Diversity of the Madden-Julian Oscillation

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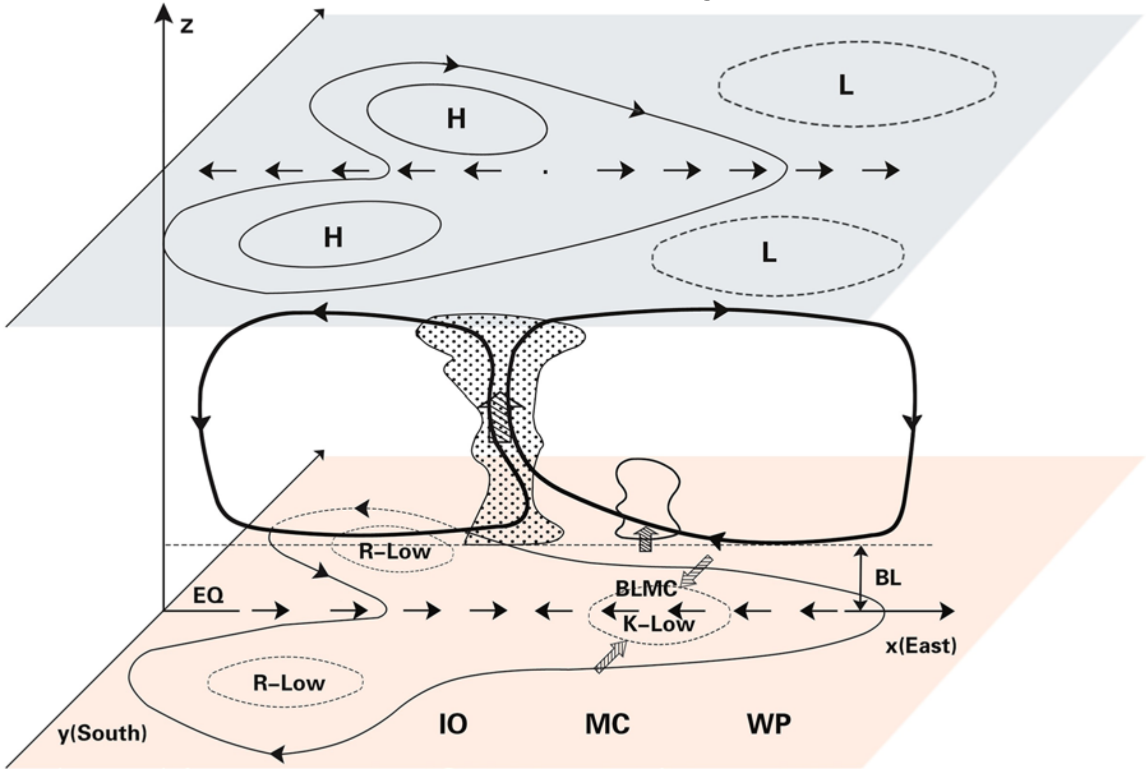
Outline

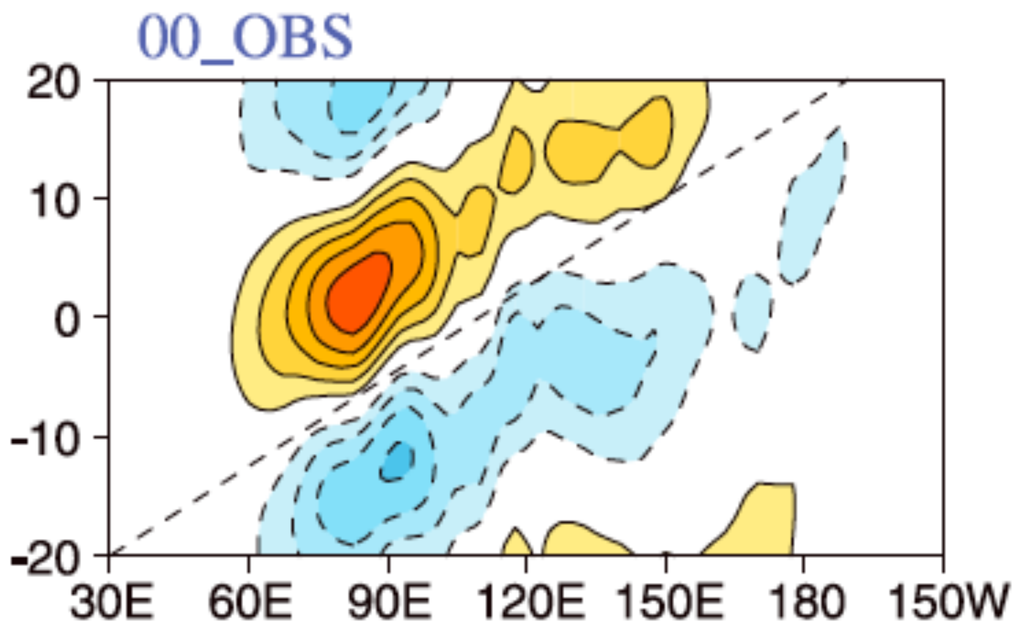
- 1. Background
- 2. Data and Method
- 3. Diversity of equatorial MJO propagation and the associated distinct dynamic structures
- 4. Mechanisms of the diversified MJO propagation
- 5. Summary

