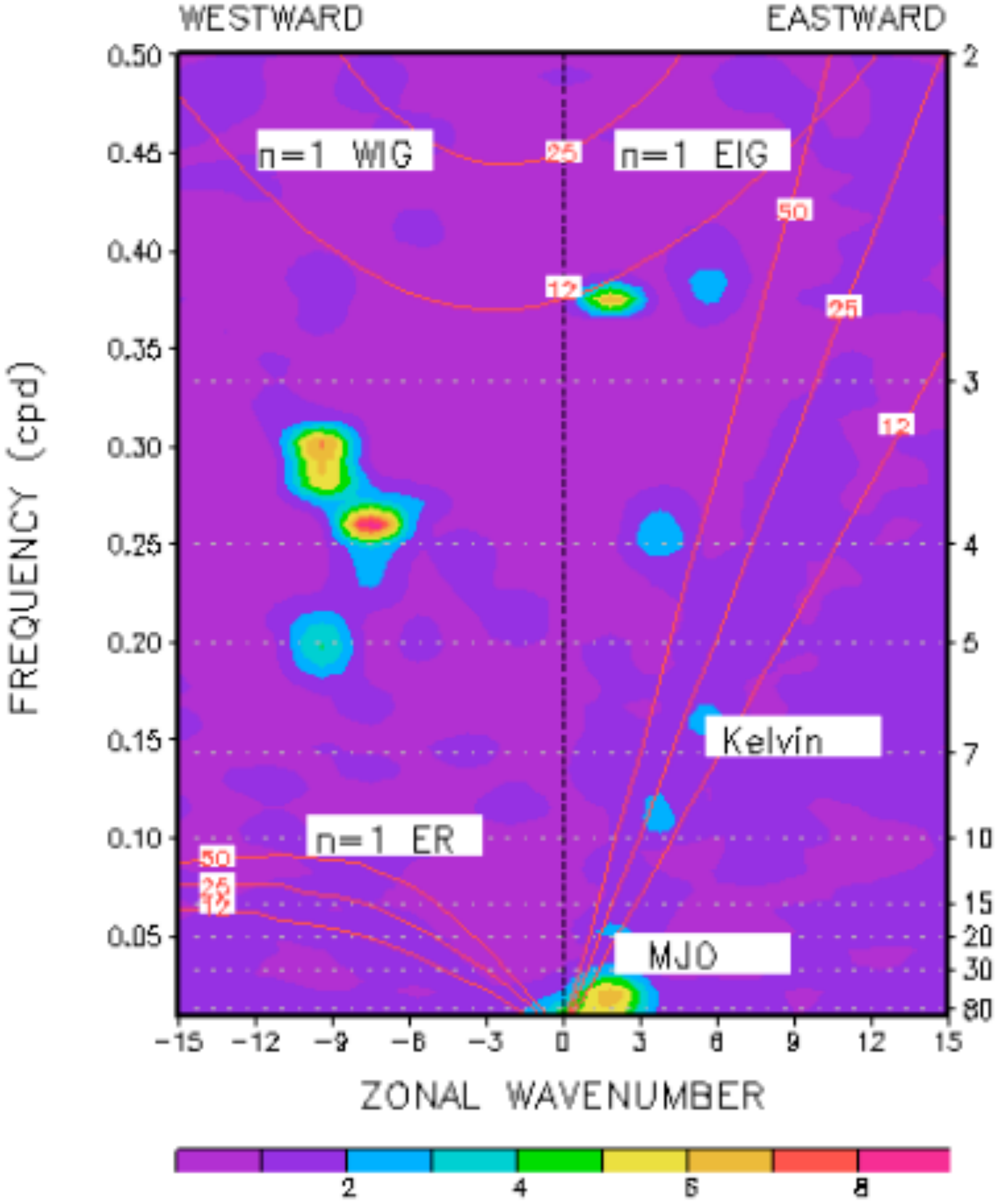
Projects onto a hypothetic MJO skeleton /Moisture mode (Majda and Stechmann, Sobel and Maloney)

Spectral Analysis

Precip.



U (200 hPa).



Sensitivity to slow variations of SST

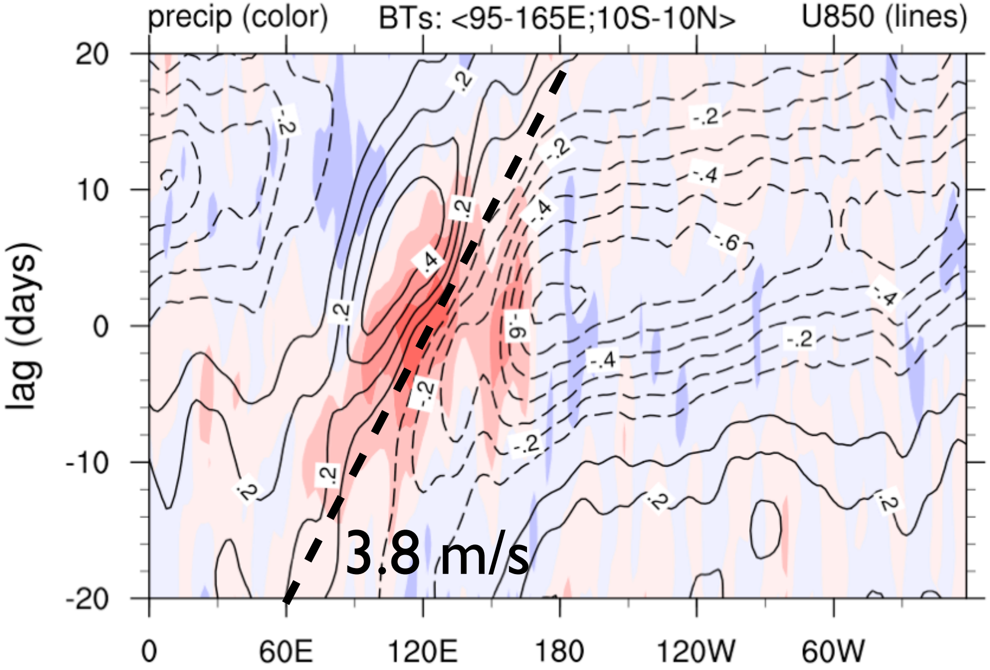
- Modify warm pool (WP) structure: width, strength and latitude
- By directly modifying surface flux of latent heat

