Distorted MJO Propagation by QBO through Multi-Scale Interactions over the Maritime Continent

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Office of Science
Biological and Environmental Research
Regional and Global Model Analysis

QBO Impacts on MJO

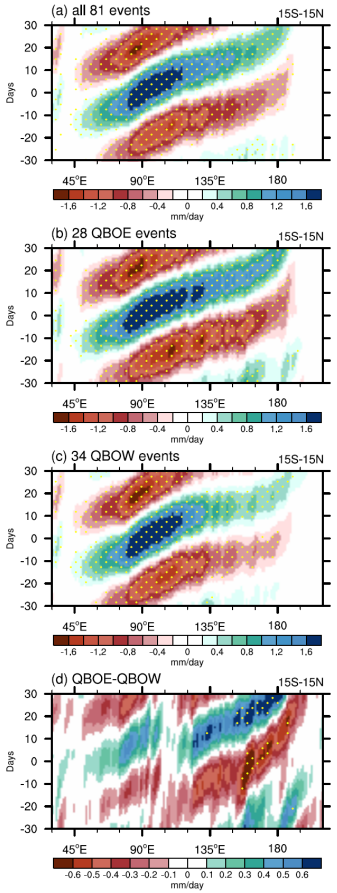
- The Madden-Julian Oscillation (MJO) is stronger and more likely to propagate across the Maritime Continent in the easterly phase of QBO than the westerly phase of QBO.
  - **Seasonality** → only in the boreal winter seasons
  - **Location Preference** → centered around the MC
  - **Uniqueness** → no impacts on other organized convective systems in tropics
  - **Emergency** → not detected before the 1980s

- Several mechanisms are proposed in the past decade, but the connection is not thoroughly understood.
  - **wind shear** (Collimore et al., 2003), **tropopause stability** (Hendon & Abhik, 2018), **cloud-radiative feedback** (Son et al., 2017), **extratropical wave forcing** (Hood & Hoopes, 2023), **solar cycle** (Hood et al., 2023), **sea surface temperature** (Randall et al., 2023) …

- All climate models suffer from the missing of such QBO-MJO connection.
  - even with a prescribed stratosphere **same as** the observations (Martin et al., 2021, Martin et al., 2023).

- The QBO-MJO connection is slightly captured by the forecast systems and MJO case simulations.
  - Martin et al., (2019) Martin et al., (2020) Back et al., (2020) Huang et al., (2023)

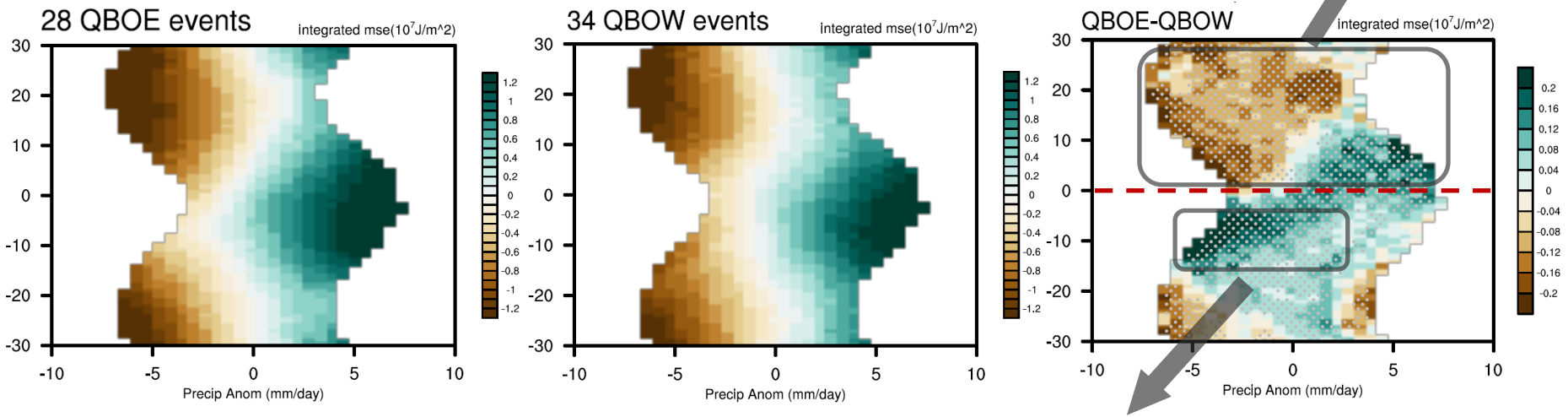
MJO Events in NDJFM
(1979-2020 of ERA-5)



