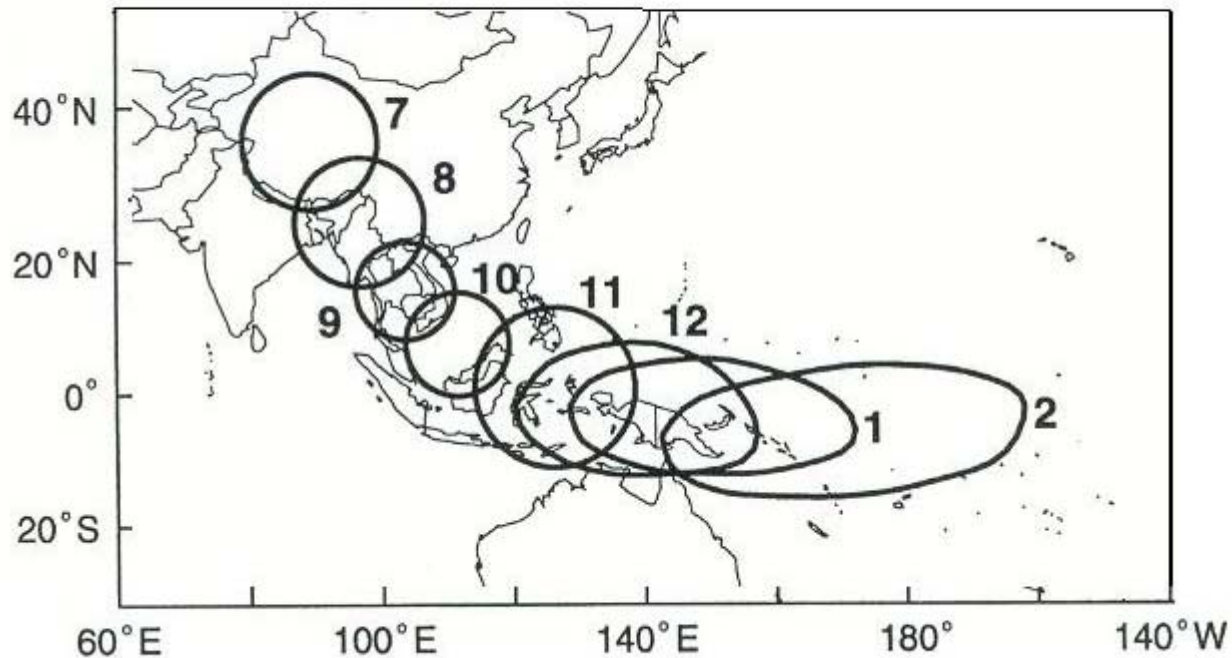


# Annual Cycle of Southeast Asia - Monsoon Rainfall

## *and the Asymmetric Seasonal Transition*

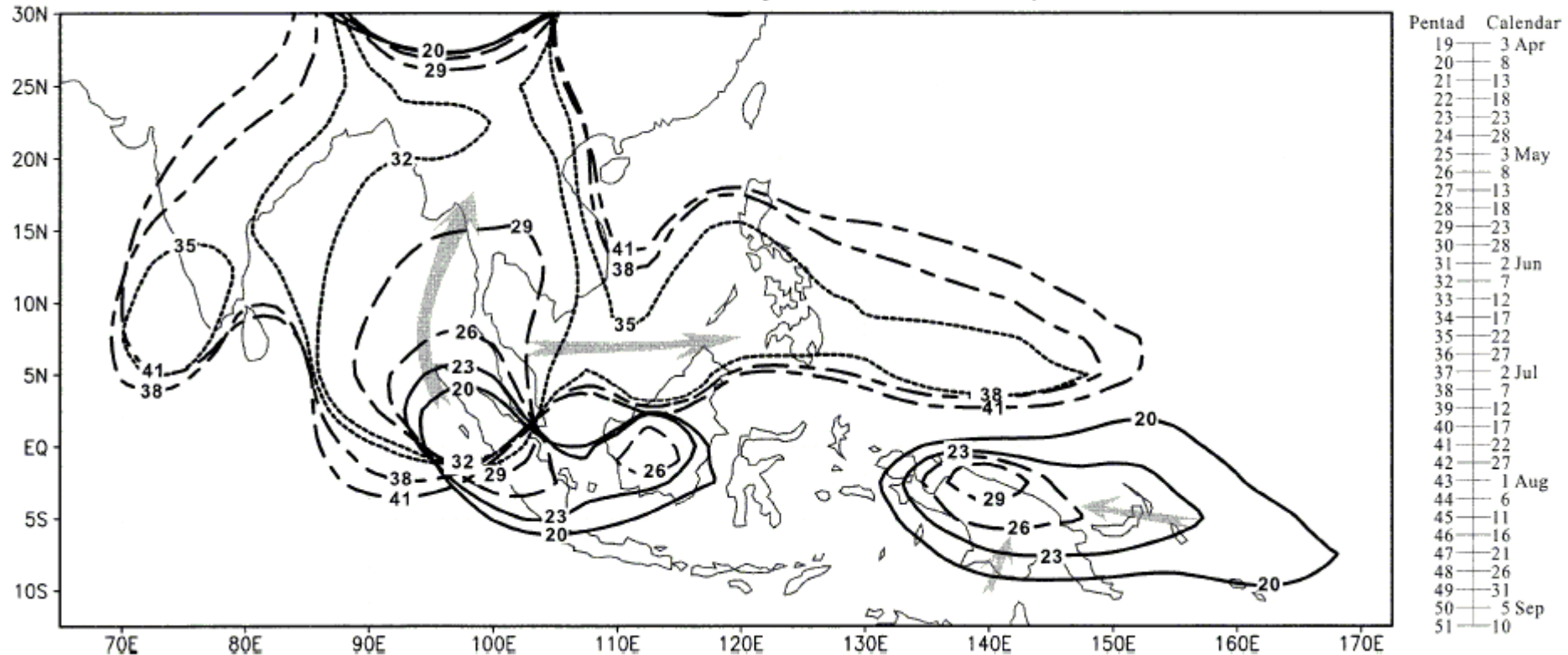
C.-P. Chang and Zhuo Wang  
Naval Postgraduate School  
Monterey, California, U.S.A.

# Seasonal Migration of Monsoon Diabatic Heat Sources during July-February (*Lau and Chan 1983*)

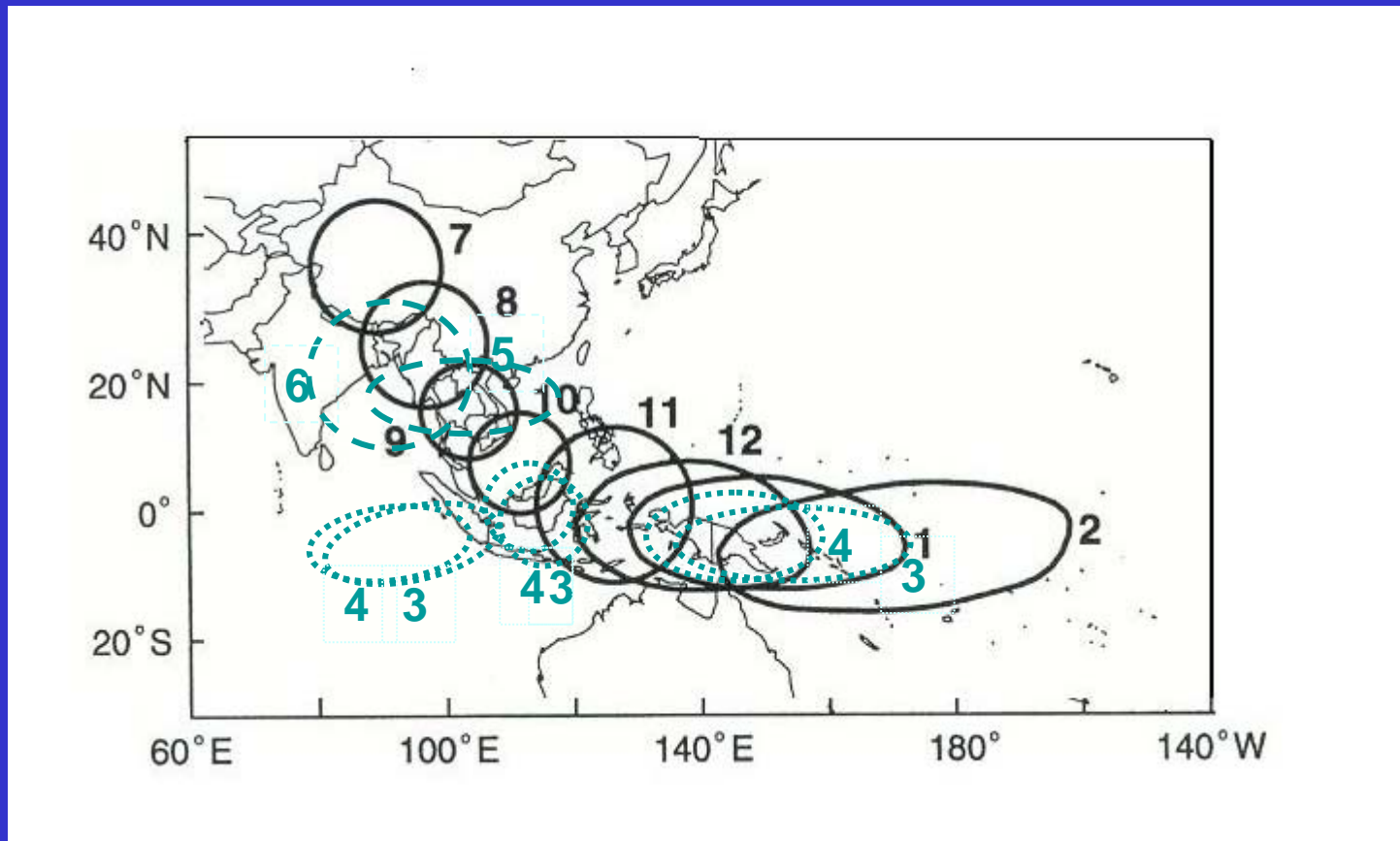


# Slow Annual Cycle (LinHo and Wang 2002)

OLR Slow Annual Cycle 20~40 ptd



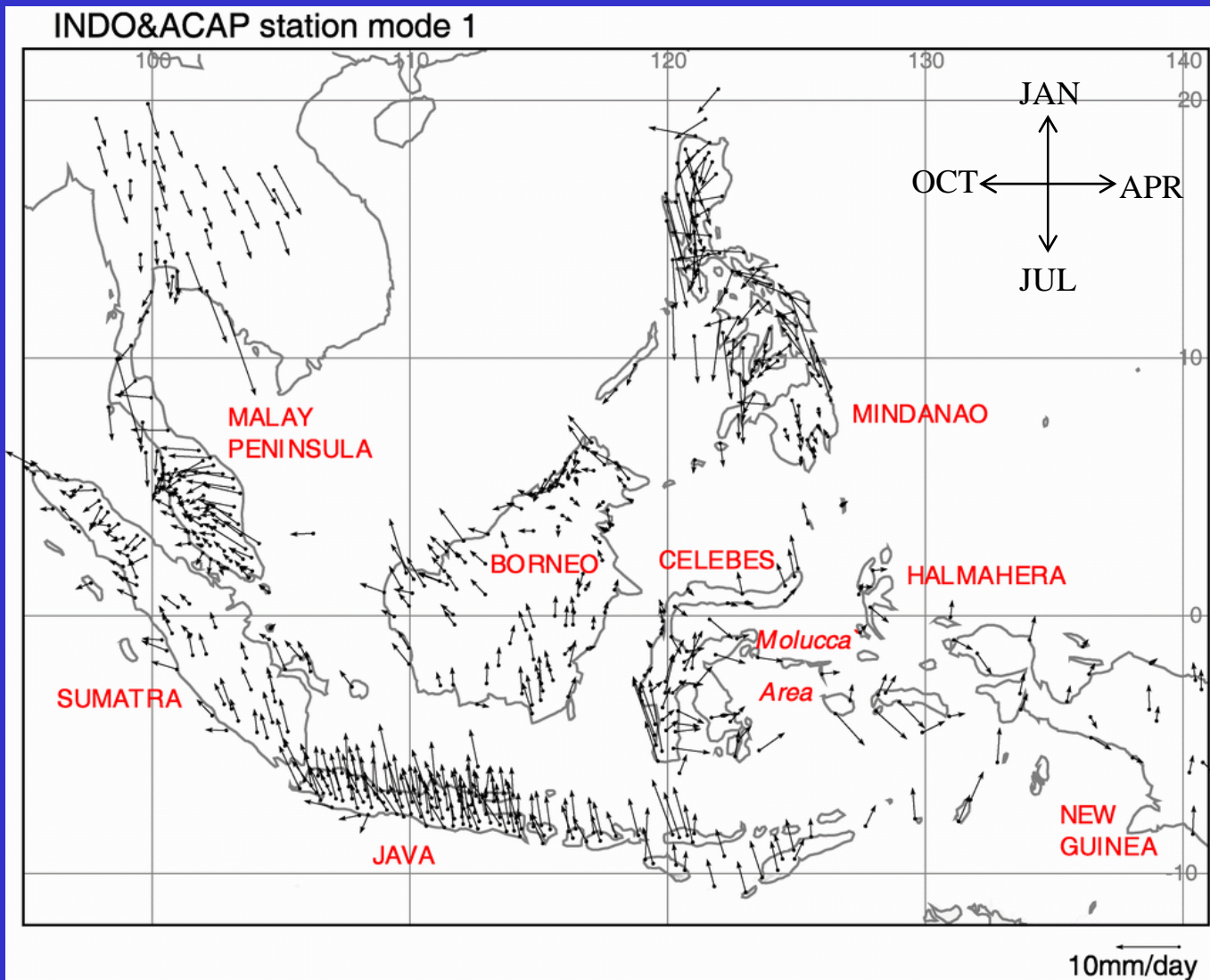
# Seasonal Migration of Monsoon Diabatic Heat Sources during July-February (*Lau and Chan 1983*)