Issue 1

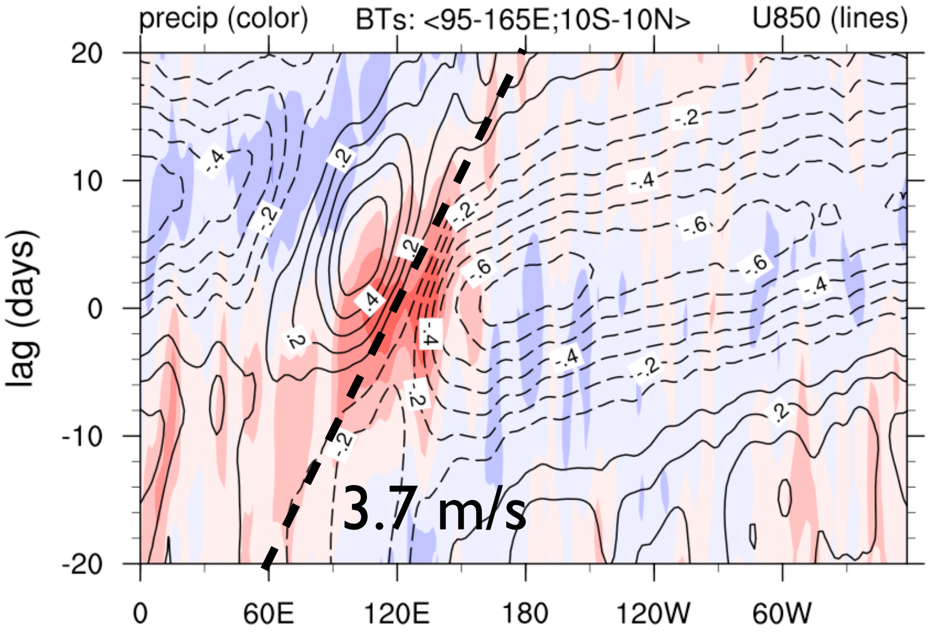
- Does MJO phase speed depend on WP width? How?
- Based on moisture fronts theory, Dias and Pauluis (2012) suggest that for Kelvin waves: Phase speed is inversely prop to ITCZ width. Wider ITCZ provides more area for moisture coupling.
- Based on boundary layer wave-CISK/multiscale theory, Kang et al. (2013) suggest that for MJO, narrow WP = fast phase speeds and wide WP lead to slow speeds.
  - Based on Gill model analogy: "Narrow WP yield CC Kelvin waves while wide WP lead to Kelvin-Rossby Gill type solution, thus slow down from retardation induced by westward movement of RW.

