Long-term trends of Asian summer monsoon and its seasonality during the recent several decades

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Issues

1. How, and to what extent has Asian monsoon changed since the late 20th century?
2. How are its regionality and **seasonality**?
3. What are dynamics of these changes in time-space?

Data set / Method

➢ Rainfall
1. CMAP (*Xie and Arkin, 1997*)
2. GPCP (*Huffman et al., 1997*)
3. APHRODITE (*Yatagai et a al., 2009*)
4. University of Delaware (http://www.esrl.noaa.gov/psd/)

➢ Water vapor flux
NCEP DOE reanalysis II (*Kanamitsu et al., 2002*)

➢ Hadley Center SST dataset *(Rayner, 2003)*

The non-parametric Mann-Kendall test was applied for assessment of the trends.

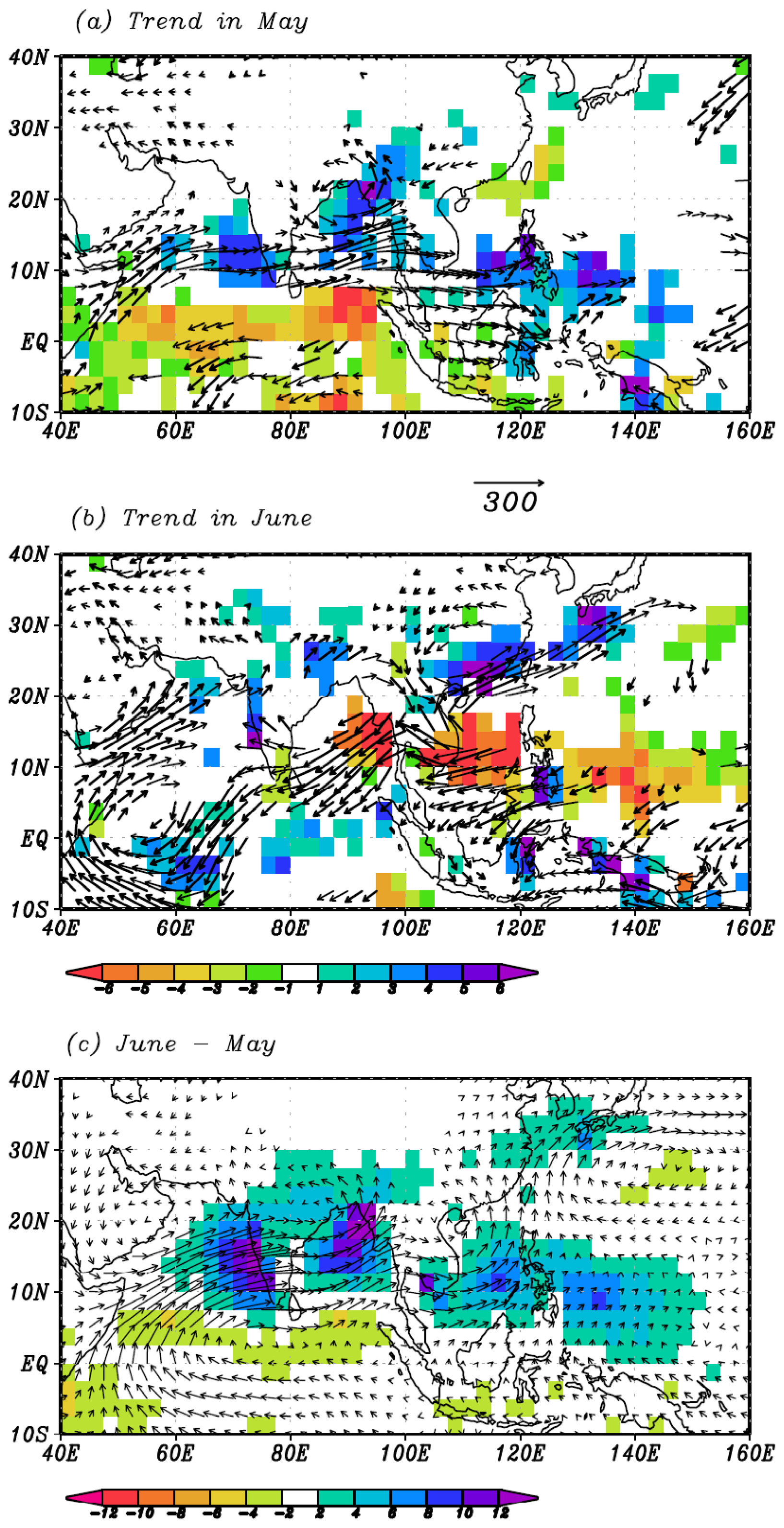

Figure 1: (a) Linear trends of rainfall (CMAP: Shading: mm/day) and vertical integrated water vapor flux ($kg\ m^{-1}\ s^{-1}$) in May. All values