2356-3

Targeted Training Activity: ENSO-Monsoon in the Current and Future Climate

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Global Monsoons Overview

MISRA Vasubandhu

Florida State University
Department of Earth, Ocean and Atmospheric Sciences
404 Love Building, 1017 Academic Way
Tallahassee FL 32306

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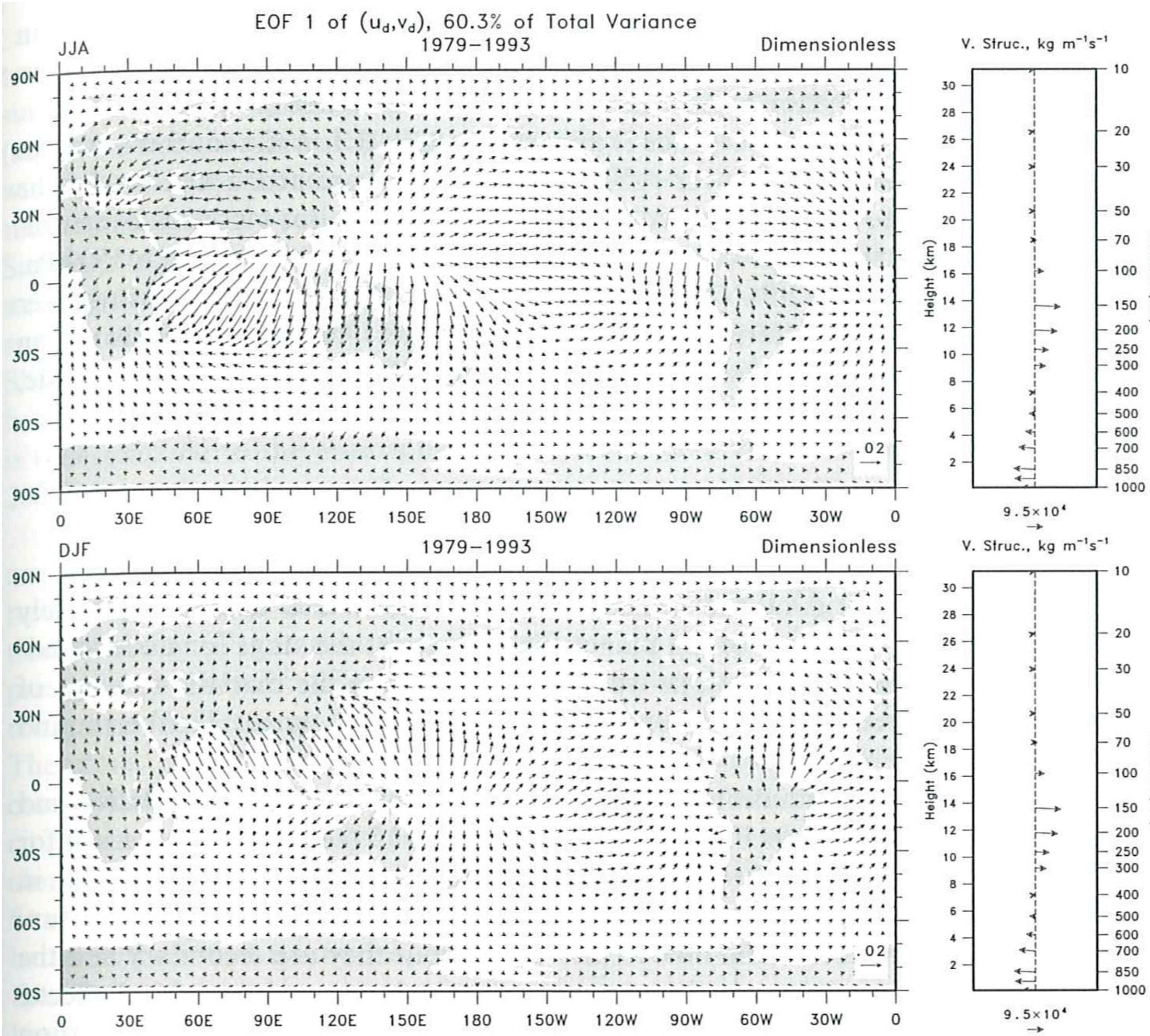
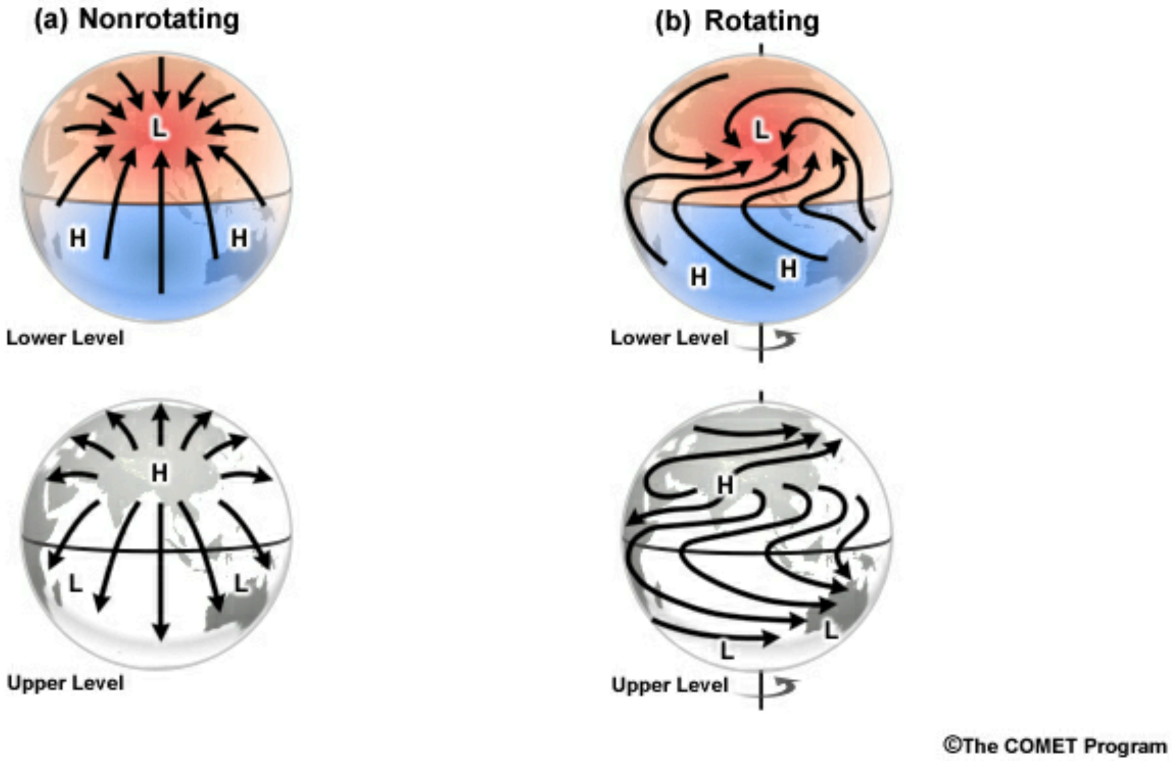
Vasu Misra,
Dept. of Earth, Ocean and Atmospheric Science (EOAS) &
Center for Ocean-Atmospheric Prediction Studies (COAPS),
Florida State University
Email: vmisra@fsu.edu

- Monsoon with origins from the Arabic “mawsim” for season refers to the seasonal variations of the winds
- Global monsoon in *some quarters* refers to the co-ordination among the regional monsoons brought about by the seasonal cycle of solar heating and the teleconnection of the global divergent circulation necessitated by mass conservation
- The Indian monsoon in particular has global repercussions……

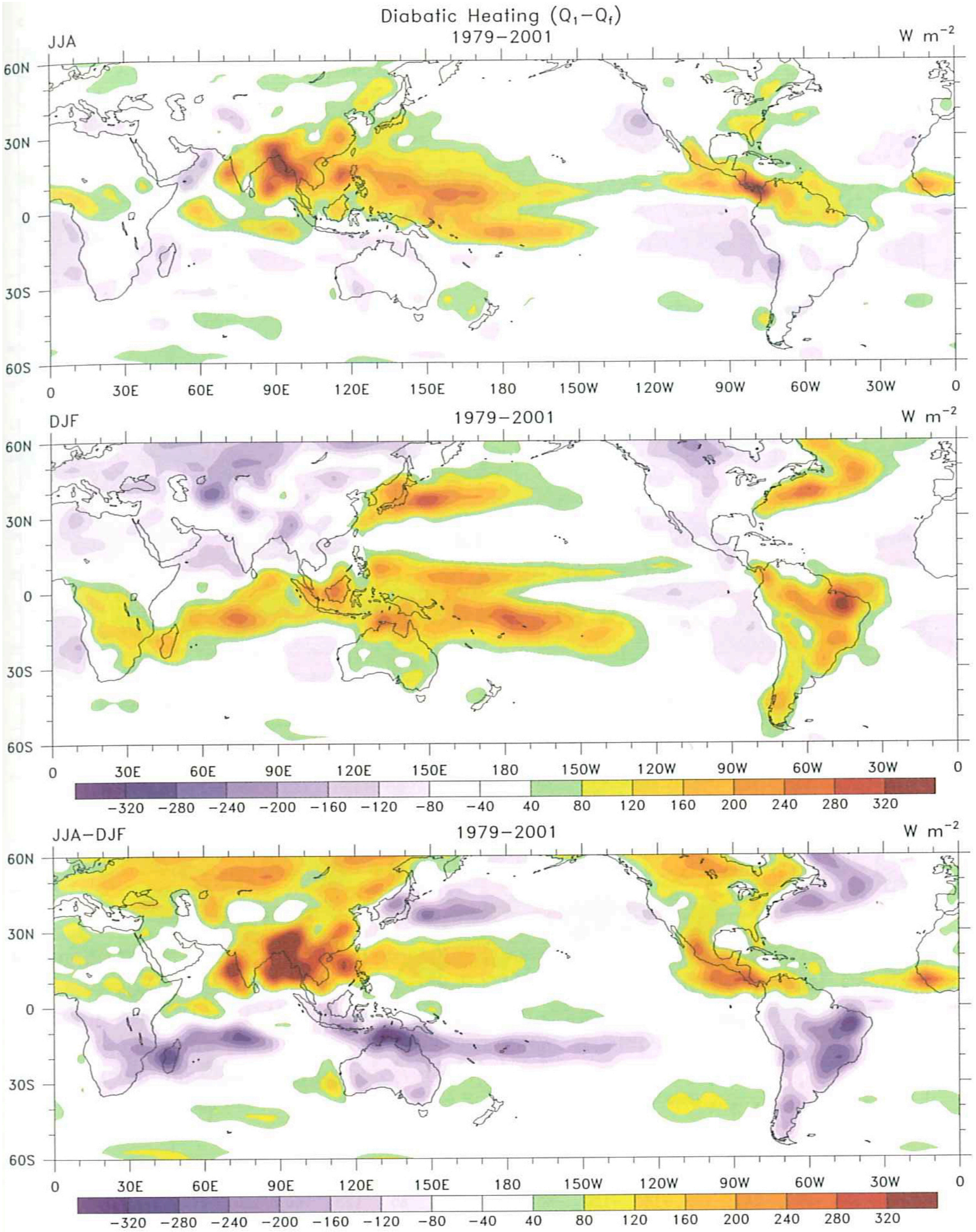


Combined EOF of mass weighted divergent wind vectors, with vertical structure of the first mode plotted as vectors in the right panel (with vectors pointing right signifying in phase and left out of phase relations with the map). Major monsoonal regions are characterized by strong divergent circulations. From Trenberth (2006).