H-MCM Sensitivity to WP Width

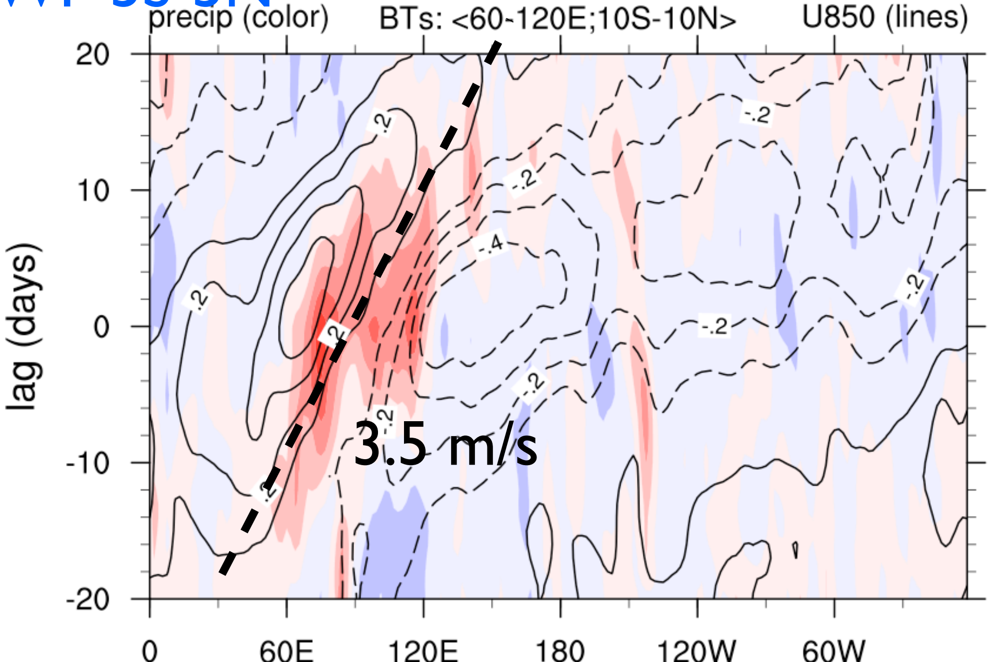
WP 15S-15N



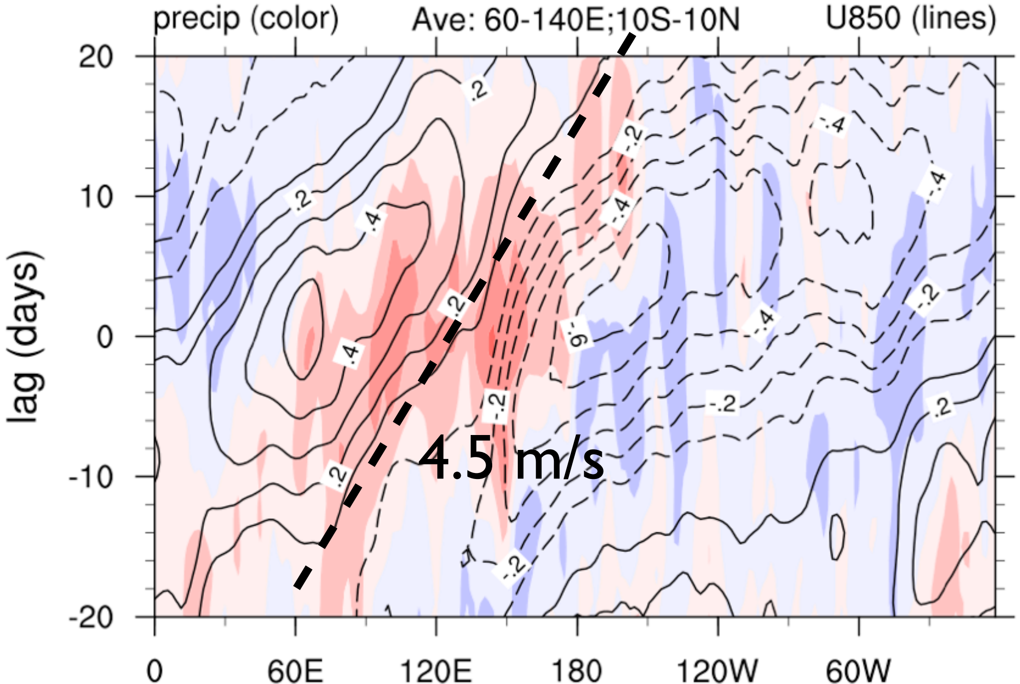
WP 10S-10N



WP 5S-5N



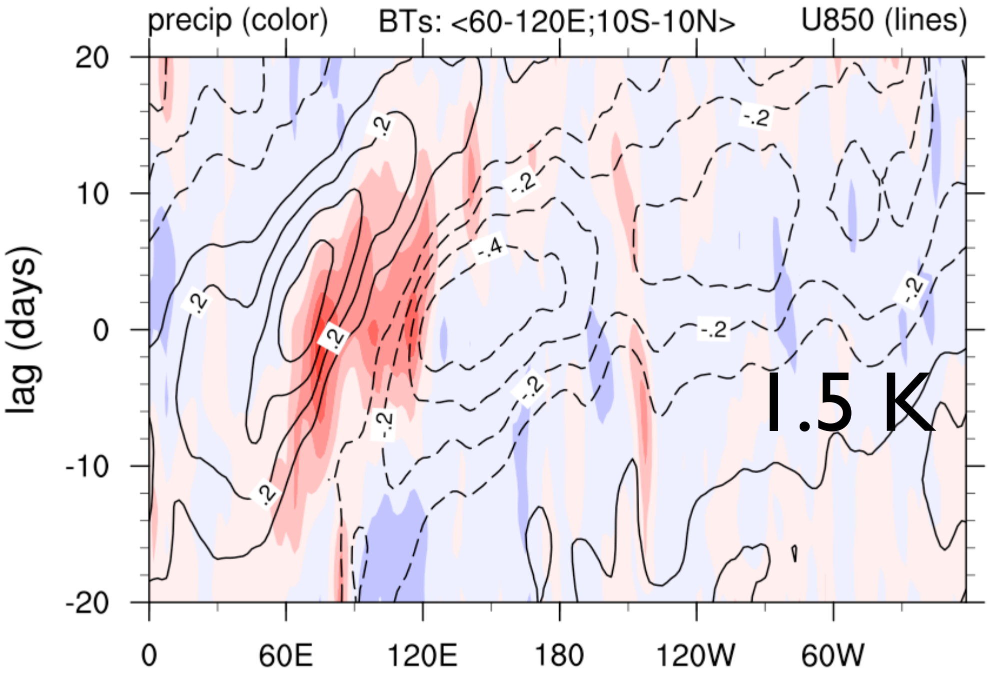
CTRL: No WP



- Result do not support previous theories
- Here MJO propagates slightly faster in wider WP
- Why? ... Don’t know! Maybe because there is more moisture to be funnelled in by Rossby gyre. More efficient engine!