QBO Modulates the Environmental Conditions for MJO Precipitation

higher MSE for positive precip
lower MSE for negative precip

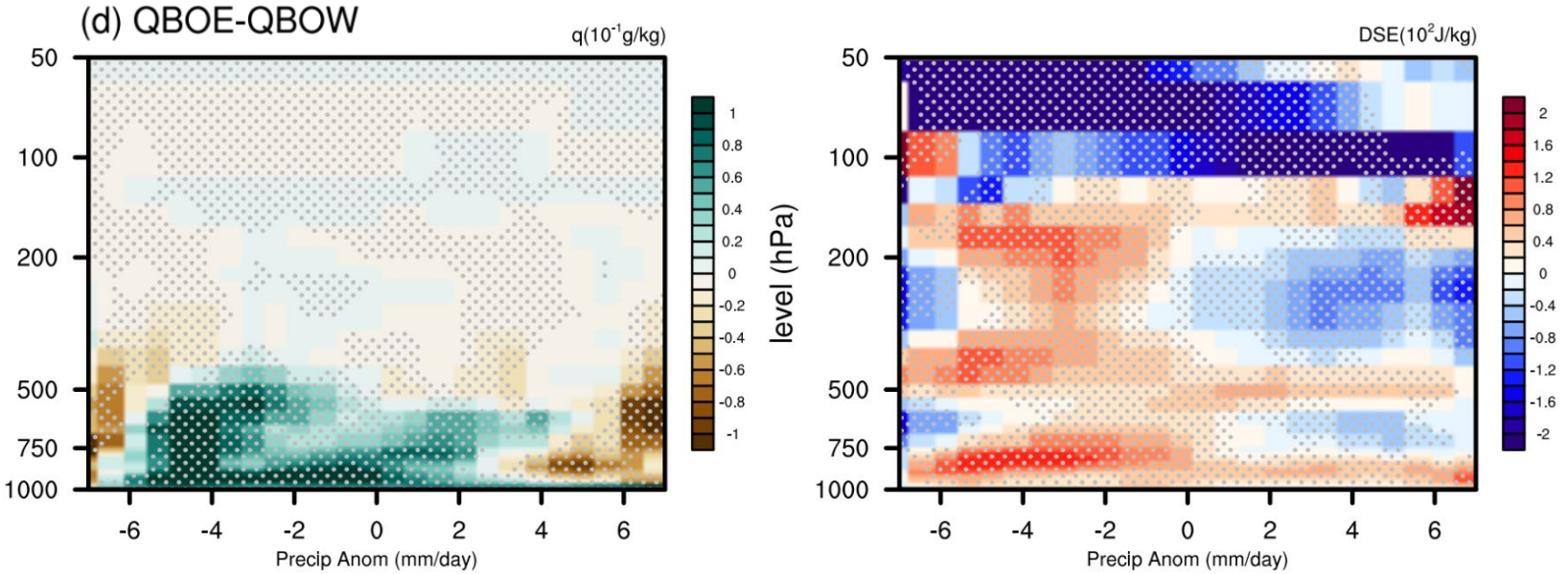
Environmental MSE for the MJO Precipitation Anomalies over the Indian Ocean Domain (70E-100E,15S-5N)



Precursors of higher MSE even for negative MJO precipitation anomalies before day 0

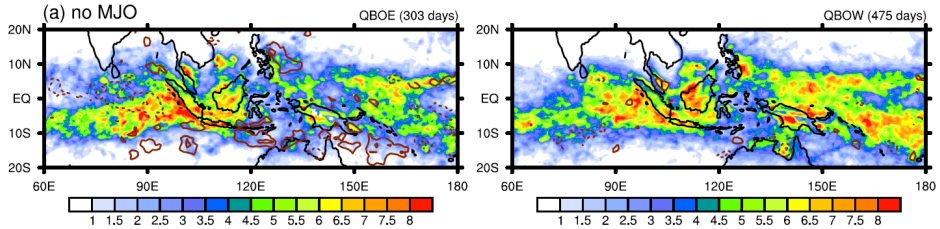
QBO Modulates the Environmental Conditions for MJO Precipitation

Environmental humidity and Dry Static Energy for MJO precipitation
from day -15 to day -5 over the Indian Ocean Domain
(70E-100E,15S-5N)

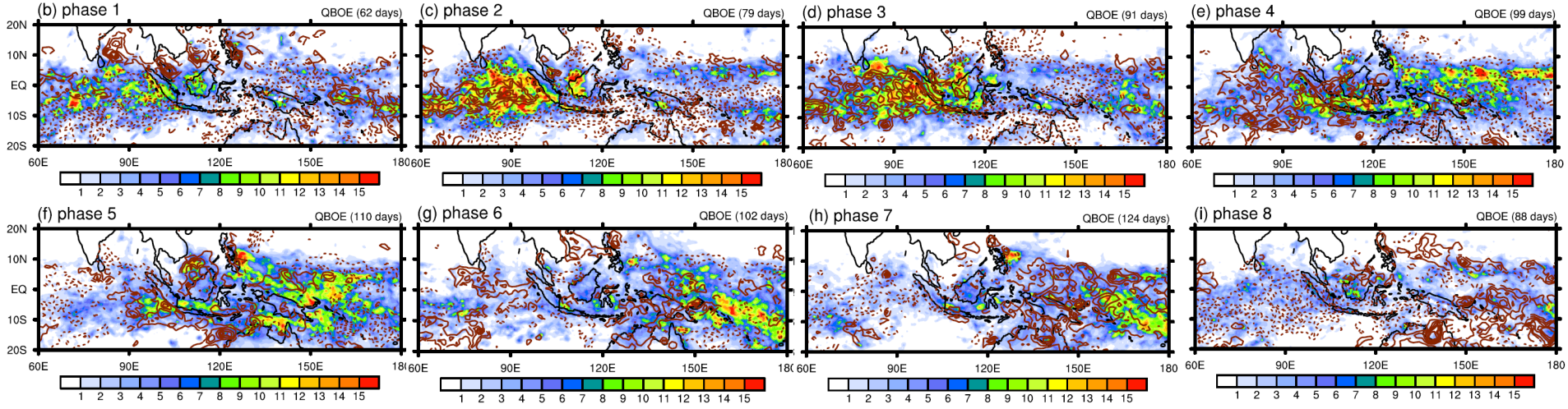


Sequencing between MJO and MCS Precipitation

Lines: MJO precip (20-100-day)
Colors: MCS precip



In QBOE phase, MCS precipitation anomalies always leads the MJO convection to propagate eastward in the following phase.