“Planetary scale” monsoon



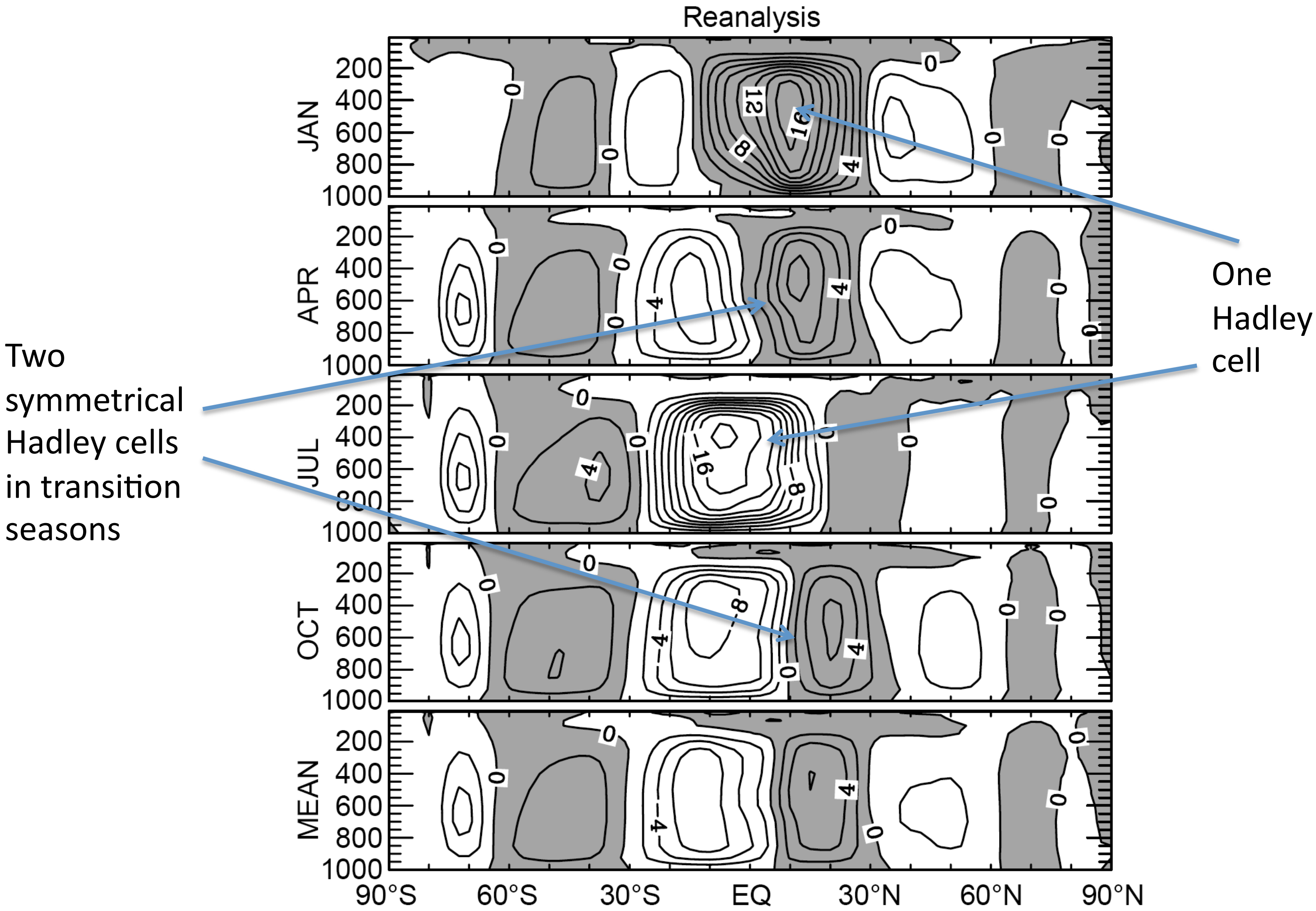
Conceptually, the global scale summer monsoon is a first response to the positive net radiation in the summer hemisphere as the surface responds to the seasonal oscillation of solar heating.



The vertically integrated diabatic heating in Wm^{-2}. The monsoonal regions of the globe are clearly identifiable, including their seasonal migration. From Trenberth (2006).

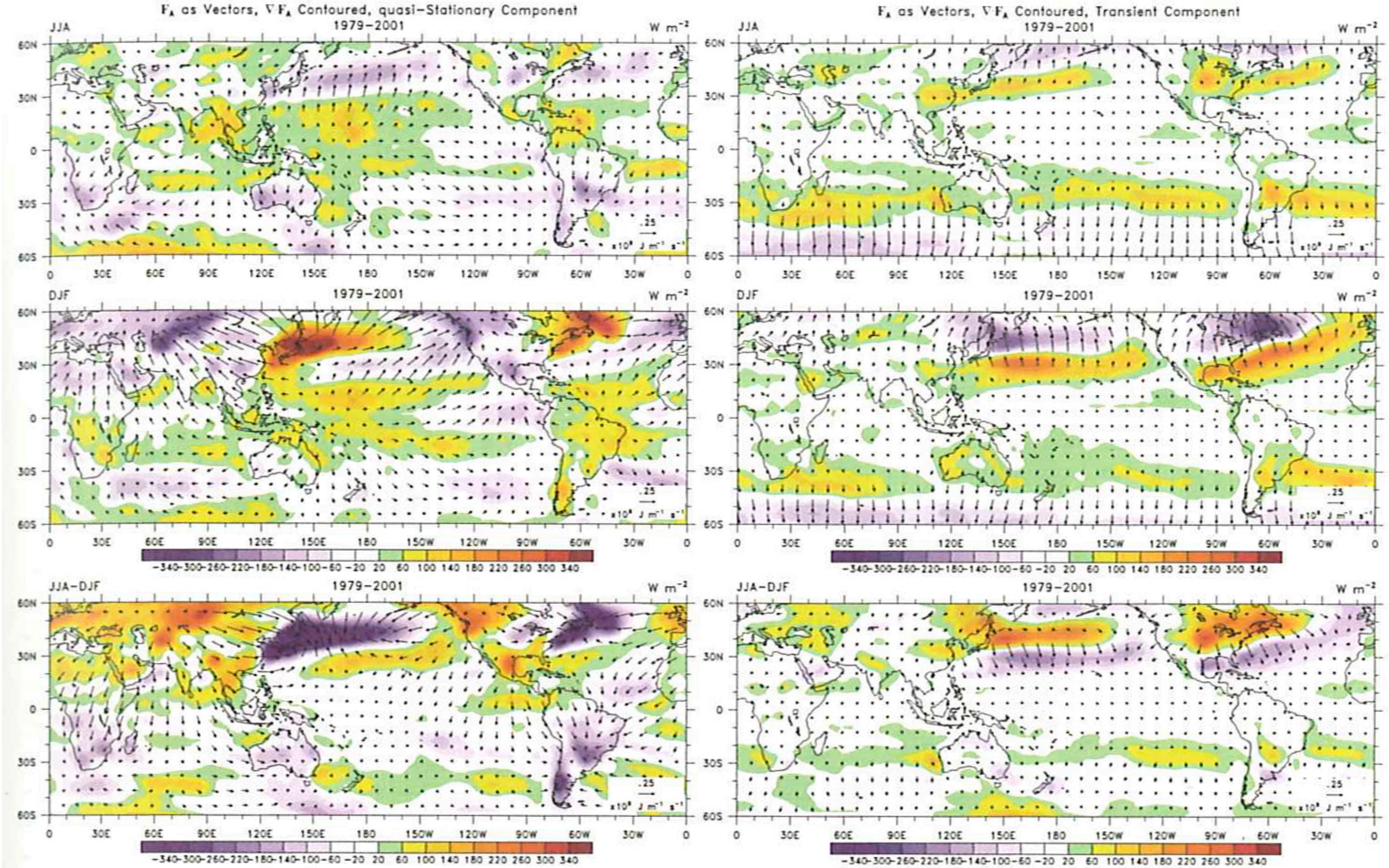
$$\frac{\partial[\overline{\psi}]}{\partial p} = [\overline{v}]\frac{2\pi r\cos\varphi}{g}$$

$$\frac{\partial[\overline{\psi}]}{r\partial\varphi} = -[\overline{\omega}]\frac{2\pi r}{g}$$

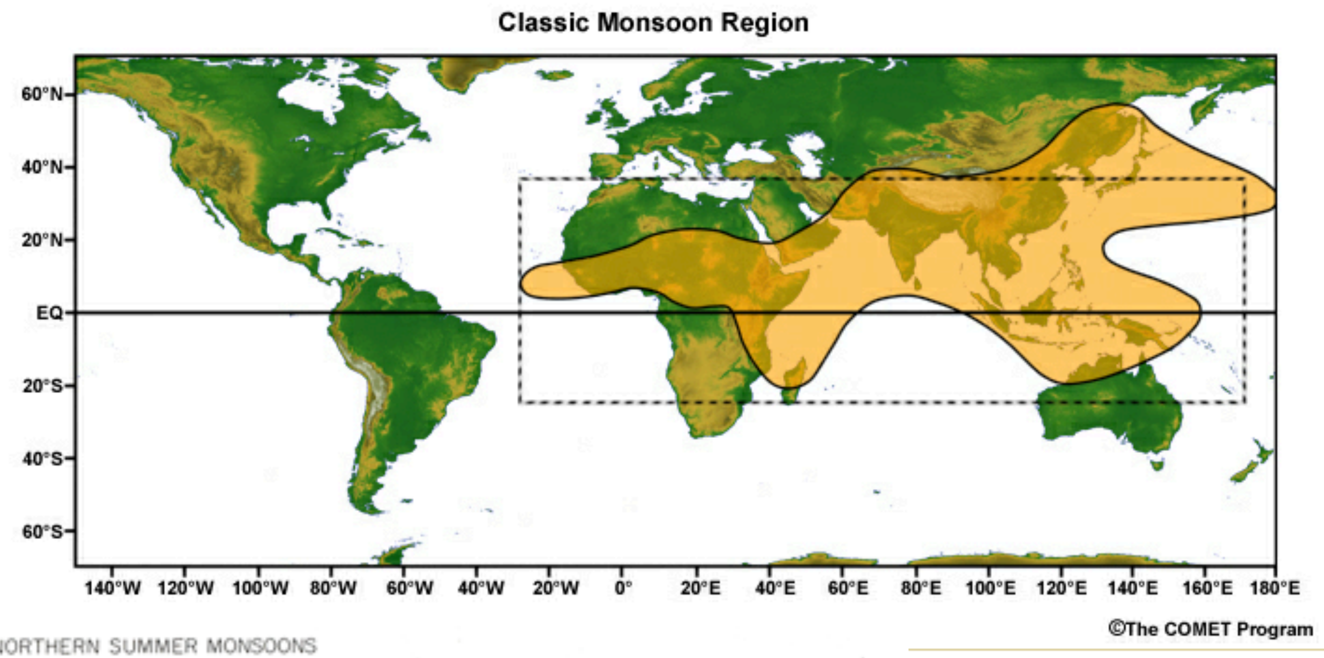

Reanalysis
JAN
APR
JUL
OCT
MEAN
200
400
600
800
1000
90°S
60°S
30°S
EQ
30°N
60°N
90°N
Two symmetrical Hadley cells in transition seasons
One Hadley cell