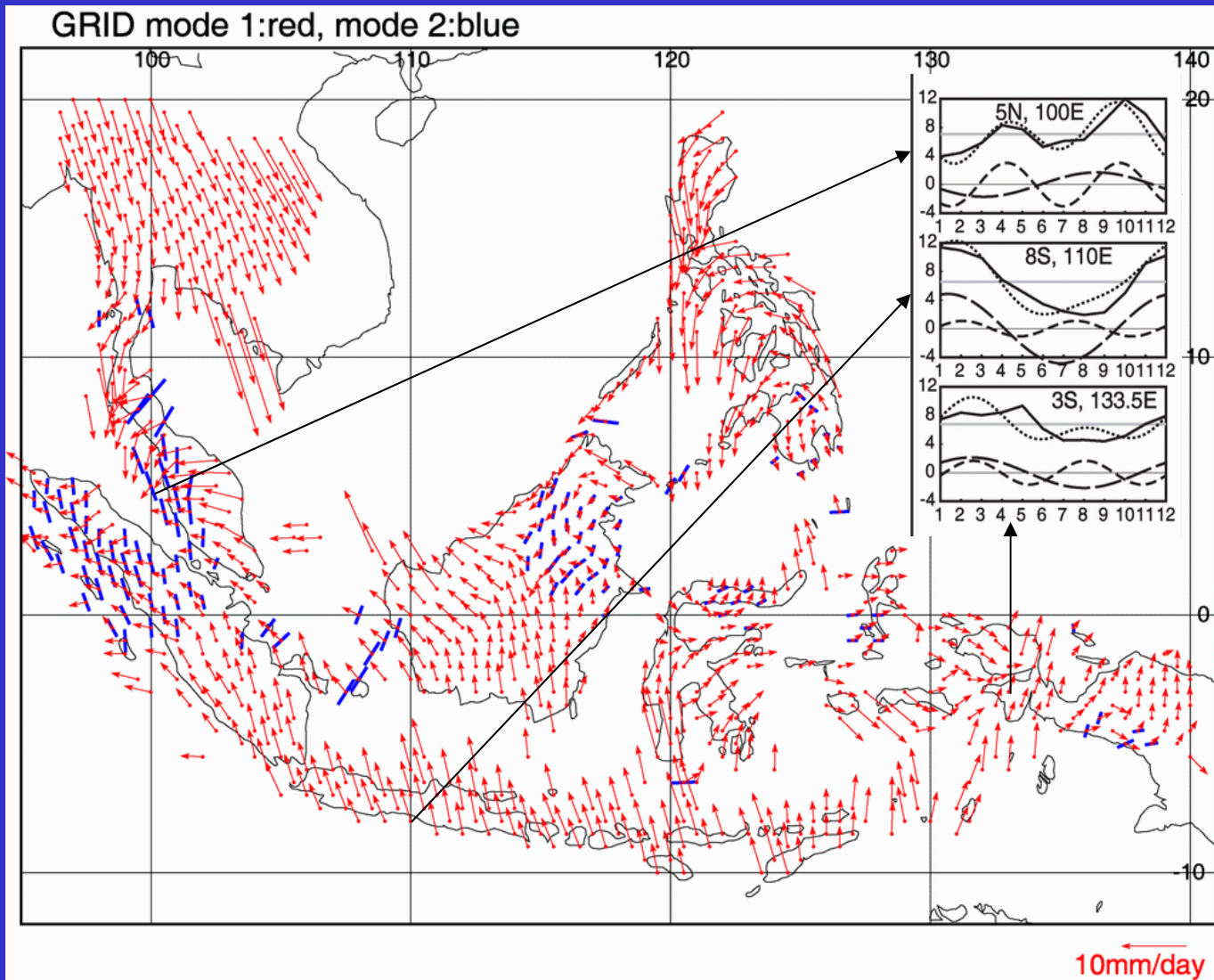
## Seasonal Transition Issues

- Annual cycles and monsoon regimes in SE Asia/MC:
  - Geographic variations due to complex terrain.  
*(Braak 1921; Wyrski 1956; Ramage 1971)*
  - Local heating vs. wind-terrain interactions?
  
- Seasonal march of max convection asymmetric:
  - SON: gradual SE march along SE Asia land bridge;
  - MAM: stays south of 5°N before northward jump.  
*(Lau & Chan 1983; Meehl 1987; Yasunari 1991; Matsumoto & Murakami 2002; Hung & Yanai 2003)*
  
- Data:
  - Historical station rainfall data;
  - Recent remote sensing data (TRMM, QuikSCAT).

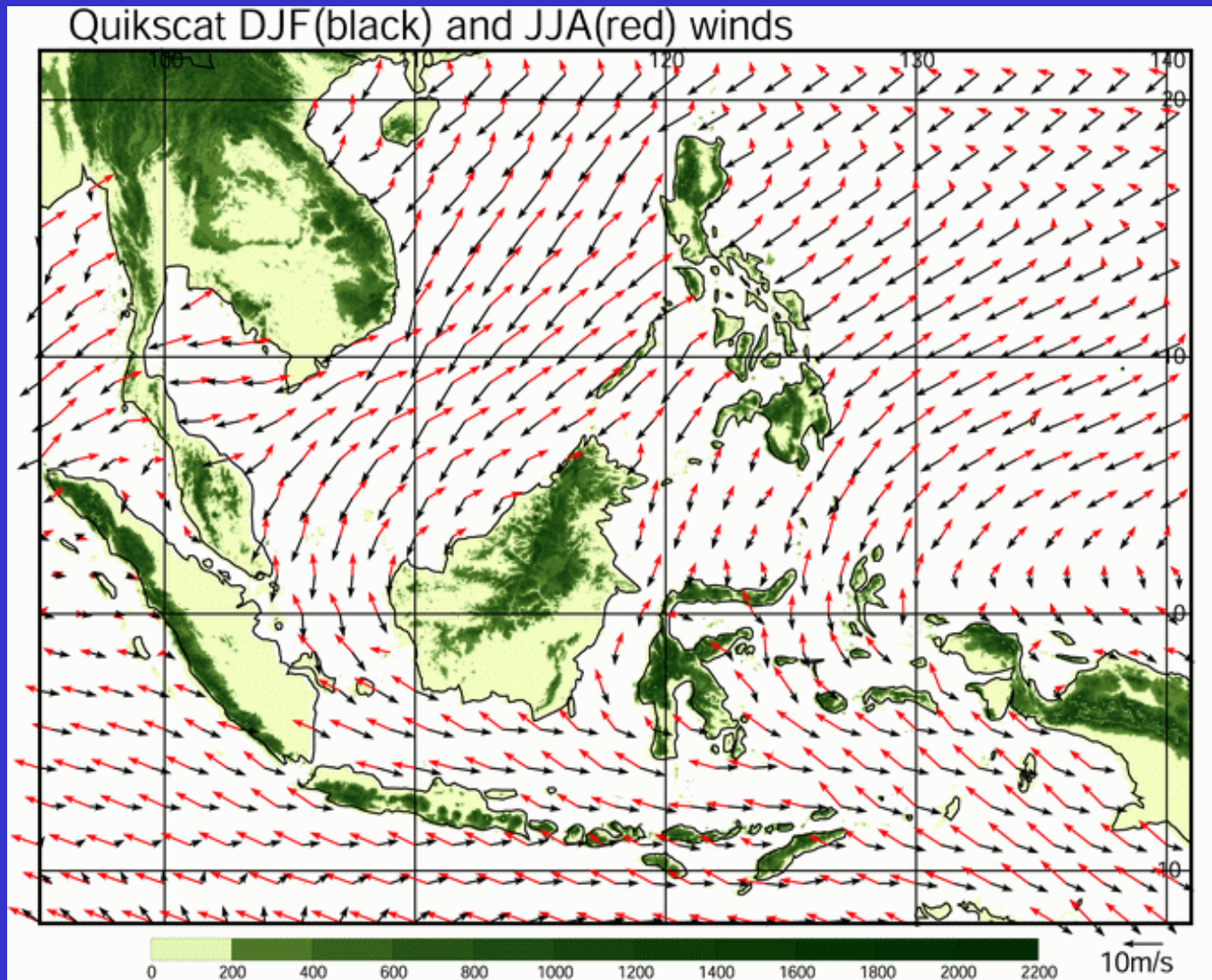
# Annual Cycle Mode at Rainfall Stations



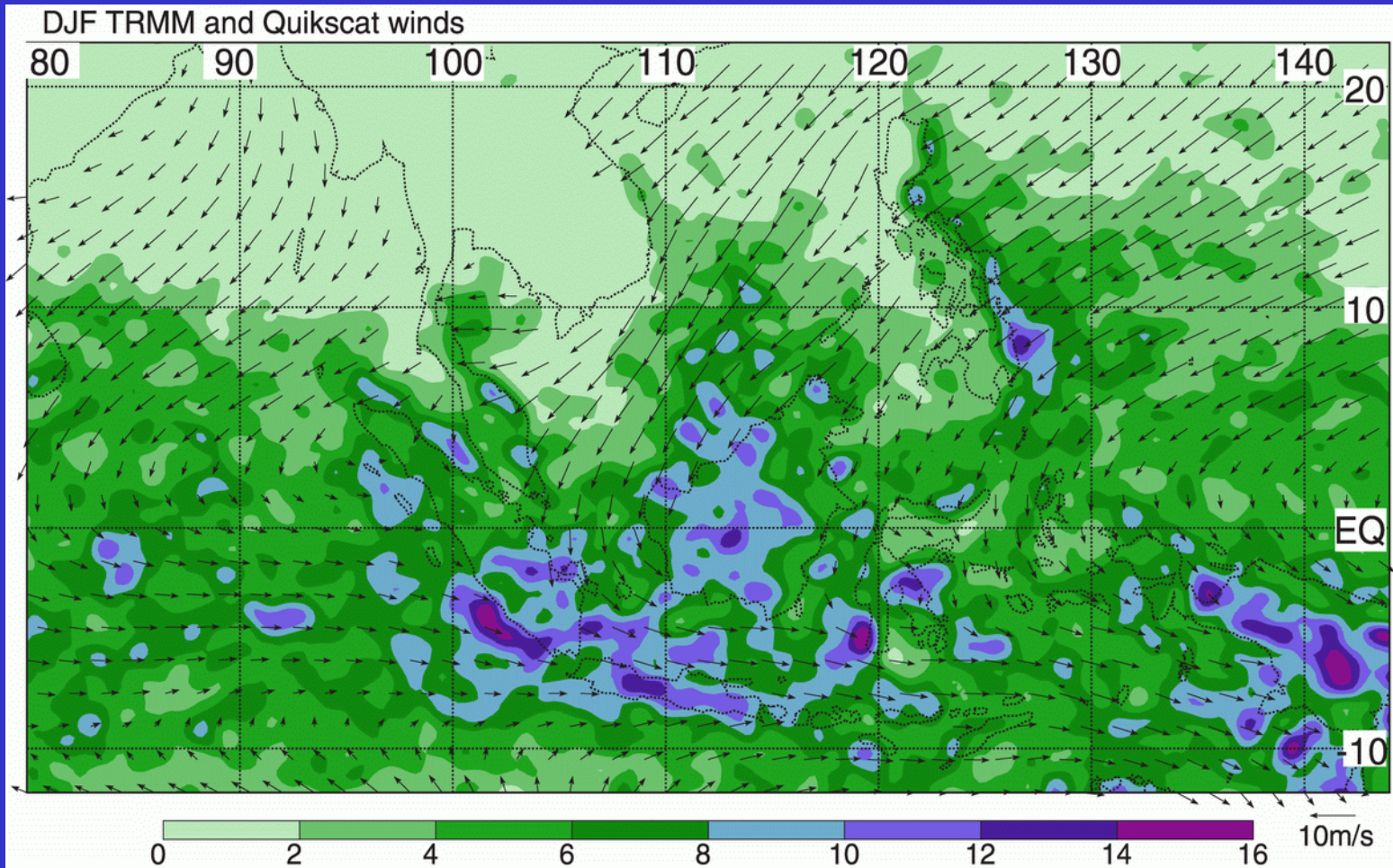
# Analyzed Annual Cycle vs. Semiannual Cycle