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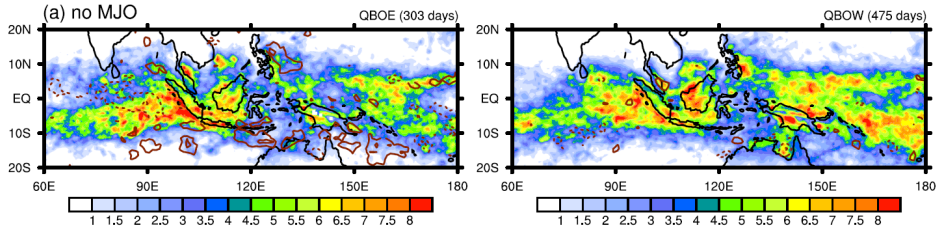
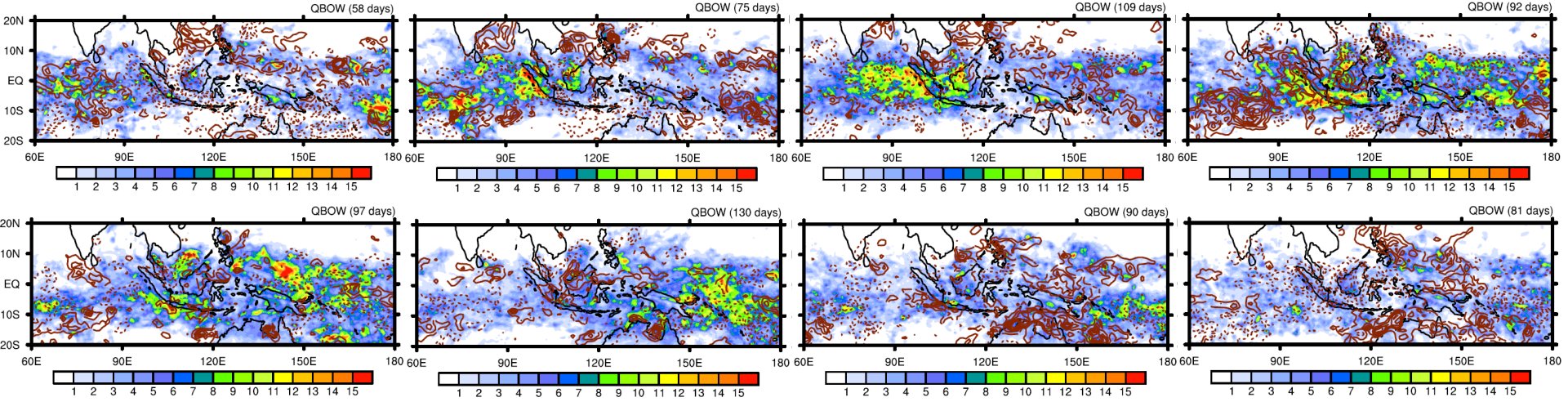


In QBOW phase, the leading MCS are suppressed over the Indian Ocean and MC, and MJO convection are weaker, less organized, and less likely to cross MC.



Take-Home Messages

- **QBO modulates the MCS propagation over the MC, leading to more local MCS activities over the Indian Ocean in the QBOE season.**

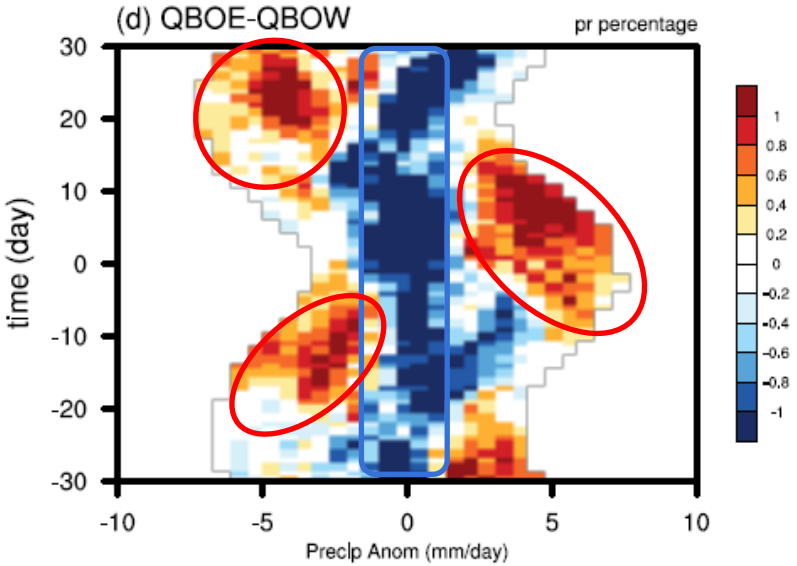
- **The increased MCS activities pump moisture from the boundary layer to the free troposphere, creating a favorable wetter and warmer environment for the following MJO convection development.**

- **MJO is therefore stronger in the QBOE phase and more likely to propagate across the Maritime Continent.**

- **This potential new mechanism could explain several QBO-MJO connection features.**
  - **Seasonality**: MJO cross the MC through the southern sea surface where the MCS activities are strong only in the boreal winter seasons.
  - **Location Preference**: MC is the area with strongest MCS activities in the tropical Indo-Pacific.
  - **Uniqueness**: MJO relies more on the moisture variation than over tropical convective systems.
  - **Emergency**: No MCS satellite observations feeding into the reanalysis datasets before the 1980s.
  - **Missing in the climate models**: MCS simulations remains a problem there.
  - **Detected in the reanalysis and prediction systems**: the regional wetting and warming effects of MCS could be assimilated to the initial fields.

QBO Modulates the Environmental Conditions for MJO Precipitation

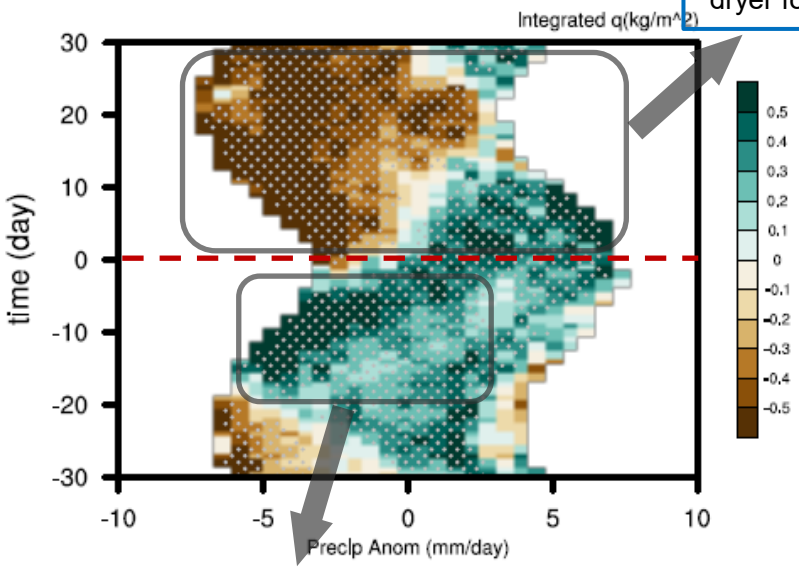
Occurrence Rate for the MJO Precipitation Anomalies over the Indian Ocean Domain (70E-100E,15S-5N)