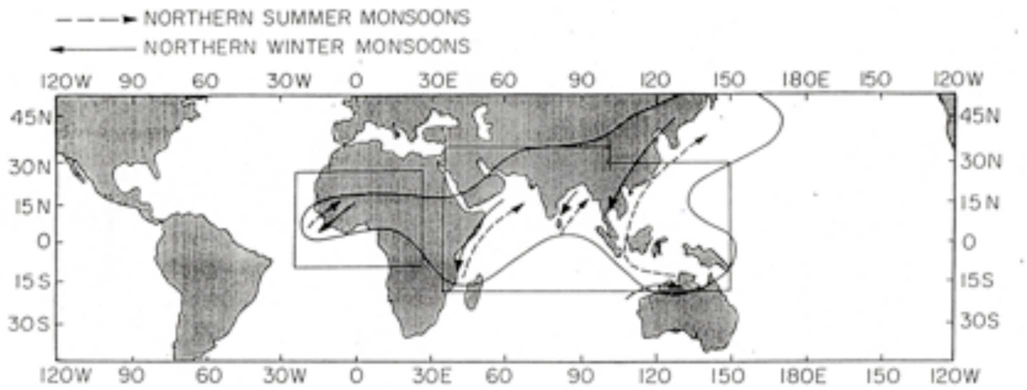
$$[Qv] = [\overline{Q}][\bar{v}] + \overline{[Q'][v']} + \overline{[Q^* v^*]}$$

$$\underset{(TT)}{\textit{Total Transport}} = \begin{matrix}\textit{Transport by the}\\ \textit{Mean Meridional}\\ \textit{Circulation (MMC)}\end{matrix} + \begin{matrix}\textit{Transport by}\\ \textit{Transient}\\ \textit{Eddies (TE)}\end{matrix} + \begin{matrix}\textit{Transport by}\\ \textit{Standing}\\ \textit{Eddies (SE)}\end{matrix}$$



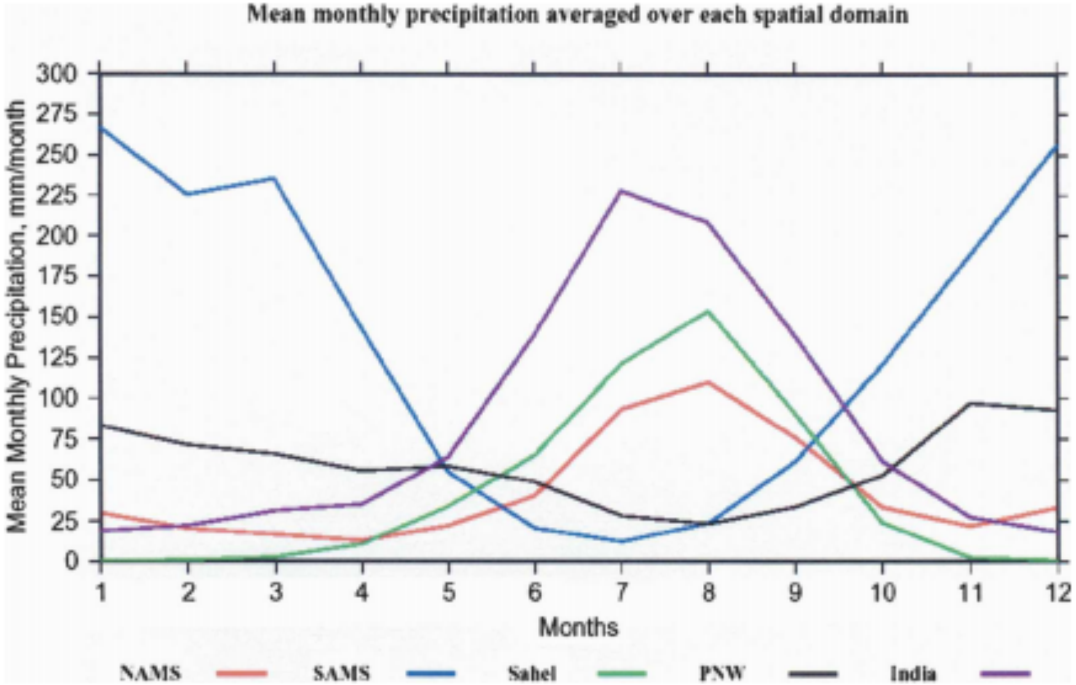
Divergence of and divergent component vectors of the vertically integrated total atmospheric energy transports for 1979-2001. Left panel shows transport by quasi-stationary flow (monthly means and longer) and right panels shows the transient flow contributions. In the monsoonal regions and seasons, the transport is essentially by the mean meridional circulation (Hadley) which is distinct from the middle latitudes where transient flow is dominant.