1. Background

Wang et al 2016



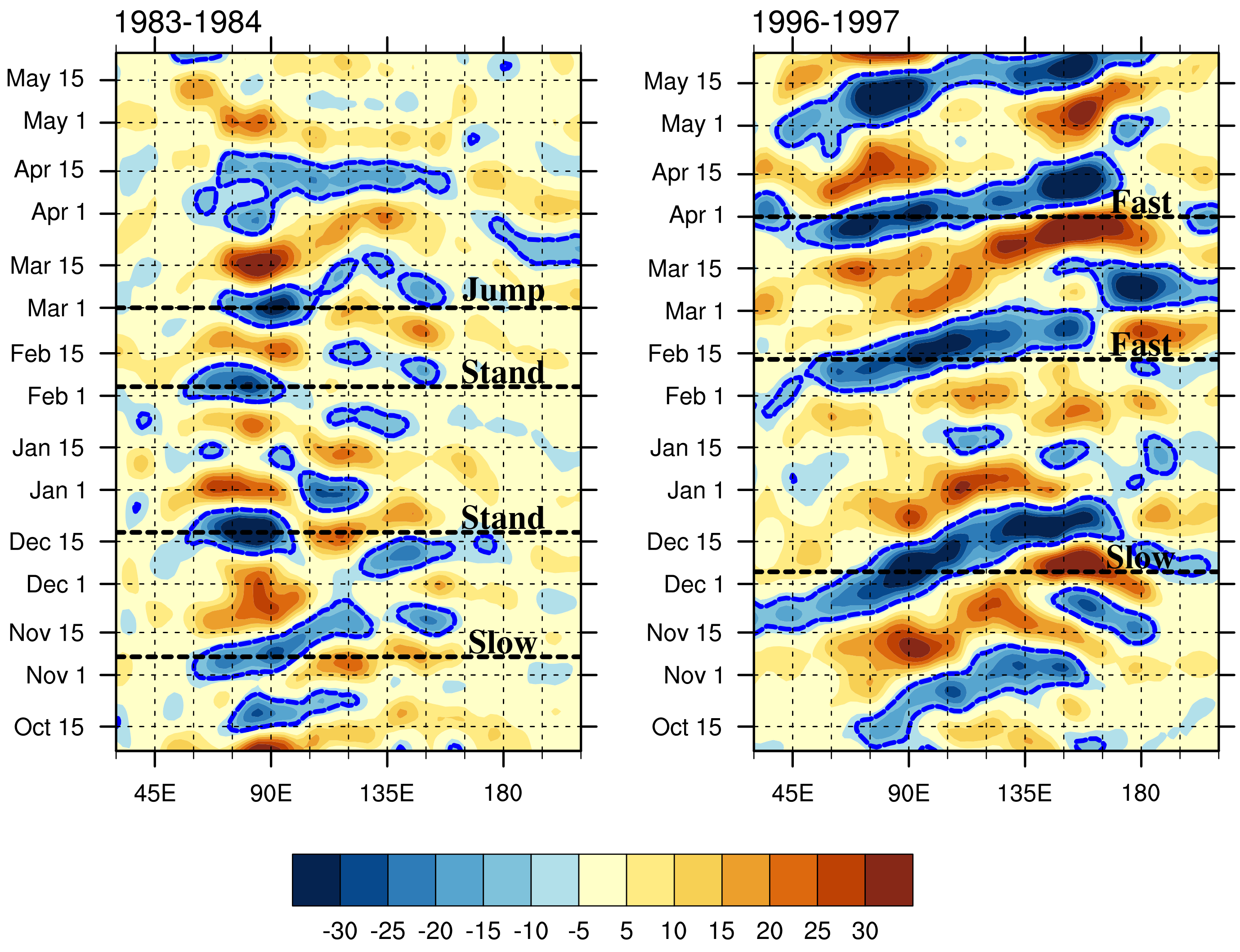
Jiang et al 2015



Canonical structural and propagation features of the MJO

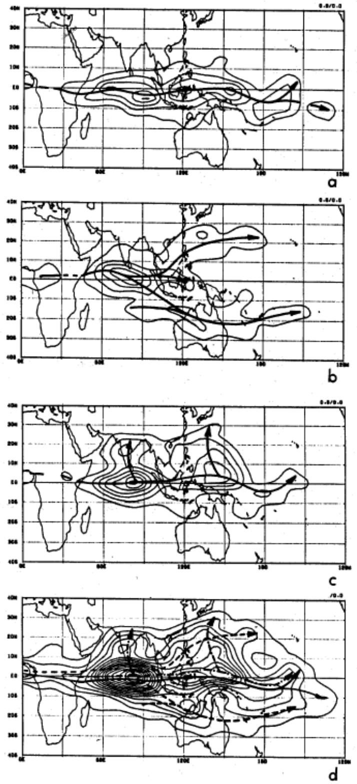
Observed diversified MJO propagation

- The majority of the MJO studies have been focused on the properties of the canonical MJO, but not every MJO event resembles the canonical form.
- The propagation, amplitude, and life cycles of the convective envelopes for individual MJO events differ considerably from event to event, as can be see in figure on the right.
- The large-scale intraseasonal convective anomalies exhibit various propagation forms along the equatorial belt, ranging from standing oscillation to systematic propagations with different speeds.



Shading: OLR

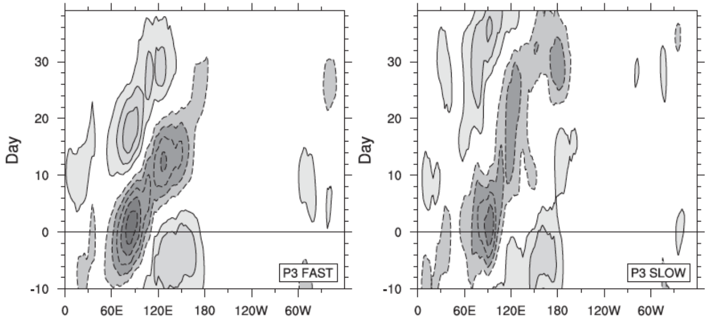
Studies of diversified MJO propagation



Wang and Rui 1990

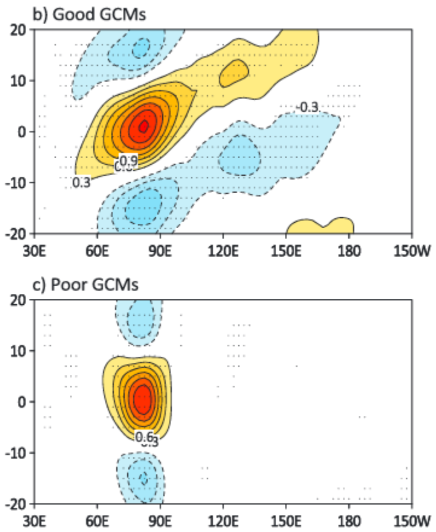
Seasonal variation of MJO propagation tracks