were multiplied by 30 (years) for the period 1979–2008. Only those that are significant at the 95% level are plotted. (b) Same as (a) but for June. (c) Climatological difference in rainfall and water vapor flux between June and May.

Results I

- ✓ Rainfall pattern in May during the recent decades has become close to that in June (Fig.1c)
- ✓ The monthly rainfall trends are robust in different rainfall datasets (Fig.2)
- ✓ The Asian monsoon rainfall has a significant trend mainly during the transitional season (Fig.3)
- ✓ The long-term trend of boreal summer mean rainfall changes significantly depending upon whether it includes rainfall in May (Fig.4).

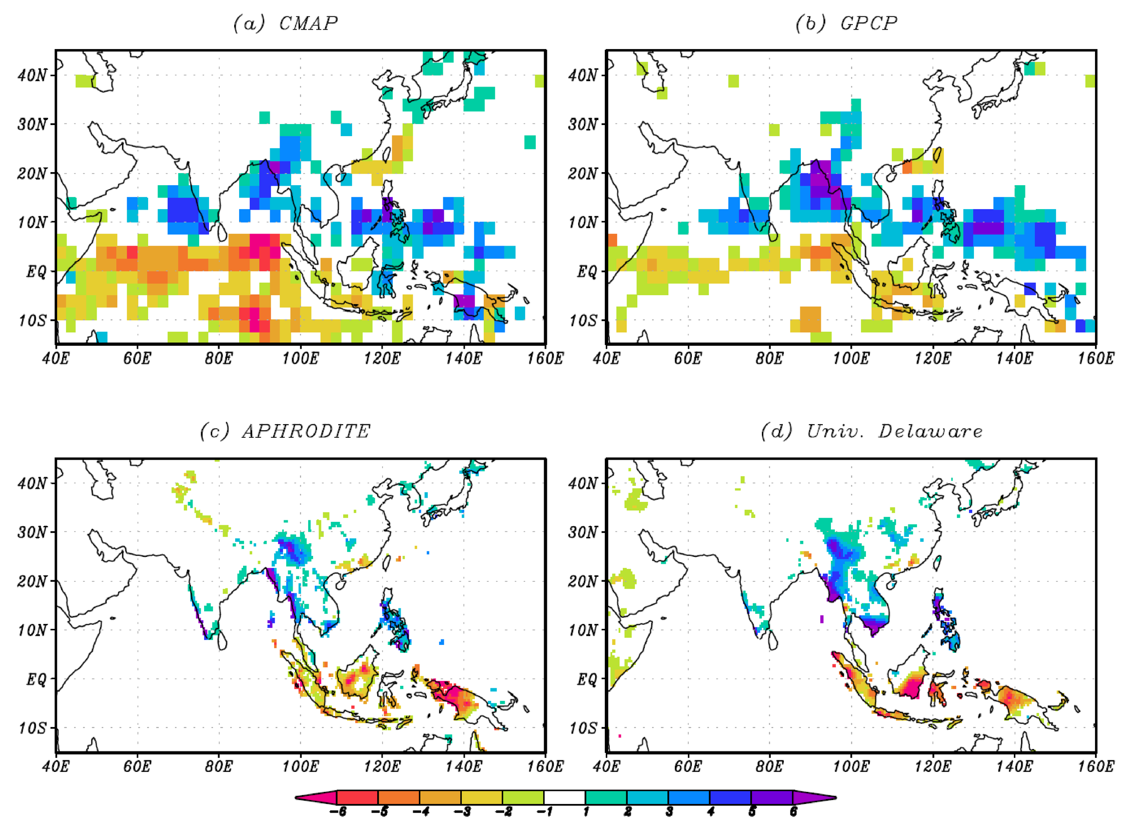

Figure 2: Linear trends of rainfall in May (mm/day) as same as Fig. 1a but for 4 different rainfall data set: (a) CMAP, (b) GPCP, (c) APHRODITE's Water Resources Project , and (d) University of Delaware Precipitation.