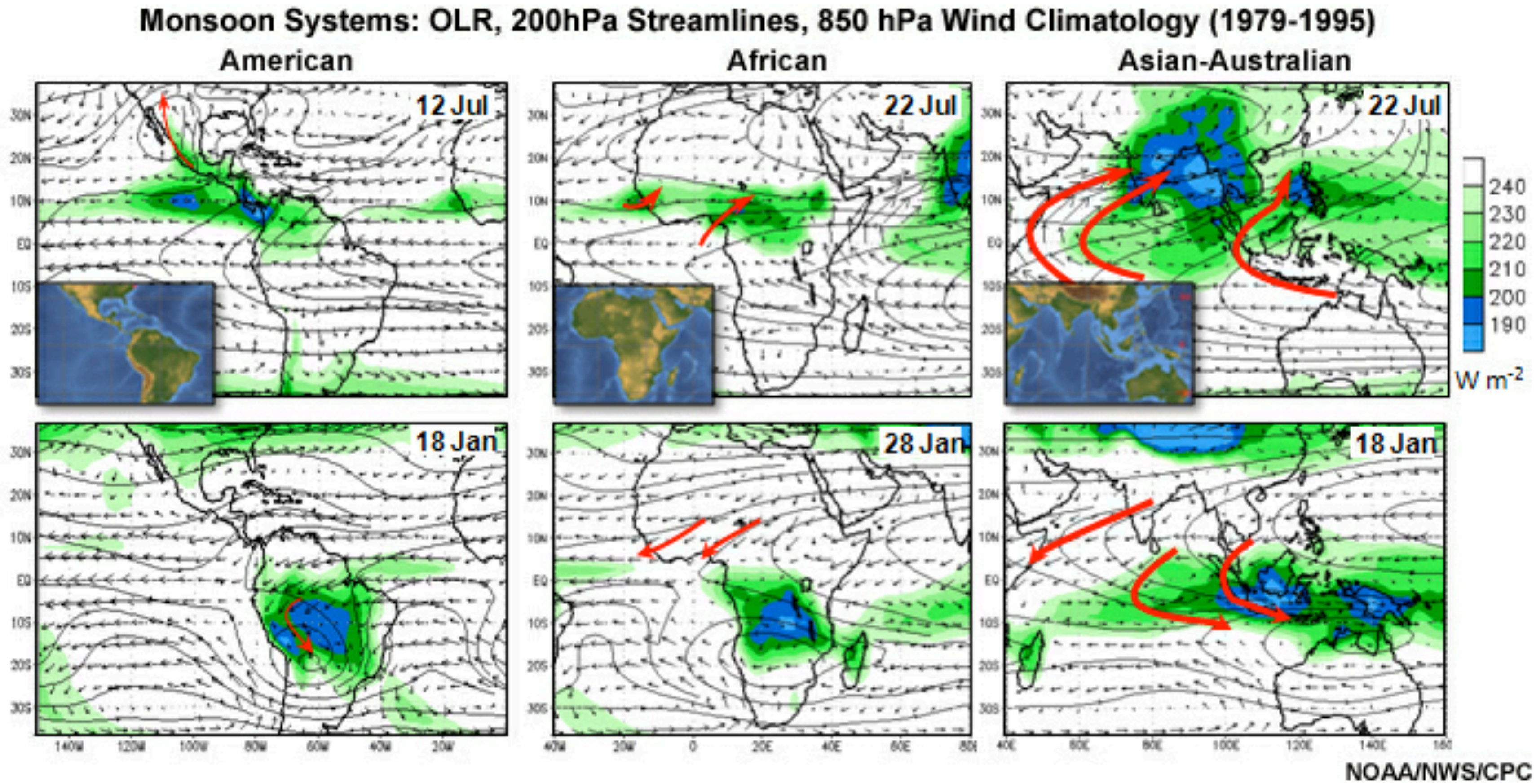




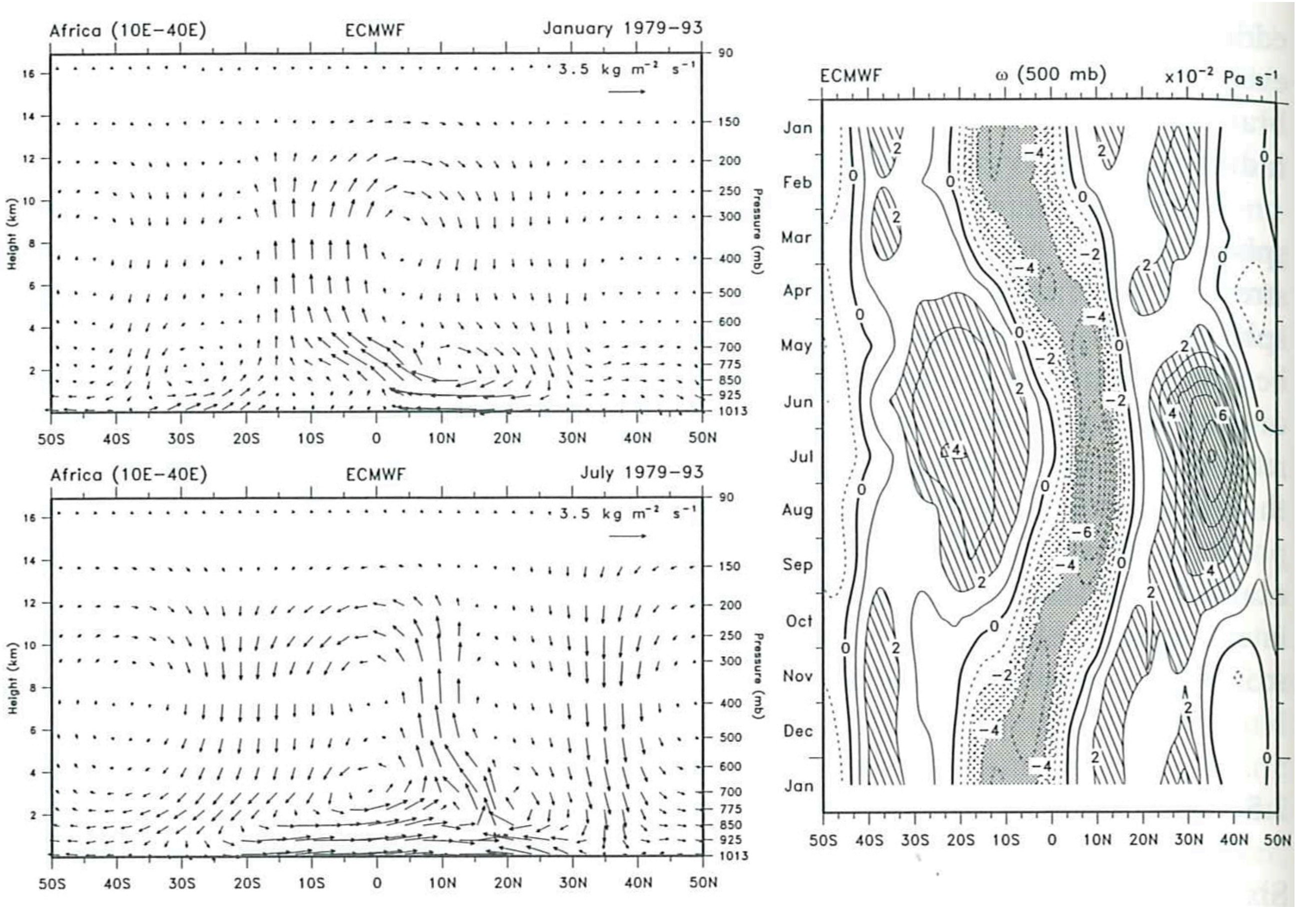
Ramage (1971) defined monsoon when

i) Prevailing winds shifts 1200 between Jan and July
ii) Average frequency of prevailing wind > 40%
iii) Speed of mean wind exceeds 3m/s

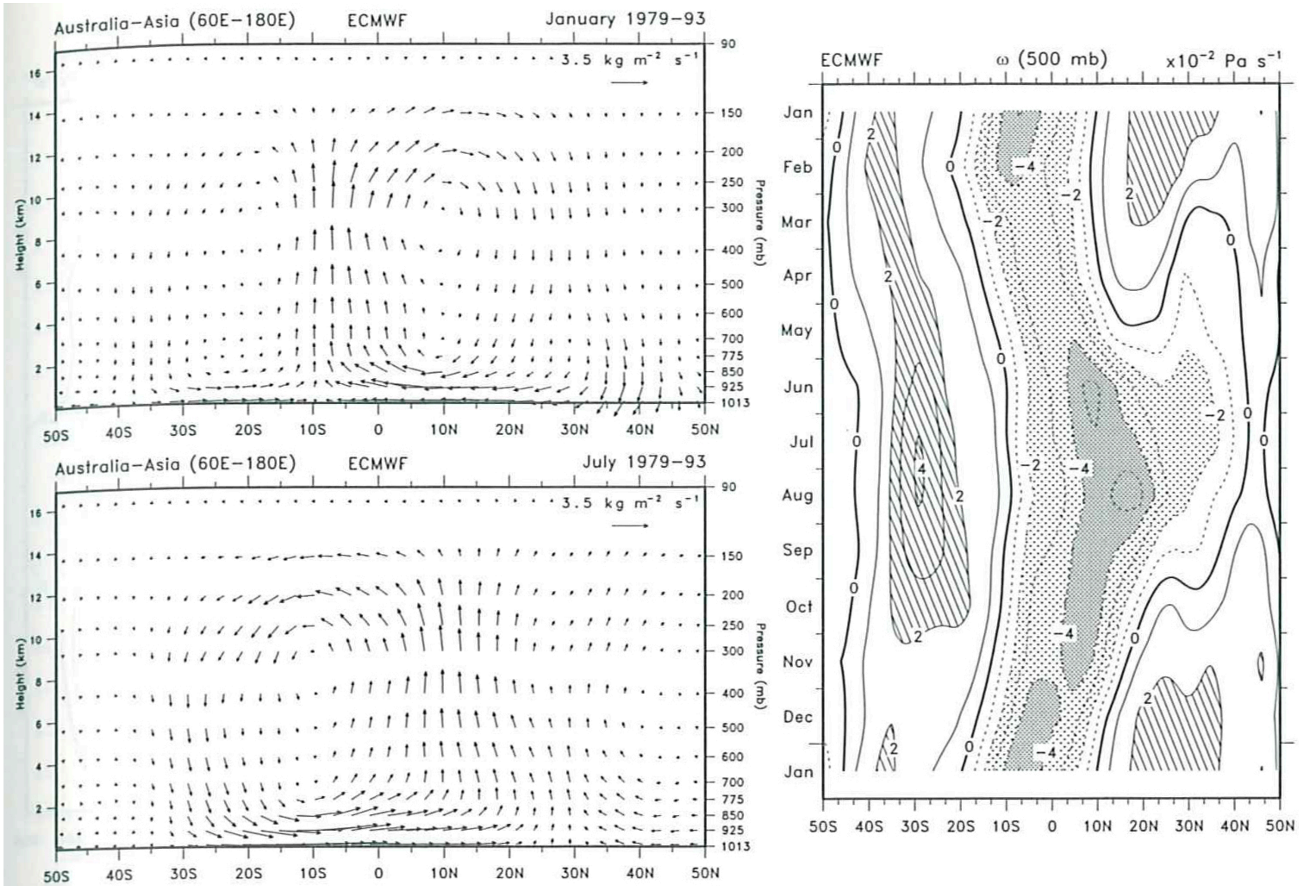

Mean monthly precipitation averaged over each spatial domain
Mean Monthly Precipitation, mm/month
300
275
250
225
200
175
150
125
100
75
50
25
0
1
2
3
4
5
6
7
8
9
10
11
12
Months
NAMS
SAMS
Sahel
PNW
India



Monsoon Systems: OLR, 200hPa Streamlines, 850 hPa Wind Climatology (1979-1995)
American
African
Asian-Australian
12 Jul
22 Jul
22 Jul
18 Jan
28 Jan
18 Jan
240
230
220
210
200
190
W m-2
NOAA/NWS/CPC

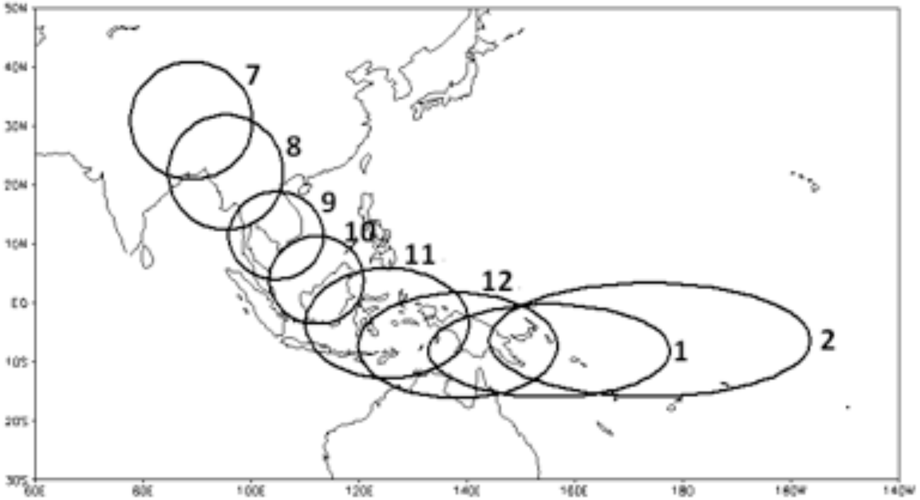


West Africa (10E-40E): Regional meridional cross-section of zonally averaged (10E-40E) divergent flow (left panels) and annual cycle of the corresponding zonally averaged omega at 500hPa. Stippling (hatching) indicates upward (subsidence) motion. Note the seasonal migration of omega across the equator, the shallow vertical circulation around 15N and 25S in January with the latter migrating northward to equator in July. From Trenberth (2006).

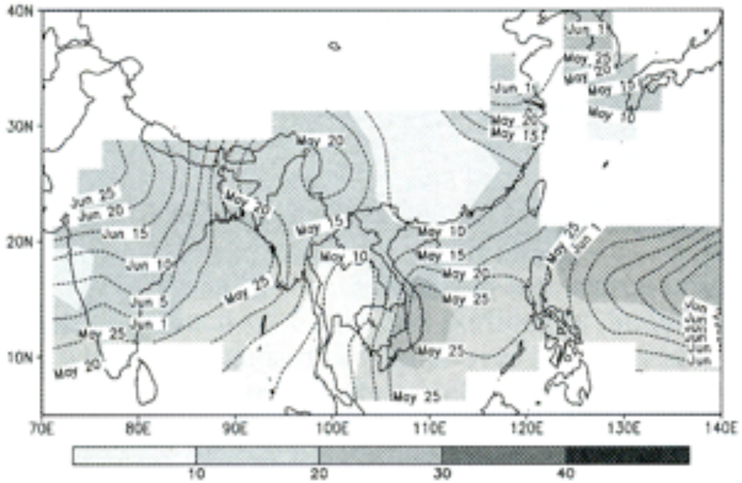


Australia-Asia (60E-180E): Shows the dominant overturning circulation. From Trenberth (2006).