Issue 2

- How does WP strength influence MJO?
- Obs show that during El-Nino, MJO expends eastward into the Pacific due extension of warm SST (Hendon in Lau & Waliser)
- During La Nina, MJO remains confined to Indian Ocean/Western Pacific WP: e.g. DYNAMO vs TOGA-COAE MJOs.
- By design of WP: mean zonal SST is conserved... Stronger WP==> "Cooler Central and Easter Pacific"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U850 (lines)
lag (days)
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60E
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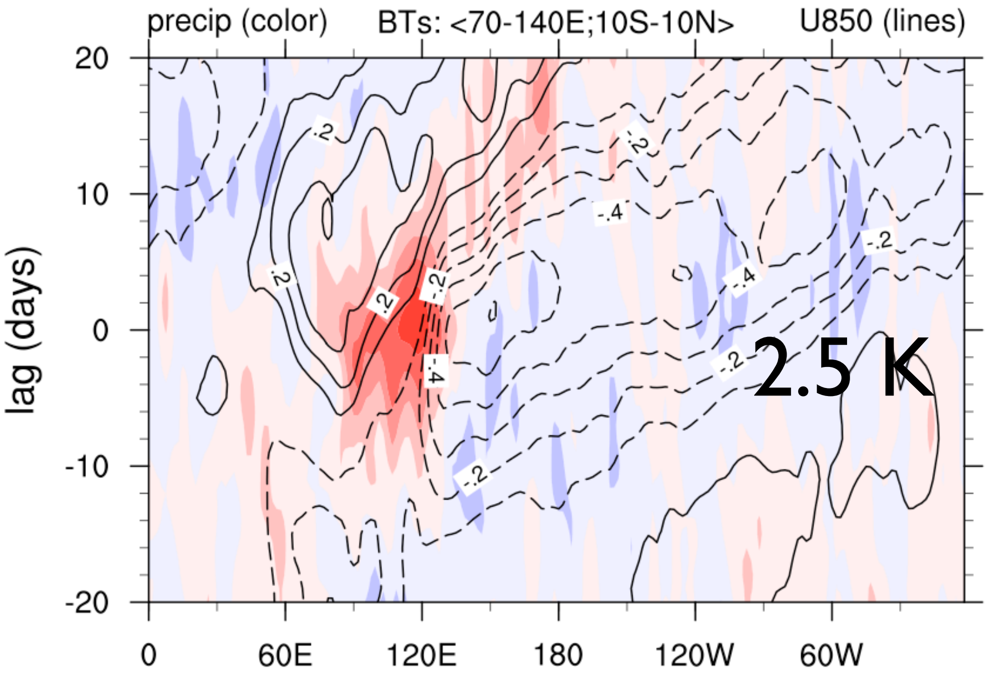
180
120W
60W
1.5 K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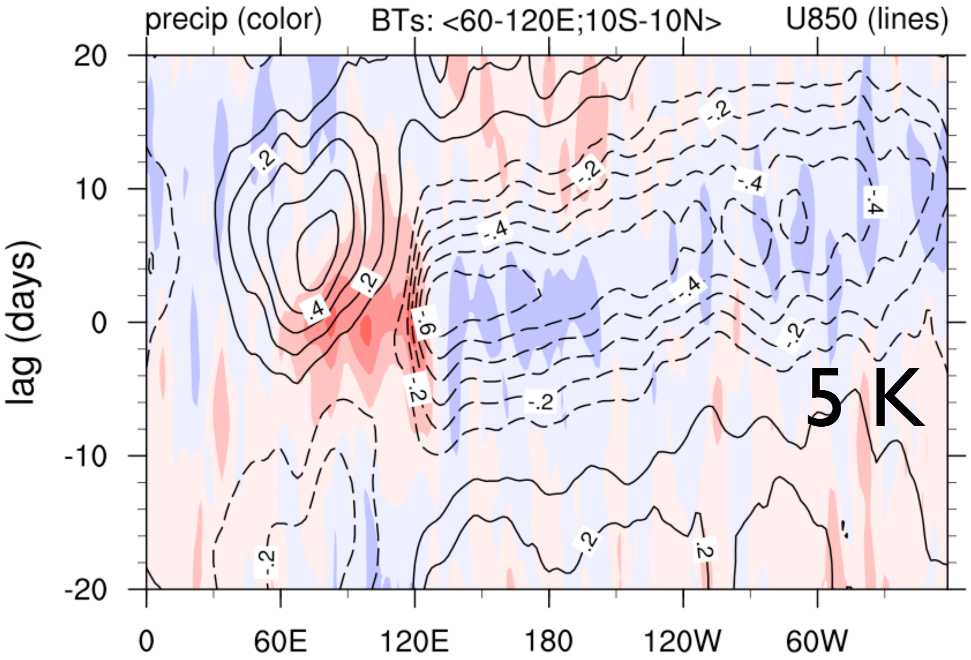
2.5 K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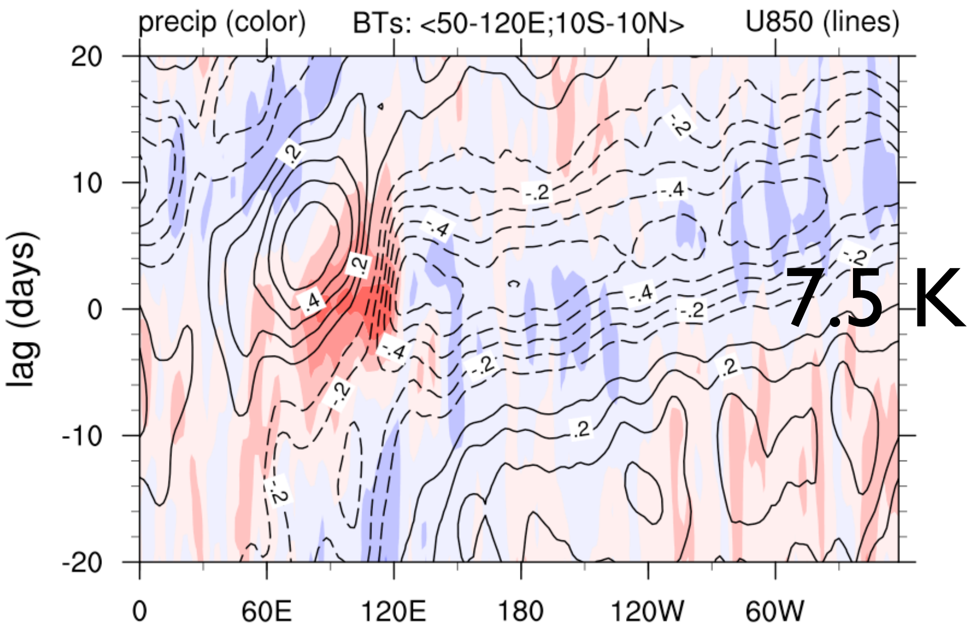
5 K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U850 (lines)
lag (days)
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60E
120E
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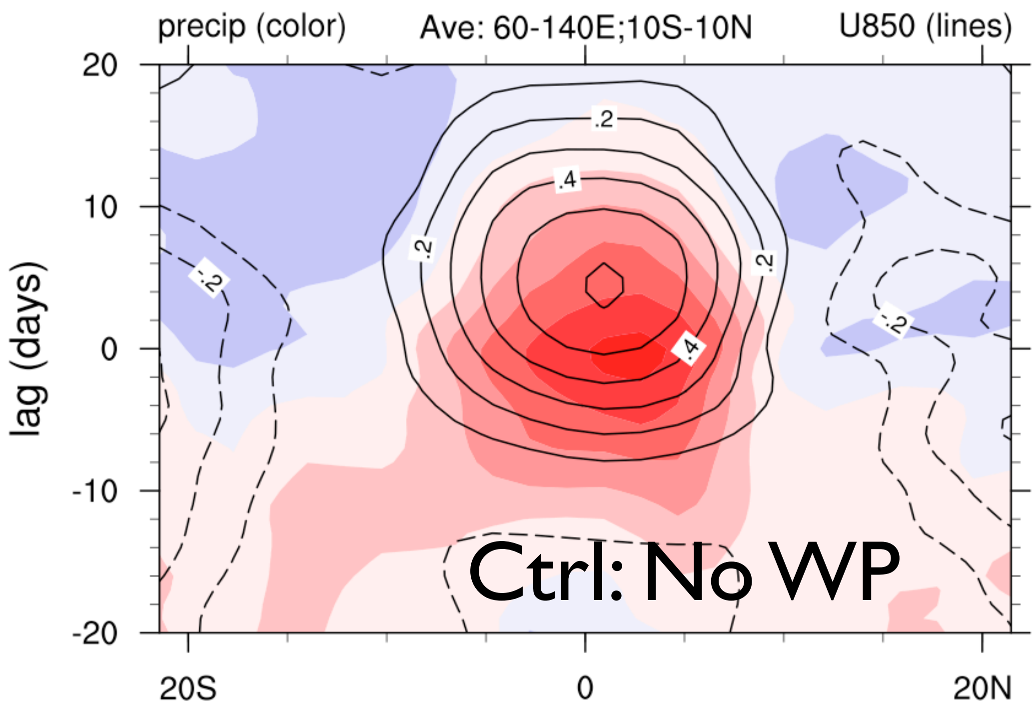
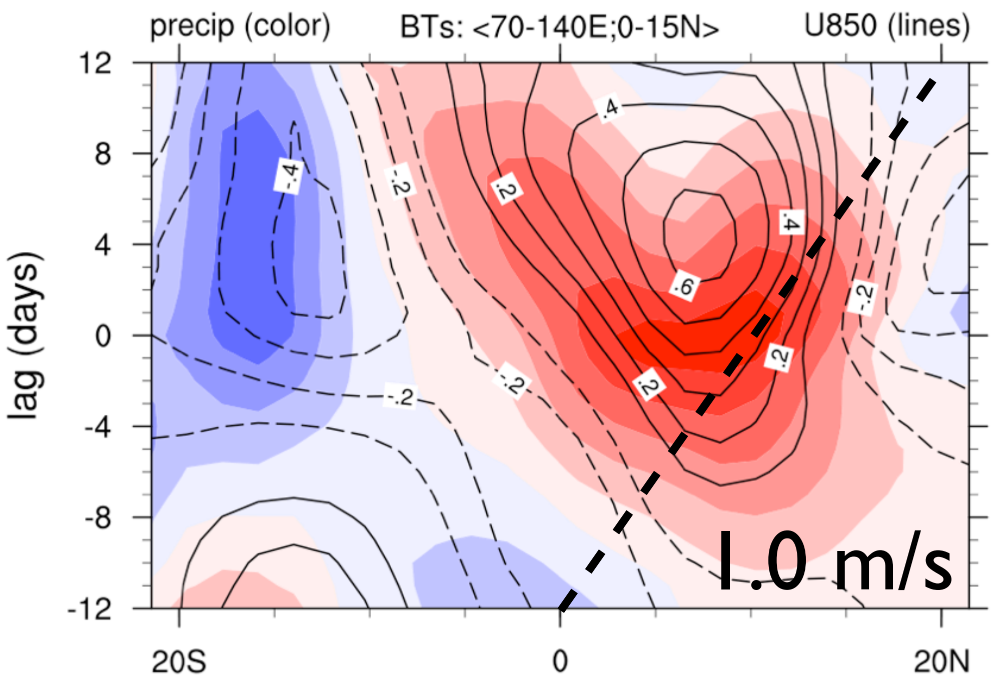
120W
60W
7.5 K