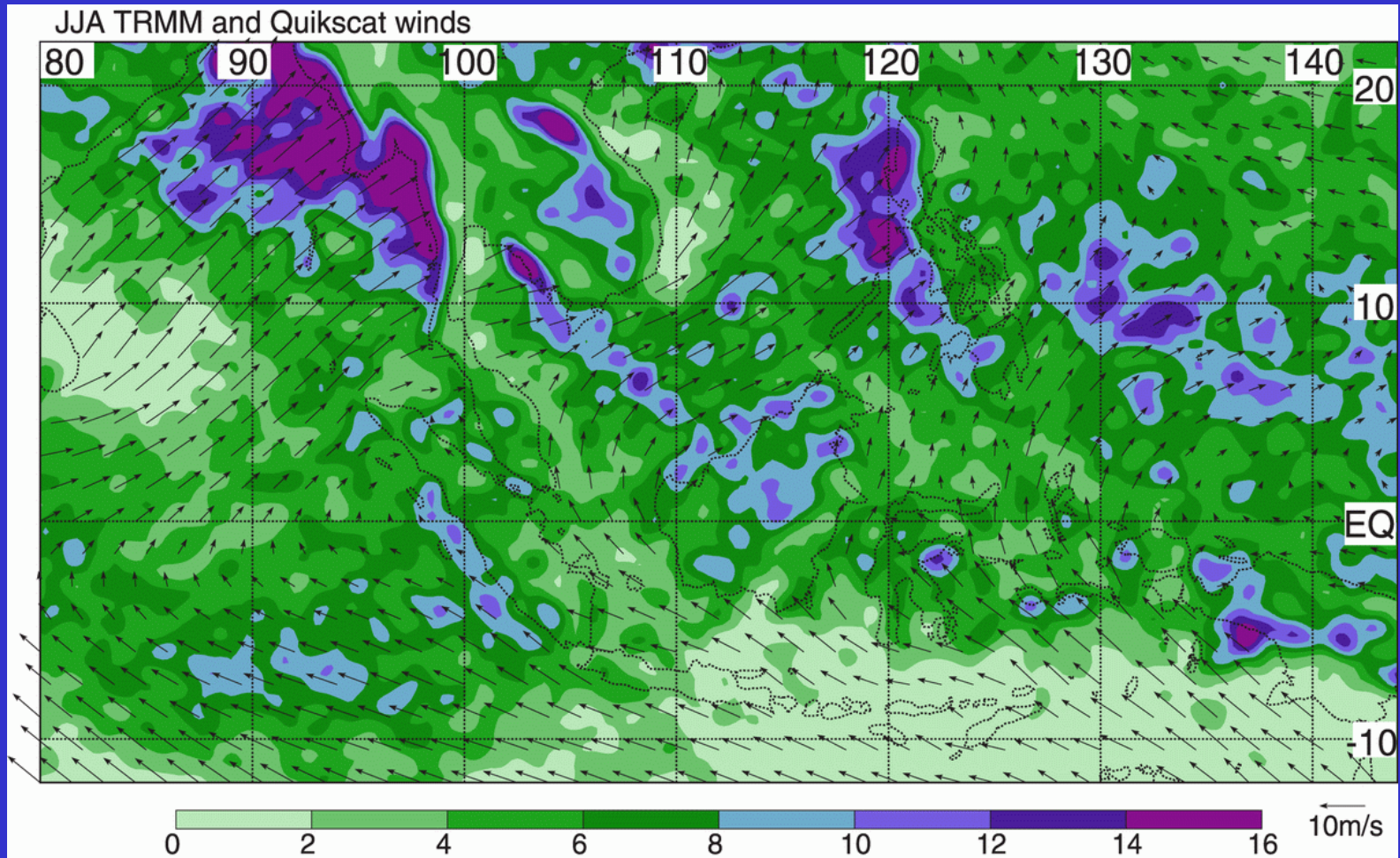
# DJF and JJA QuikSCAT Winds



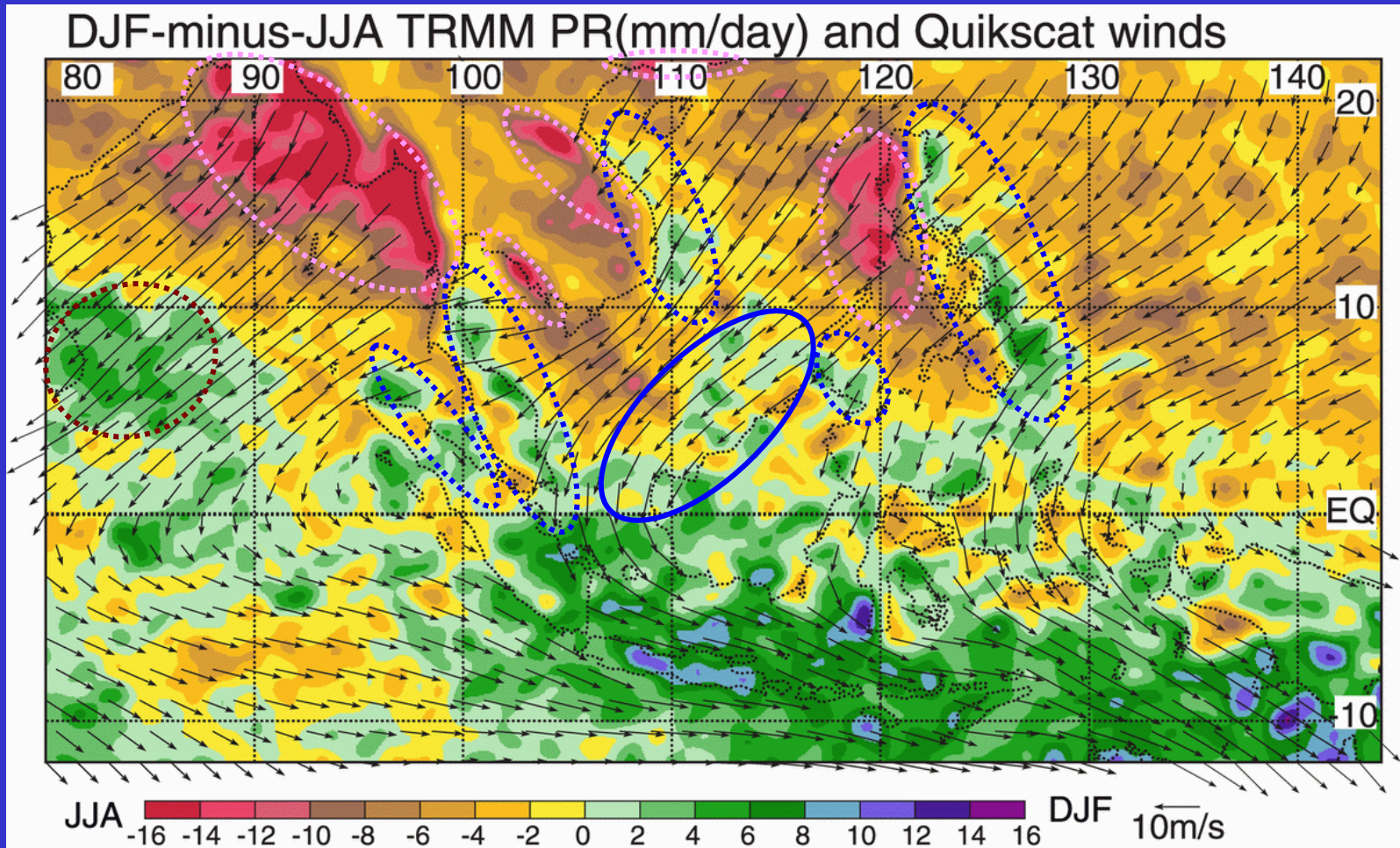
# DJF TRMM and QuikSCAT



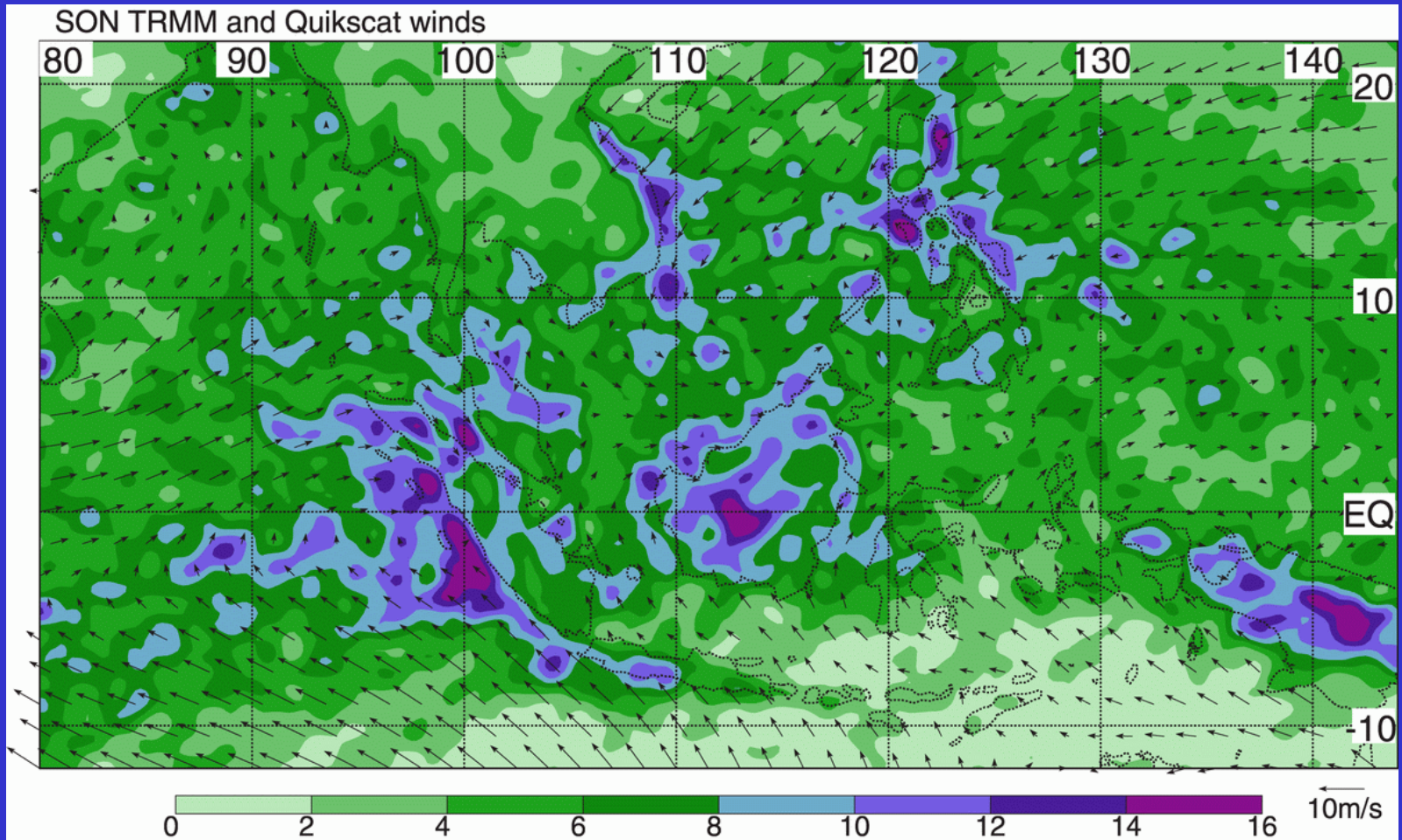
# JJA TRMM and QuikSCAT



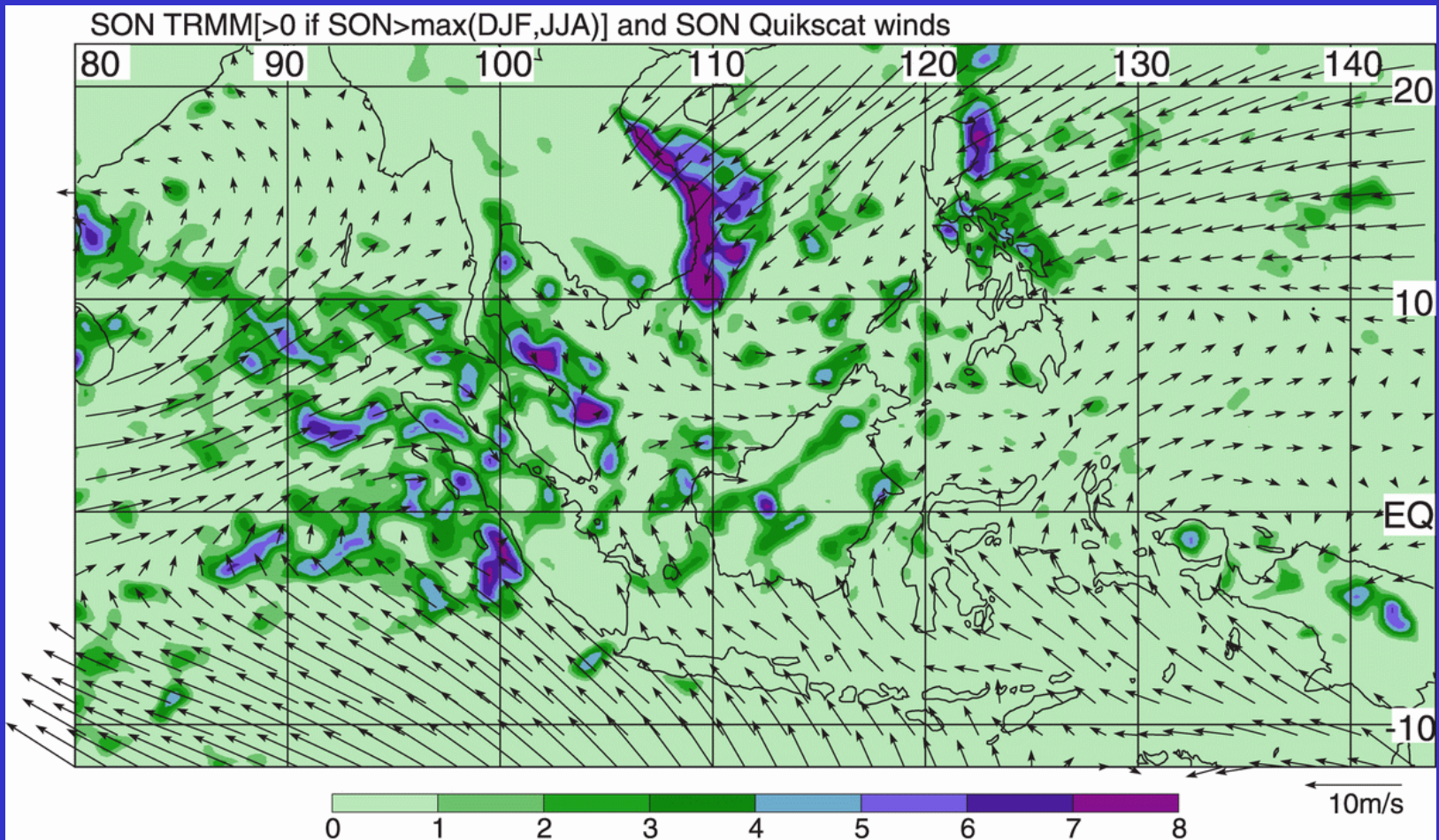