Principal Axis of the Asian Monsoon

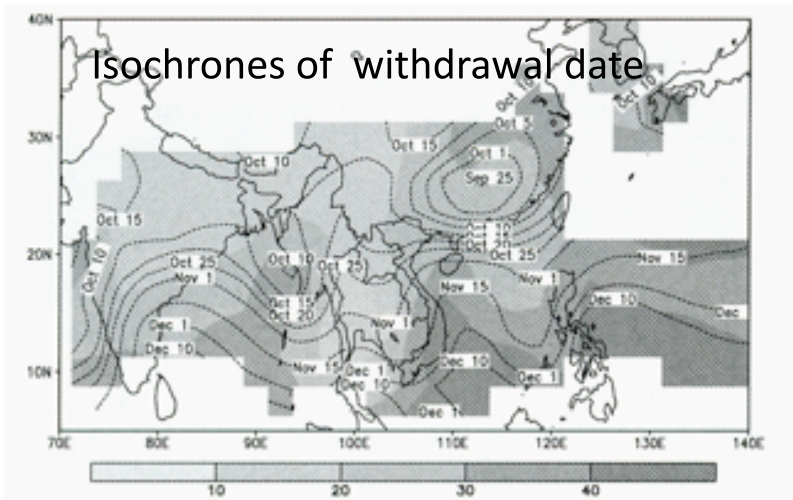


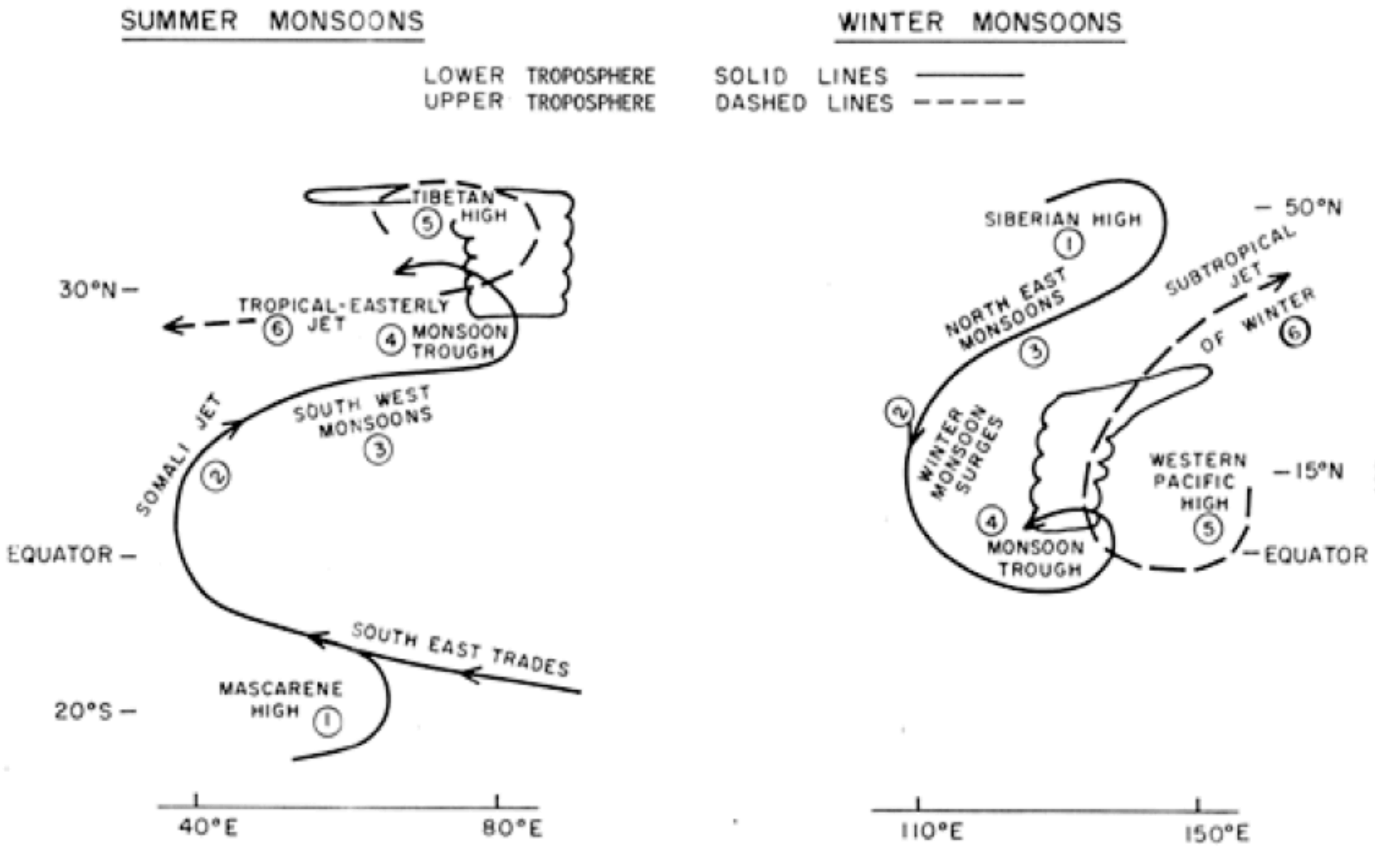
Isochrones of onset date

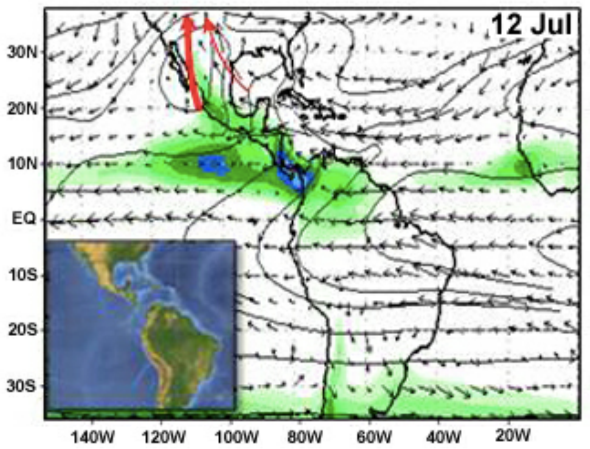


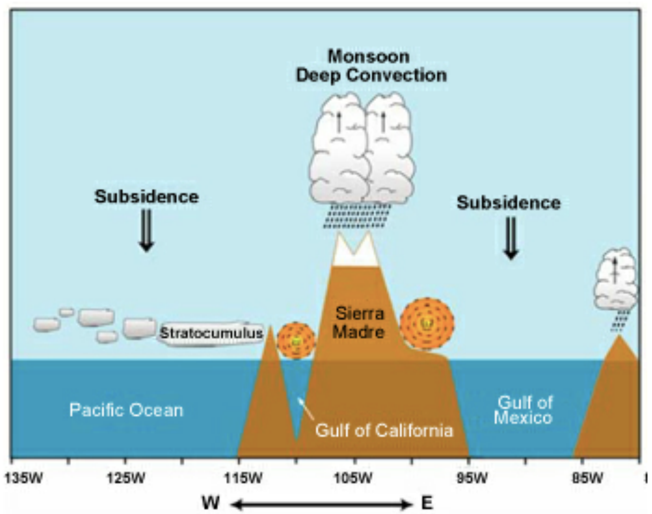
Propagation and extent of the monsoon heat sources between months of July and February. From Chang et al. (2004).

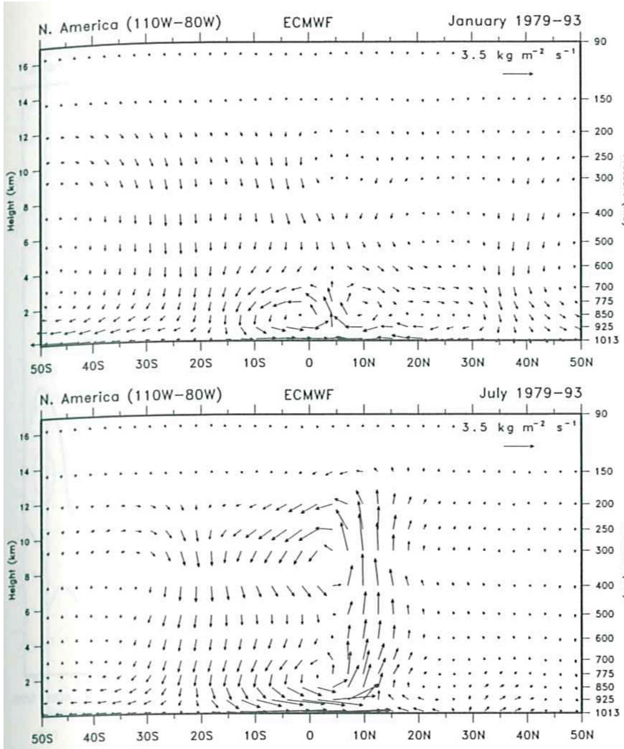
Isochrones of withdrawal date

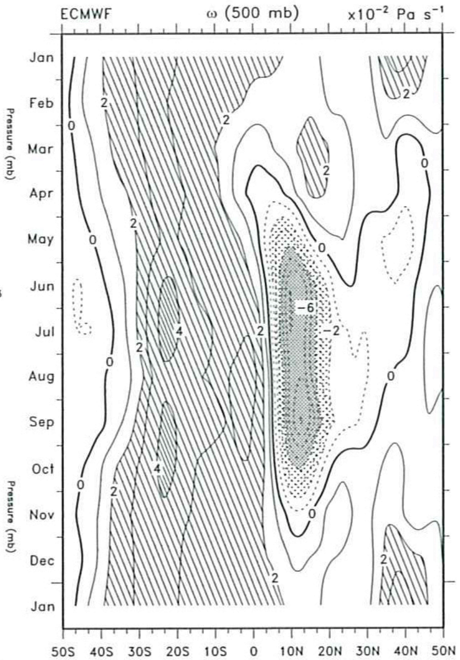



SUMMER MONSOONS
WINTER MONSOONS
LOWER TROPOSPHERE SOLID LINES
UPPER TROPOSPHERE DASHED LINES
TIBETAN HIGH
5
TROPICAL-EASTERLY JET
6
4 MONSOON TROUGH
SOUTH WEST MONSOONS
3
SOMALI JET
2
SOUTH EAST TRADES
MASCARENE HIGH
1
30°N
EQUATOR
20°S
40°E
80°E
SIBERIAN HIGH
1
NORTH EAST MONSOONS
3
SUBTROPICAL JET OF WINTER
6
2
WINTER MONSOON SURGES
4
MONSOON TROUGH
WESTERN PACIFIC HIGH
5
50°N
15°N
EQUATOR
110°E
150°E

