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# Modulation of global monsoon systems by the equatorial Quasi-Biennial Oscillation

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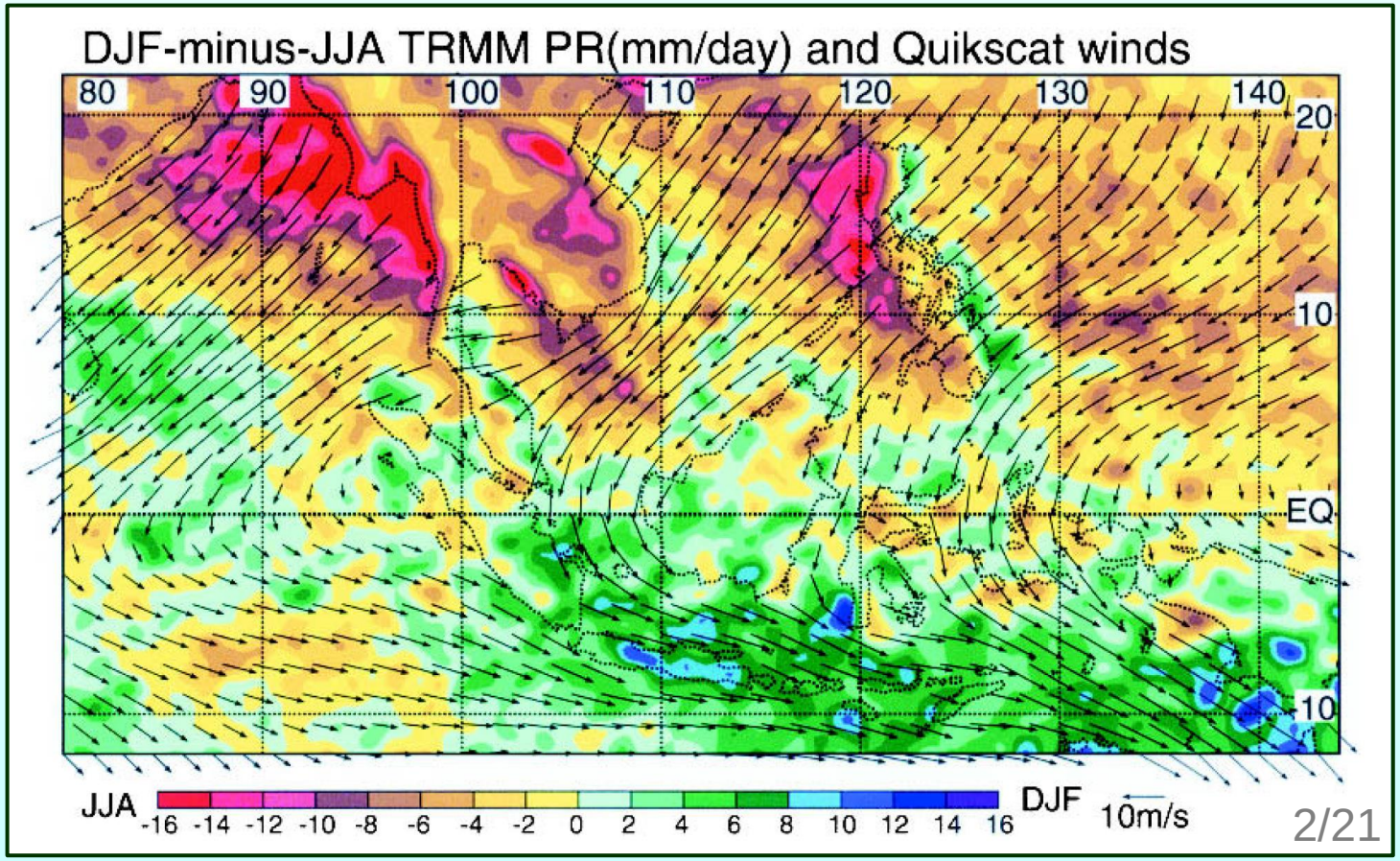
# 1. Introduction

- Monsoon
  is a periodic annual-cycle response of a large-scale circulation system in low- and mid-latitudes to the annual solar forcing variation due to the revolution of the Earth around the Sun.
- It is driven by
  a continental-scale contrast between lands and oceans.

Chang et al. (Eds., 2017)
"The Global Monsoon System. Research & Forecast - 3rd Ed."

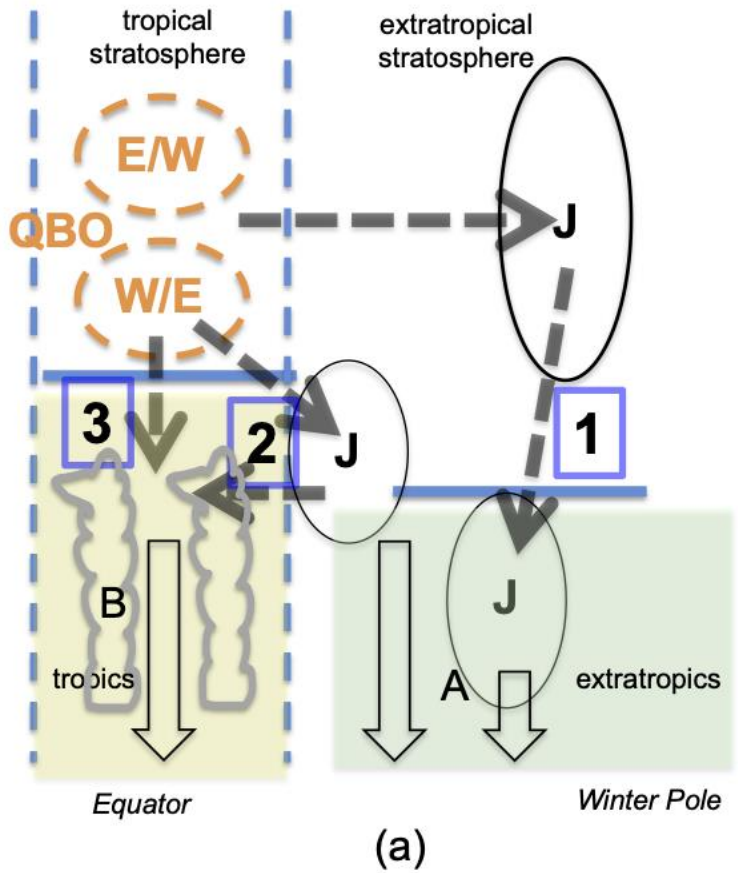
Chang et al. (2005)
SE Asia - Maritime Continent rainfall and the asymmetric monsoon transition



# ❖ Stratosphere-troposphere dynamical coupling in the tropics

- WCRP/SPARC SATIO-TCS:
  Stratospheric And Tropospheric Influences On Tropical Convective Systems
  - Haynes et al. (2021, *JMSJ*) "The influence of the stratosphere on the tropical troposphere"
  - Martin et al. (2021, *Nature Rev. Earth & Environment*) "The influence of the QBO on the MJO"

Haynes et al. (2021)