Yadav and Straus 2017

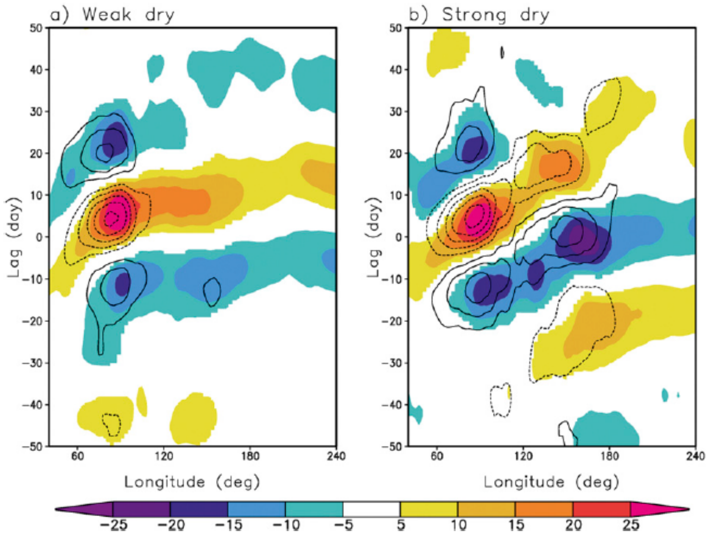


Fast VS Slow MJO

Kim et al 2014



Jiang et al 2015



Propagating VS Nonpropagating MJO

A systematic and objective delineation of MJO diversity has not yet emerged in terms of the propagation pattern, intensity, and associated teleconnection and impacts.

- **Problems:**
  - The complex forms and causes of MJO diversity have not been explored systematically
  - No systematic and objective delineation of MJO diversity

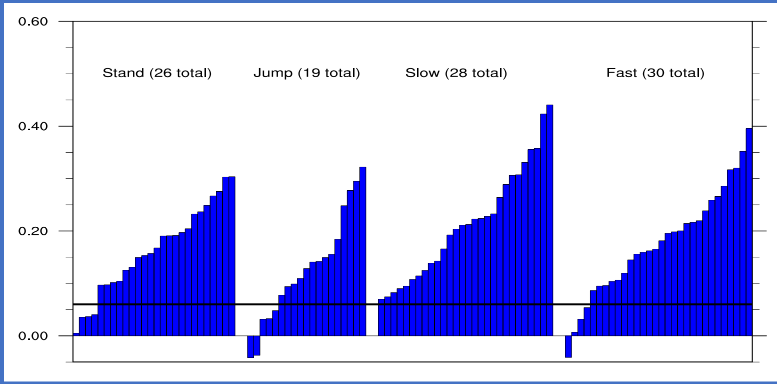
- **Targets:**
  - Propose a way to objectively delineate different propagation forms of the observed MJO
  - Unravel their relationships with MJO circulation and moist thermodynamic structures, as well as to seek for the root causes of the MJO diversity

2. Data and Methods

- **Data**
  - ERA-interim
  - NOAA interpolated OLR
  - NOAA ERSST
  - 2.5°×2.5° resolution
  - 1979-2013
  - Boreal winter (NDJFMA)

- **Methods**
  - Band-pass filter (20-70 day)
  - K-means cluster analysis
  - Composite analysis

silhouette values for the clustered MJO events

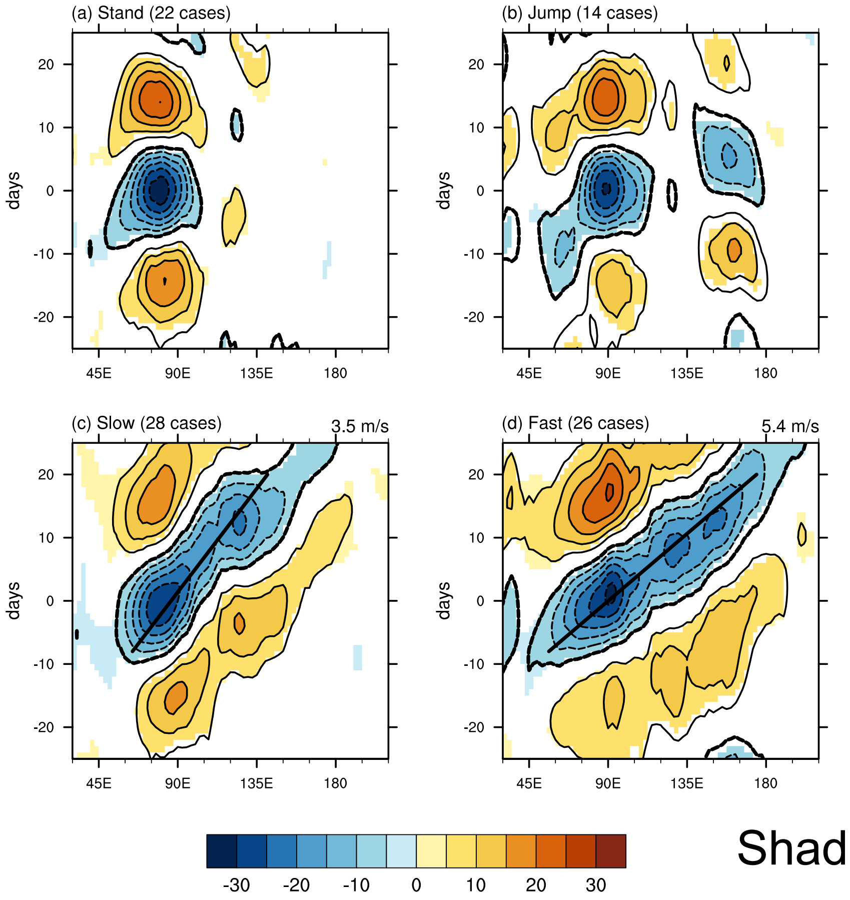


Cluster analysis

- **1. Selecting the MJO cases**
  - The MJO cases are selected when the box-averaged OLR over the eastern Indian Ocean (10ºS-10ºN, 75º-95ºE) is below one standard deviation for 5 successive days.
  - There are total 103 selected cases during the 35 boreal winters of 1979-2013
- **2. Performing K-means cluster analysis**
  - For an MJO case, the cluster analysis domain in the Hovmöller diagram covers a 30-day period from day -10 to day 20 and a longitudinal extent from 60ºE to 180ºE.
  - Calculating silhouette value, which indicates how similar a member is to its own cluster compared to other clusters
  - Four clusters are optimal in terms of the silhouette values
  - The members having a silhouette value lower than 0.06 were excluded from the corresponding clusters. As a result, 13 cases are removed and only 90 cases are remained.