Increased occurrence rates at both tails and decreased occurrence rates for mild anomalies suggests a stronger MJO variation in QBOE than QBOW seasons.

Environmental Humidity for the MJO Precipitation Anomalies over the Indian Ocean Domain (70E-100E,15S-5N)

wetter for positive precip
dryer for negative precip



wetting precursors even for negative MJO precipitation anomalies before day 0

QBO Modulates the Environmental Conditions for MJO Precipitation

Environmental humidity and dry static energy for MJO precipitation
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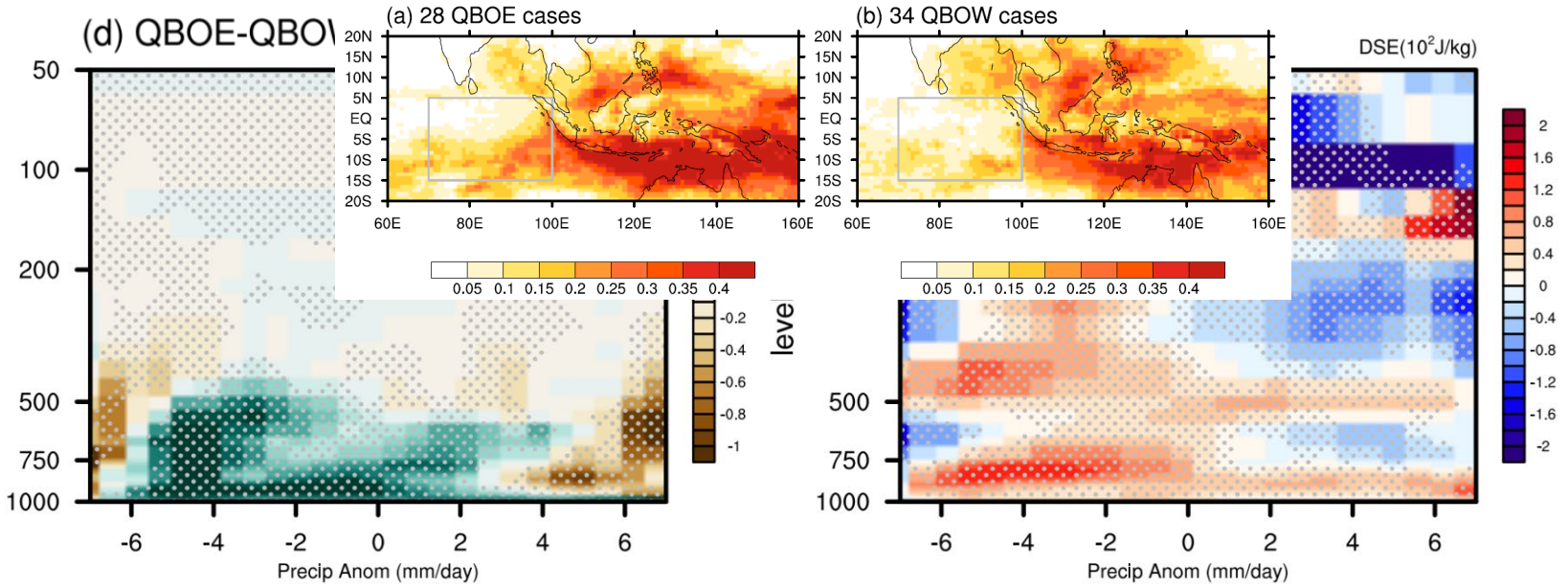
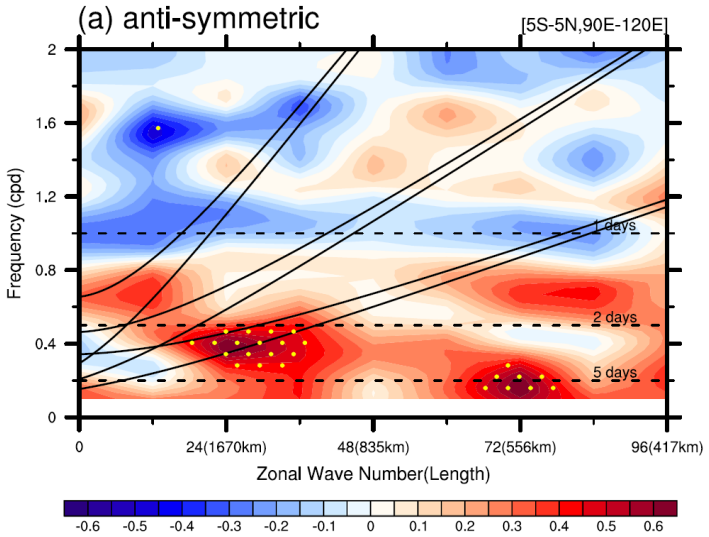