# DJF minus JJA TRMM and QuikSCAT



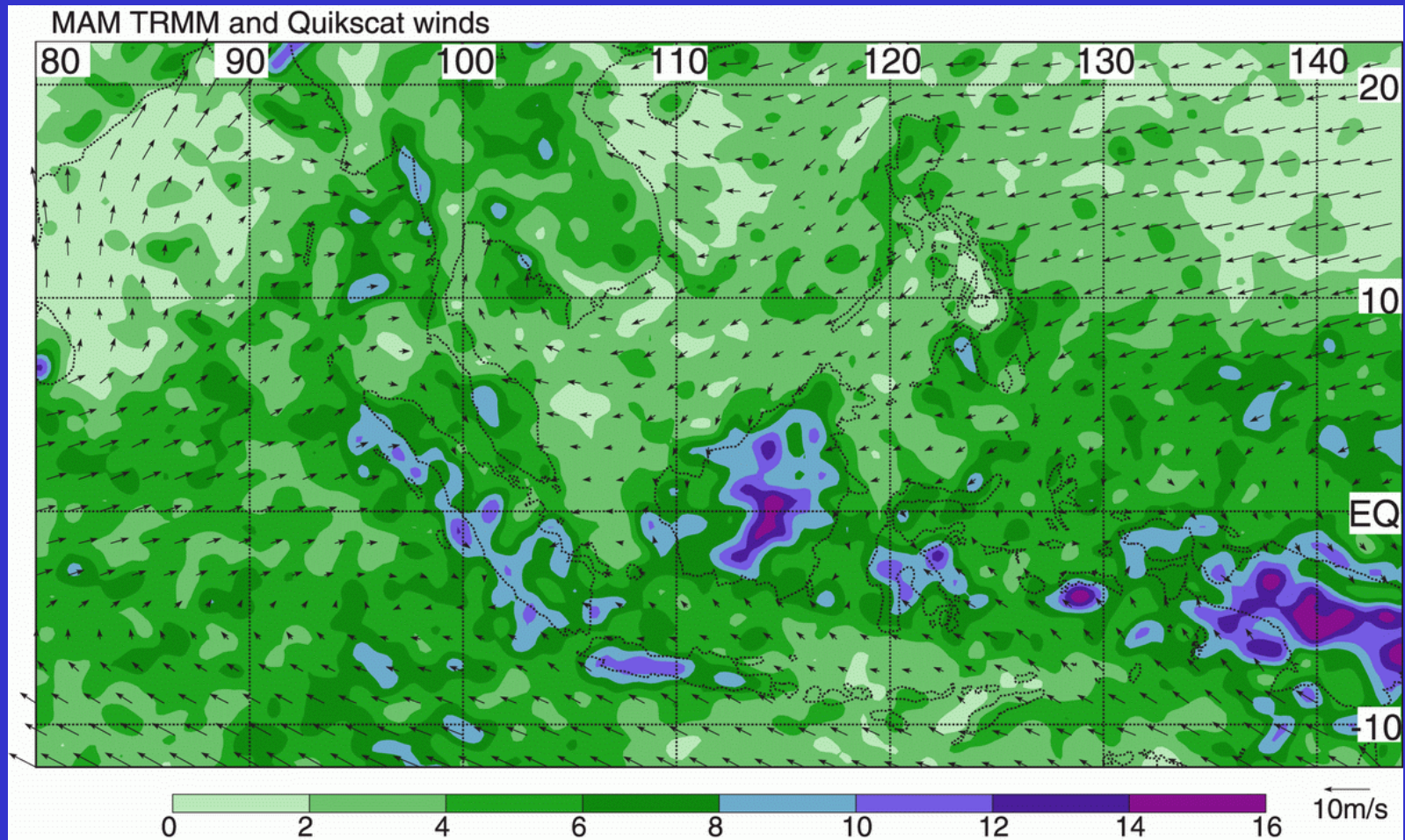
# SON TRMM and QuikSCAT



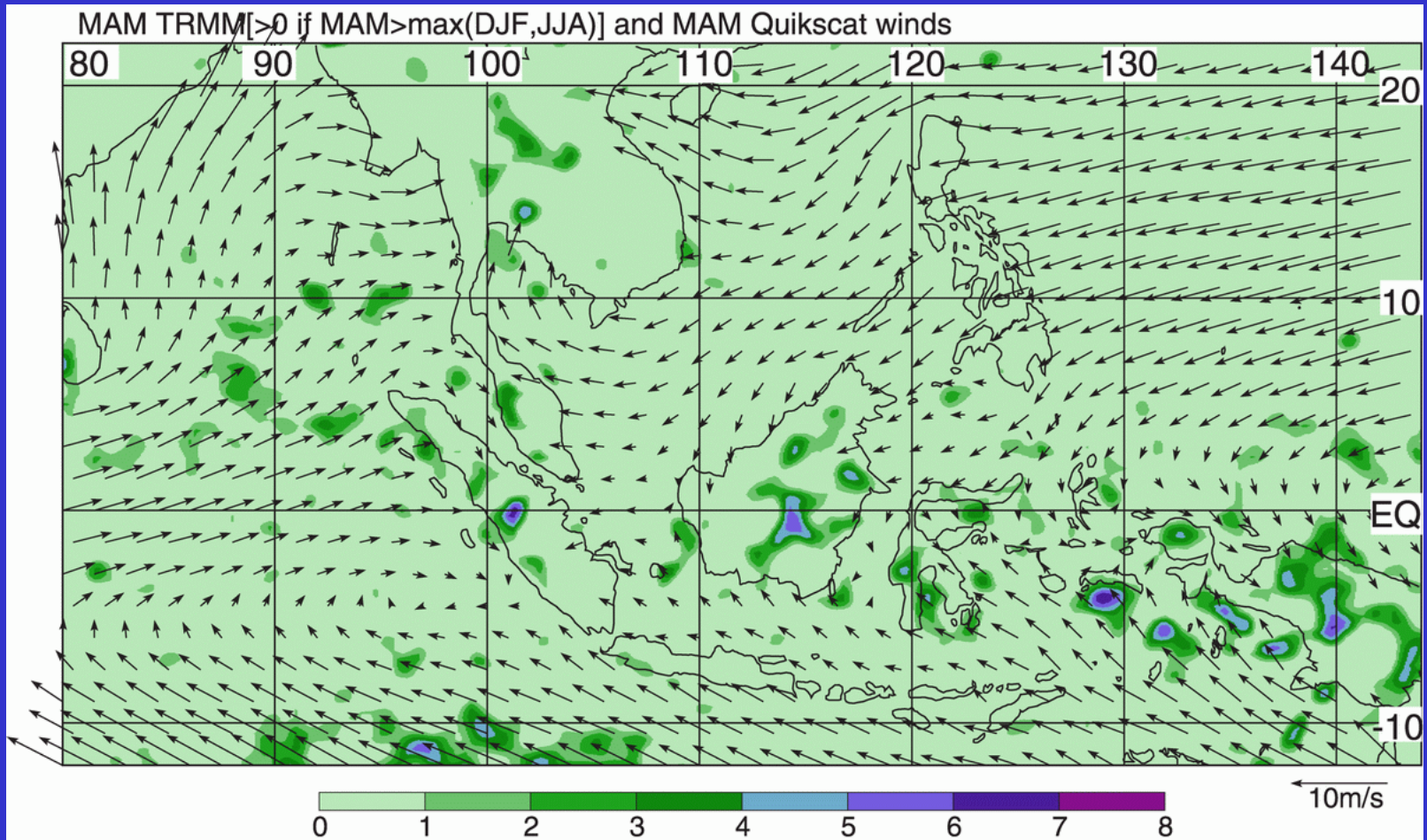
# SON TRMM [*minus* max(DJF,JJA)] & QuikSCAT