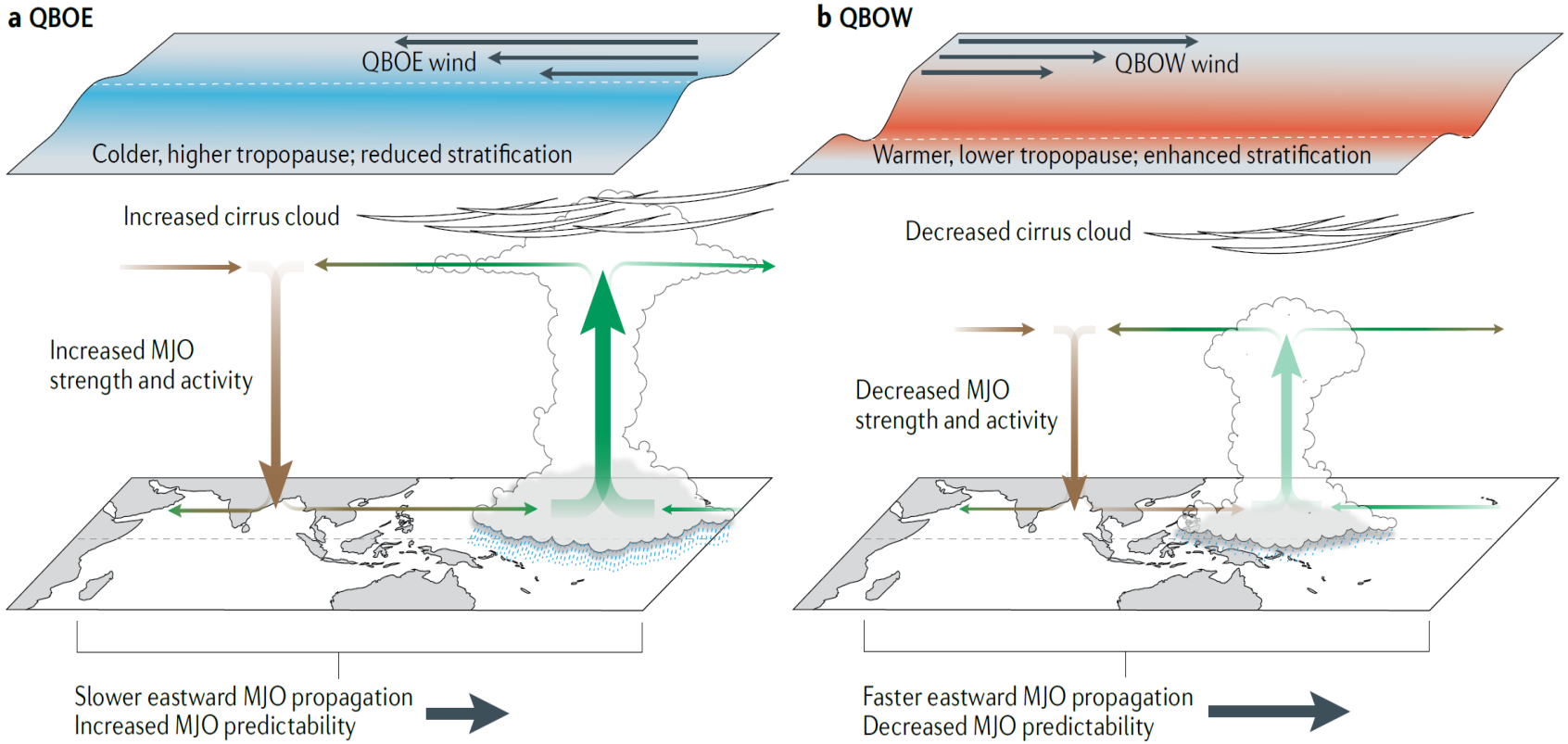
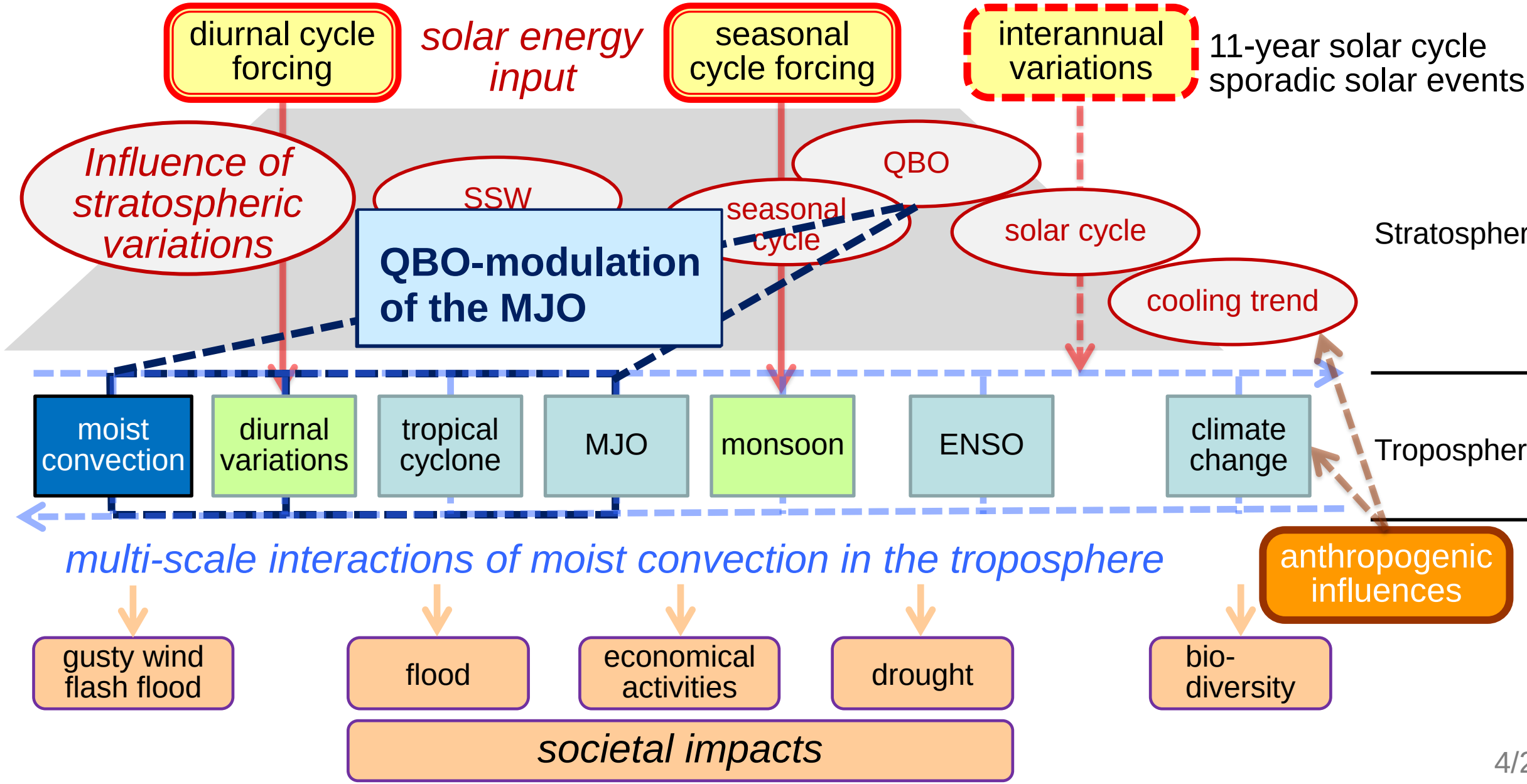



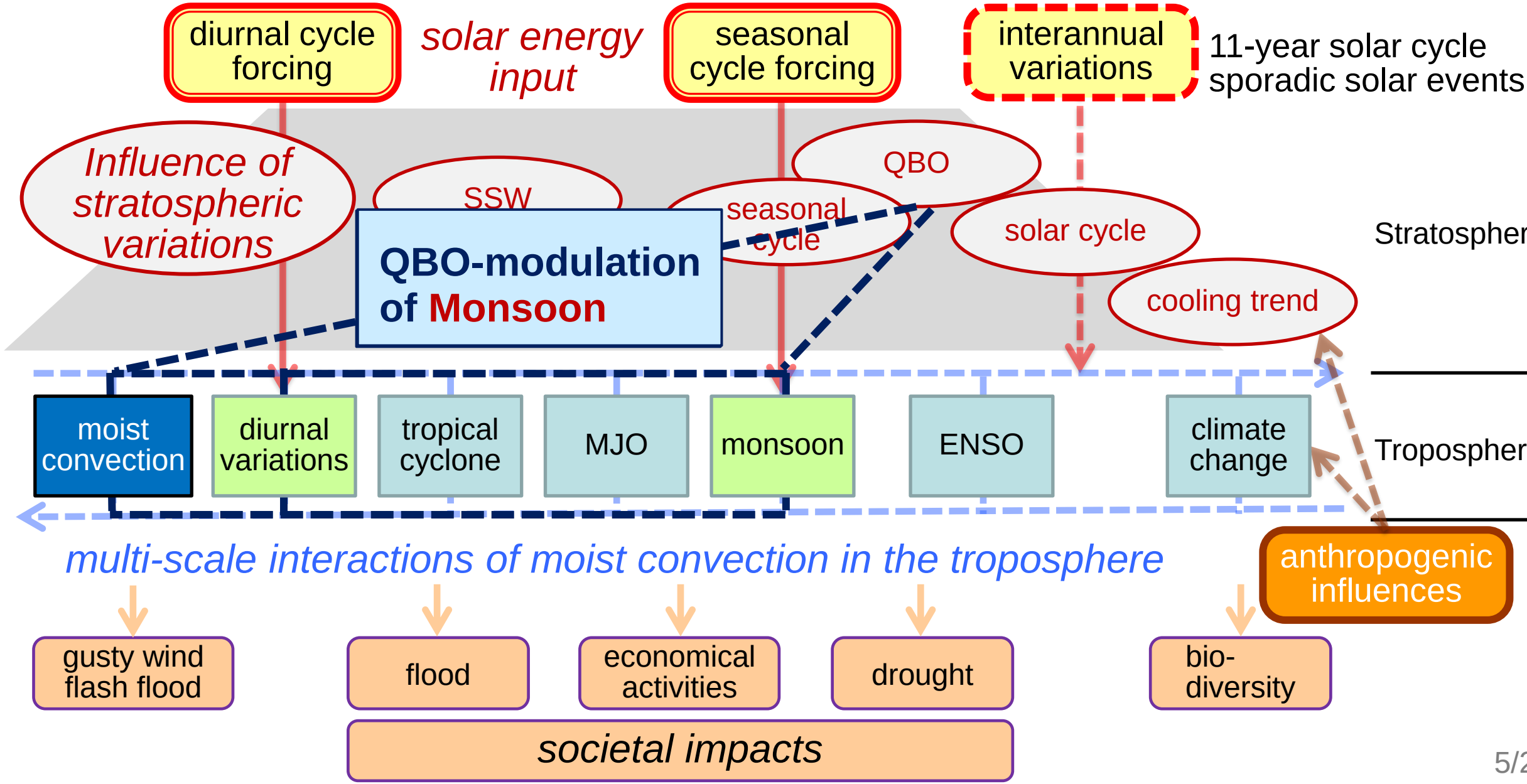

Fig. 5 | **Schematic illustration of the OBO–MIO connection.** Mechanisms and impacts of quasi-biennial oscillation

Martin et al. (2021) **https://rdcu.be/cl9ah**, which includes 120 references

# Stratospheric influence on tropical tropospheric processes on different timescales and possible couplings between them



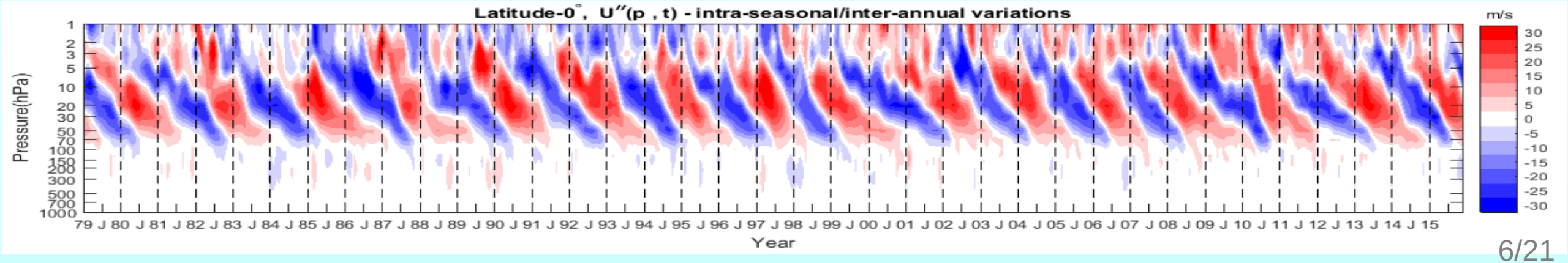
# Stratospheric influence on tropical tropospheric processes on different timescales and possible couplings between them



❖ In this study, we investigate
the QBO modulation of global monsoon systems, which include multi-scale interactions associated with moist convection in the tropics.