Issue 3: Northward Propagation

- Monsoon ISO precipitation propagates Northward at ~ 2 m/s. Monsoon breaks when IO convection is at the Equator. Eastward propagation is also observed at the same time.
- Can HOMME-MCM reproduce this northward propagation?
- Move WP centre to Northern Latitudes

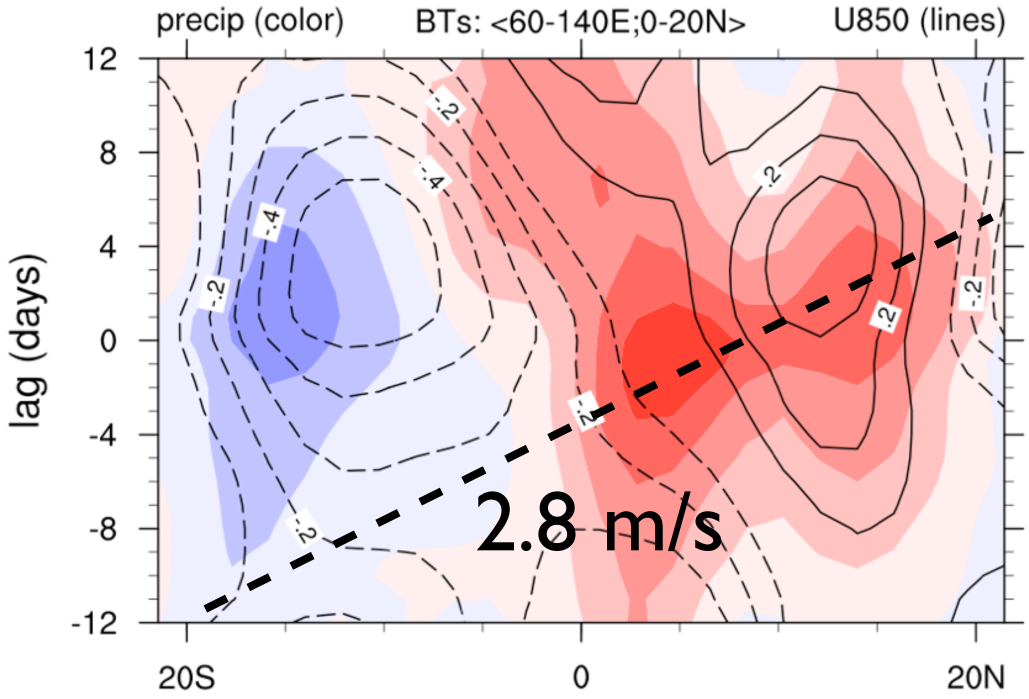


Ctrl: No WP



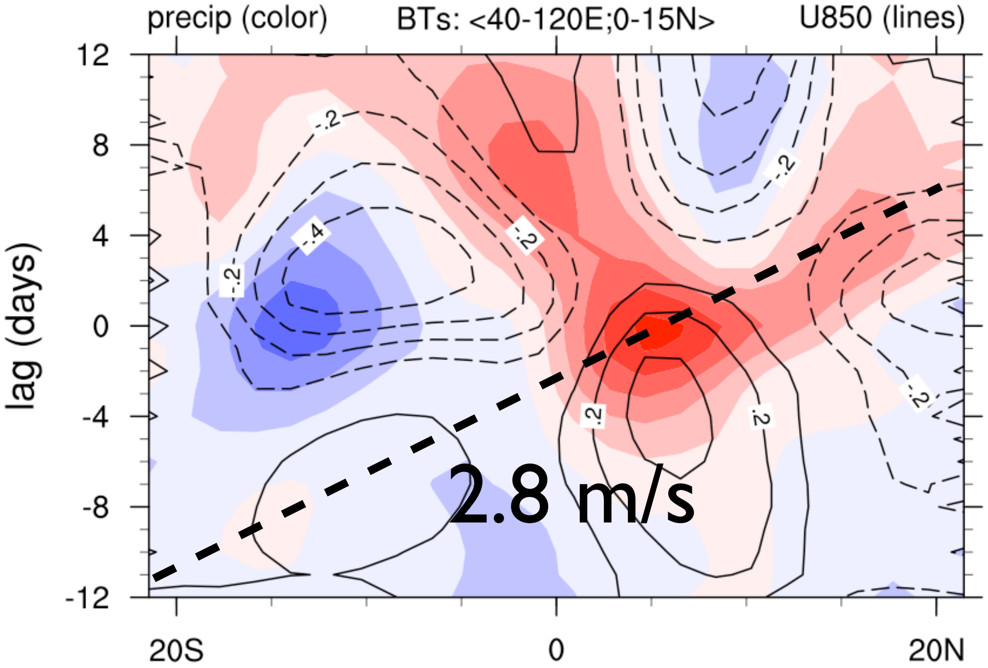
1.0 m/s

WP @5N



2.8 m/s

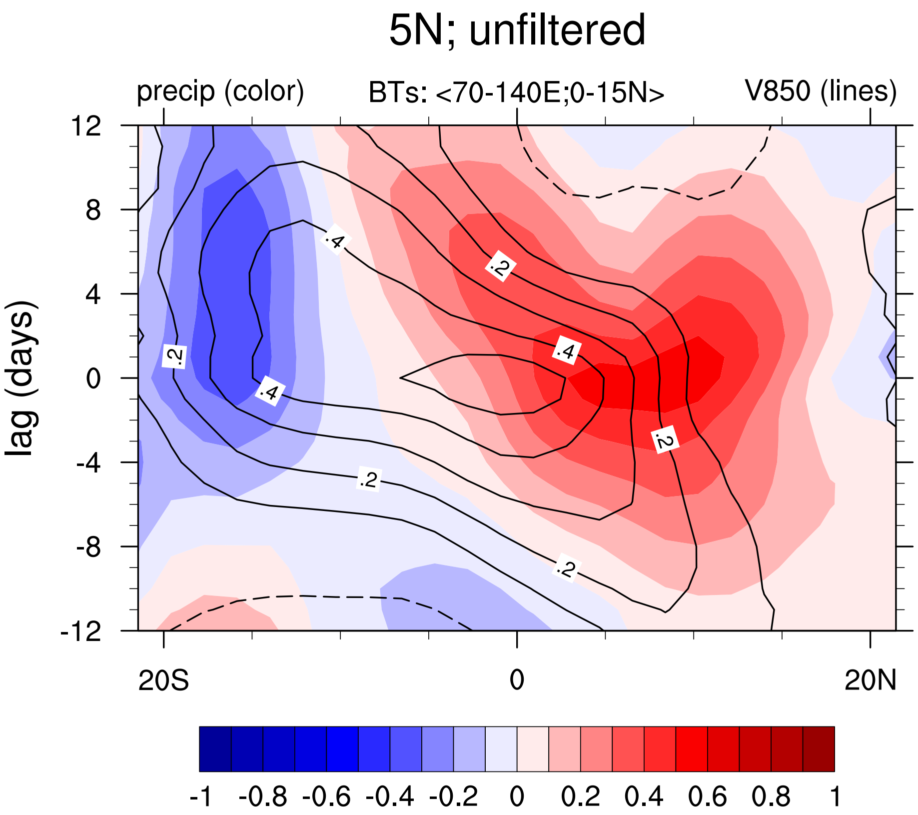