3. Diversity of equatorial MJO propagation and the associated distinct dynamic structures

- The k-means cluster analysis obtains four archetypes of MJO propagation:
  - Standing MJO
  - Jumping MJO
  - Slow Propagating MJO
  - Fast propagating MJO



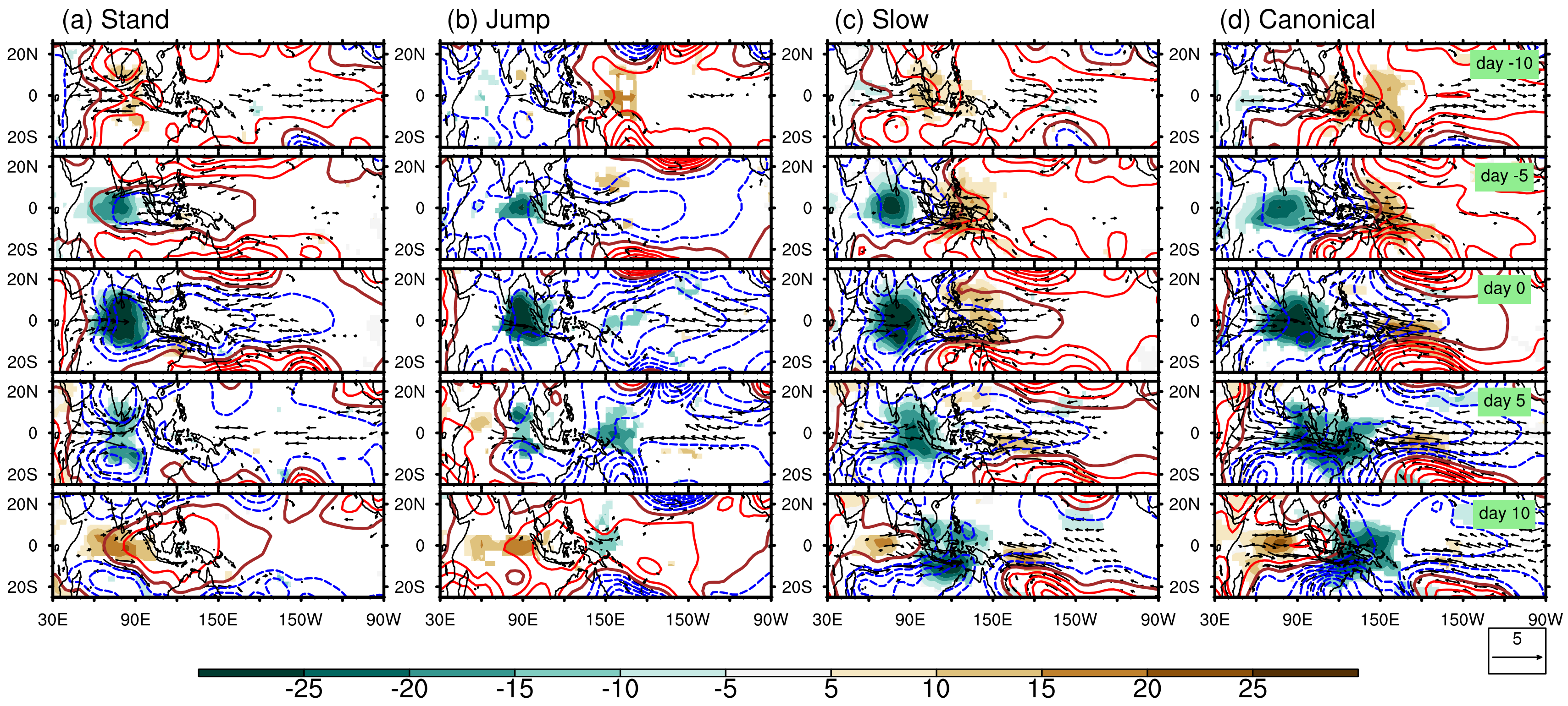
Shading: OLR

Evolution of horizontal Structures

Shading: OLR;

Contour: 850-hPa geopotential height;

Vectors: horizontal wind



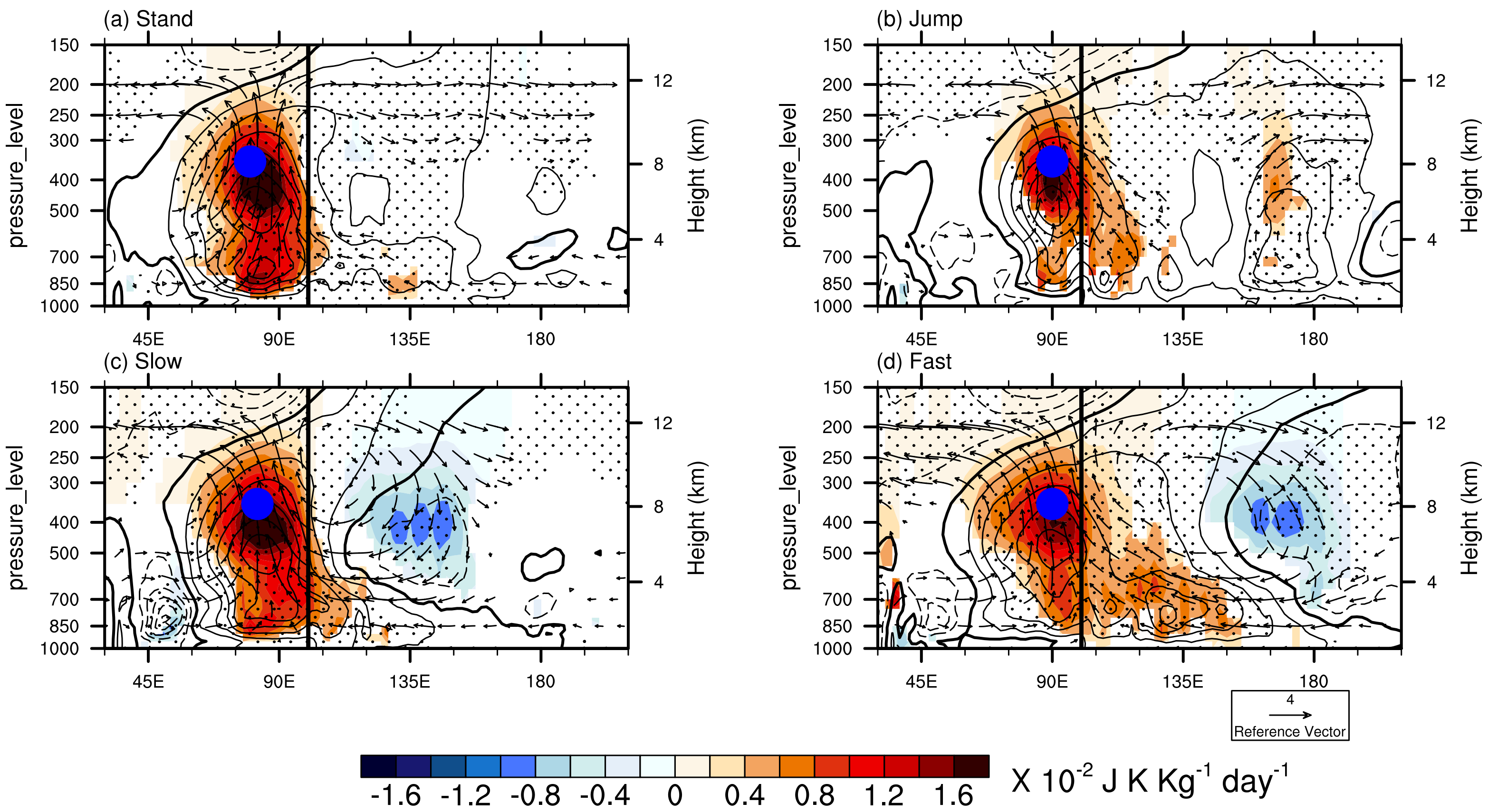
- A prominent forerunner that distinguishes propagating from nonpropagating events is the strength of the Kelvin wave response and its coupling to the east of the MJO main convection:
  - The Kelvin wave response is strong and tightly coupled with the MJO major convection in the propagating groups (slow and fast) while it is veryweak and tends to decouple from the major convection in the nonpropagating groups (standing and jumping).
  - The strength and length scale of the Kelvin wave response also distinguish the slow and fast propagation groups: The fast group has stronger and longer low-level Kelvin wave response.