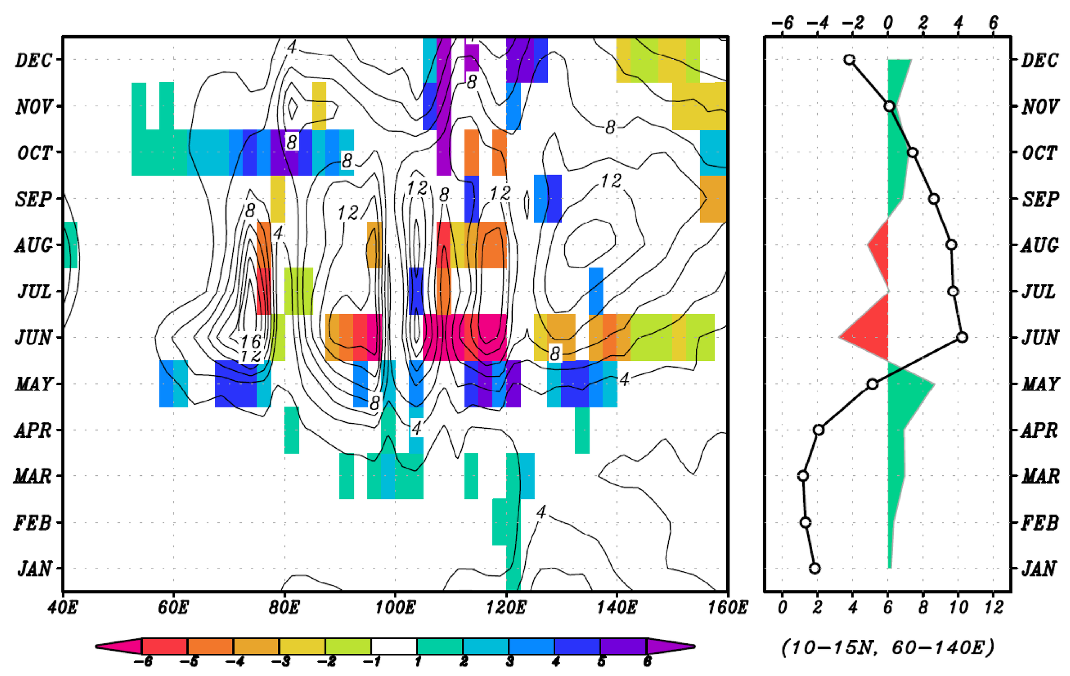

Figure 3: (Left) Latitude-time section of trend (shading) and climatology (contour) of CMAP rainfall along 10–15N. Shadings are the same as in Fig 1. (Right) Time series of trend (shading: top axis) and climatology (line: bottom axis) of rainfall averaged over the area (10–15N, 60–140E).