QBO Influences on Meso-scale Convective Systems

Correlation of the E/W Ratio against the QBO index



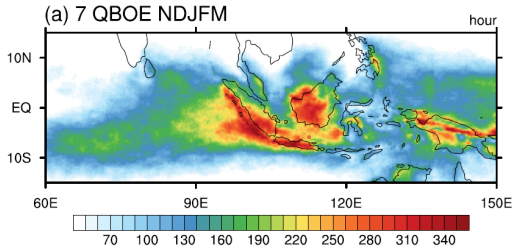
- Global Precipitation Measurement Mission satellite data
- half-hourly
- 0.1 degree by 0.1 degree
- 2000 to 2020

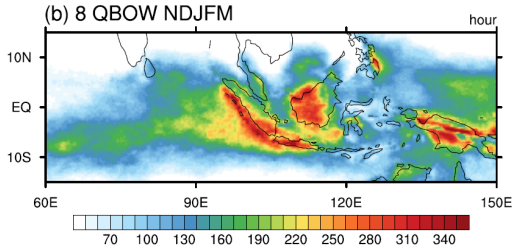
- MCS tracking algorithm and data from Dr. Zhe Feng at PNNL

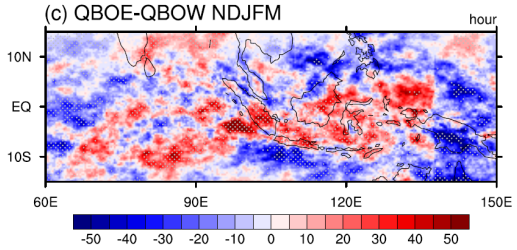
- The 2-5-day, small-scale waves are more westward-propagating in the QBOE than QBOW NDJFM seasons.

- The MCS west of the Sumatra Island can extend more westward into the deep Indian Ocean in the QBOE NDJFM seasons as a result.

accumulated MCS hours

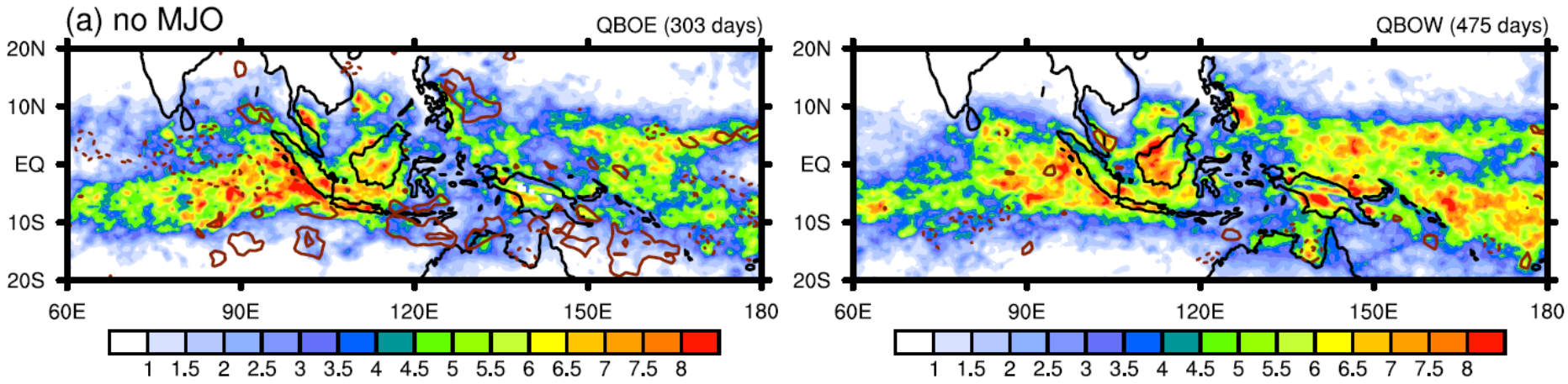






Sequencing between MJO and MCS Precipitations

Lines: MJO precip (20-100-day)
Colors: MCS precip



The more westward-propagating MCS in the QBOE phase is also seen here

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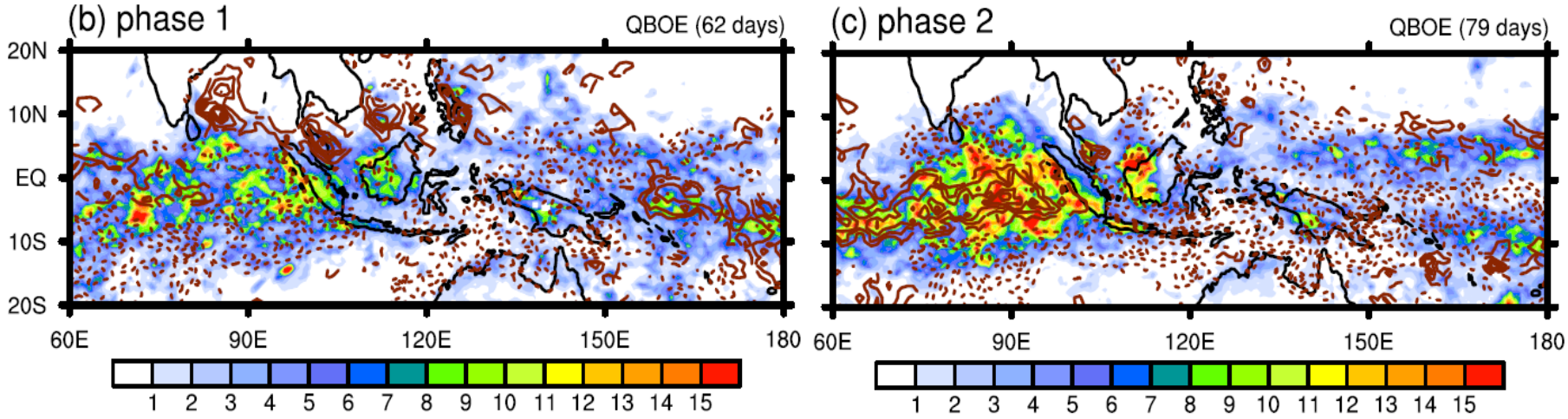

In QBOE phase, MCS precipitation provides favorable pre-conditioning for MJO convection from RMM phase 1 to phase 2.