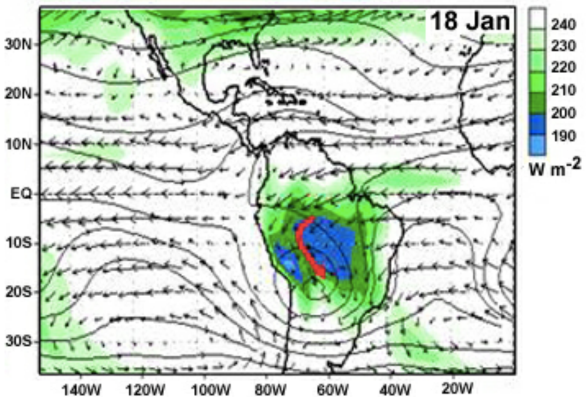


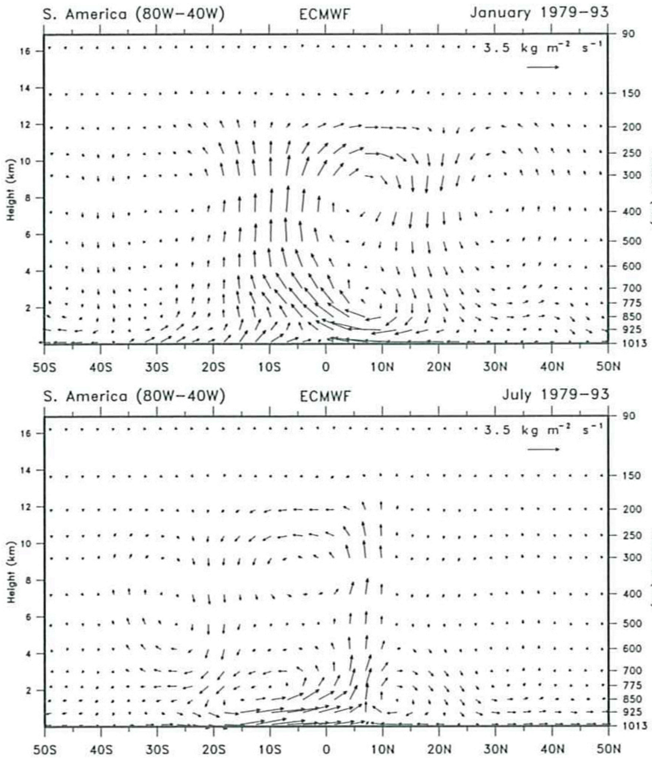


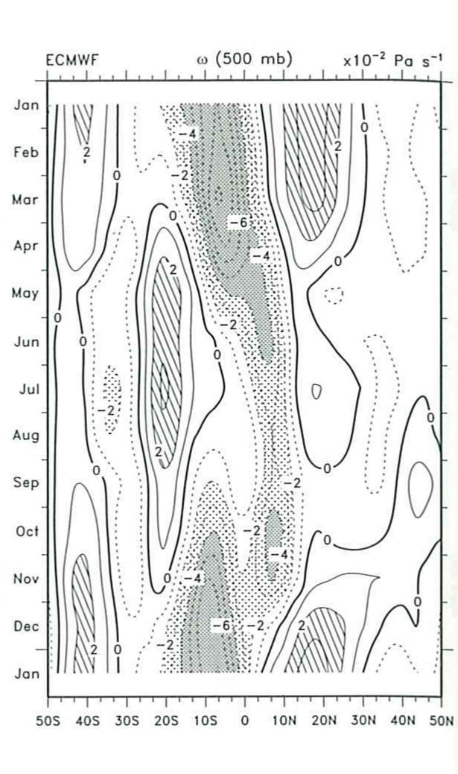


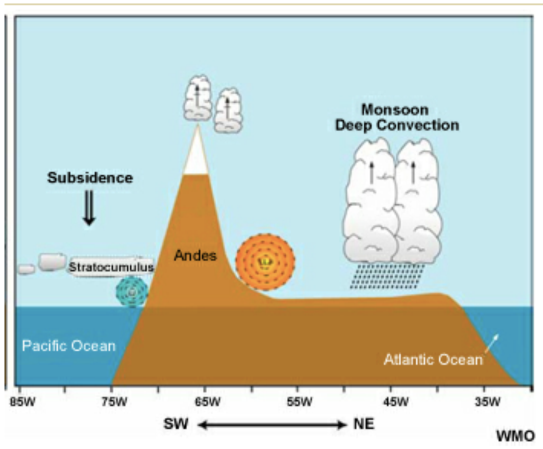


North America (110W-80W): Deeper vertical cell appears in summer only, while in winter subsidence dominates at 500hPa. From Trenberth (2006).



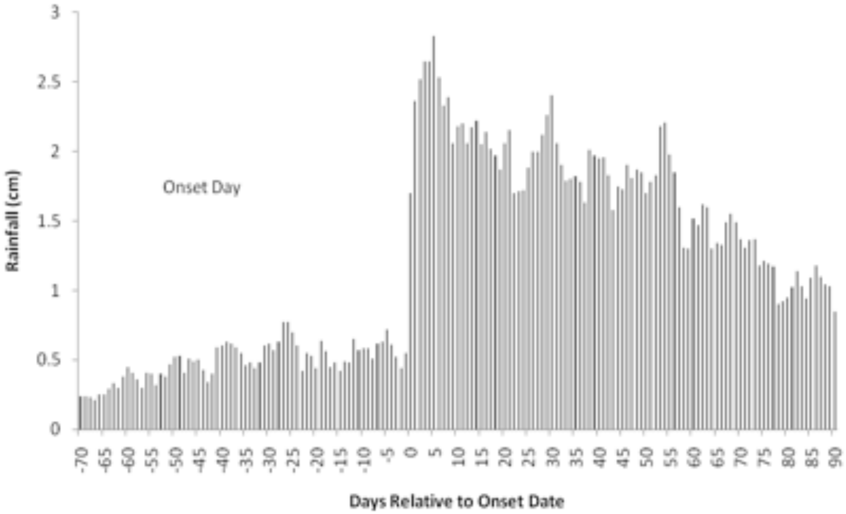




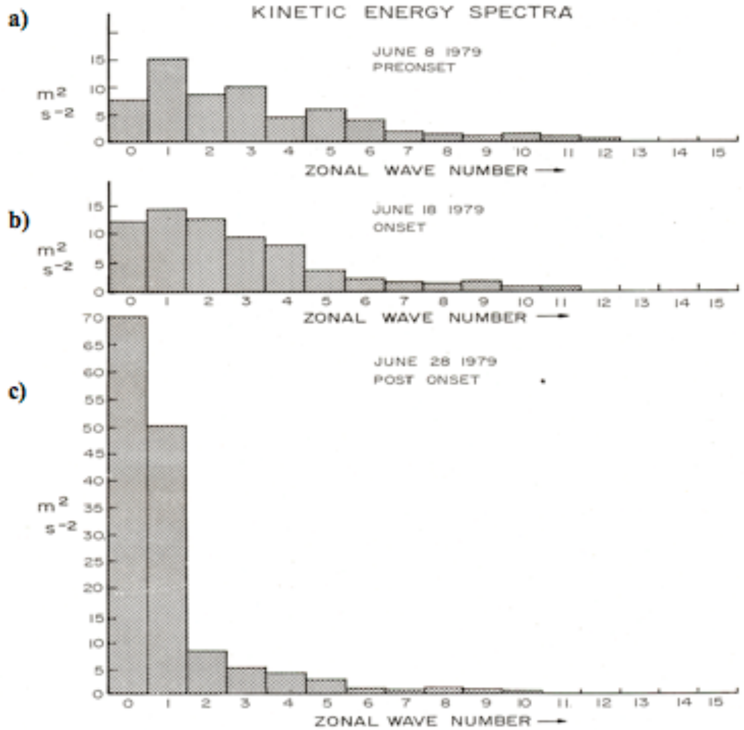


South America (80W-40W): Shallow overturning circulations dominate north and south of ITCZ (7N) in austral winter. From Trenberth (2006).

Global influence of the Indian Monsoon

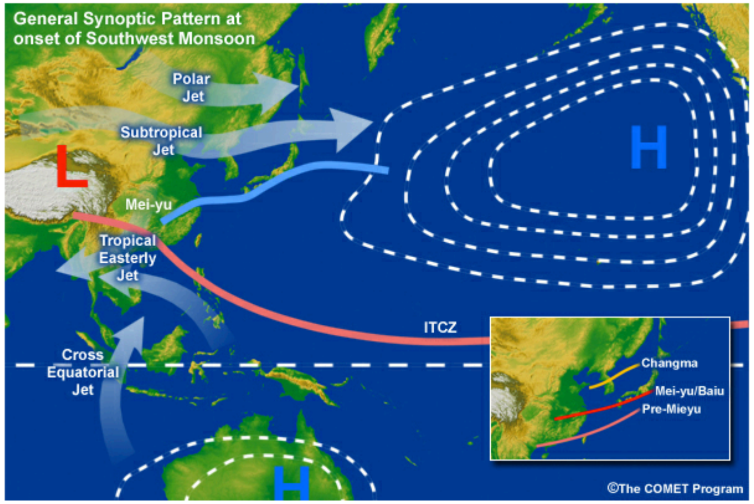


Composite climatology of daily rainfall amount as a function of time before and after onset date over Kerala. Adapted from Ananthakrishnan and Soman (1988).



Kinetic energy as a function of zonal wave number for a) pre-onset, b) onset, and c) post-onset of monsoon. From Krishnamurti and Ramanathan (1982).

The dramatic onset of the Indian monsoon is associated with a comparable increase in the kinetic energy of the zonal wavenumbers 0-4 suggesting its global influence.