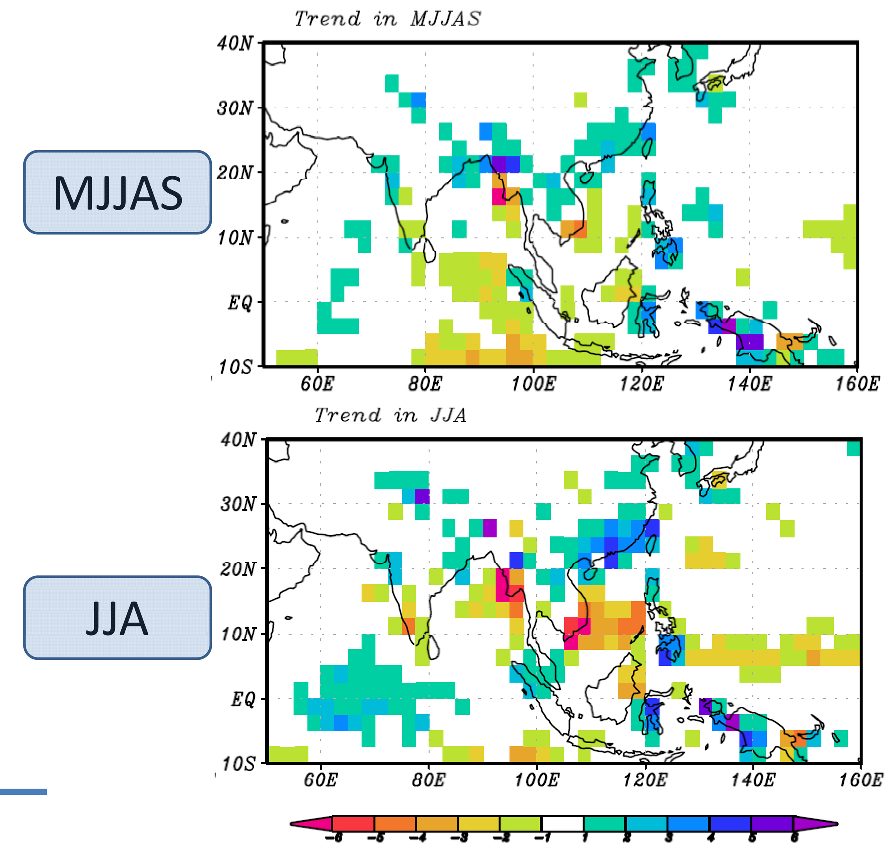

Figure 4: Linear trends of rainfall in (a) May – Sep (MJJAS) and (b) Jun-Aug (JJA) (mm/day)