- analyze only neutral ENSO periods, excluding the influences of El Nino or La Nina
- separating the analysis for two solstice seasons:
  boreal summer (Jun., Jul., Aug.; JJA) and austral summer (Dec., Jan., Feb.; DJF)
- not only precipitation and its proxy data, but also circulation fields (monthly mean)
  GPCC precipitation; NOAA OLR; ERA-Interim **U**(U,V,W), MSLP, $Div_2$**V**, T, q (specific humidity)
- long dataset as possible = 40 years for 1979 to 2018
  → statistical significance of composite differences between opposite QBO phases

Monthly-mean zonal-mean zonal wind anomaly, U" (deviation from the climatological annual cycle)



# 2. Monsoon Climatology for neutral ENSO periods

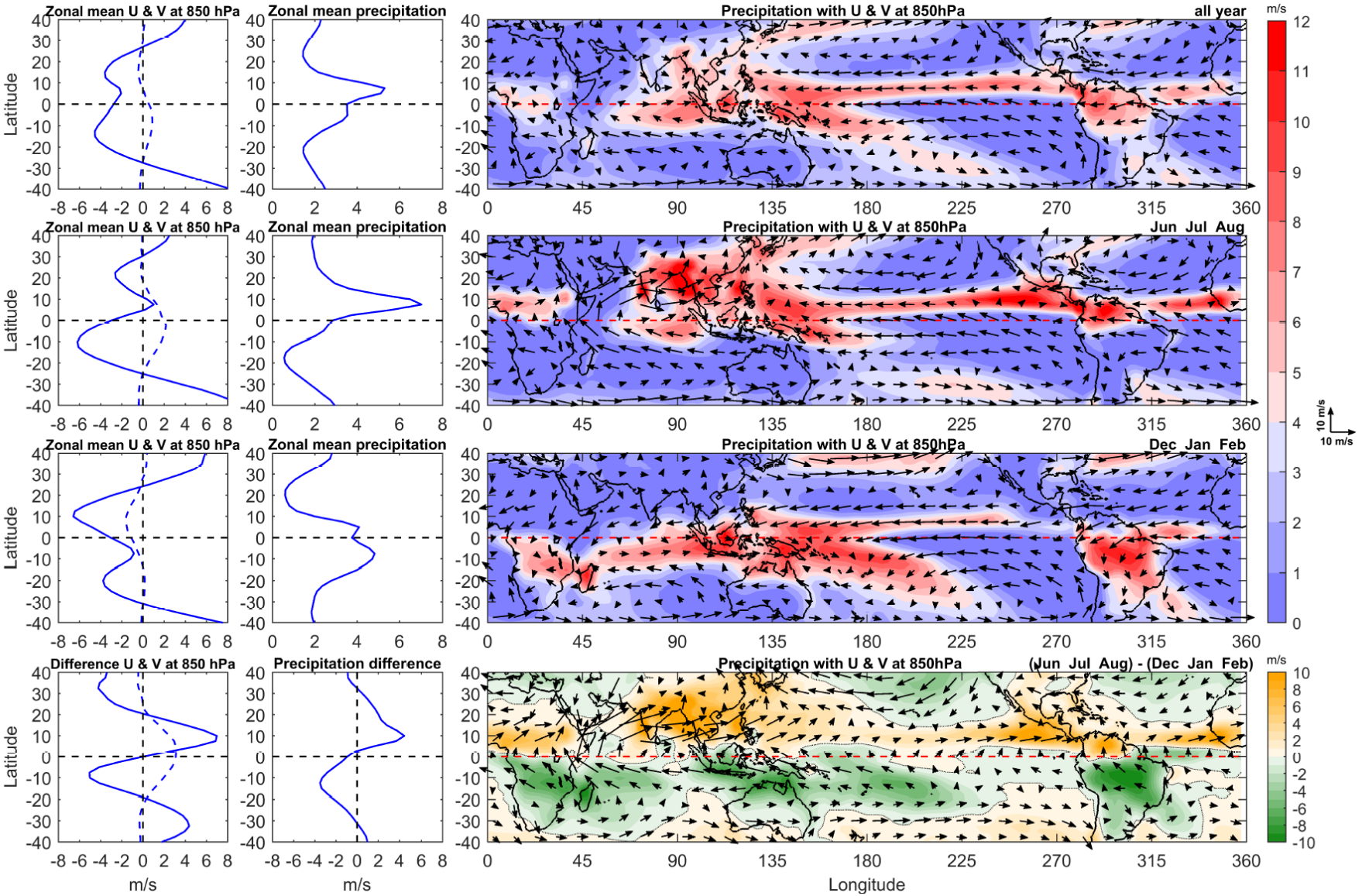
- GPCP precipitation + (U,V) @850hPa

All year

JJA

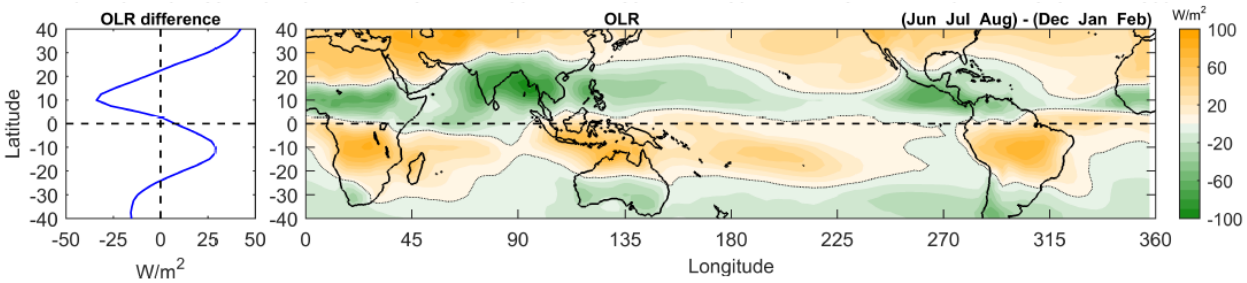
DJF

JJA - DJF

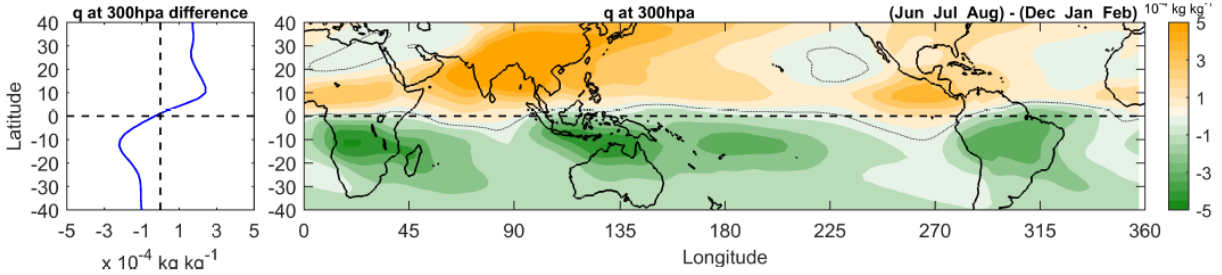