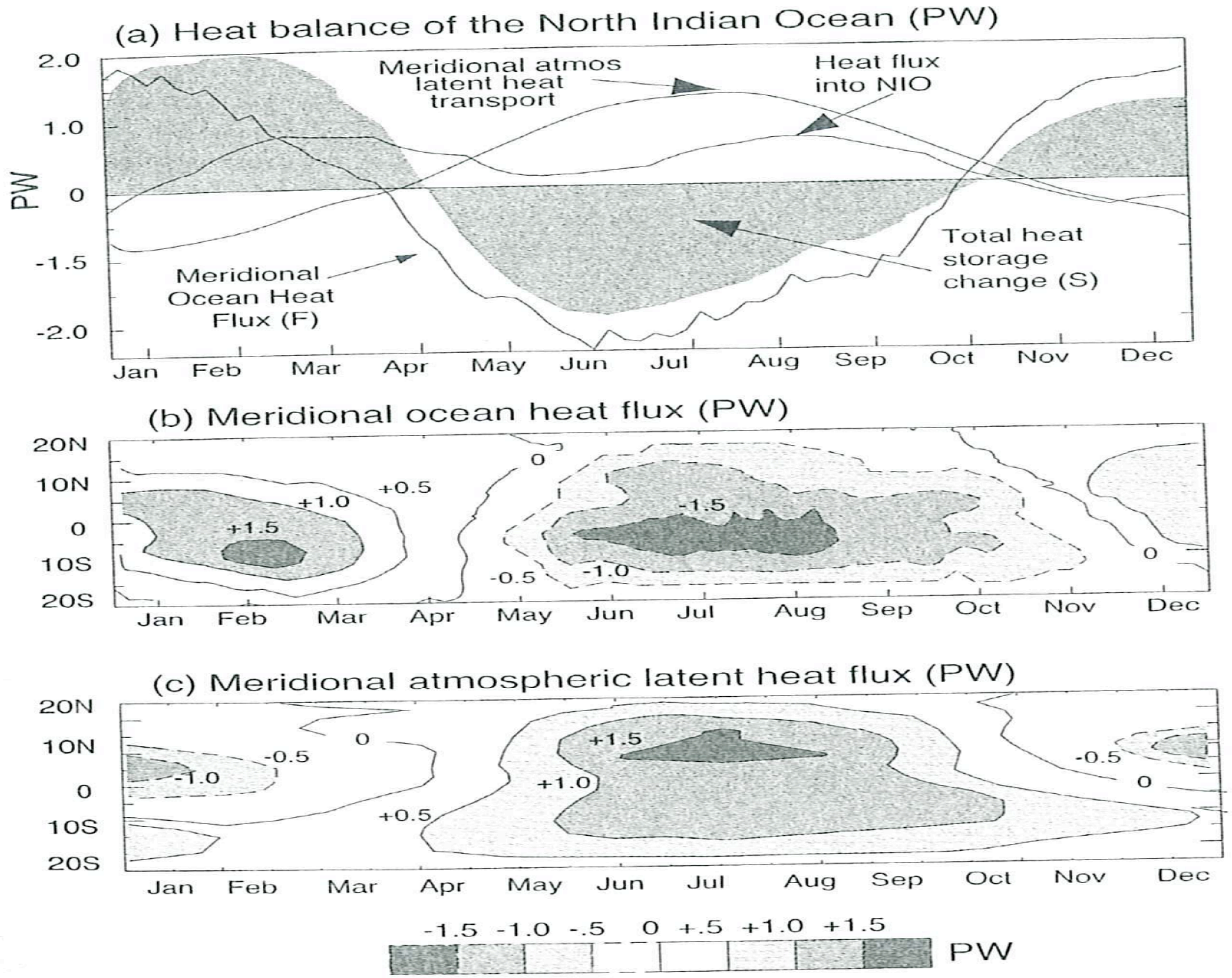
The East Asian Monsoon

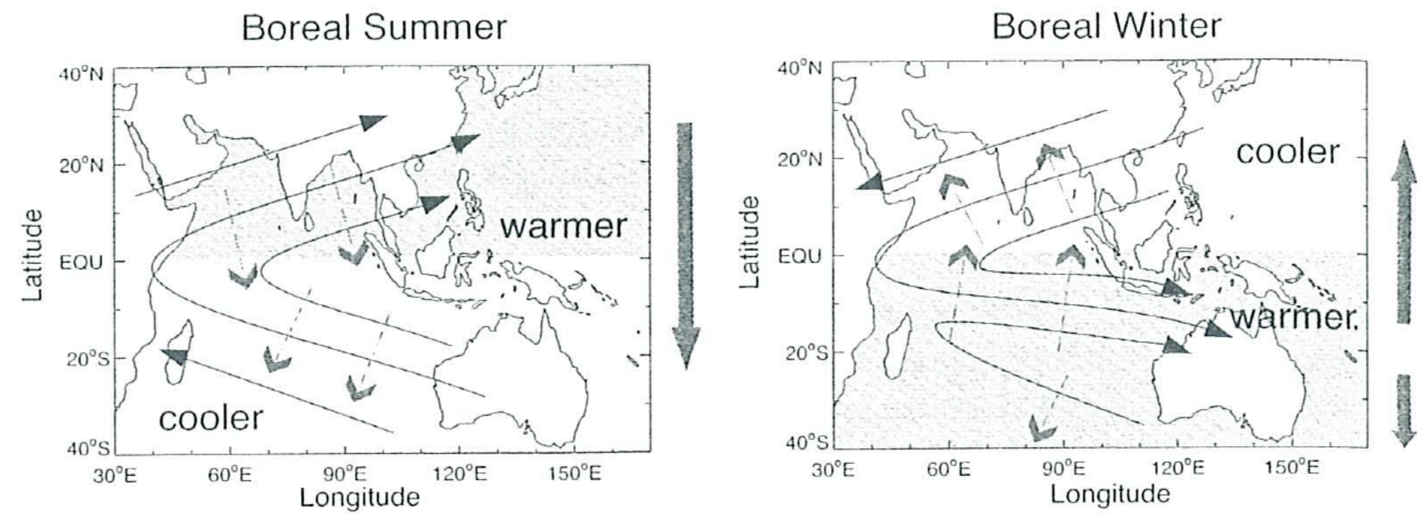
The annual cycles of the monsoons over India and East Asia are different primarily because the atmospheric response to heating is affected by land-ocean distribution and topography.

The strong north-south gradient between the warm land and the cool ocean, enhanced by the heating of the elevated Tibetan Plateau, creates a strong monsoon over India.

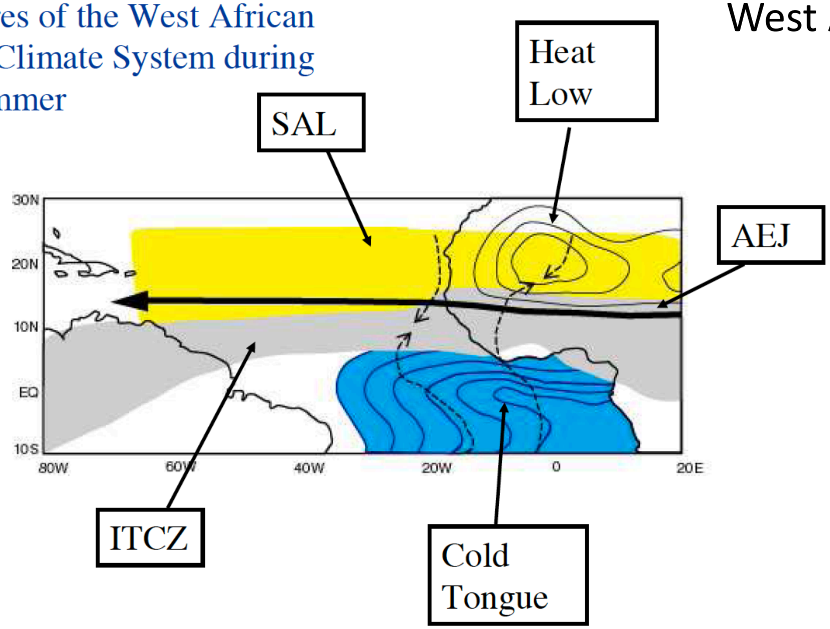
Over East Asia, the situation is more complex. The forcing comes from both the north-south gradients between cool Australia and warm western north Pacific and east-west gradient between the heated Asian landmass and the cooler Pacific. The result is a weaker monsoon circulation and bands of precipitation along the tropical monsoon circulation and subtropical frontal zones

The Indian monsoon is a coupled ocean-atmosphere phenomenon

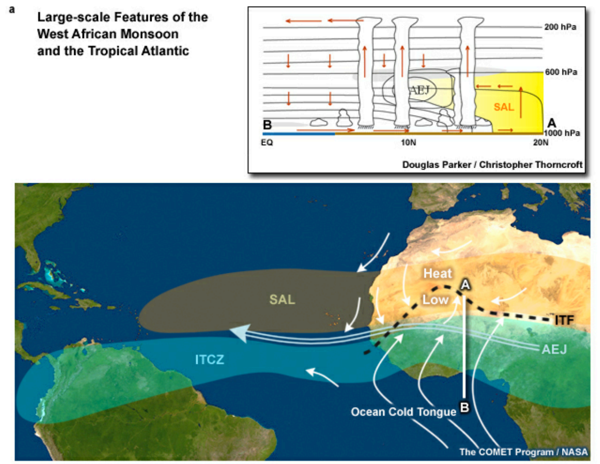


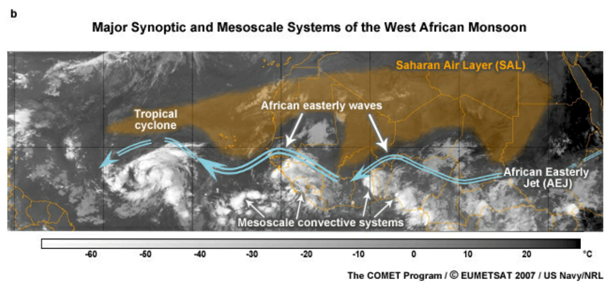

Boreal Summer
warmer
cooler
Latitude
Longitude
40°N
20°N
EQU
20°S
40°S
30°E
60°E
90°E
120°E
150°E
Boreal Winter
cooler
warmer
Latitude
Longitude
40°N
20°N
EQU
20°S
40°S
30°E
60°E
90°E
120°E
150°E

Key features of the West African Monsoon Climate System during Boreal summer

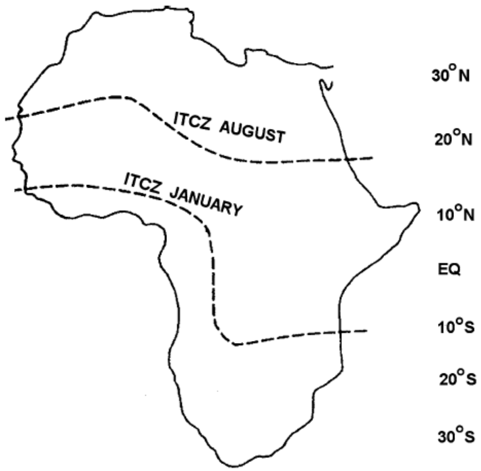


West African Monsoon

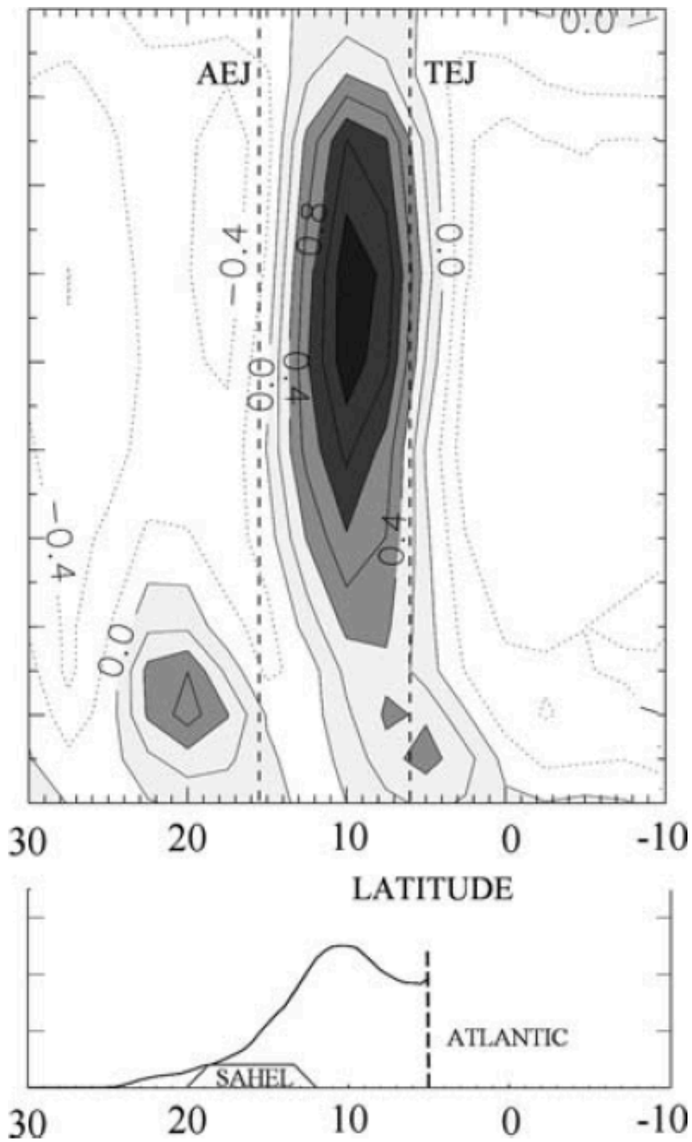


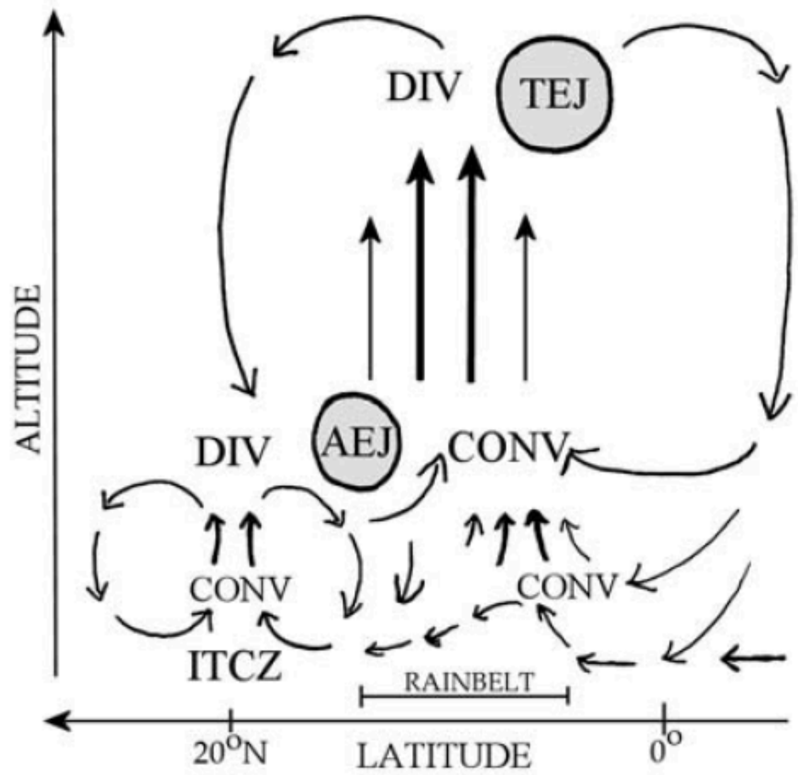


Saharan Air Layer (SAL) is an elevated layer (~1500-5500m) of extremely warm, dry, dust-laden and strong midlevel easterly winds that form over west Africa and spread across North Atlantic and migrate as far west as Caribbean Sea and Gulf of Mexico.