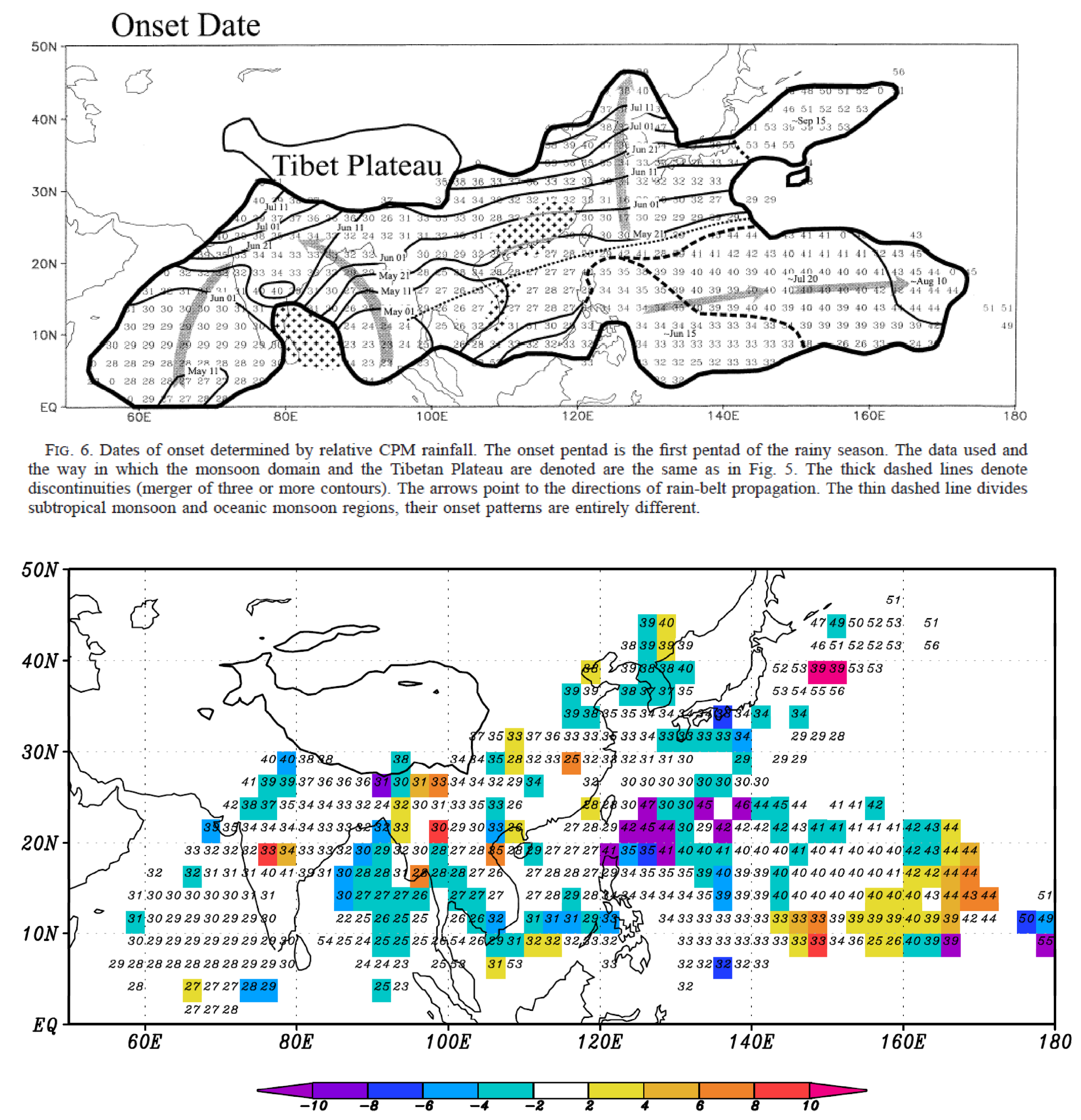

Figure 5: Date of climatological monsoon onset during 1979–1993 (Digit). The onset pentad was determined by the method of Wang and Linho (2002). The shading denotes the difference in the monsoon onset between 1994–2008 and 1979–1993.

Results II

- ✓ The monsoon onset dates over the BoB, Indochina Peninsula, and western-north Pacific have shifted earlier for about 10-15days in the recent decades (Fig.5)
- ✓ Warming trend over the continent in May (Fig. 6c) has induced earlier seasonal overturning of land-sea heat contrast (Fig.6a).
- ✓ Overall weakening (intensified) moisture convergence has become significant over land (sea) in the main monsoon months except in May and September (Fig. 7)