Vertical structure differences among four MJO clusters

Shading: moisture sinks, which could be considered as condensational heating

Contour: equivalent potential temperature (EPT)

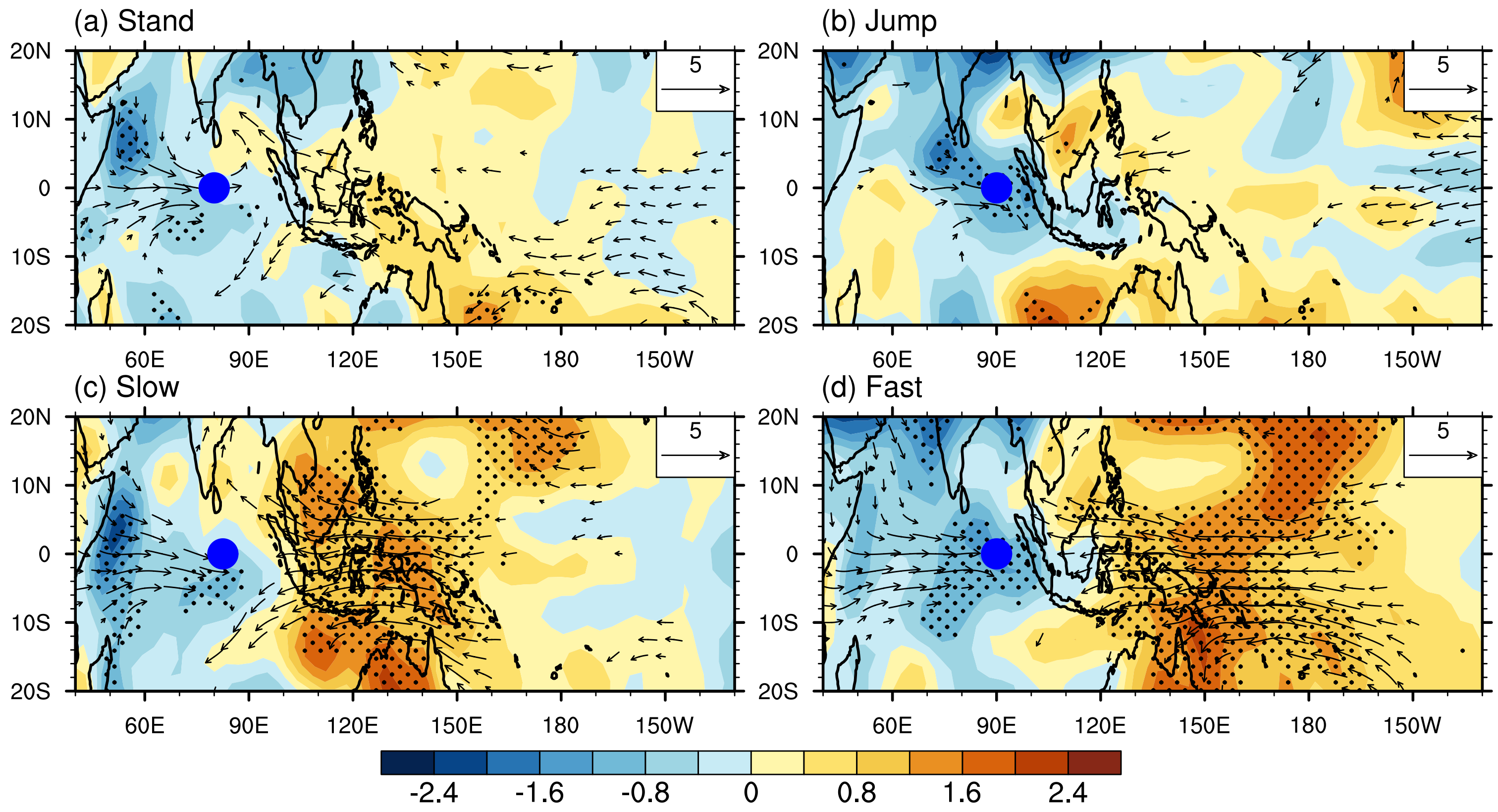
Vectors: wind vectors



- The thermodynamic structures show pronounced differences among the four clusters in consistence with the east-west asymmetric circulation patterns, as seen by the structures of the EPT anomalies.
- The enhanced low-level EPT favors the development of shallow and congestus clouds, as seen by the low-level condensational heating anomalies.