# ❖ JJA - DJF

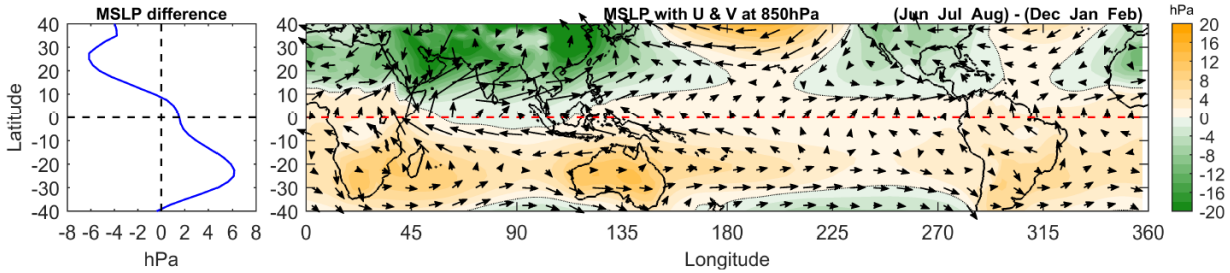
## OLR



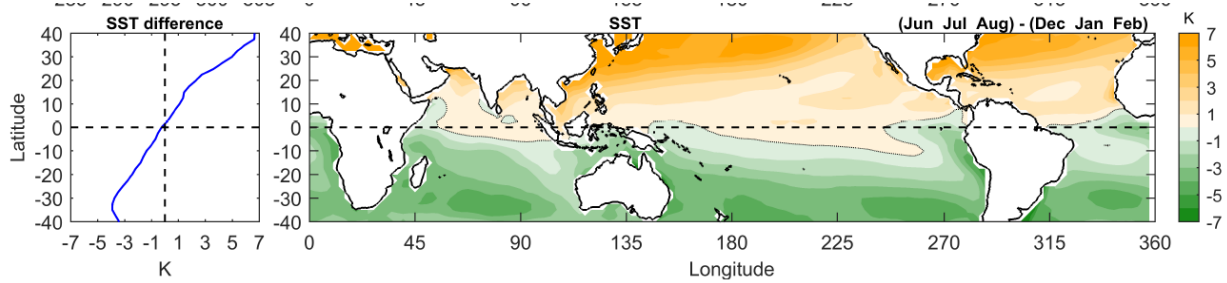

## specific humidity, q @300hPa



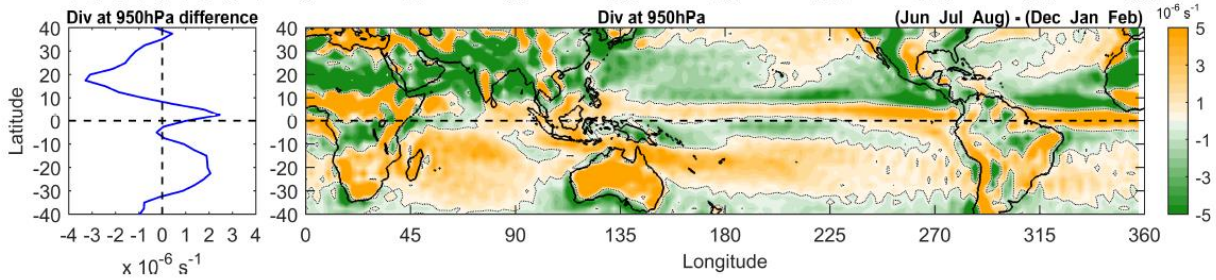

## MSLP + (U,V) @850hPa



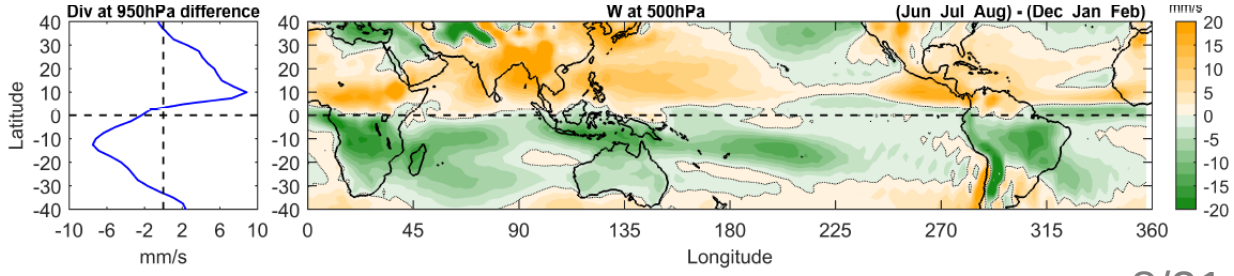

## SST




## $Div_2(U,V)$ @950hPa

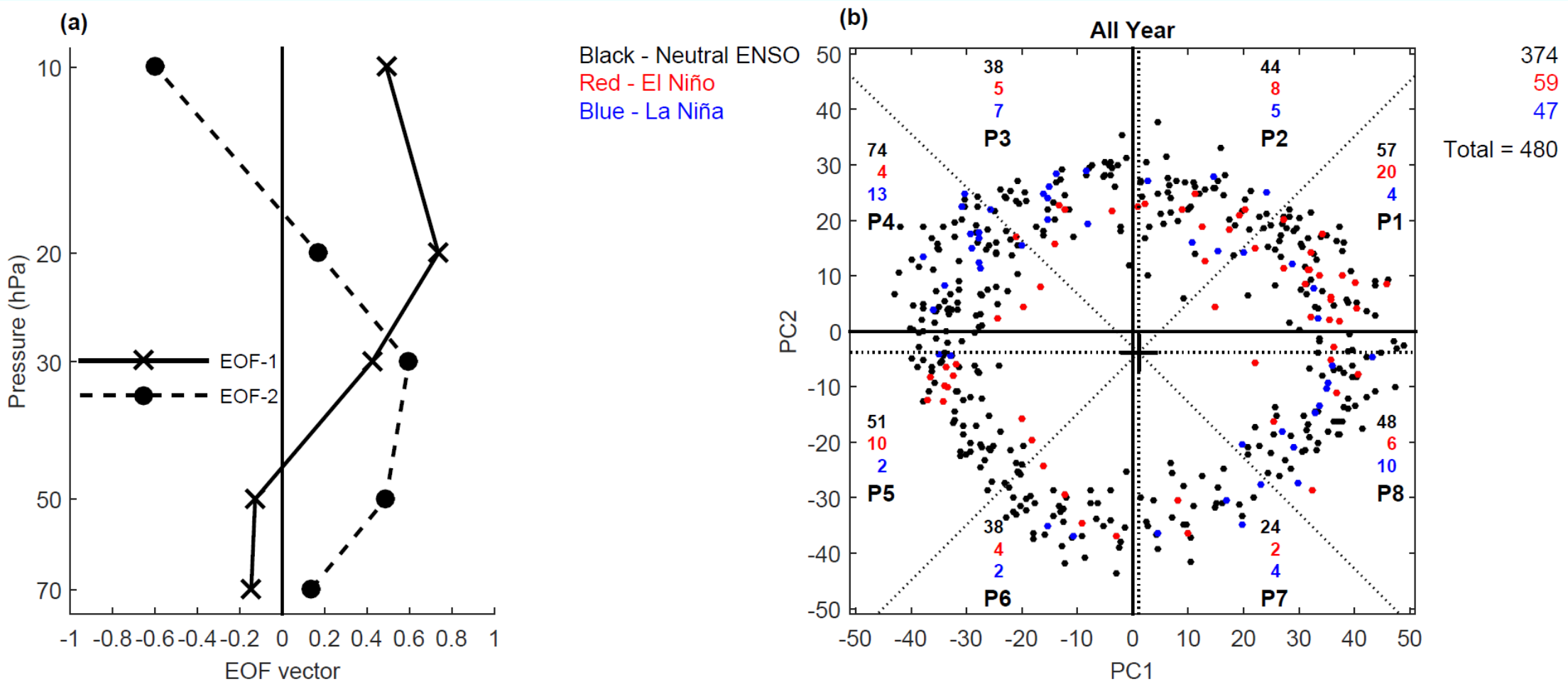



## W @500hPa

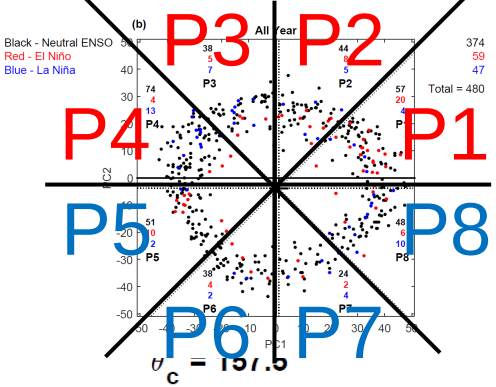


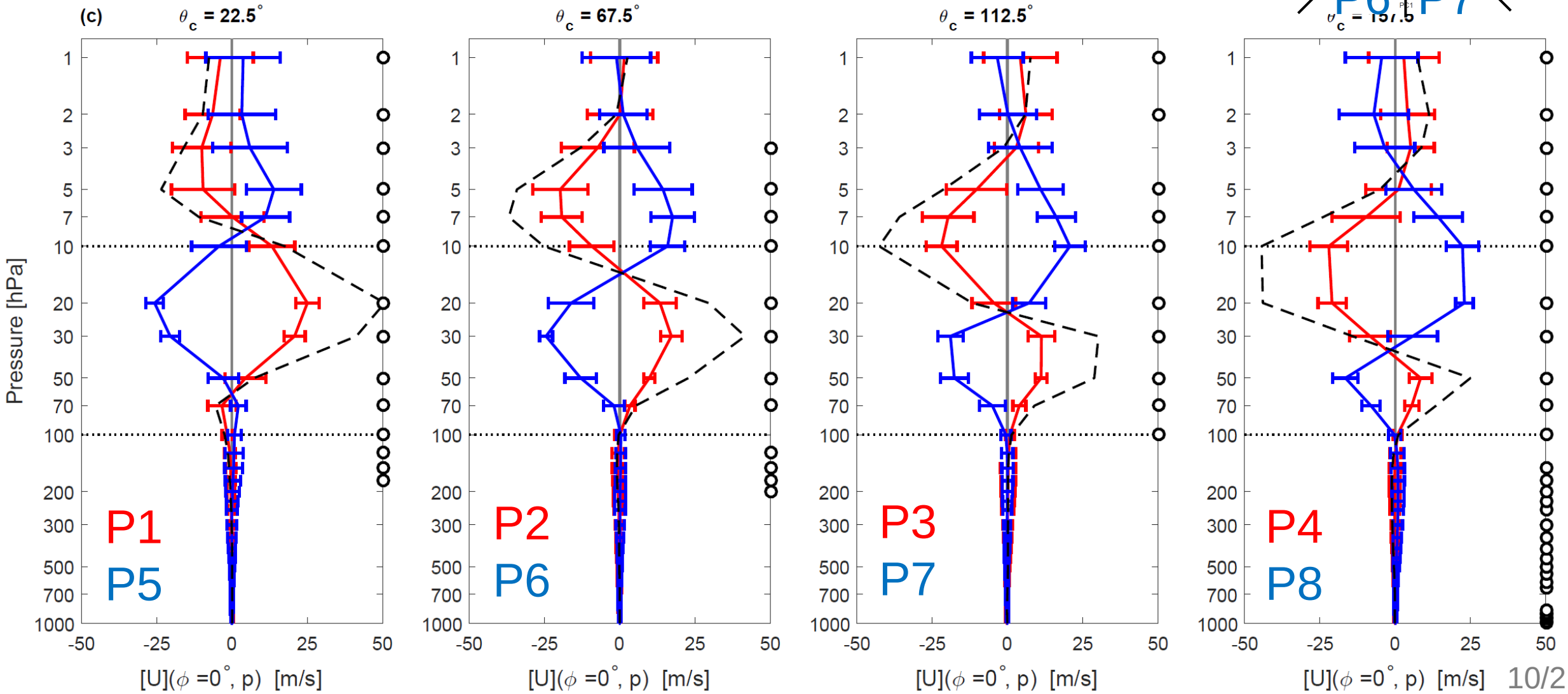
# 3. Equatorial Quasi-Biennial Oscillation

- EOF analysis of mean zonal wind [U] in the equatorial lower stratosphere
  - lat=0, p=10~70hPa
  - EOF1 (59.7%), EOF2 (34.9%) → PC1(t), PC2(t)



- divisions into eight QBO phases
  - - - - - - composite difference of [U”(p,$t_1$)]
  - o statistically significant with > 95%
- mostly focus on Phase 4 – Phase 8 (~ QBO-W @50 hPa)

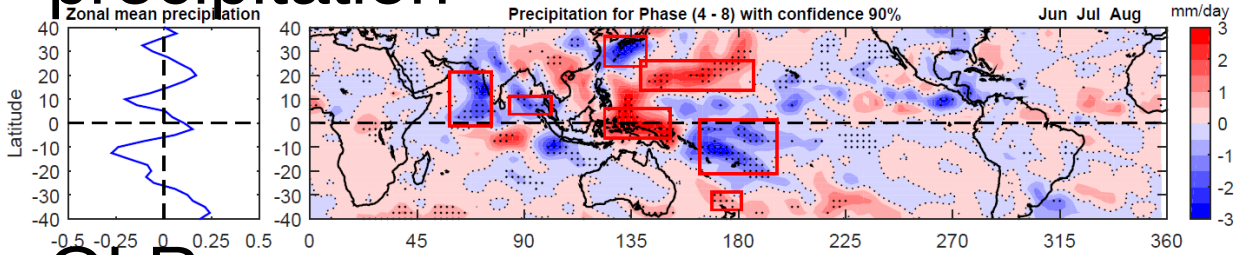


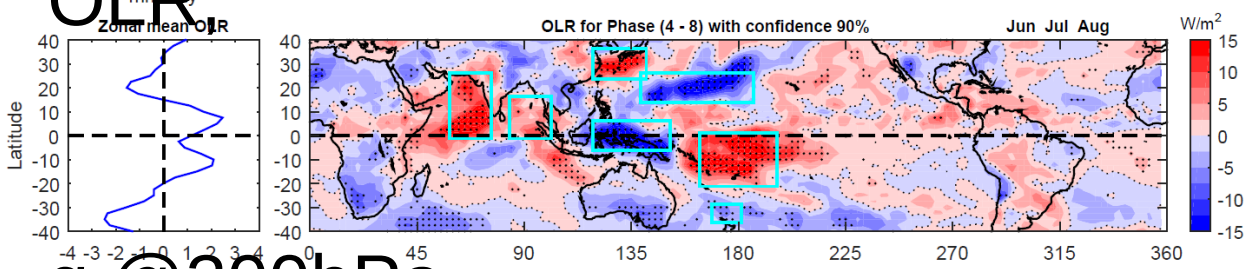
# 4. Composite differences between opposite QBO phases