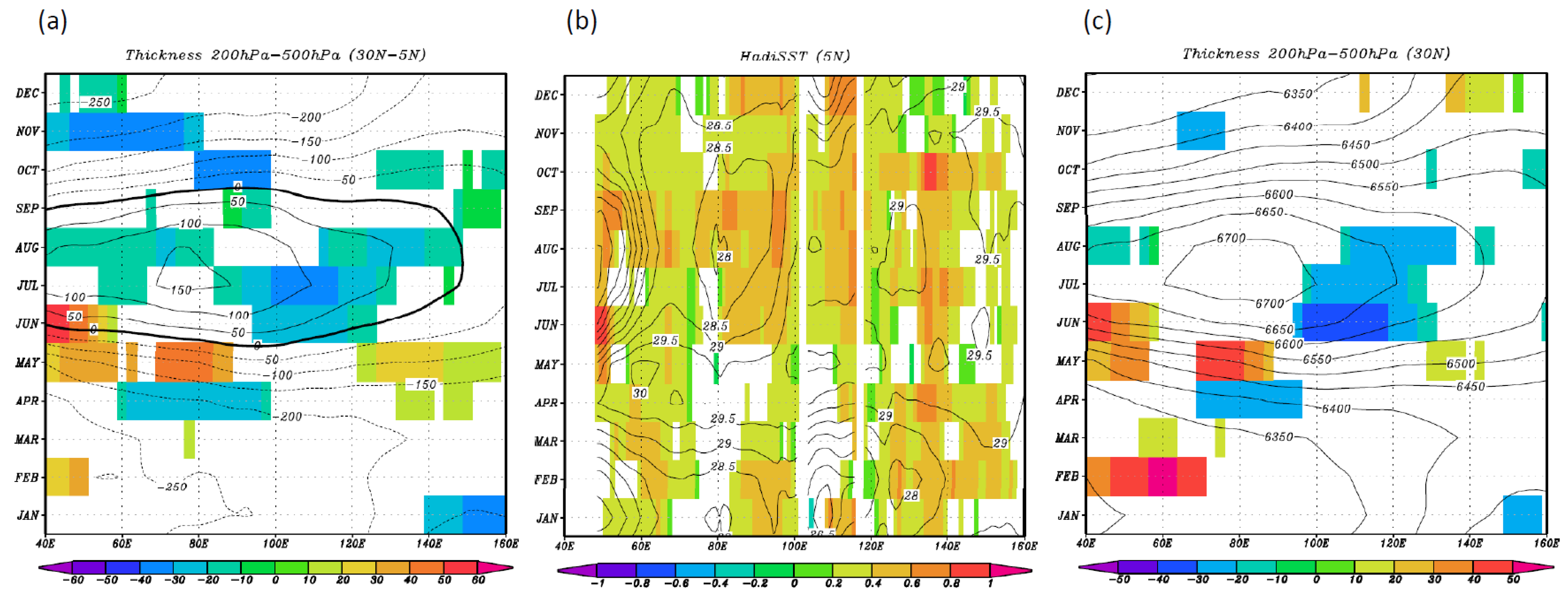

Figure 6: (a) Longitude-time section of the trend and climatology of the difference in atmospheric thickness (200–500 hPa) between land (30N) and ocean (5N) areas. Trends are multiplied by 30 (years) for the period 1979–2008. Only those that are significant at 95% level are plotted. (b) Same as (a) but for SST along 5N. (c) Same as (a) but for along 30N.

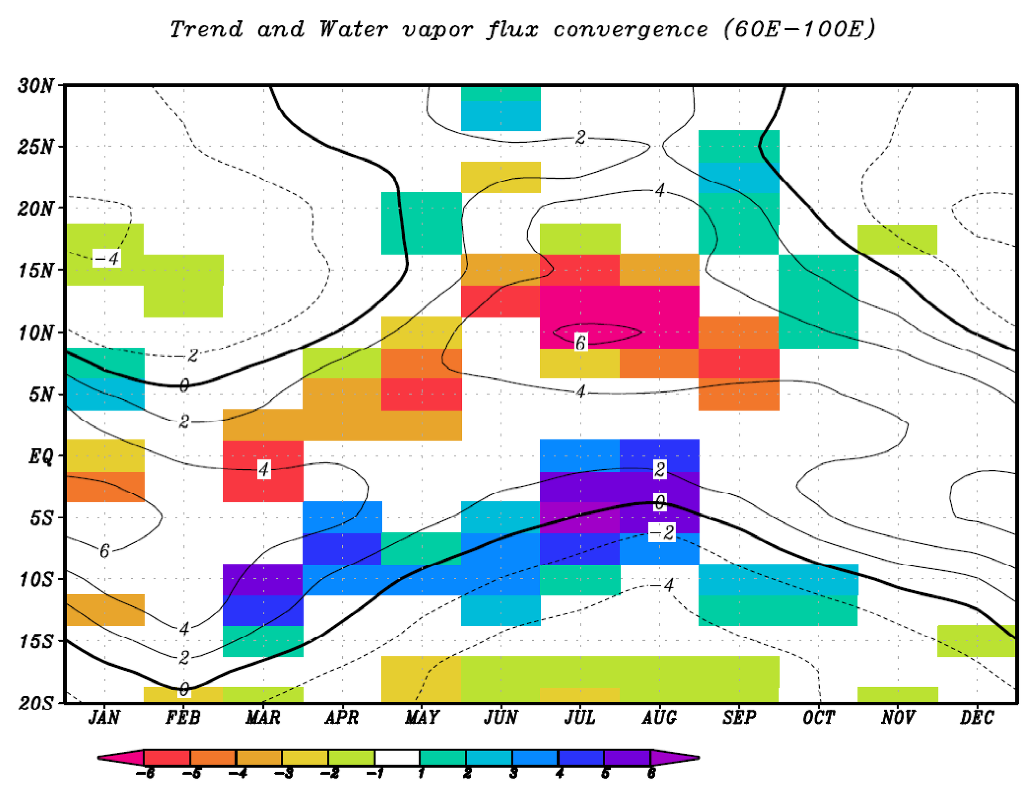

Figure 7: Latitude-time section of water vapor flux converngece trend averaging between 60-100E. Only those that are significant at 95% level are plotted.

Summary

We have elucidated the significant **seasonality** in long-term trends in the Asian monsoon.

1. Increasing rainfall trend in May along 10N correspond to the earlier monsoon onset.
2. Rainfall trends in July and August have been less significant.
3. The earlier monsoon onset and weakening of the monsoon are most likely to be attributed to the stronger heating over land in May, and stronger heating over the tropical sea in June through August.
4. These changes of seasonal land-sea heating contrast may be presumed to be related to changes of anthropogenic aerosol forcing and SST.

References

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Kajikawa, Y., T. Yasunari, S. Yoshida and H. Fujinami, 2011: Advanced Asian monsoon onset in recent decades. *Geophys. Res. Lett.*, submitted.

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