Sequencing between MJO and MCS Precipitations

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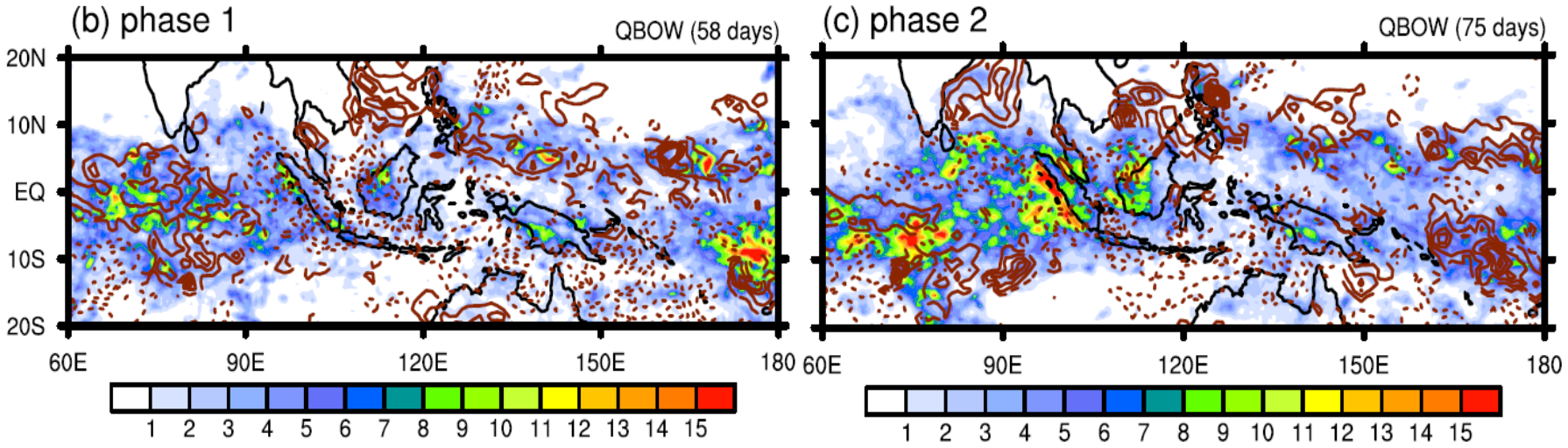

In QBOW phase, the leading MCS are suppressed over the Indian Ocean in RMM phase 1 and 2, and MJO convection are weaker and less organized.

Sequencing between MJO and MCS Precipitations

Lines: MJO precip (20-100-day)
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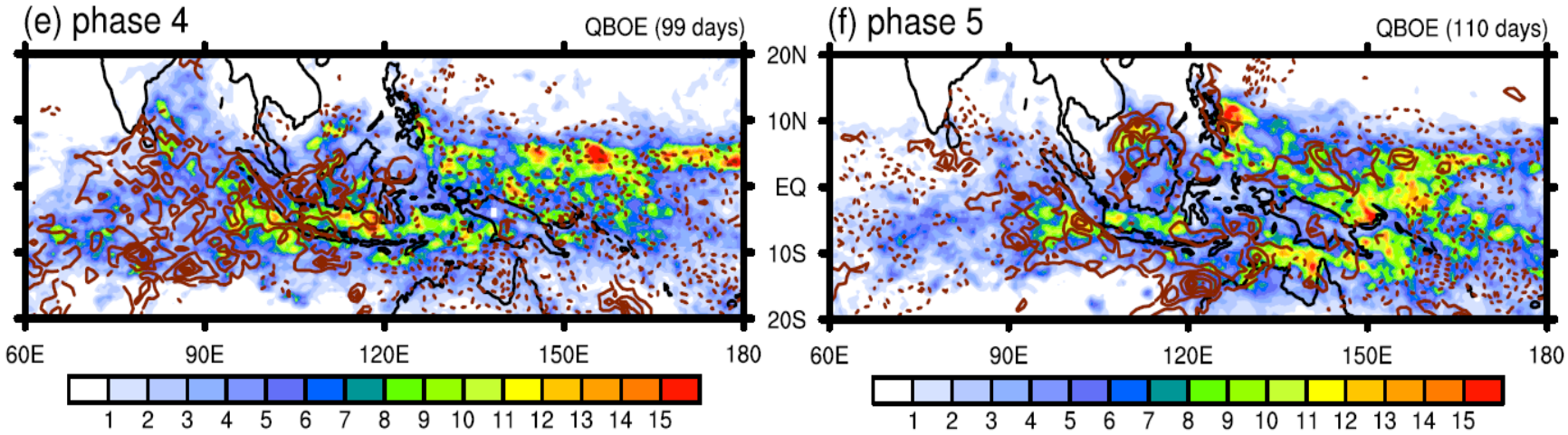
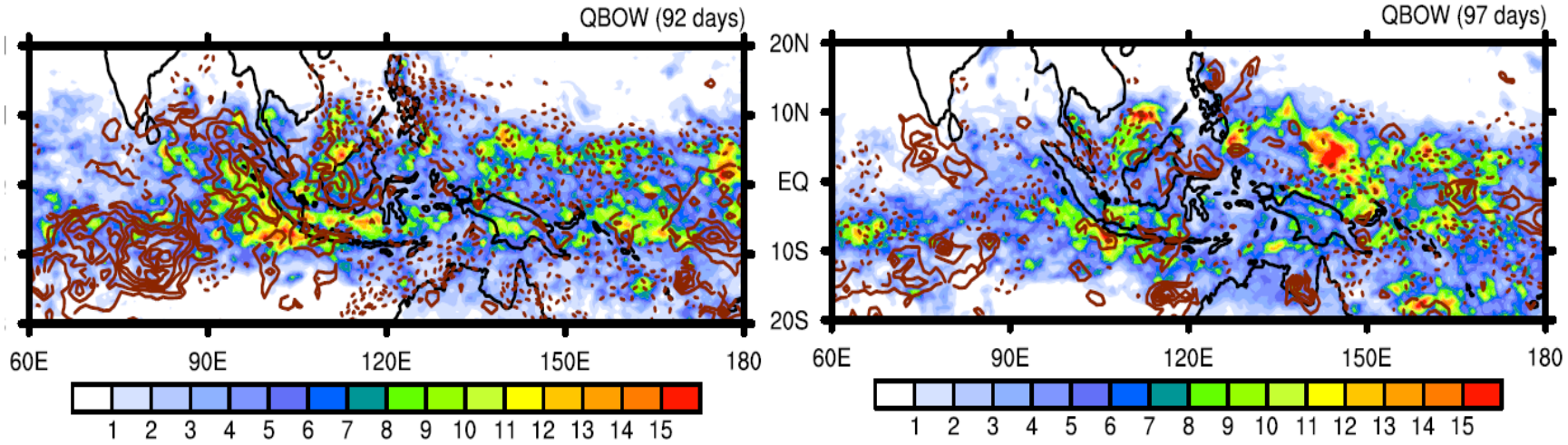