❖ boreal summer, JJA, between (Phase 4 – Phase 8) : W'ly – E'ly @50 hPa

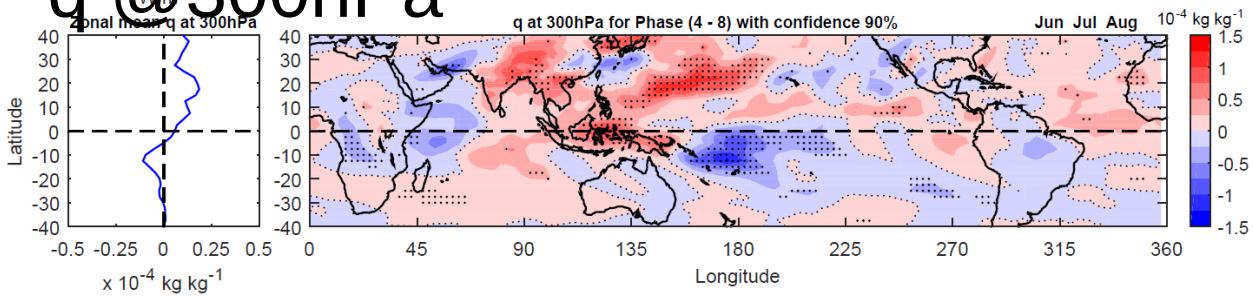
precipitation



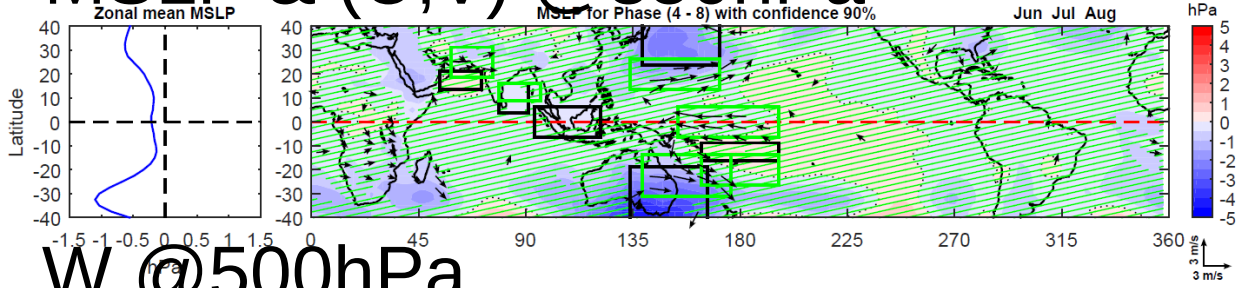

OLR



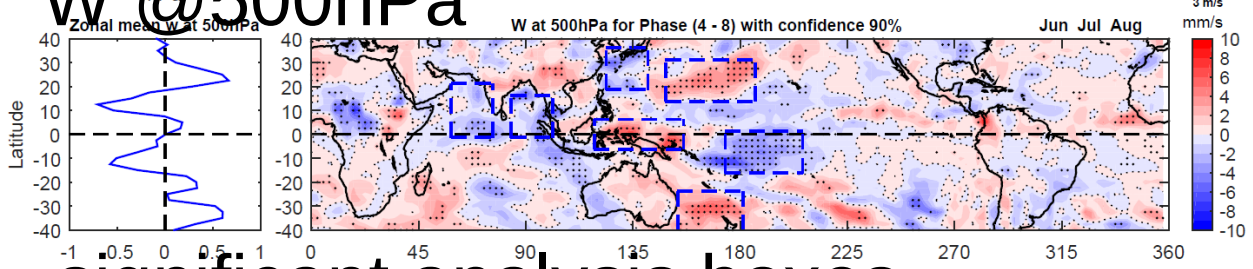

q @300hPa



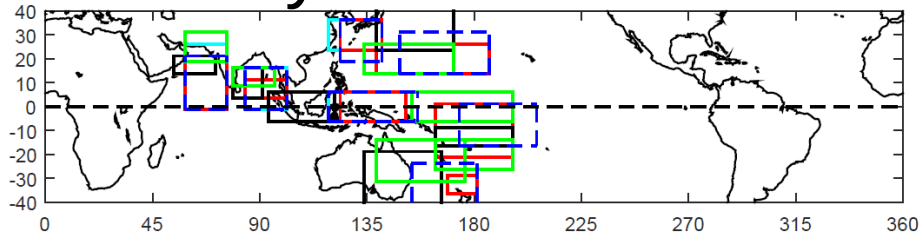

MSLP & (U,V) @850hPa




W @500hPa



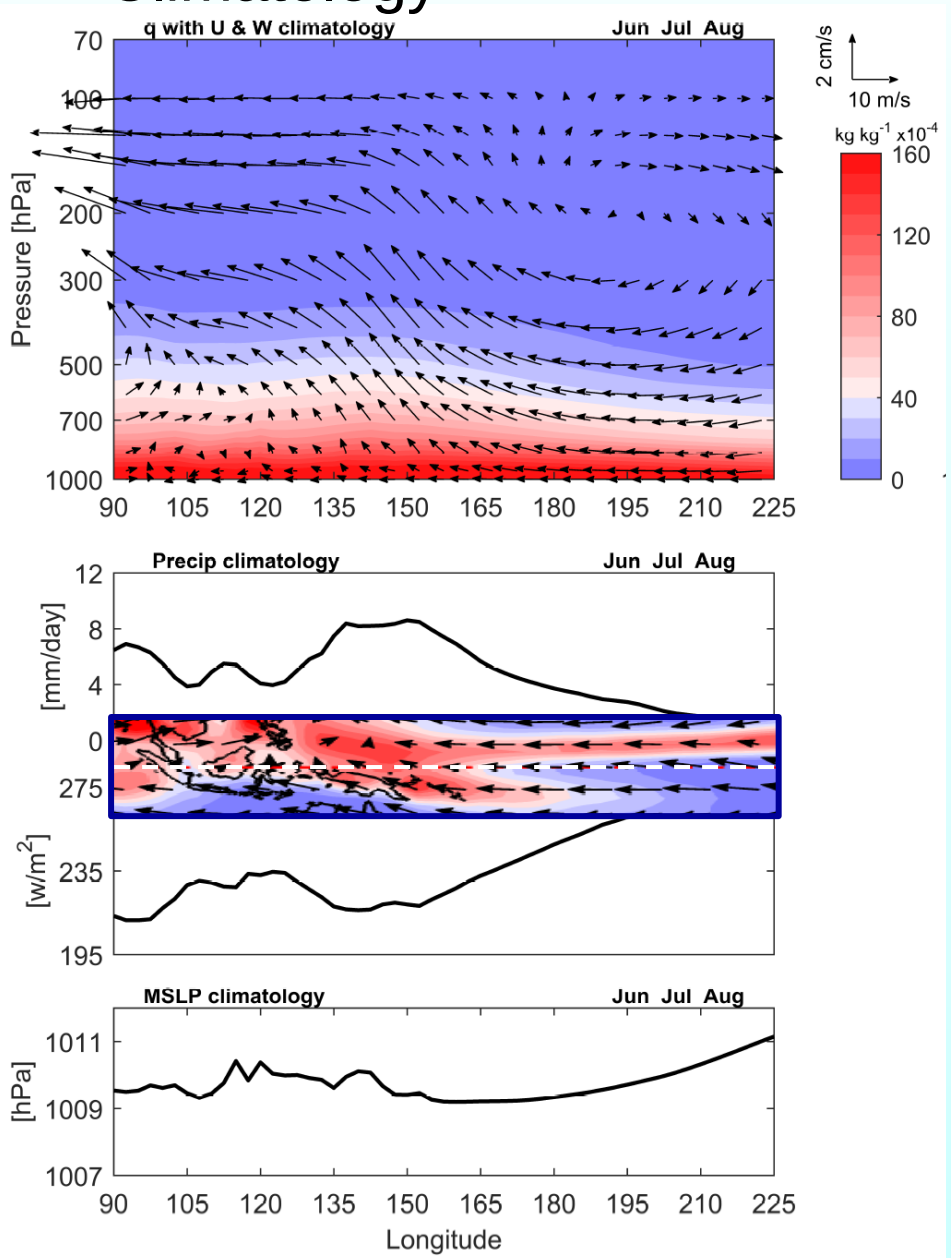

significant analysis boxes



- NH: Arabian Sea, Bay Bengal, W. Pacific di-pole
- EQ: W. Pacific (MC), C. Pacific
- SH: W. Pacific