Zonal asymmetries in convective instability

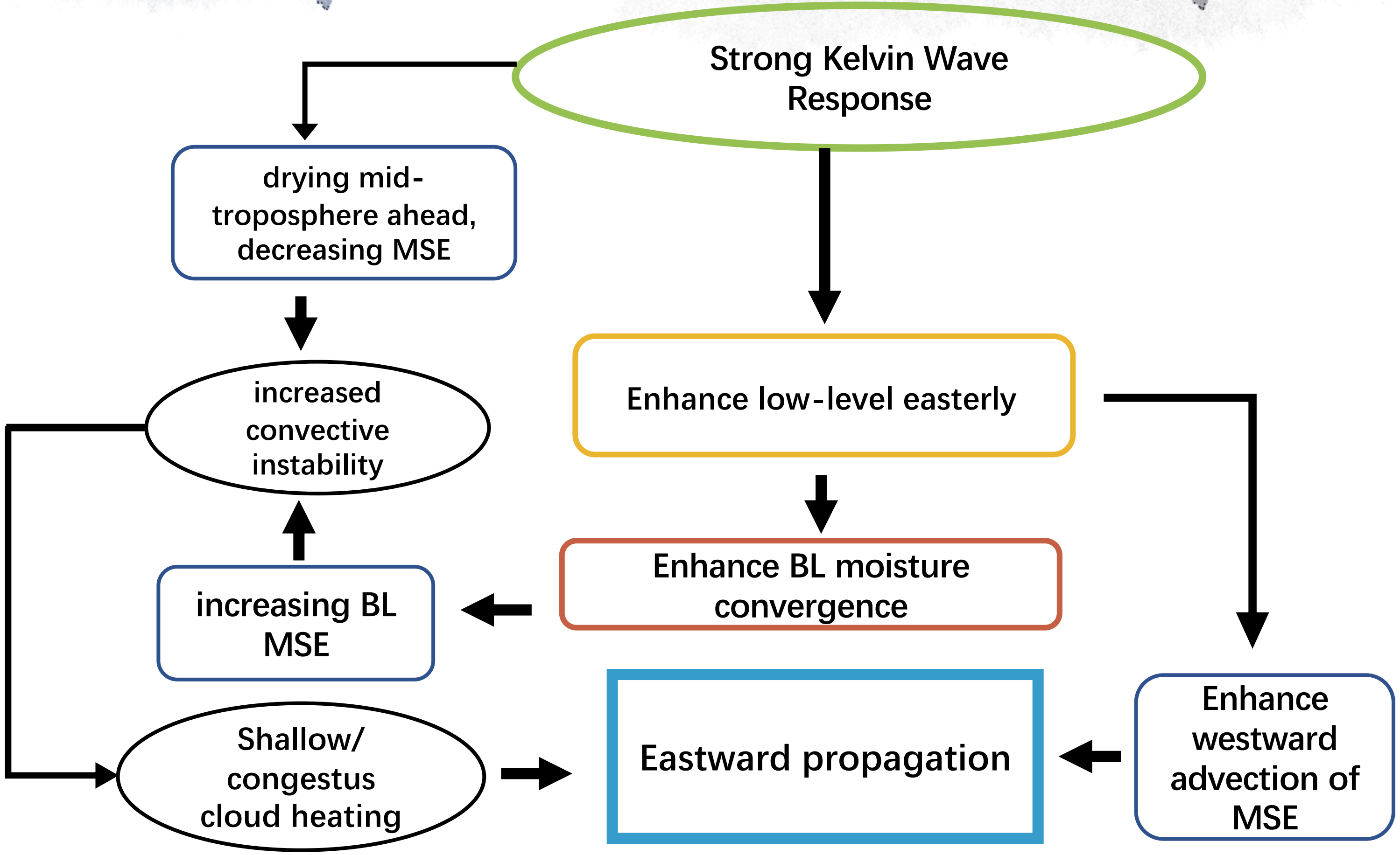
- Shading: convective instability (EPT 400hPa – EPT 850hPa)
- Vectors: wind vectors at 700-hPa



- The propagating clusters are characterized by strong lower tropospheric convective instability located over the Maritime Continent (105°E to 150°E) for the slow cluster and located further east over the eastern Maritime Continent- Western Pacific (130°E to 180°E) for the fast cluster.
- The regions of convective instability in the slow and fast clusters coincide with their respective longitudinal locations of enhanced low-level easterlies.
- In sharp contrast, no significant regions of convectively unstable layer are found in the standing and jumping clusters.