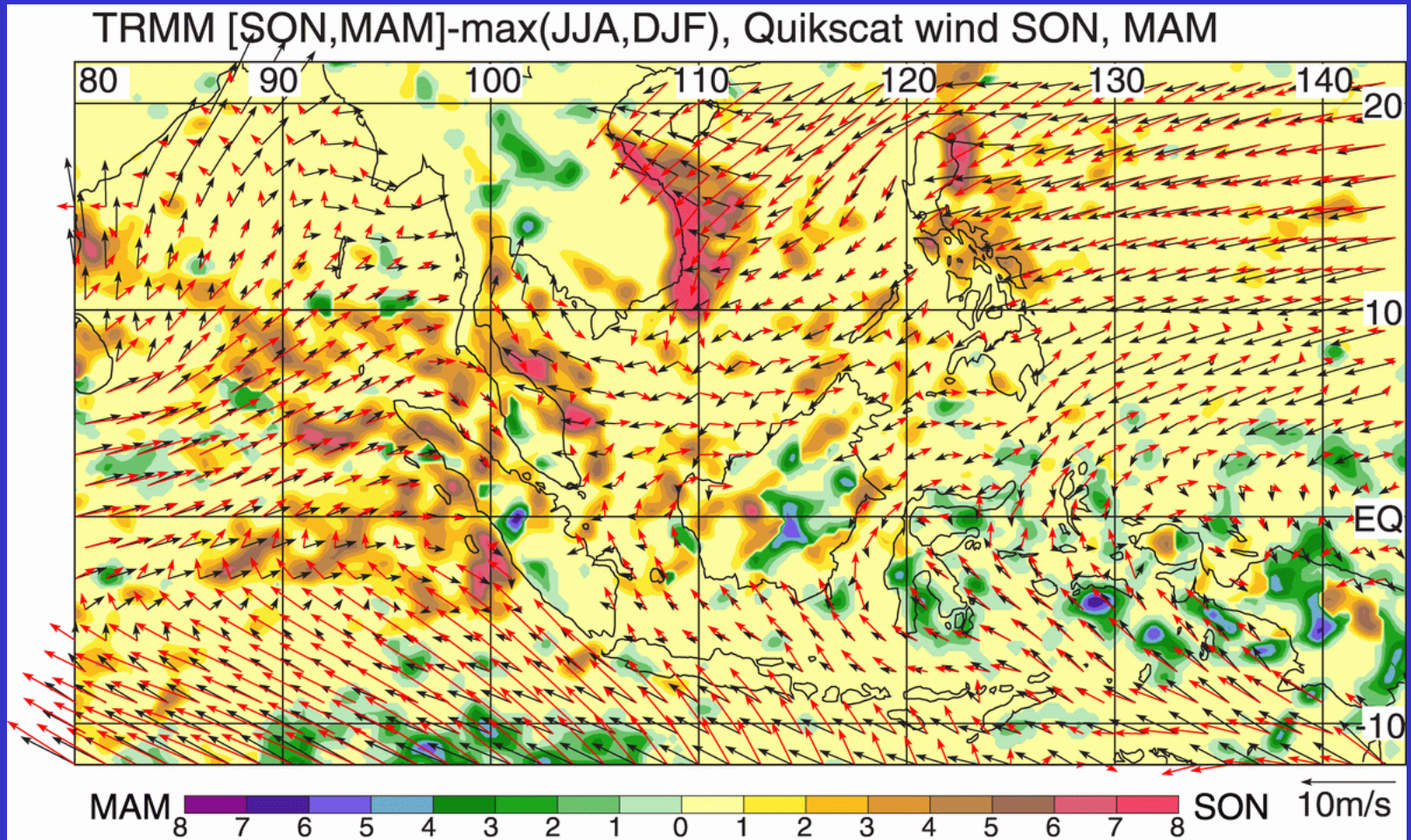
# MAM TRMM and QuikSCAT



# MAM TRMM [*minus* max(DJF,JJA)] & QuikSCAT



# MMA & SON TRMM [*minus* max(DJF,JJA)] & QSCAT



## Possibly Mechanisms

### Walker circulation strength?

E. Pac cold tongue peaks in boreal fall. (*Li & Philander 1996*)

W. IO warmest in boreal spring. (*Webster et al. 1998*)

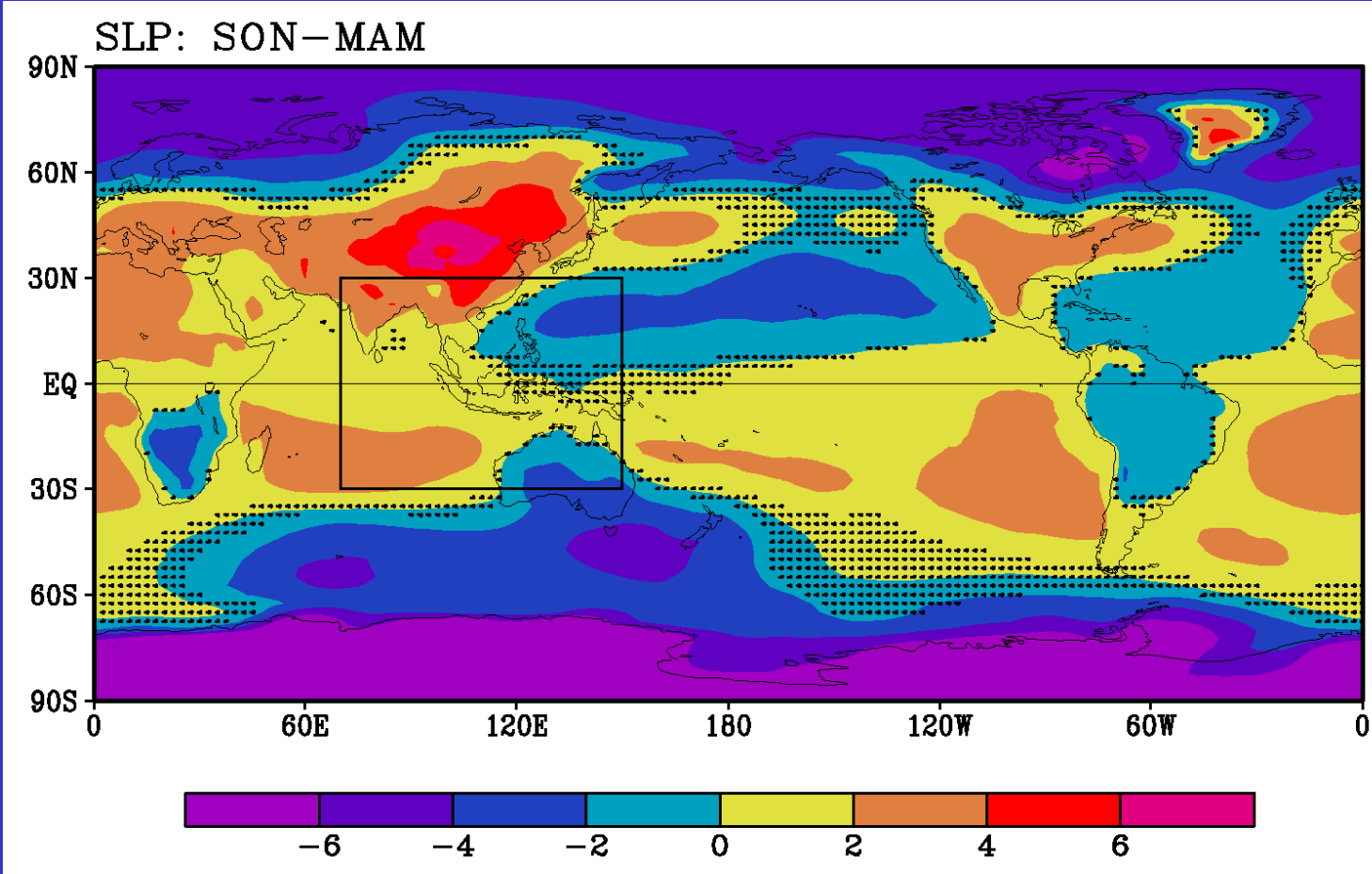
### Rossby-wave response?

Northward march of ITCZ in boreal spring blocked by subsidence in oceanic regions west of heat sources (India, Indochina, Philippines). (*Hung and Yanai 2003*)

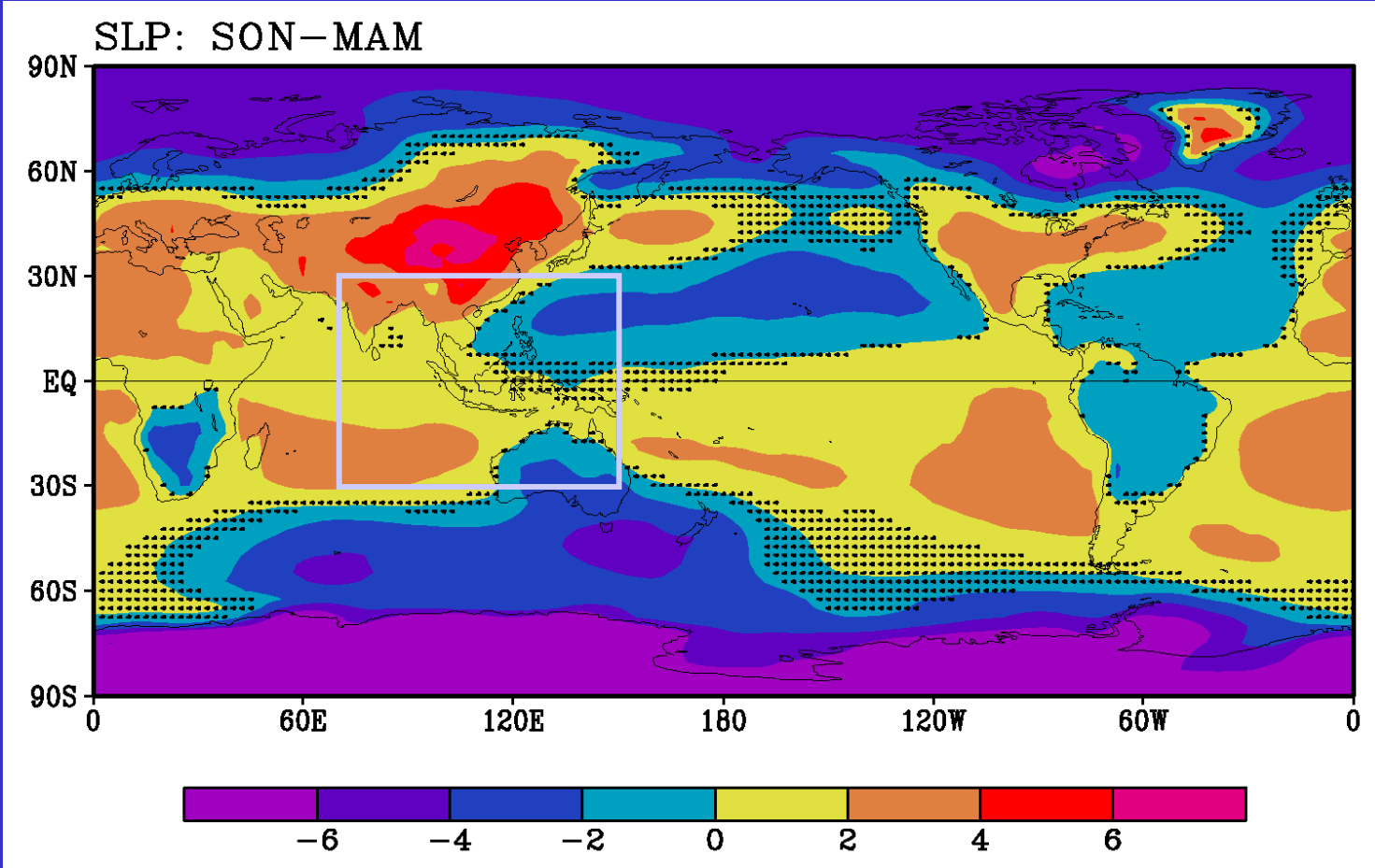
### Boundary Layer convergence?

