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# Roles of the westward propagating waves and the QBO in limiting MJO propagation

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## I. Four types of MJO

1. Apply the k-means cluster analysis by OLR Hovmöllor diagrams of MJO cases.
2. Examine the silhouette score for each cluster member.

+Details can be found in Wang et al., 2019

### ➢ Data

- Era-Interim Reanalysis
- NCEP/NOAA-interpolated OLR
- Extended Reconstructed Sea Surface Temperature version 5 (ERSSTv5) dataset

### ➢ Method

- Composite analysis
  - student-t significance test
- Moisture budget analysis

Non-Penetrating (NP) and Eastward-Penetrating (EP) MJO

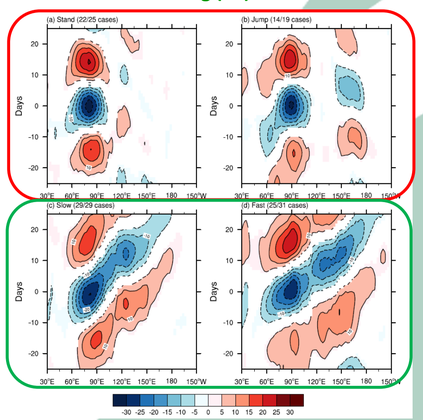


**Fig. 1 Composited OLR Hovmöllor diagrams (10S-10N) for four types of 104 MJO cases identified in 1979-2013.** Stand and Jump MJO cases are viewed as **non-penetrating (NP) MJO** while slow and fast MJO cases are seen as **eastward-penetrating (EP) MJO**.

## II. QBO and ENSO phase preferences among MJO types

### ➢ NP MJO:

- An apparent preference of QBOW phase.
  - Stand MJO: a preference of La Nina condition.

### ➢ EP MJO:

- No preference of QBO phase.
  - Fast MJO: a preference of El Nino condition.

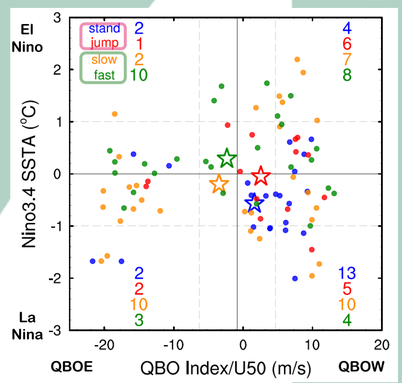


**Fig. 2 Phase diagram of QBO and ENSO for MJO cases.** X axis refers to the QBO index defined as global mean of equatorial (5S-5N) monthly zonal wind. Y axis refers to the ENSO index using monthly Nino3.4 index.

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+Wang B, Chen G, Liu F. Diversity of the Madden-Julian oscillation[J]. Science Advances, 2019, 5(7): eaax0220.

## III. Disrupted pre-moistening over MC due to westward-propagating waves (WPW)

### ➢ NP MJO

**i.** Active convection of WPW hinders the descending branch of MJO circulation.

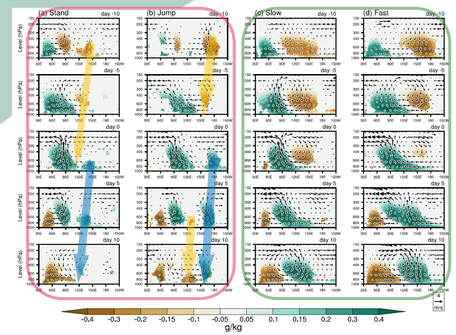


**Fig. 3 Vertical sections of equatorial intraseasonal wind (vectors) and specific humidity (shadings) anomalies for four MJO types.**

**ii.** Weakened/missing poleward wind anomalies over the southern sea surface of MC.

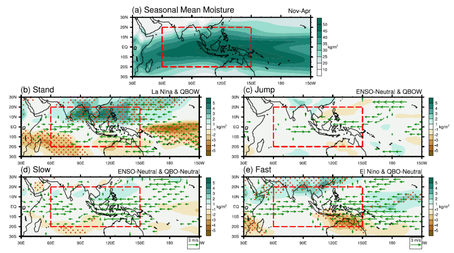


**Fig. 4 Composited maps of (a) seasonal-mean integrated (surface to 100hPa) specific humidity climatology, (b)-(d) intraseasonal wind anomalies (vectors) and deviations of the integrated specific humidity from its climatology in (a) for four MJO types.**

**iii.** Insufficient meridional moisture advection leads to in sufficient pre-moistening over the southern sea surface of MC.