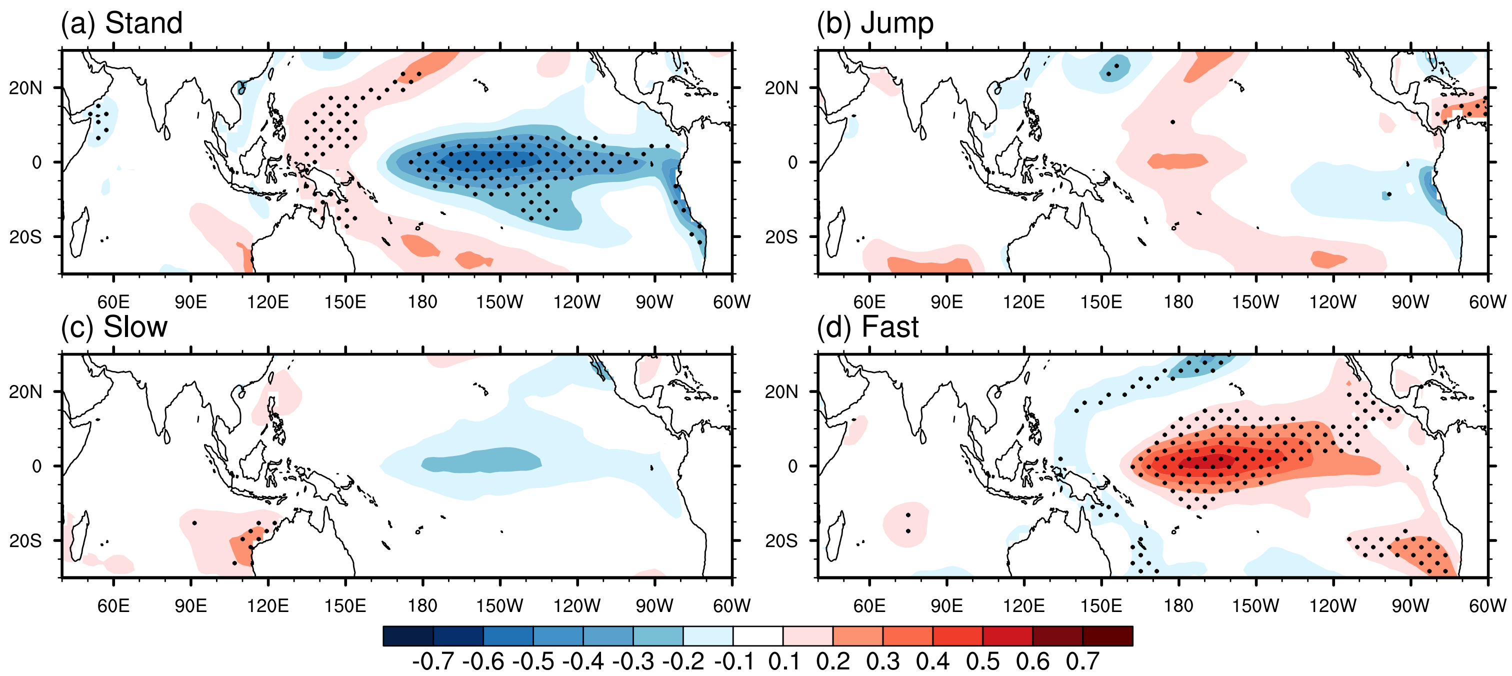
4. Mechanisms of the diversified MJO propagation

Based on the results shown in previous slides, the mechanism for MJO propagation diversity is illustrated in this schematic diagram



Root cause of variations in the strength of the Kelvin wave response

- The most notable feature is that the standing cluster is associated with a significant sea surface cooling over the central and eastern Pacific, reminiscent of a La Niña state, while the fast cluster is associated with a significant warming over the central and eastern Pacific, reminiscent of an El Niño state.
- The slow cluster is associated with a weak central Pacific cooling, while the jumping cluster is associatedwith aweak central Pacific warming, but these background SST anomalies are not statistically significant. Thus, the SST status for these two MJO groups can be considered as normal condition.
- Question: Since the strength of the Kelvin-wave response distinguishes different MJO clusters, how does the SST variation over the central Pacific affect the strength of the Kelvin-wave response?



Background SST anomalies for different MJO clusters

How background SST controls the strength of the Kelvin-wave response

Central Pacific warming

Expanded Indo-Pacific warm pool

Eastward expansion of MJO activity

Increase in MJO zonal scale

Stronger Kelvin wave response

\+ MJO is active over warm ocean — Zhang 2005

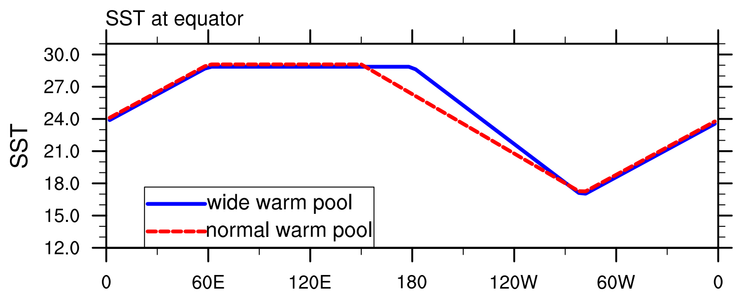
\+ MJO tends to amplify on larger zonal scale — (Adames and Kim 2016; Fuchs and Raymond 2017; Chen and Wang 2019)

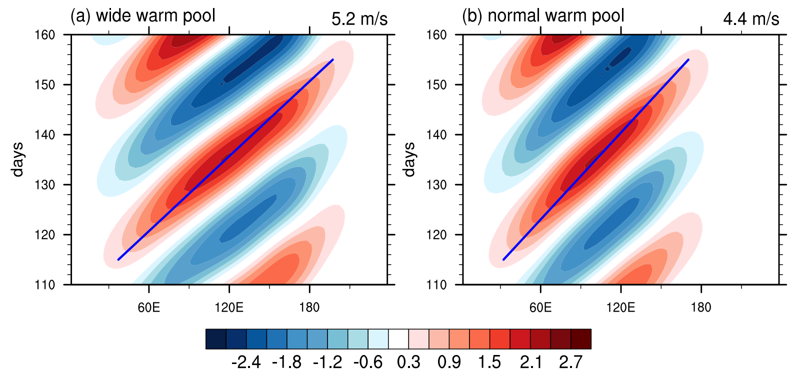
\+ Boundary layer convergence feedback tends to amplify the Kelvin wave response on larger zonal scale

Chen, G*., and B. Wang, 2019. *Clim. Dyn.*, 52, 5127.

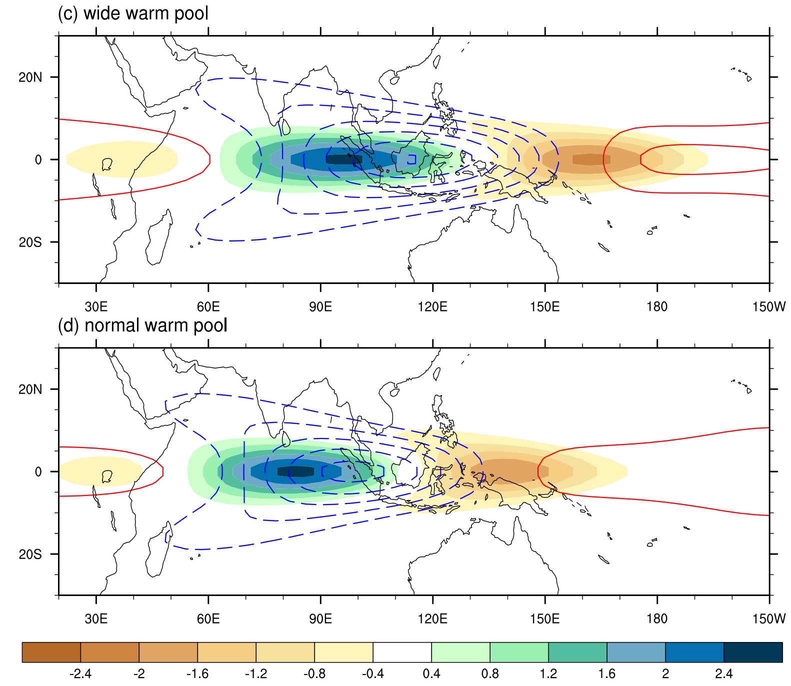
Numerical results

- Theoretical Model: Wang and Chen 2017, Climate Dynamics
- Modification: assuming linear heating (precipitation)
- Warm pool SST configuration (Gaussian distribution in meridional direction) for experiments, see figure on the right