Tendency of Eastward Propagation

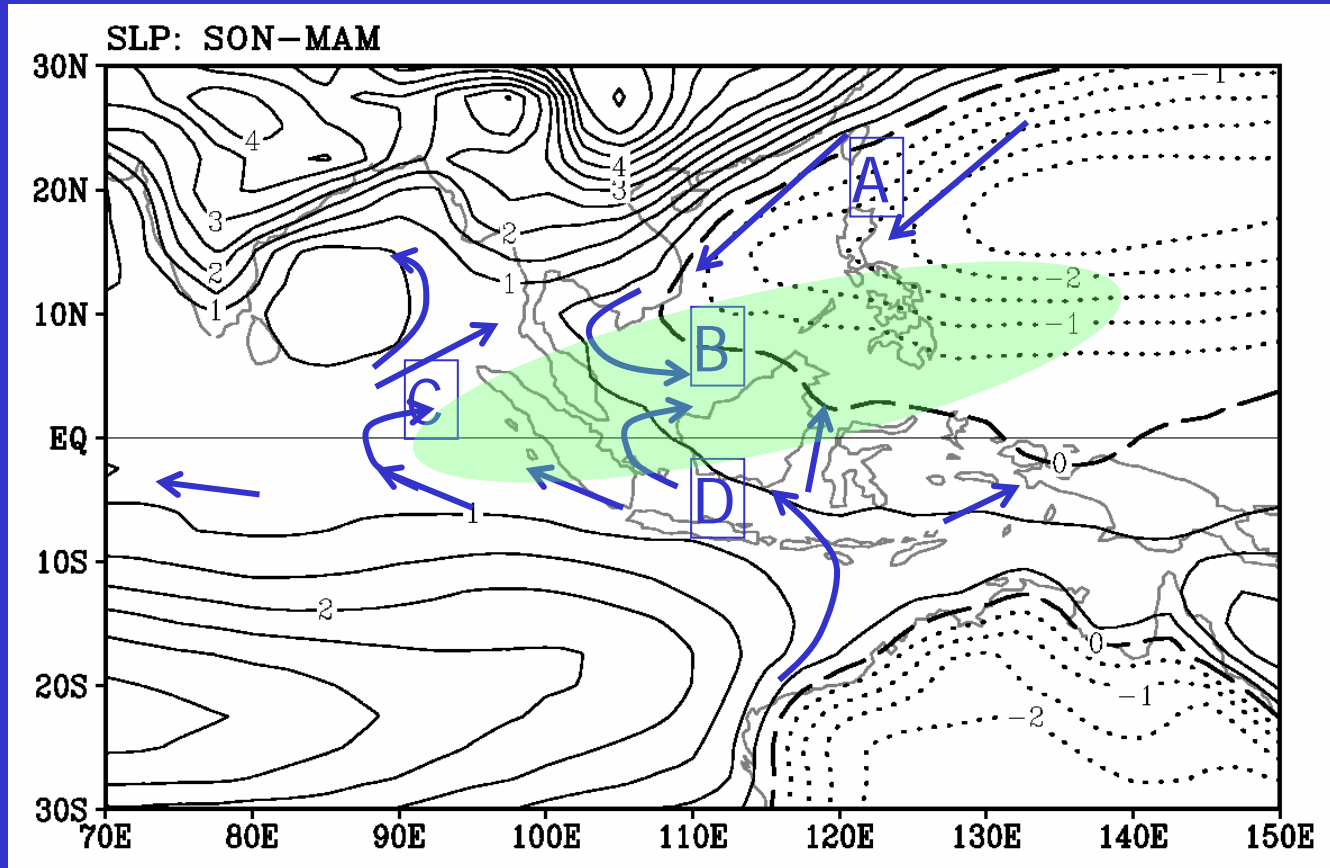
# SON minus MAM SLP



# SON minus MAM SLP



# SON minus MAM SLP



## Observation Summary

- ❑ AC is dominated by interactions between complex terrain and simple reversal of large-scale surface monsoonal winds.
- ❑ Comparable Semi-AC over some equatorial landmasses, but very small area reflects twice-yearly crossing of the sun.
- ❑ Boreal summer and winter regimes intertwine across the equator. Winter regime extends far northward along eastern flanks of major landmasses.  
(*Exception: west coast of Borneo: winter vortices*)

## Observation Summary (Continued)

### □ Asymmetric seasonal march:

*Boreal Fall:* Max. convection at midpoint of the SE-ward progression of Asian (summer to winter) monsoon.

*Boreal Spring:* Max. convection stays near or south of EQ.

### □ Hypothesis:

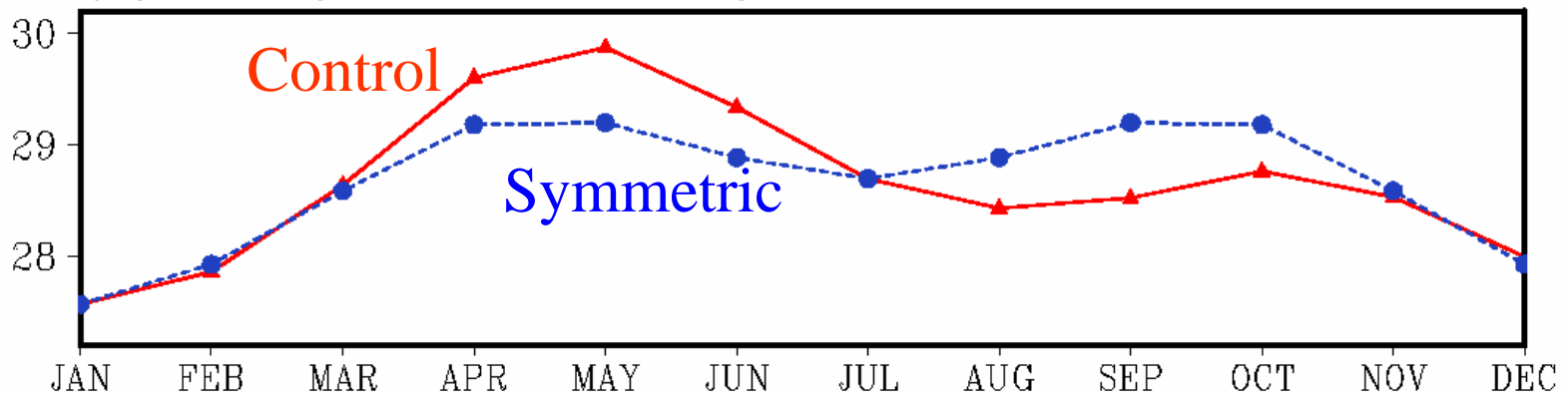
Different thermal memories during spring and fall → mass redistribution between land and ocean areas:

- Orientation of Asian-Australian landmasses → asymmetric SLP patterns → (1) asymmetric wind-terrain interactions, & (2) asymmetric low-level divergence.
- Both promote SE-ward march of max. convection during boreal fall but oppose NW-ward march during spring.

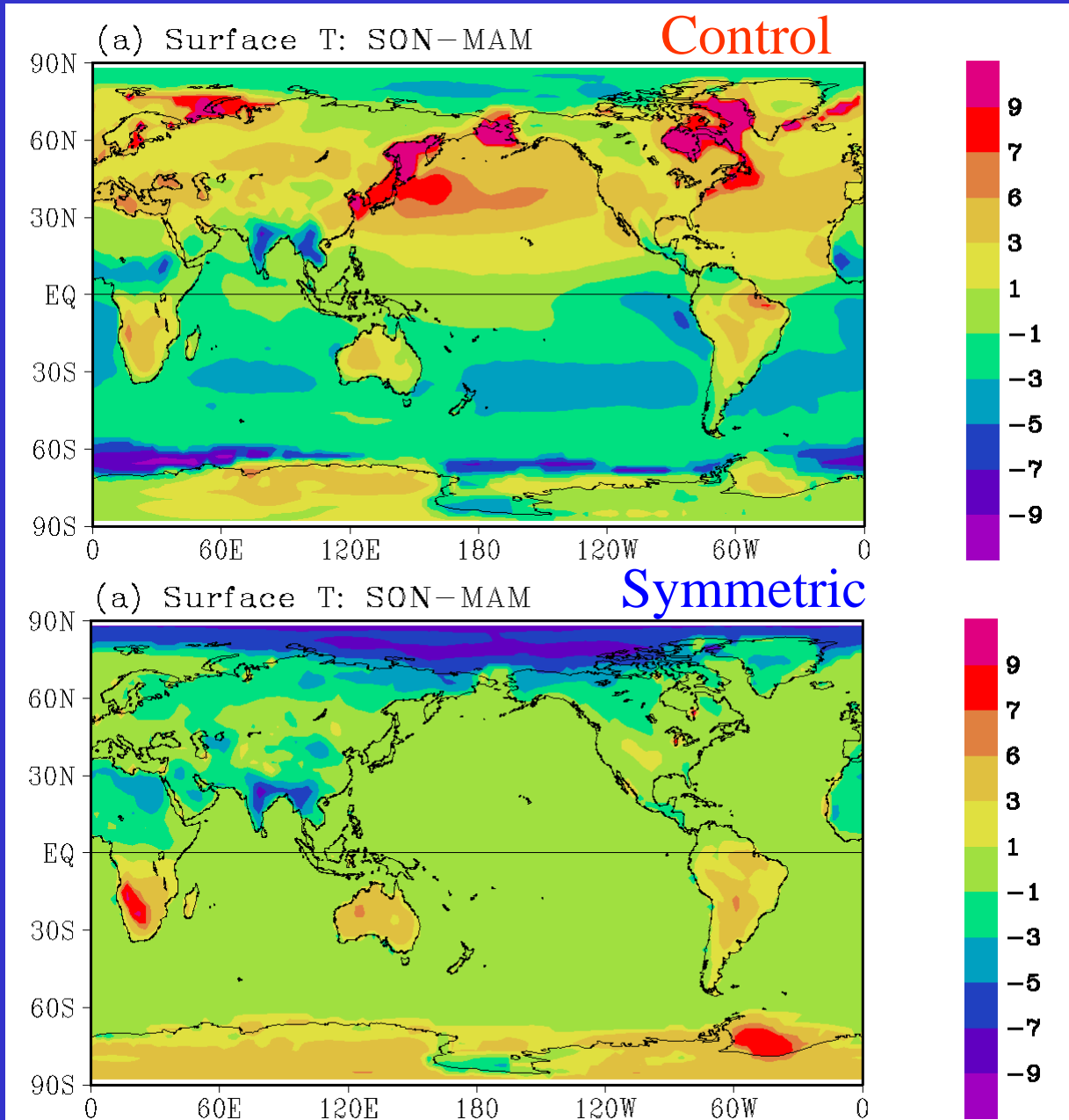
# SST Forcing

$$SST(i) = \begin{cases} 0.5(SST_{obv}(i) + SST_{obv}(14-i)), & \text{for } i \neq 1 \text{ or } 7 \\ SST_{obv}(i), & \text{for } i = 1, 7 \end{cases}$$