# ❖equatorial pathway in boreal summer, JJA: MC - W.Pacific - C.Pacific

## Climatology



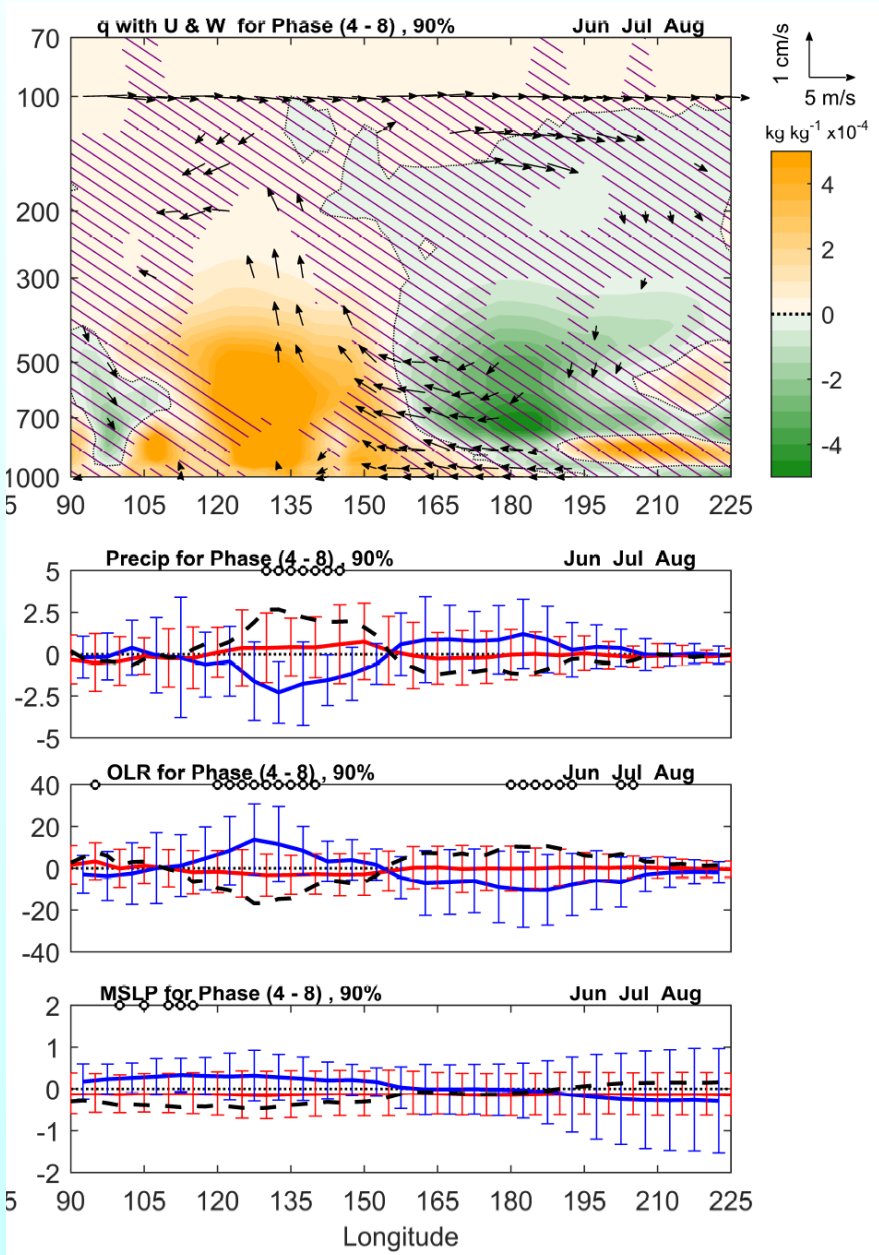

(U,W) + q

Precipitation

OLR

MSLP

## Phase 4 – Phase 8

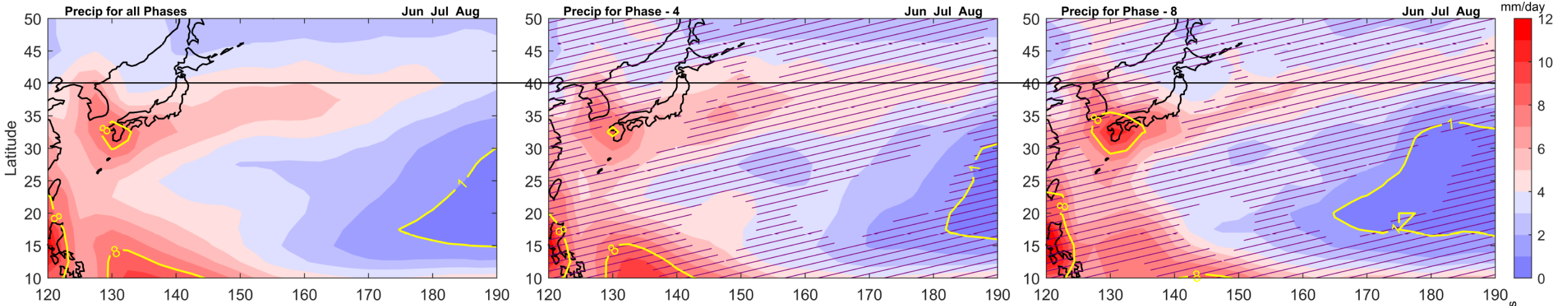


# ❖subtropical pathway in boreal summer, JJA : NH W. Pacific

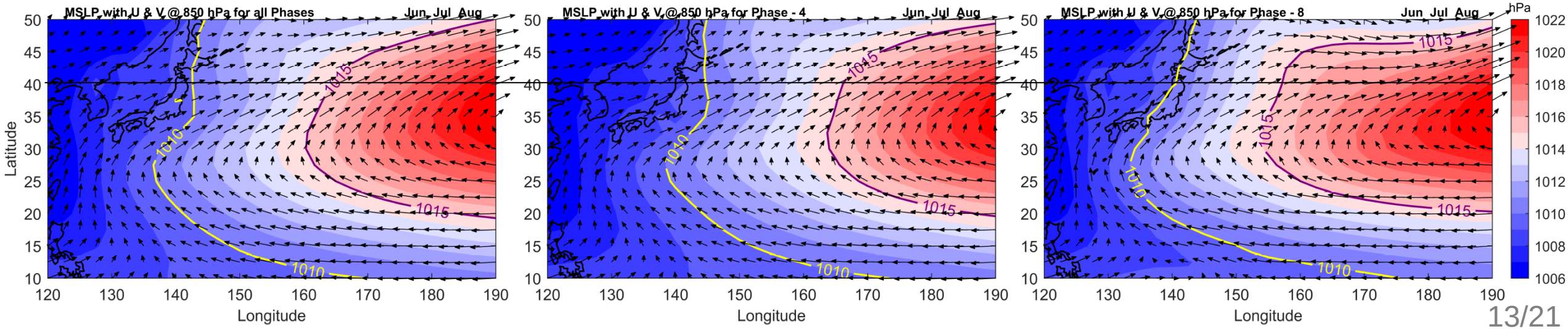
Climatology
Precipitation

Phase 4
W'ly @50 hPa

Phase 8
E'ly @50 hPa

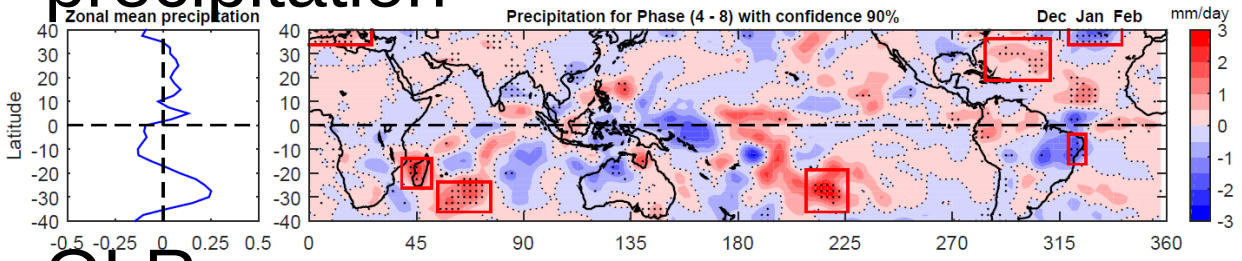



(U,V) @850hPa + MSLP

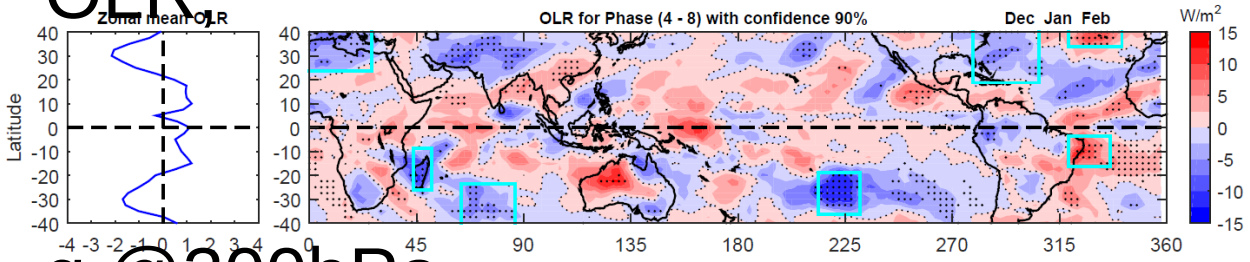


# ❖ austral summer, DJF, between (Phase 4 – Phase 8) : W'ly – E'ly @50 hPa

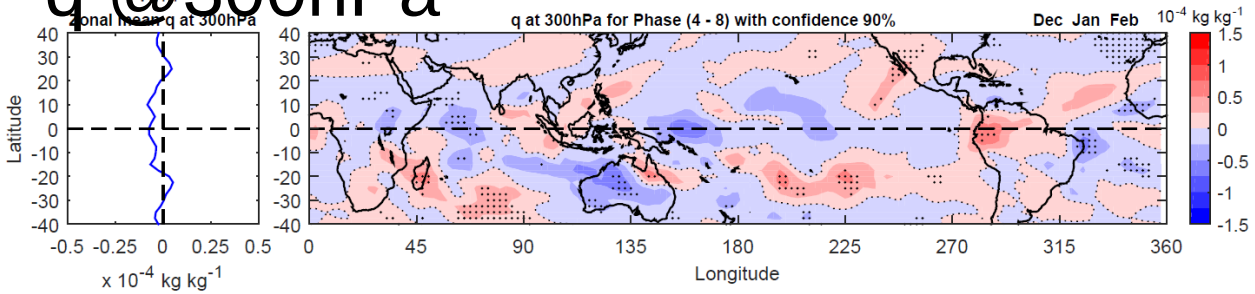
## precipitation



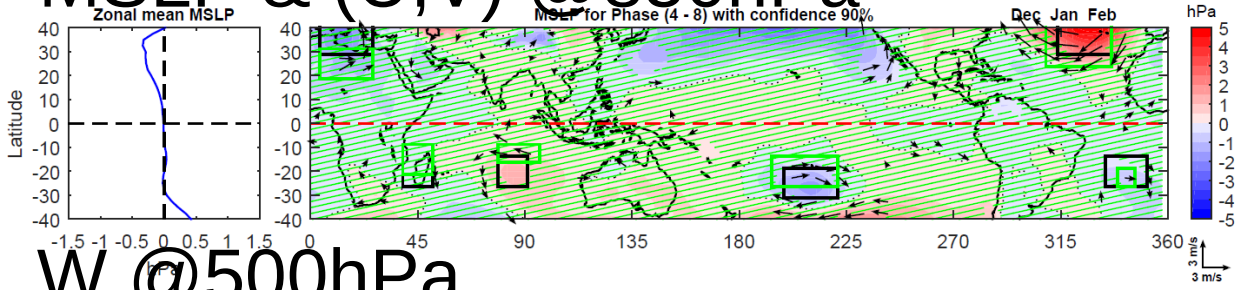

## OLR



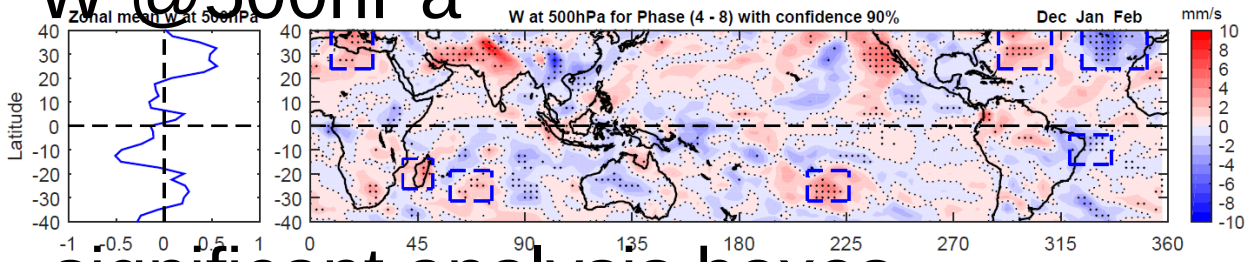

## q @300hPa



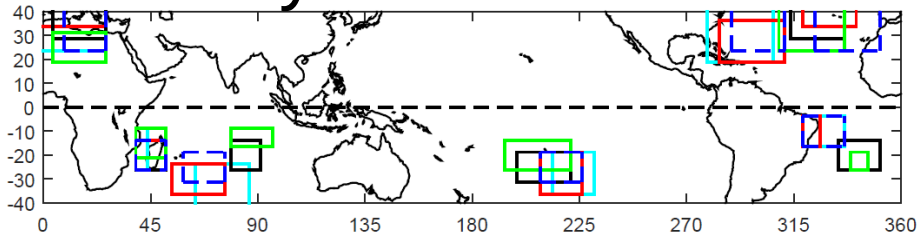

## MSLP & (U,V) @850hPa




## W @500hPa




## significant analysis boxes



- NH: Mediterranean, Atlantic di-pole
- EQ: - - -
- SH: Madagascar, Indian Ocean, C. Pacific, S. America