(a)-(b) Propagation patterns for the two experiments.
(c)-(d) Horizontal patterns for the two experiments



The numerical work verifies that the zonally expanded warm pool favors faster propagation of MJO through enlarging the MJO zonal scale and enhancing the Kelvin-wave response

A narrow warm-pool configuration experiment (not shown here) shows that the ”MJO” signals become nonpropagating and the associated Kelvin-wave responses are weak, reminiscent of standing MJO.

Chen and Wang (2020), Journal of climate

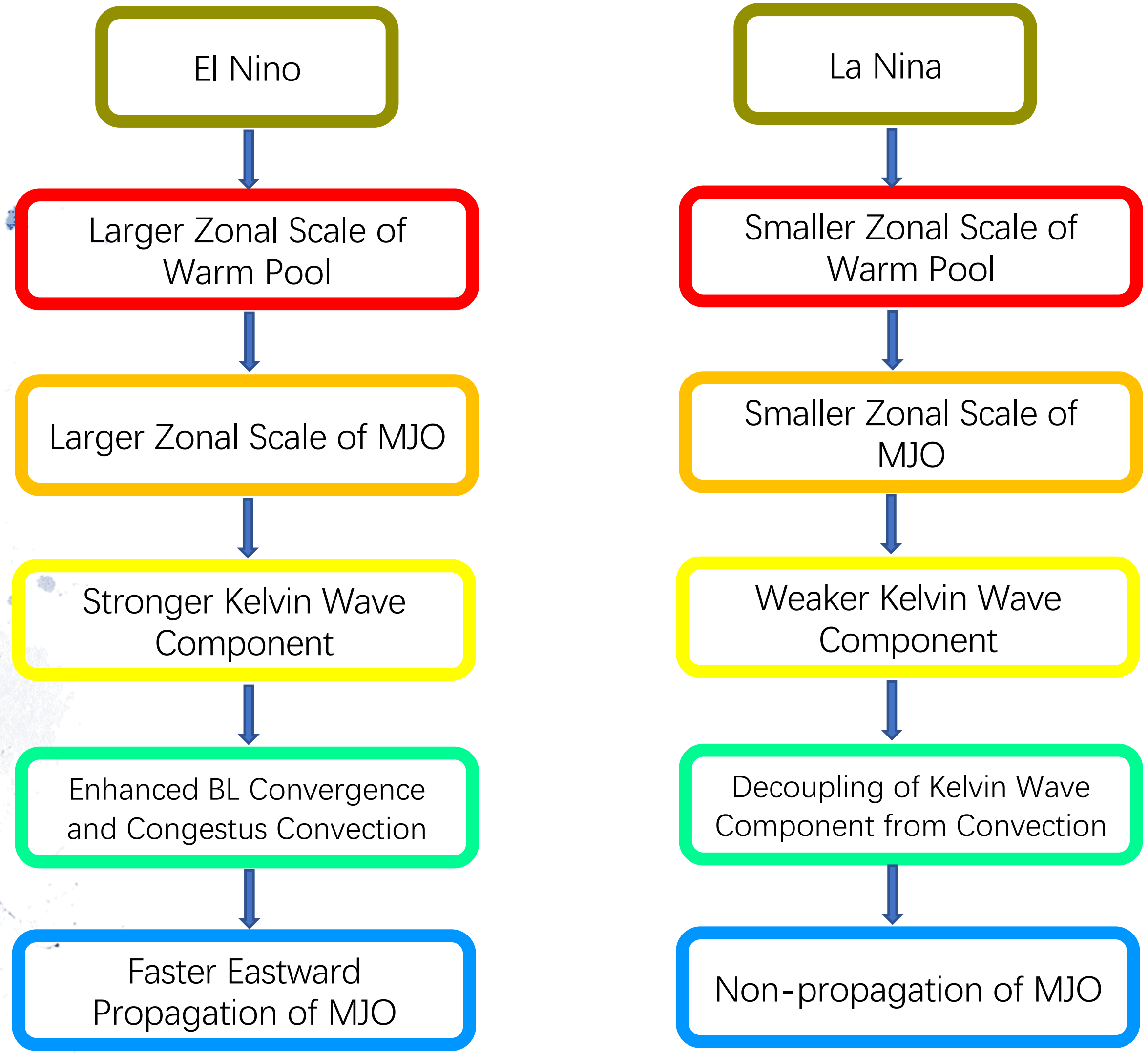
Summary

By using the K-means cluster analysis, the observed MJO propagation patterns during boreal winter can be objectively and systematically delineated into four archetypes of clusters: standing, jumping, slow eastward propagation, and fast eastward propagation.

Each type of MJO propagation exhibits distinctive circulation and thermodynamic structures. The Kelvin wave response to the MJO major convection and the associated features of the east-west structural asymmetry provide a set of indicators for predicting the ensuing propagation when MJO major convection center is established in the eastern Indian Ocean

The background SST condition affects the Kelvin wave response: An El Niño state tends to increase the zonal scale of Kelvin wave response, to amplify it, and to enhance its coupling to the convection, resulting in fast propagating MJO, while a La Niña state tends to decrease the zonal scale of Kelvin wave response, to suppress it, and to weaken its coupling to the major convection, resulting in standing MJO.

Schematic diagram for the mechanism of MJO propagation diversity



References:

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3. **Chen*, G.**, & Wang, B. (2019). *Climate dynamics, 52*, 5127.
4. Wang*, B., & **Chen, G**. (2017). *Climate dynamics, 49*(7), 2309-2328.

Thank you!