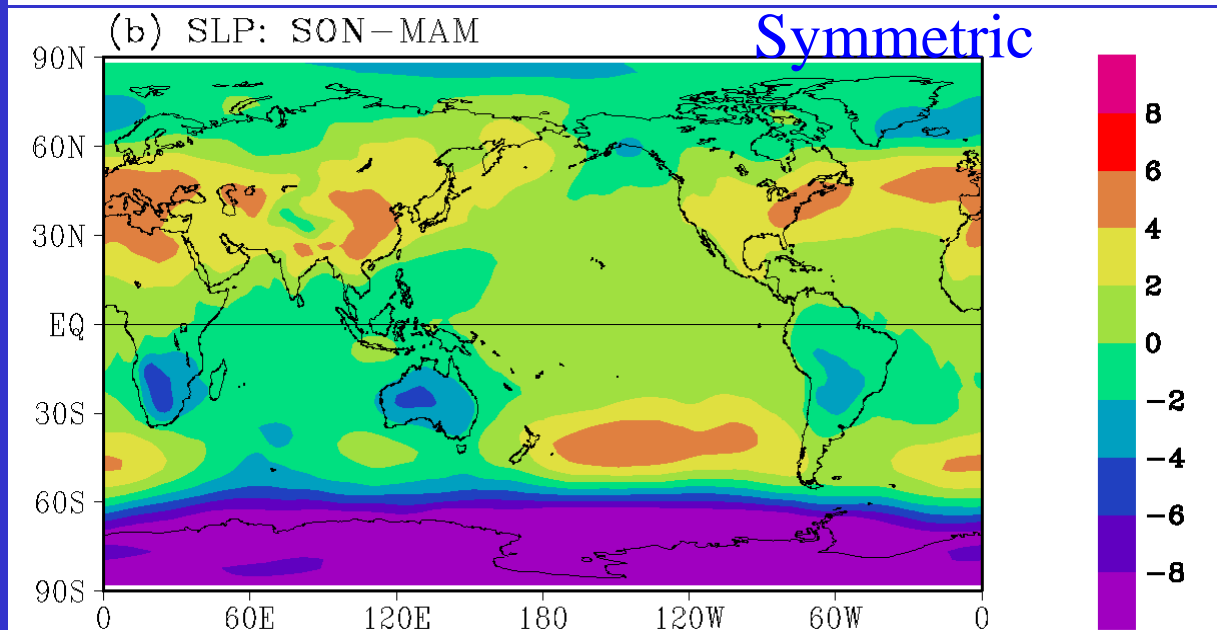
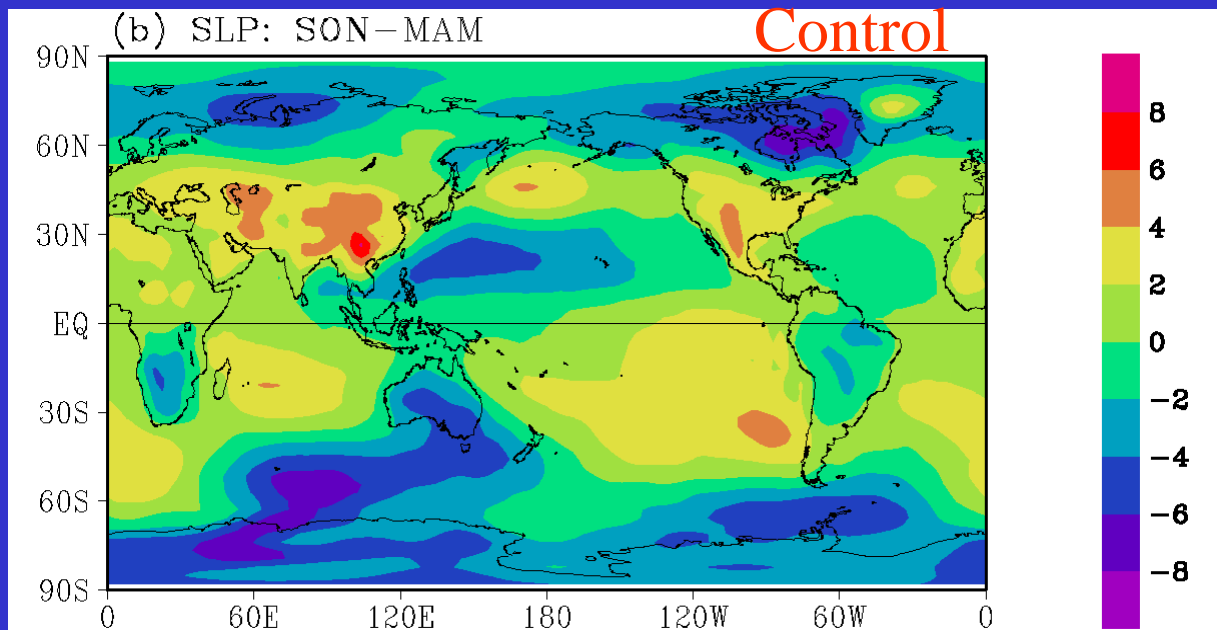
(d) SST (0–20N, 70–90E)



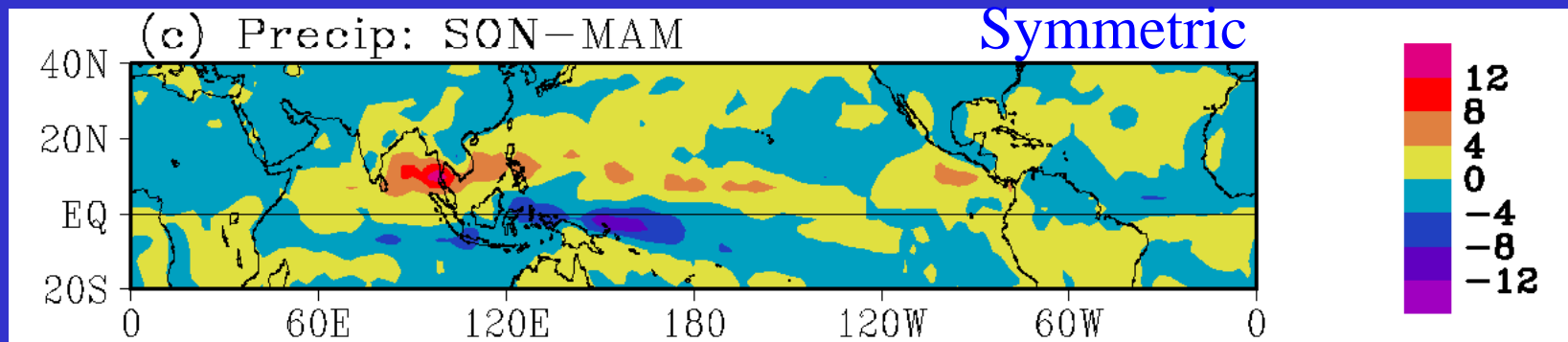
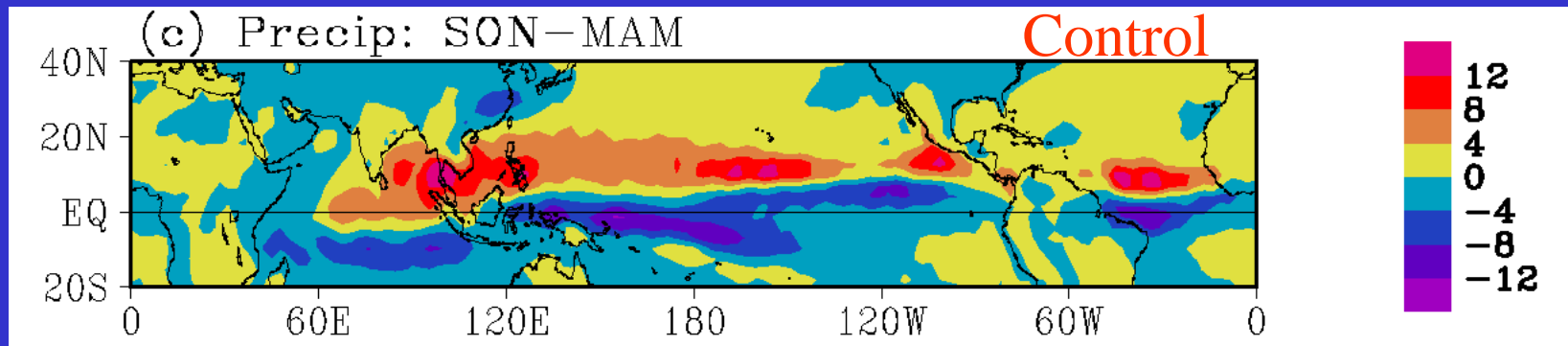
# Sfc T SON-MAM



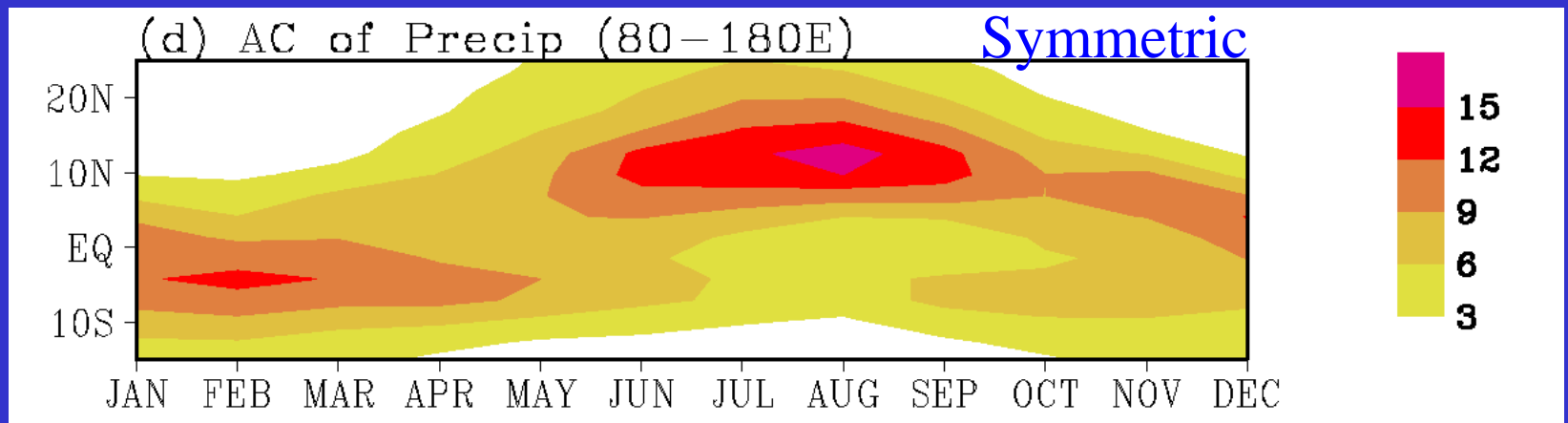
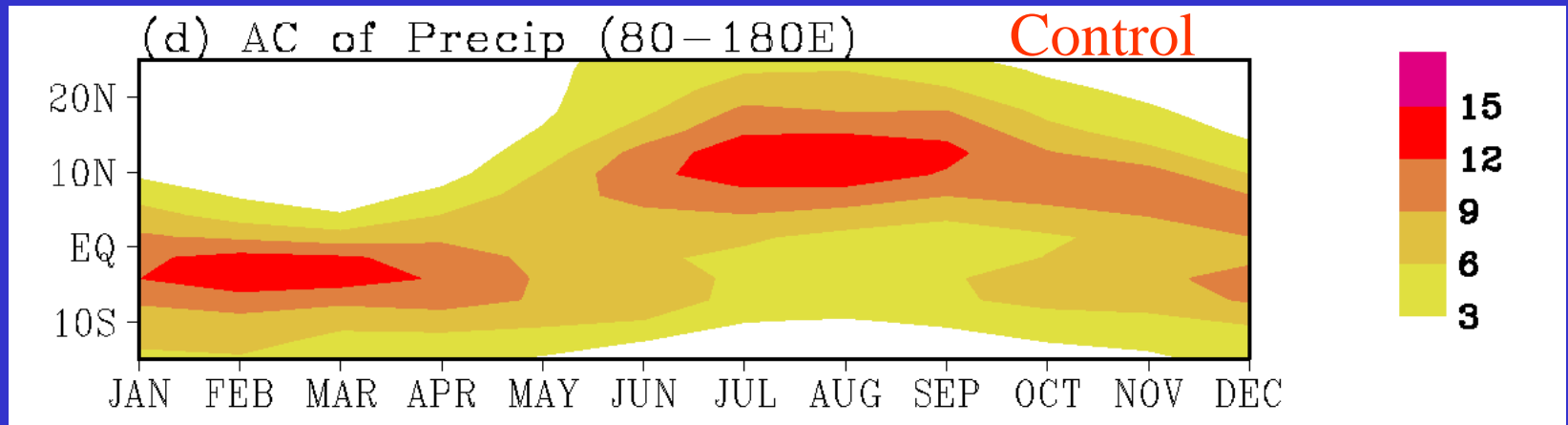
# Sfc P SON-MAM



# Precipitation SON-MAM

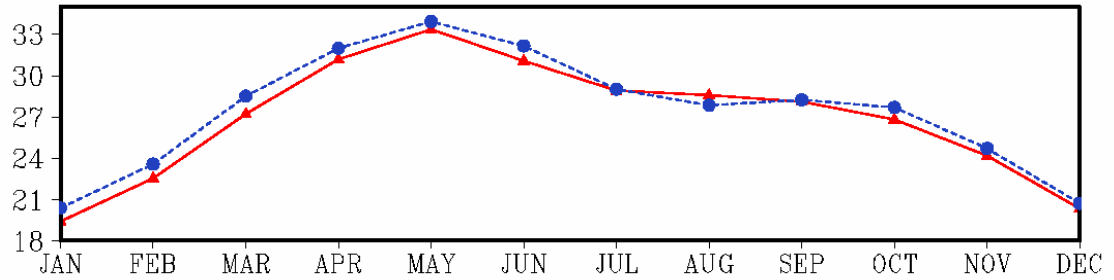


# Precipitation Annual Cycle

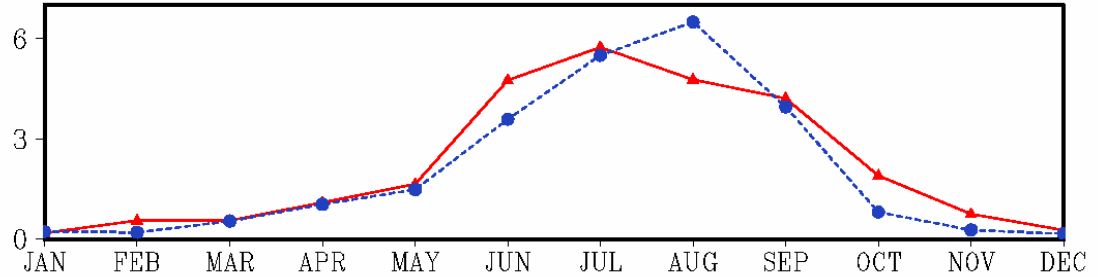


# Indian Monsoon Annual Cycle

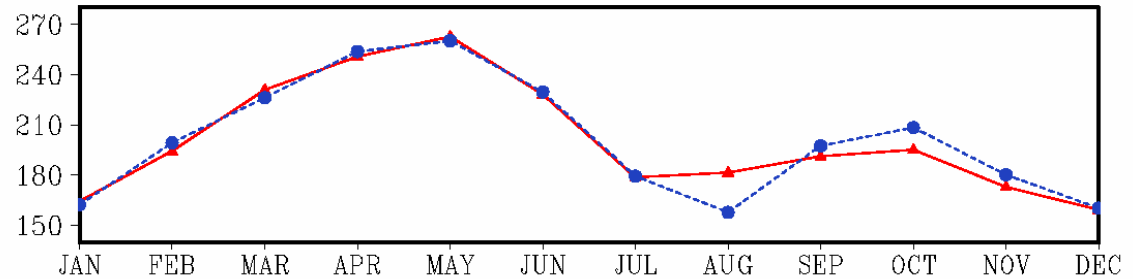
(a) Surface T over Land (17.5–25N, 70–90E)