# ❖ subtropical and stratospheric (Holton-Tan)? pathways in austral summer, DJF : NH North Atlantic

Climatology

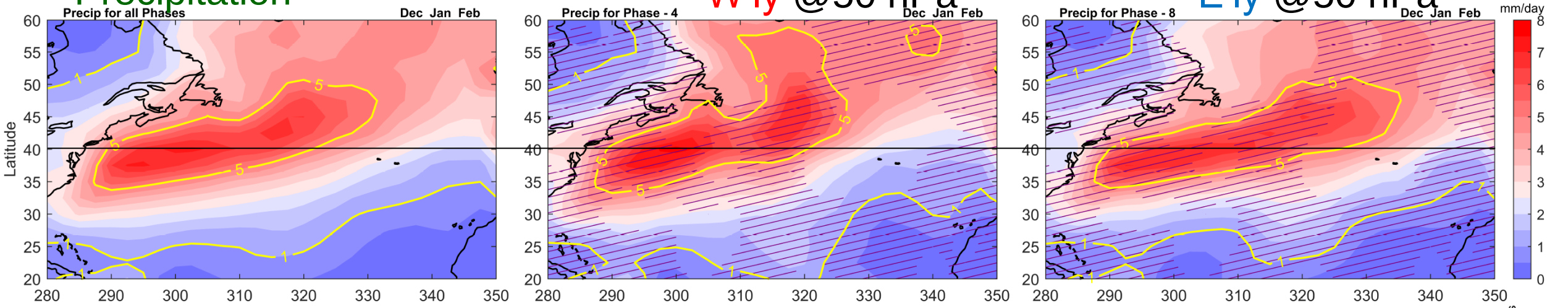
Precipitation

Phase 4

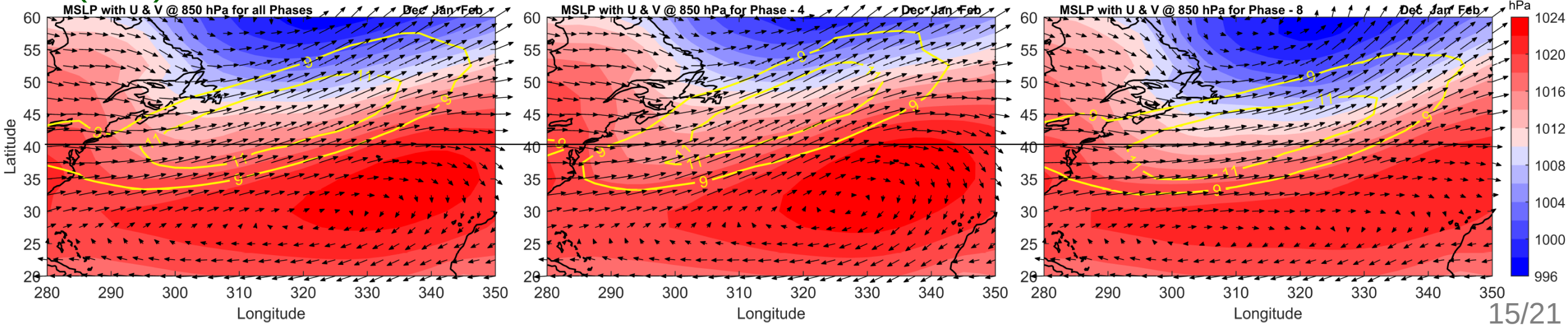
W'ly @50 hPa

Phase 8

E'ly @50 hPa

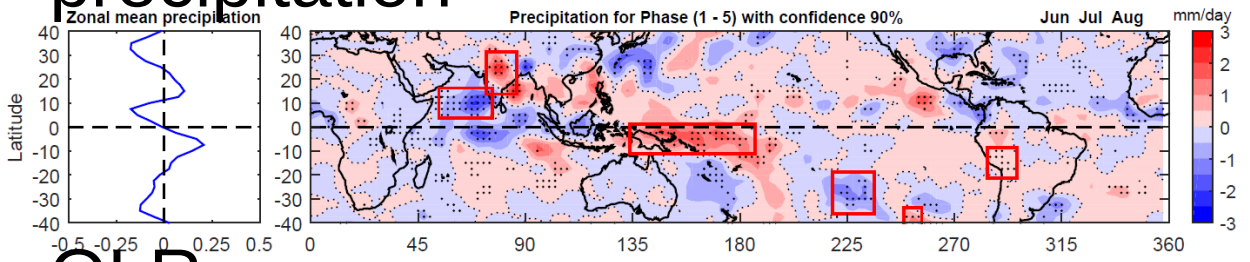



(U,V) + MSLP

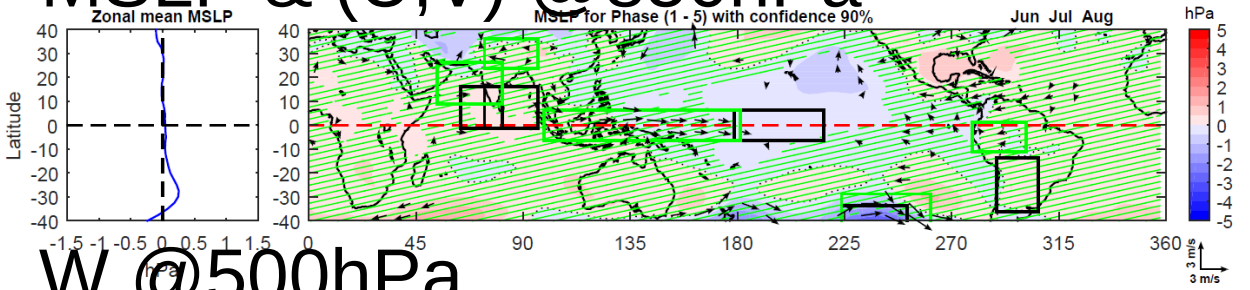


# ❖ boreal summer, JJA, between (Phase 1 – Phase 5) : E'ly – W'ly @70 hPa

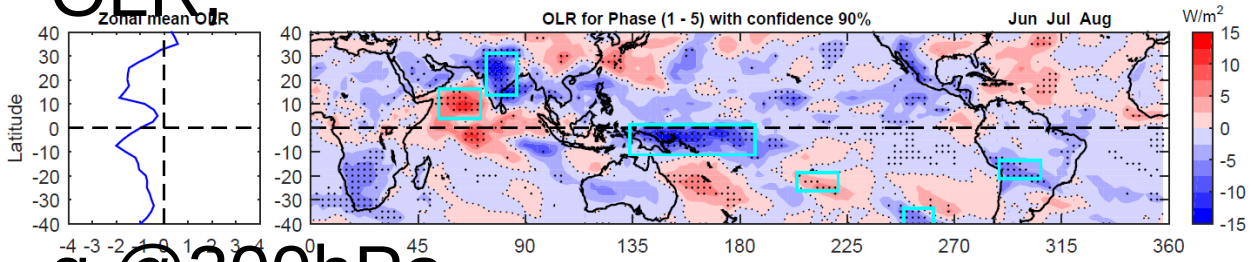
## precipitation



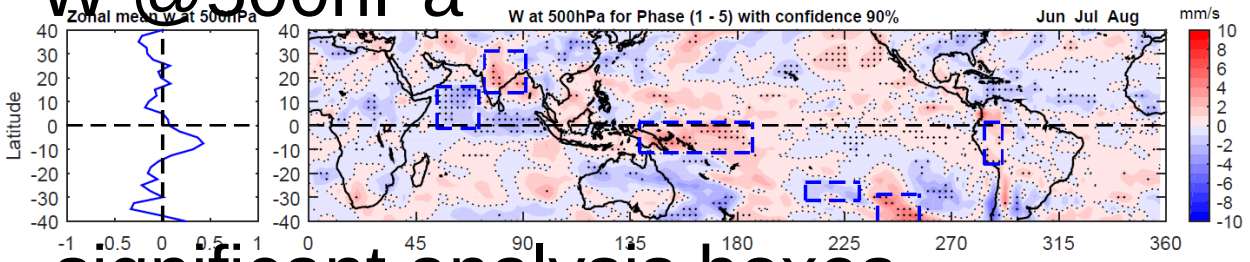

## MSLP & (U,V) @850hPa



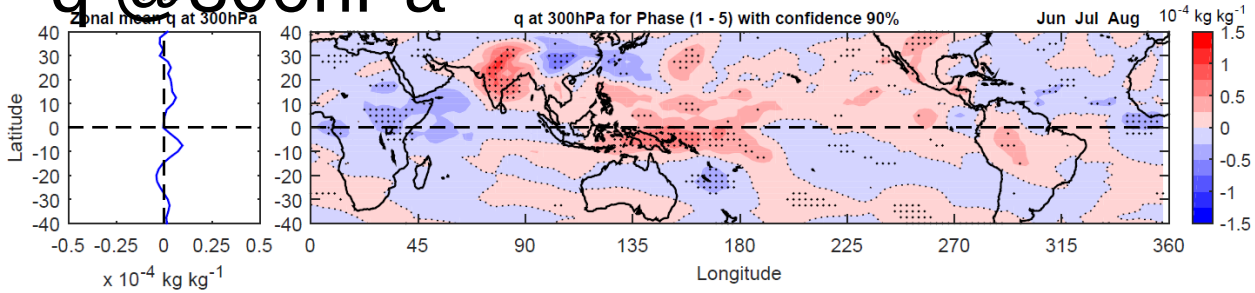

## OLR



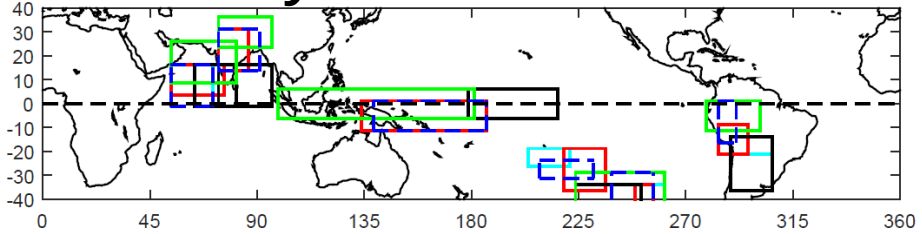

## W @500hPa




## q @300hPa



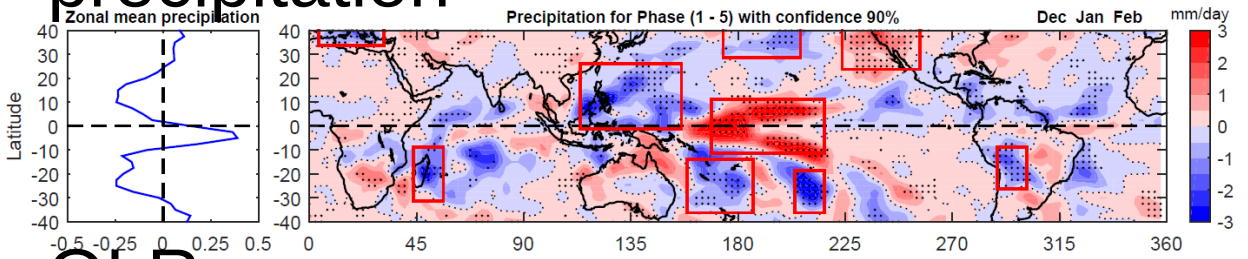

## significant analysis boxes



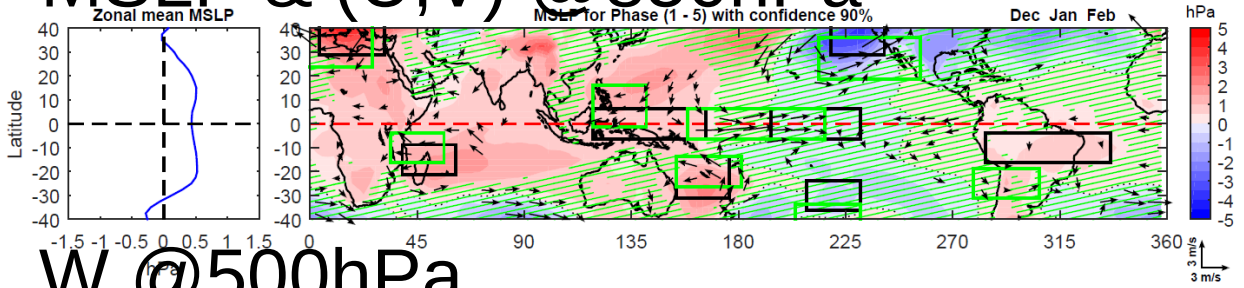
- NH: Arabian Sea, India
- EQ: W. Pacific
- SH: C. Pacific di-pole, S. America

# ❖ austral summer, DJF, between (Phase 1 – Phase 5) : W'ly – E'ly @70 hPa

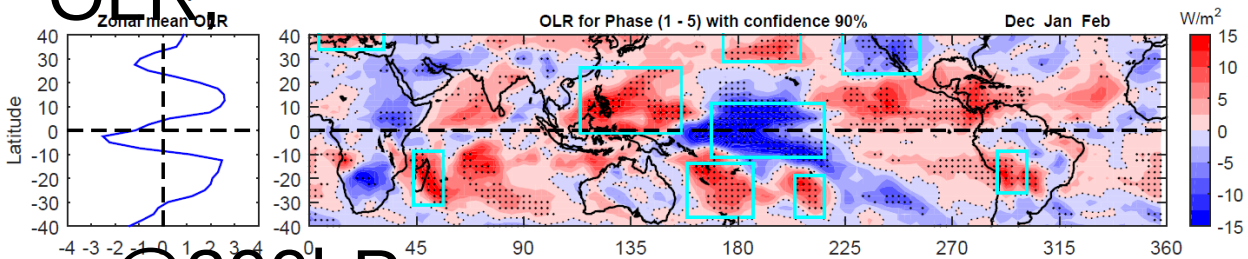
## precipitation



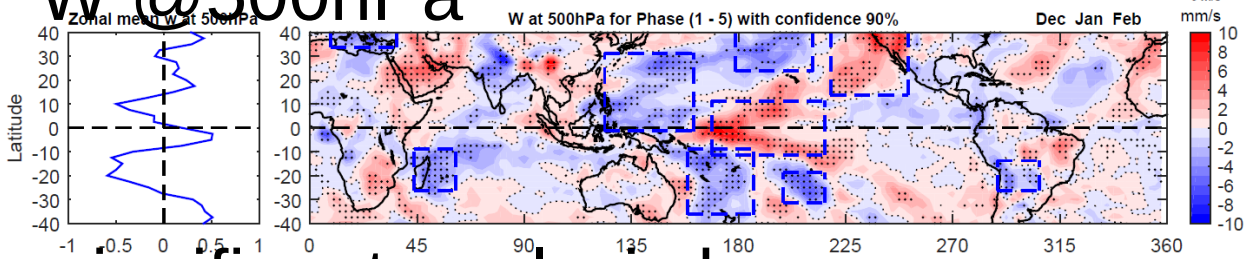

## MSLP & (U,V) @850hPa



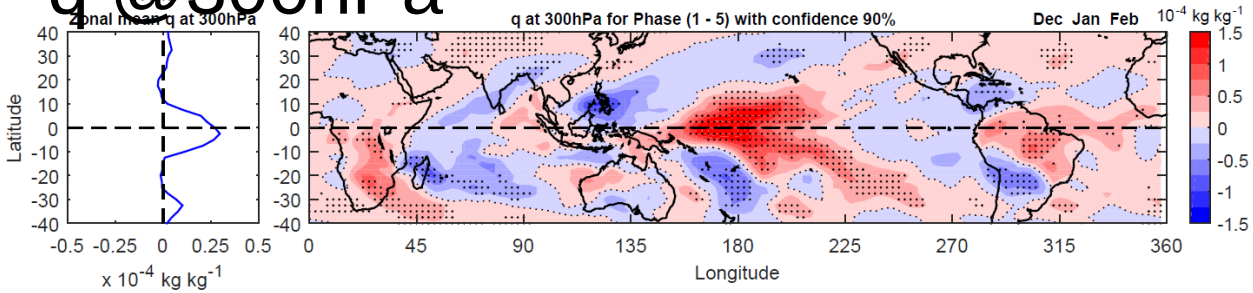

## OLR



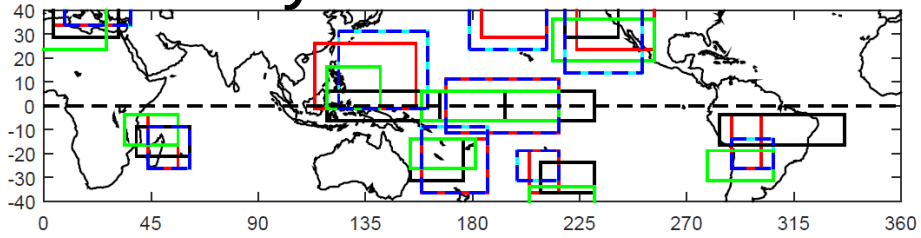

## W @500hPa




## q @300hPa




## significant analysis boxes



- NH: Mediterranean, E. Pacific di-pole
- EQ: W. Pacific (MC), C. Pacific
- SH: Madagascar, W. Pacific, C. Pacific, S. America

# 5. Summary and Remarks

- By using global data for 40 years from 1979 to 2018, climatology of global monsoon systems was summarized for only neutral ENSO period excluding the influences of El Nino or La Nina.
  - clear signals of zonally symmetric components (e.g., NH ITCZ) and intrinsic non-zonal asymmetric ones with contrast between the two hemispheres
- Eight QBO phases (P1 to P8) were defined by an EOF analysis of deseasonalized zonal mean zonal wind in the lower stratosphere.