WP @10N

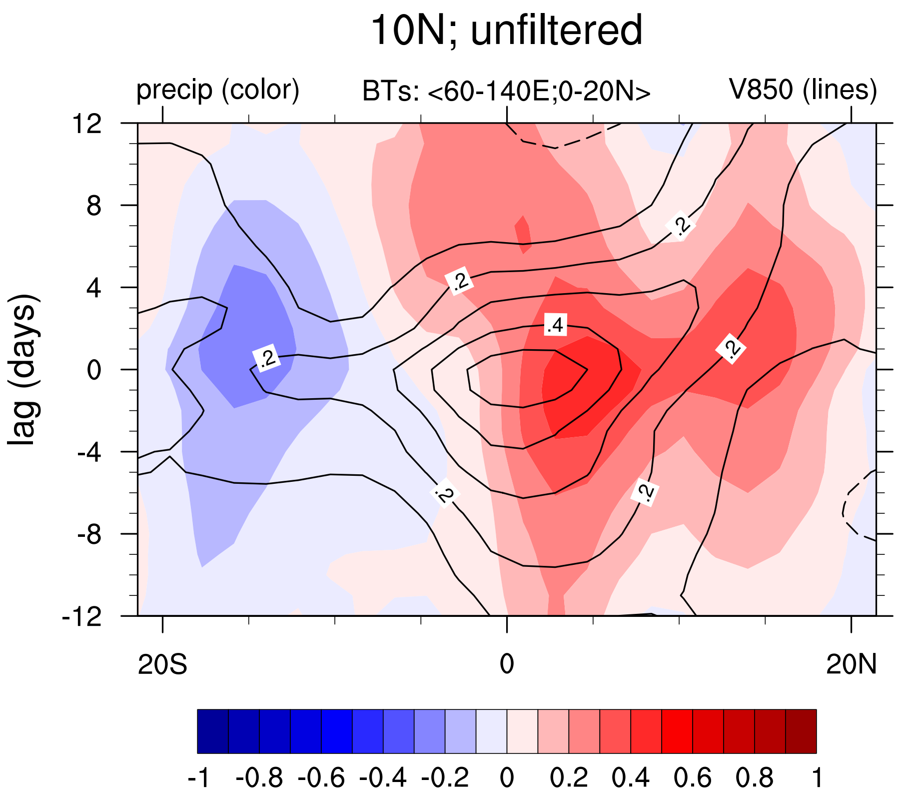


2.8 m/s

WP@15N

Meridional Wind & Northward Propagation

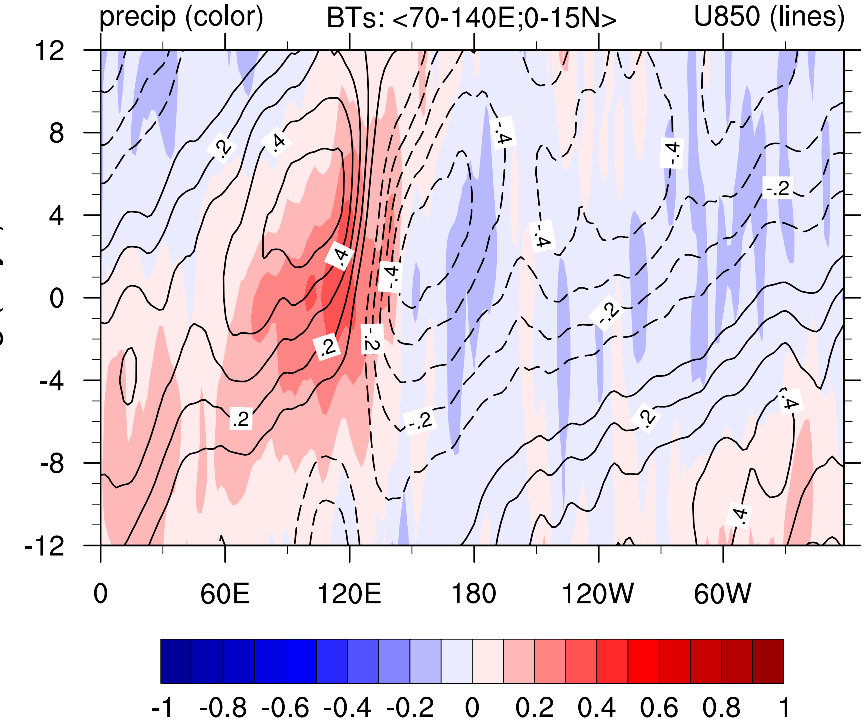

5N; unfiltered


10N; unfiltered

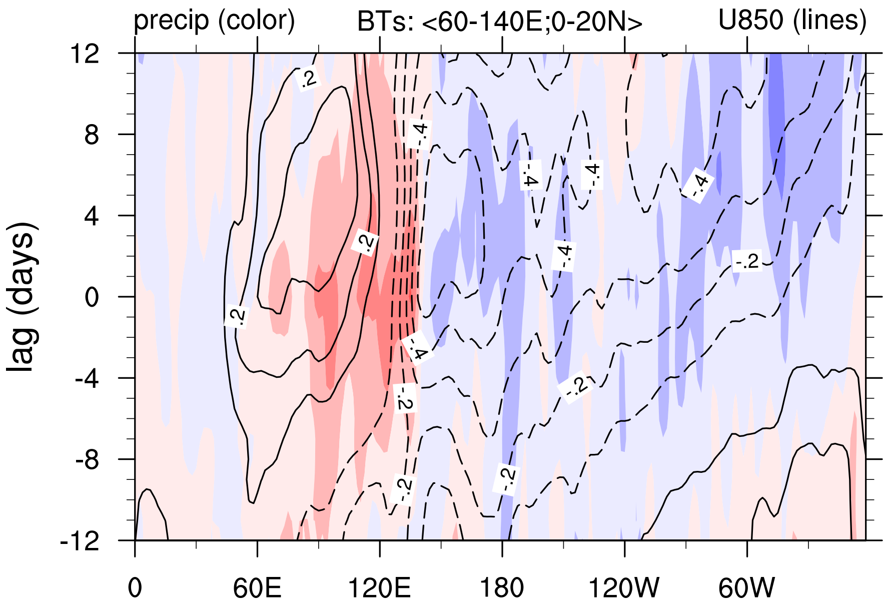
- Meridional convergence lead northward propagation of precipitation... (cf. 10 N)
- Same multicloud/moisture coupling dynamics as for eastward propagation at play!?
- Southerly cross equatorial winds play role of "WWB".