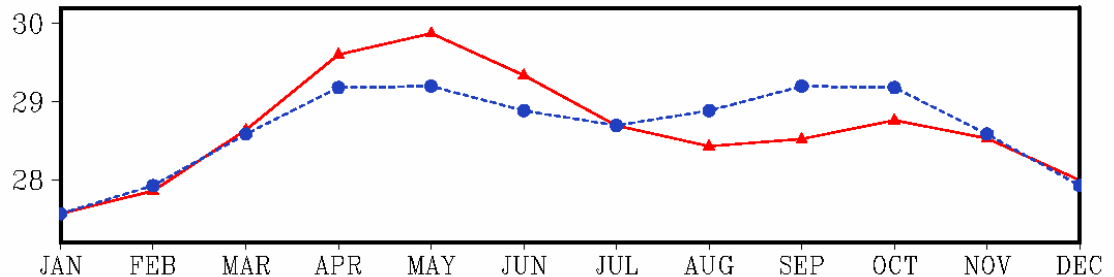
(b) Precip (17.5–25N, 70–90E, mm/day)



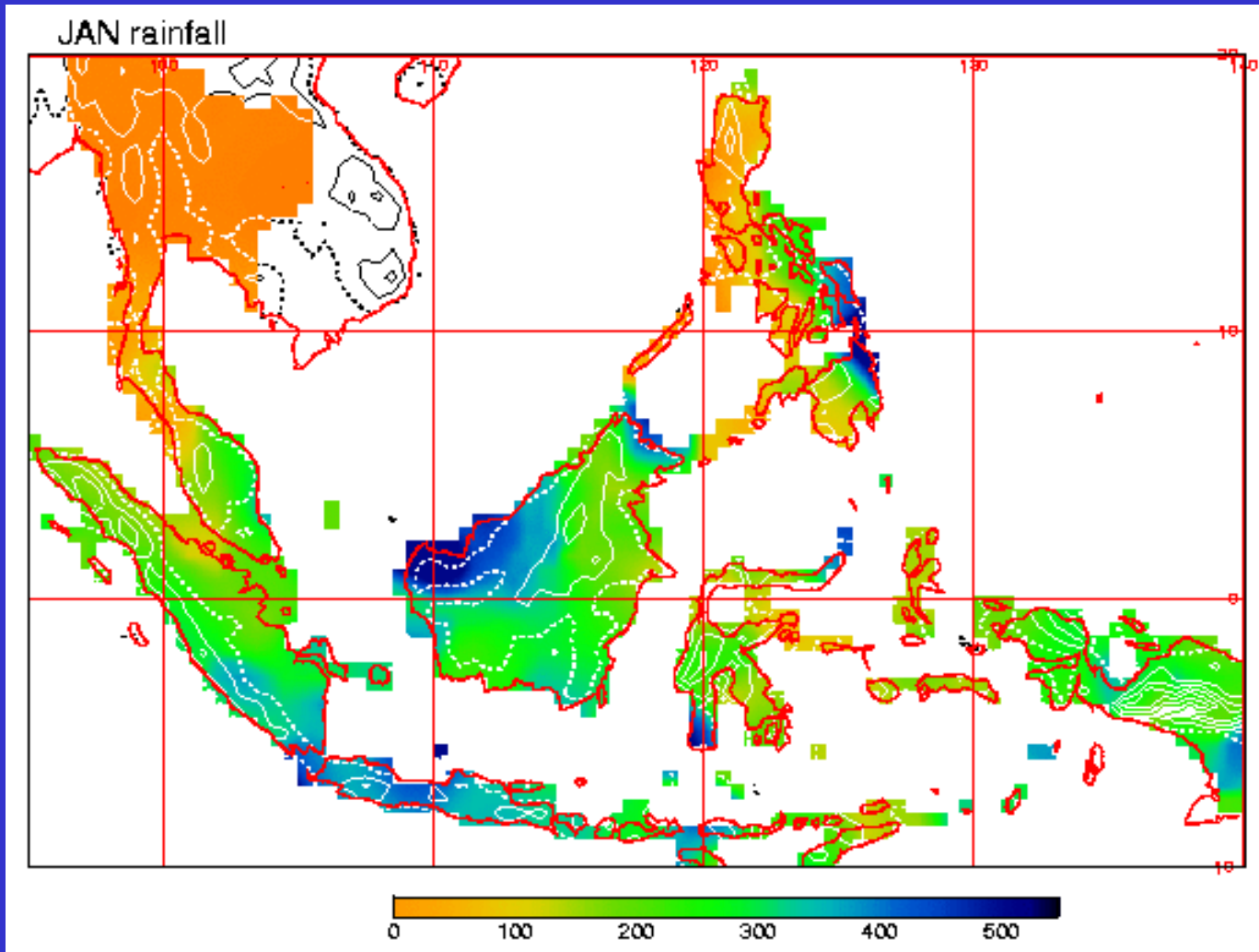
(c) Surface Solar Radiation (17.5–25N, 70–90E)



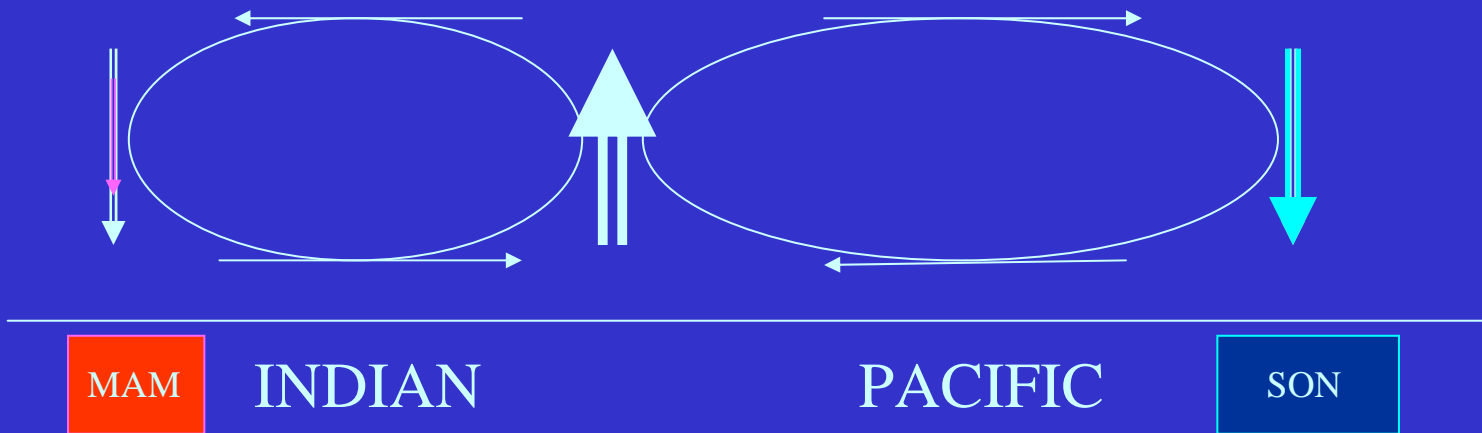
(d) SST (0–20N, 70–90E)



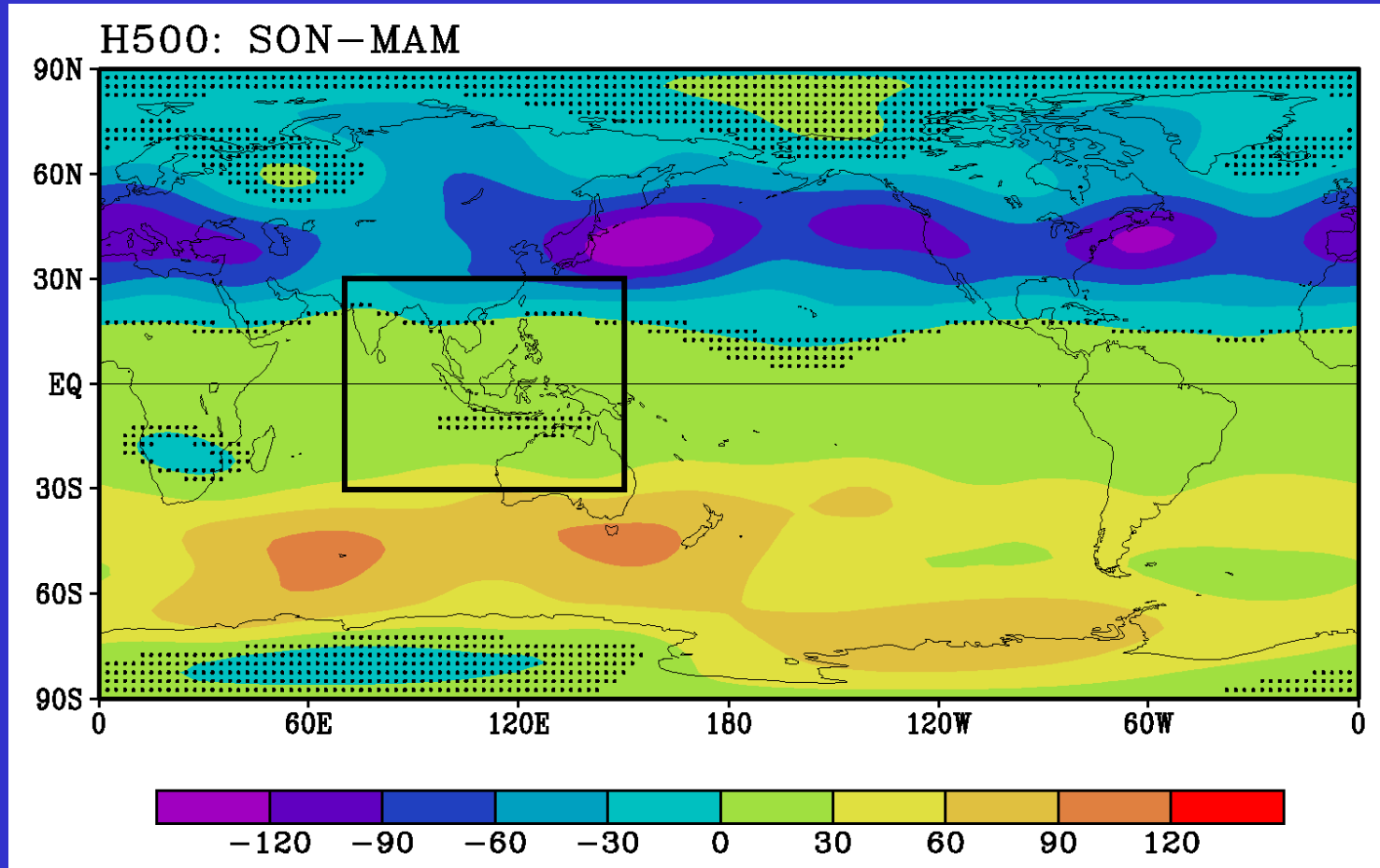
# Monthly Mean Rainfall



# Anomalous Walker Cell



# SON minus MAM 500 hPa



# Monsoon Onset Dates (Tanaka, 1994)