  - Student's t-test for showing statistical significance of the difference of composite means of opposite QBO phases
  - although there are limitation of sample sizes in some phases and seasons
- The QBO modulation of global monsoon systems is investigated for boreal summer, JJA and austral summer, DJF separately.

- Precipitation, its proxy data, and circulation fields show statistical significant composite differences between QBO Phase 4 – Phase 8: (W'ly – E'ly @50 hPa)
  - boreal summer, JJA
    - NH: Arabian Sea, Bay Bengal, W. Pacific di-pole
    - EQ: W. Pacific (MC), C. Pacific
    - SH: W. Pacific
  - austral summer, DJF
    - NH: Mediterranean, Atlantic di-pole;
    - EQ: - - -
    - SH: Madagascar, Indian Ocean, C. Pacific, S. America
- Also, between QBO Phase 1 – Phase 5 (E'ly – W'ly @70 hPa)
  - boreal summer, JJA
    - NH: Arabian Sea, India; EQ: W. Pacific; SH: C. Pacific di-pole, S. America
  - austral summer, DJF
    - NH: Mediterranean, Pacific di-pole; EQ: - - -;
    - SH: Madagascar, Indian Ocean, C. Pacific, S. America

- Some typical examples for QBO modulation of global monsoon systems between Phase 4 – Phase 8 (W'ly – E'ly @50 hPa)
- equatorial pathway in boreal summer, JJA over MC - W.Pacific - C.Pacific
  - weakening of the Walker circulation and reduction of precipitation over W.MC in Phase 8
- subtropical pathway in boreal summer, JJA over W.Pacific (di-pole)
  - intensification of west side of Ogasawara (Bonin) high, i.e., higher MSLP and less precipitation in Phase 8
  - whereas more precipitation over W. Japan in Phase 8
- subtropical pathways in boreal winter, DJF over North Atlantic
  - intensification of Atlantic low and more precipitation in higher latitudes in Phase 8
  - another possible pathway could be stratospheric one, i.e., Holton-Tan (1980) relationship + N. Annular Mode ?
    ← E'ly@50 hPa ~ weaker polar vortex in the stratosphere
    ~ low-index (more wavy) in the troposphere


# Thank you !!