Lag-Lon plots

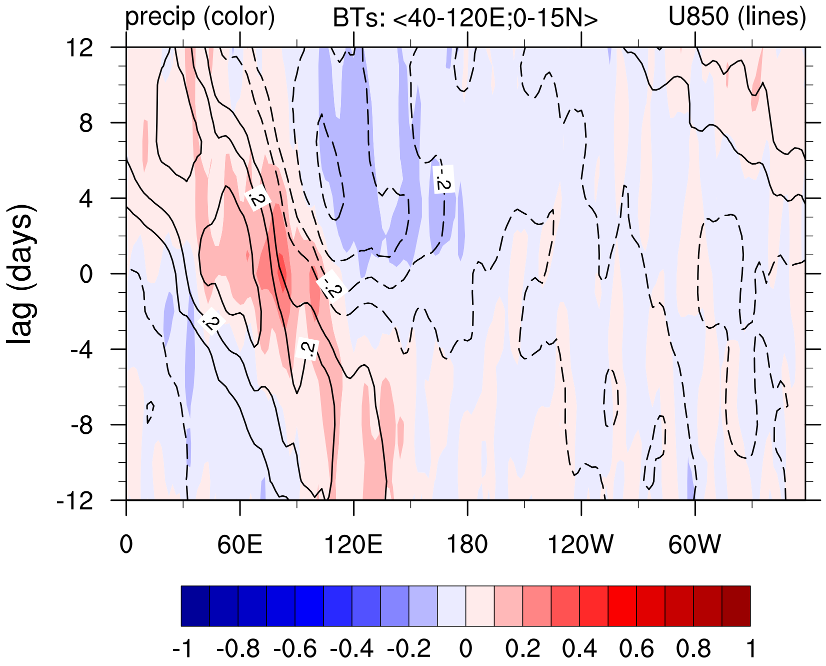
5N; unfiltered



10N; unfiltered



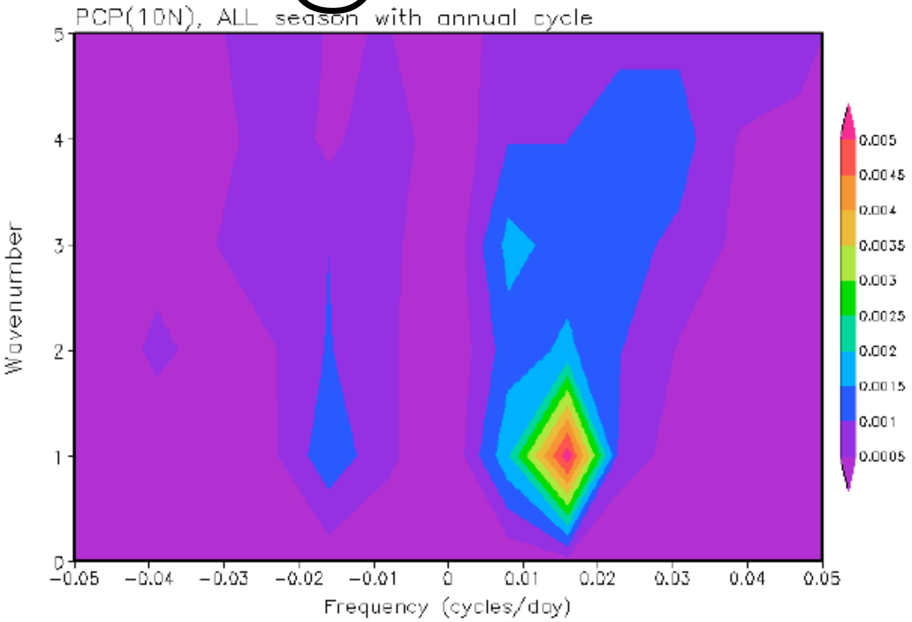
15N; unfiltered



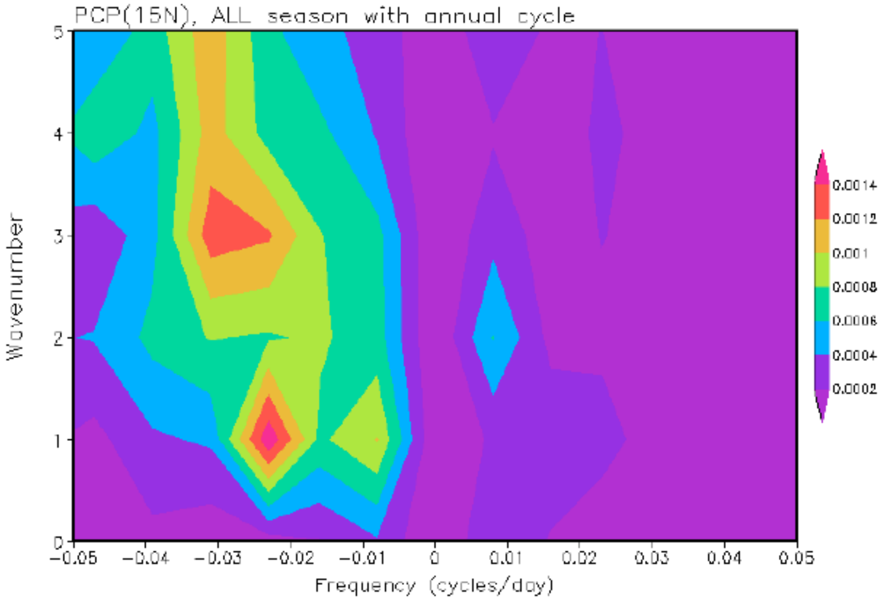
- Eastward propagation is attenuated between 0-15 N
- Westward propagation for WP@15N: Rossby waves?

Equatorial Space-Time Spectra

WP @10 N



WP @15 N



- WP 10N: Along Equator Eastward propagation dominates in Precipitation and Zonal Win. Average Eastward propagation speed: 8 m/s

- WP 15N: Only Westward propagation of synoptic scale waves

Conclusion

- Used a simple multicloud model as a parameterization in an aquaplanet GCM
- Based building block paradigm of key three cloud types and their interaction with/through mid-level moisture:
  - Congestus clouds precondition mi-troposphere prior to deep convection via second-baroclinic convergence
  - Stratiform clouds lagging deep convection induce downdrafts play role of cold pools
- Eastward and northward propagating of ISO-like waves successfully simulated, for various surface-flux configurations, as in observations---> importance of multicloud paradigm in dynamics of tropical convective systems through interactions across scales.

- Absence of mechanisms reported in literature as being important for MJO initiation and/or maintenance: WISHE, Wave-CISK, cloud radiative forcing, extra-tropical influence, ocean-coupling
- In WP simulation: second baroclinic dry Kelvin waves circling the globe seem to help organize convection to effectively project onto a planetary-scale MJO skeleton/moisture mode
- Unlike what previously reported, WP width doesn't decrease MJO phase speed
- "Strengthening" of WP leads to contraction of MJO (La Nina)
- Northward propagation of ISO is captured under "summer monsoon conditions", suggesting same multicloud and multiscale mechanism as for MJO.