In QBOE phase, MCS precipitation also promotes the MJO propagation across the MC from RMM phase 4 to phase 5

Sequencing between MJO and MCS Precipitations

Lines: MJO precip (20-100-day)
Colors: MCS precip



In QBOW phase, MCS precipitation are suppressed over central-eastern MC, and the MJO propagation from RMM phase 4 to phase 5

What is the mechanism behind?

Geophysical Research Letters

Research Letter | Free Access

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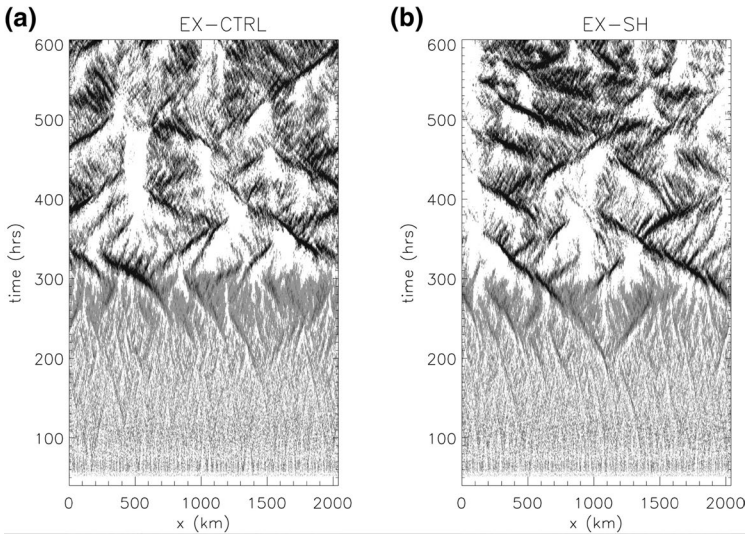
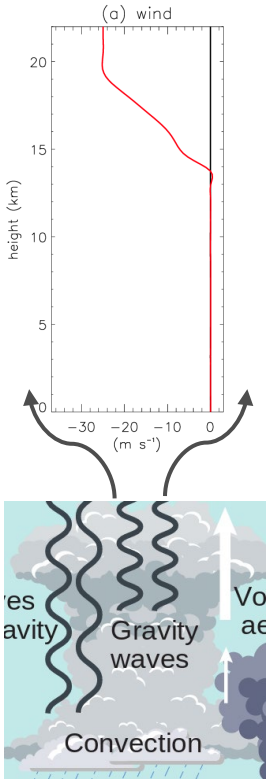
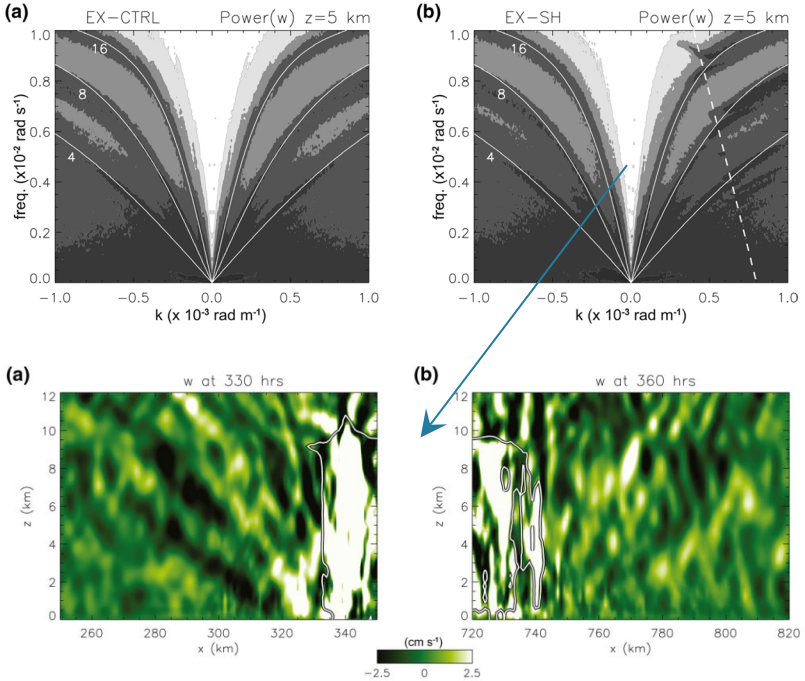
Todd P. Lane