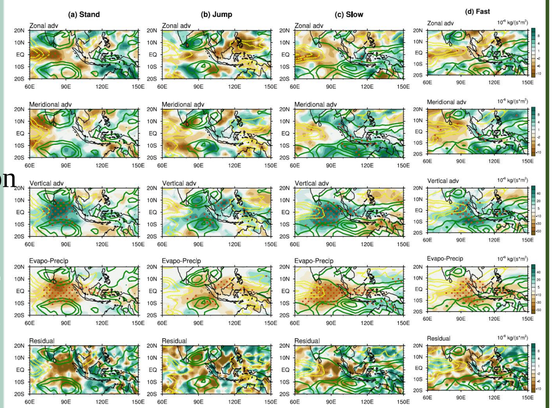


**Fig. 5 Composited maps of intraseasonal moisture tendencies (lines) and right-hand-side terms of moisture budget analysis (shadings) for four MJO types.**

## IV. Decoupled tropopause instability due to preferred QBOW phase

### ➢ NP MJO

- Dissipated heating structure.
- Decoupled, propagating tropopause instability.

### ➢ EP MJO

- Well-organized heating structure.
- Coupled tropopause instability.

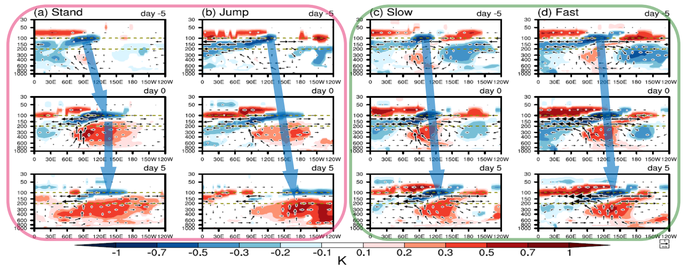


**Fig. 6 Vertical sections of equatorial intraseasonal wind (vectors) and temperature (shadings) anomalies for four MJO types.**

### ➢ NP MJO

Fails to penetrate MC due to missing pre-moistening caused by WPWs

- **Jump MJO (QBOW)**

Decoupled tropopause instability enhances WPWs over central Pacific and leads to the independent convection as in Fig. 1b.

- **Stand MJO (QBOW + La Nina)**

Decoupled tropopause instability, but La Nina-like cool SST confines WPW over western Pacific.

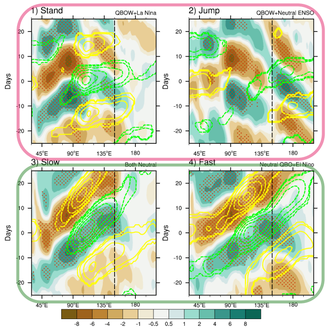


**Fig. 7 Hovmöllor diagrams (10S-10N) of intraseasonal tropopause instability (T100-T200, lines) and moisture tendency (shadings) for four MJO types.**

## V. Caveats and future work

- ❑ Limited sample size especially for jump MJO cases.
- ❑ Correlation does not guarantee causality.
- ✓ Diagnostics and sensitivity experiments using climate models.

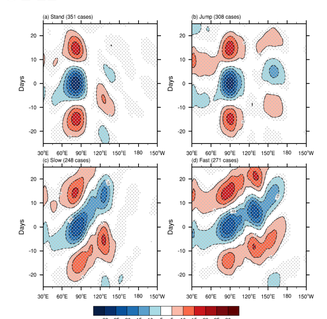


**Fig. 8 OLR Hovmöllor diagrams (10S-10N) of for four types of 1,178 MJO cases in CESM2 historical ensemble simulations for CMIP6.**