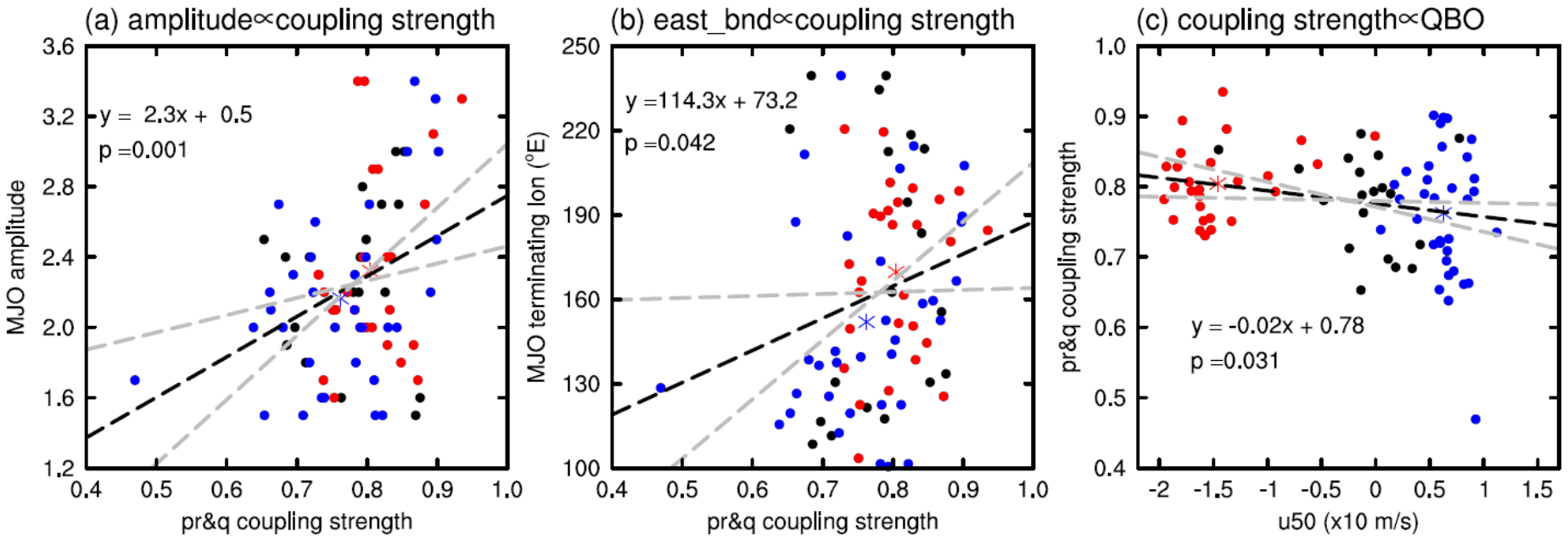
First published: 12 January 2021 | https://doi.org/10.1029/2020GL091025 | Citations: 6

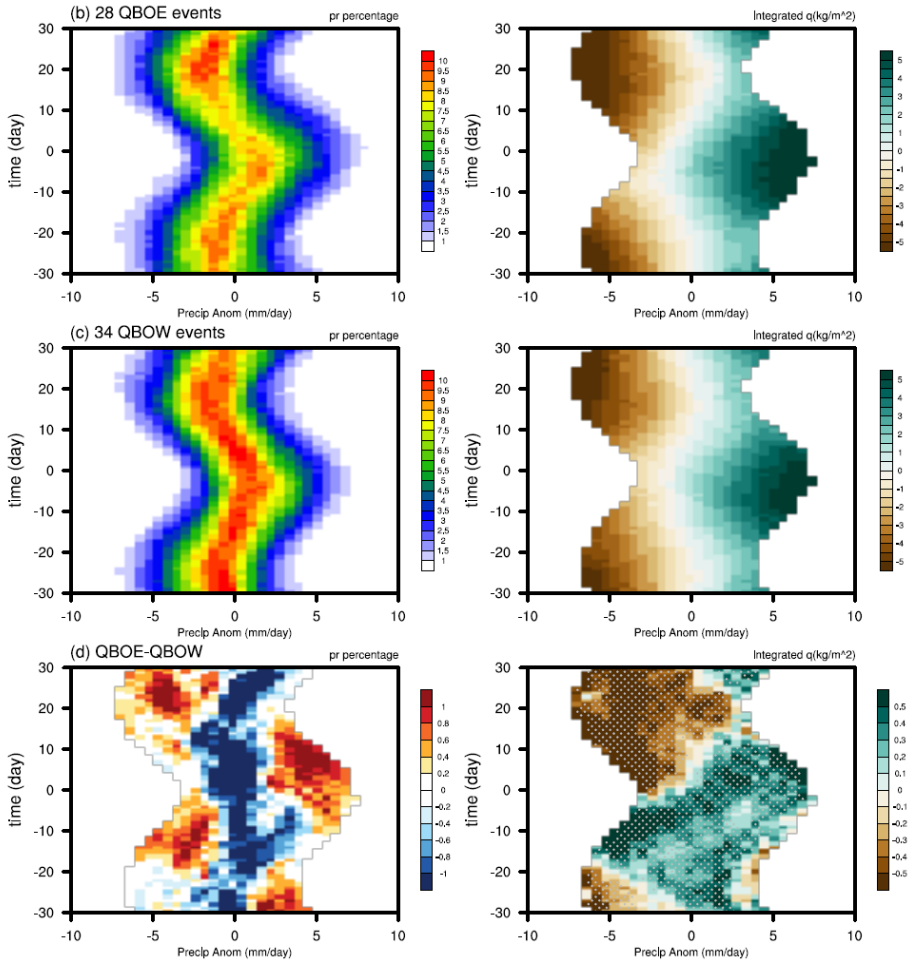






Linear Regressions between the MJO Pr&q Coupling Strength against MJO Properties and QBO index




(b) 28 QBOE events
pr percentage
Integrated q(kg/m^2)
(c) 34 QBOW events
pr percentage
Integrated q(kg/m^2)
(d) QBOE-QBOW
pr percentage
Integrated q(kg/m^2)
time (day)
Preclp Anom (mm/day)

NDJFM SST (2000-2020)