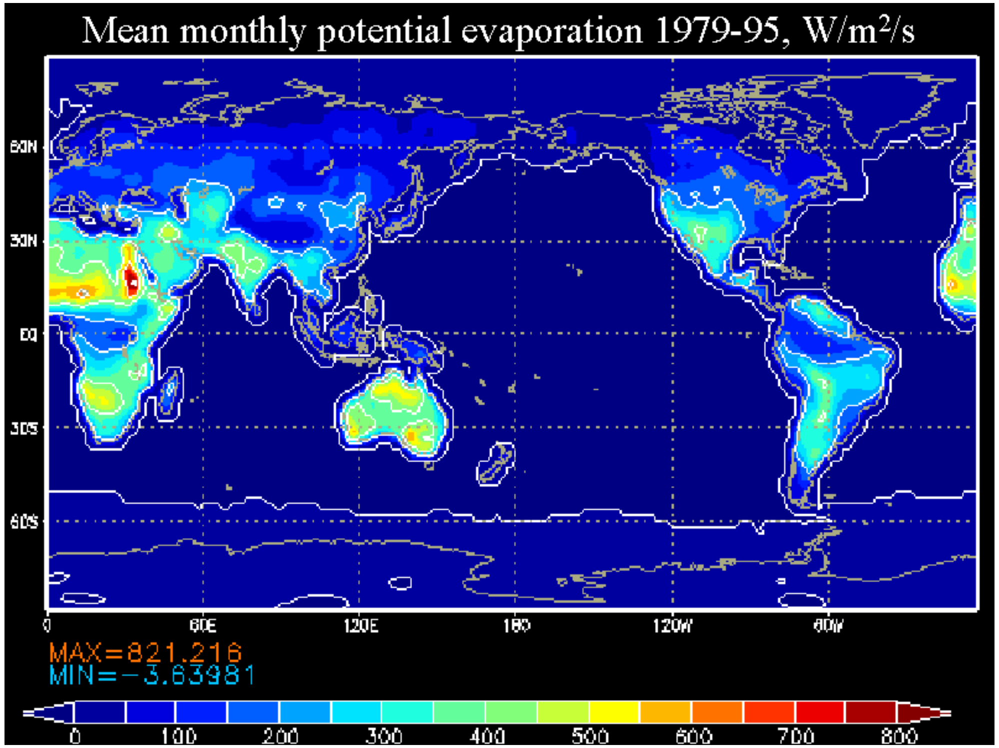
A popular but contentious viewpoint of the African monsoon is that it is the meridional migration of the ITCZ. However it is argued that the main rainbelt is observed to be equatorward of the ITCZ position (as determined from the surface convergence of the dry Harmattan winds with the moist southwesterlies).





From Nicholson (2009)

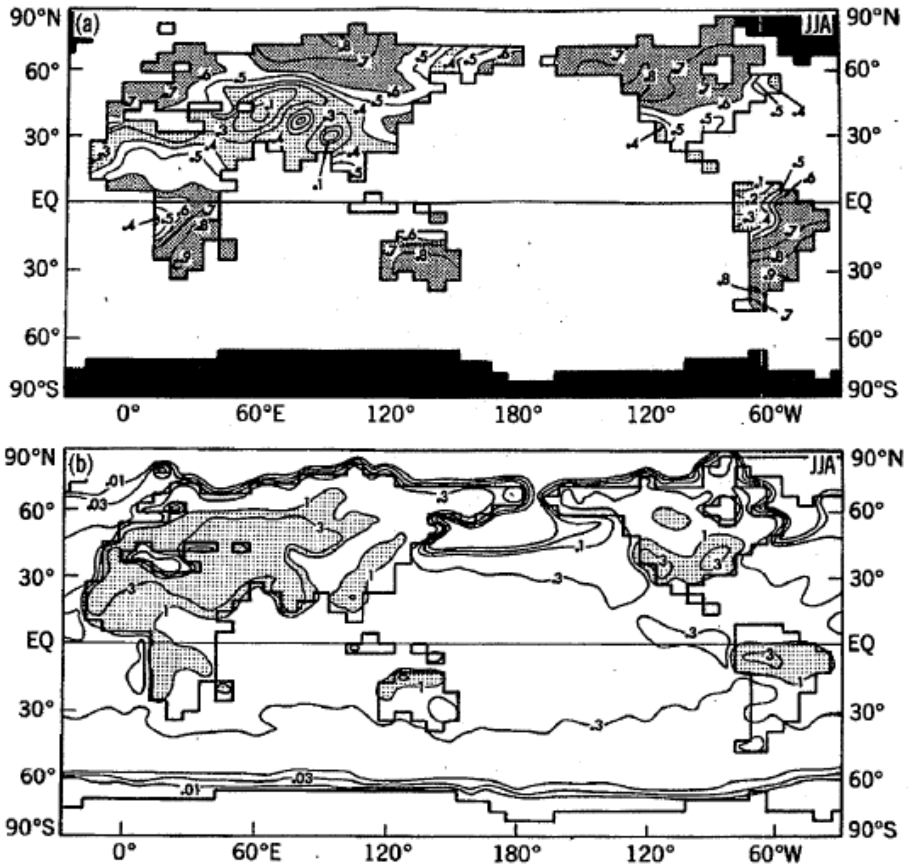
Land-Atmosphere interactions of the monsoons



Potential evaporation is defined as the amount of water that could be evaporated were it available. It is a function of surface and air temperatures, insolation, and wind, all of which affect water-vapor concentrations immediately above the evaporating surface. The broad definition of a dryland is a place where annual potential evaporation exceeds annual rainfall. In the hot deserts of the Earth, then, potential evaporation is uniformly high. The hot deserts are clearly indicated as having very high values. While there is nowhere near enough water available to satisfy potential evaporation in these hot deserts, the parameter can be thought of as a harshness force, a measure of an ecosystem forcing function.

Calculation of potential evapotranspiration can be done from a variety of formulas:

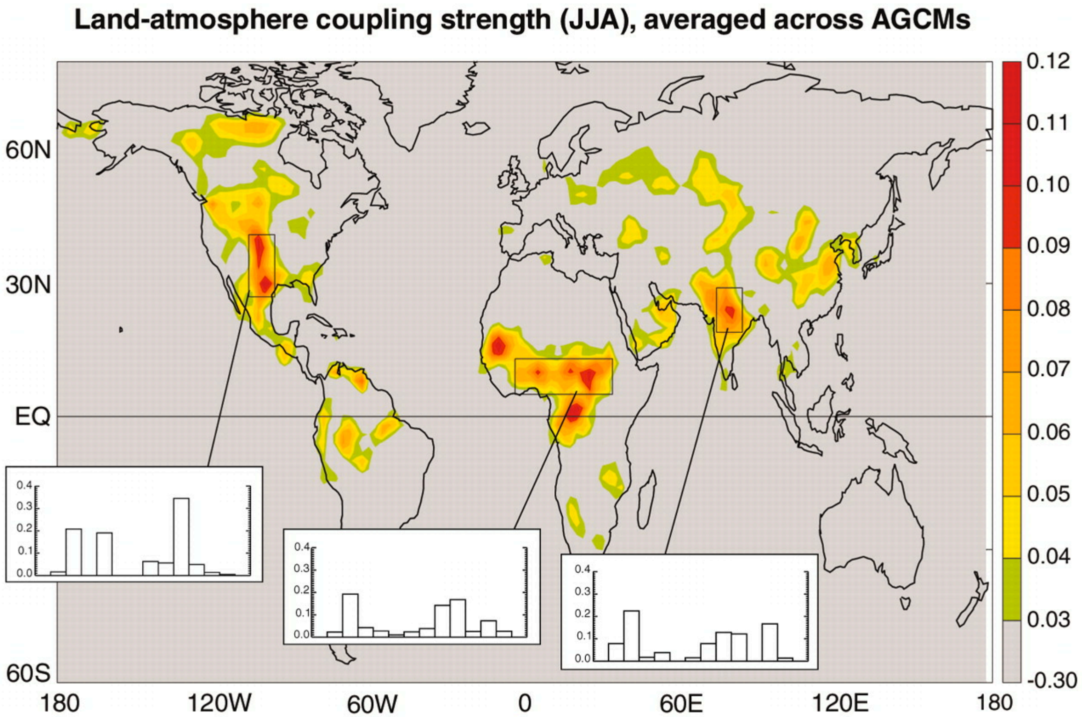
1) Thornthwaite
2) Penman
3) Penman-Monteith



Using a simple bucket model with one soil layer having 15cm water holding capacity Delworth and Manabe (1988) showed that the autocorrelation of soil moisture was relatively low in humid tropics and high in mid-latitudes. This was dictated by P/E_P ratio, which was higher in mid-latitudes. In the humid tropics or monsoon regions where P is large enough to saturate the soil layer, soil moisture anomaly does not make sense as a source of climate memory.

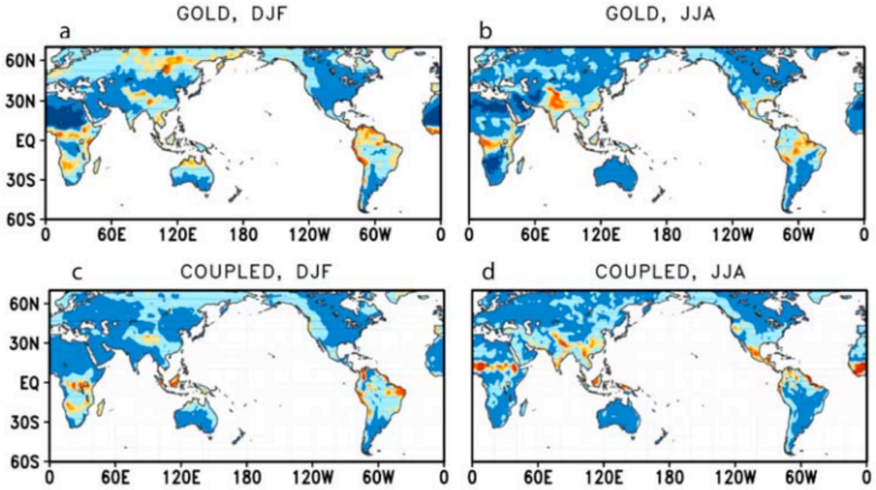
Yasunari et al. (2009)

Figure 8.4 (a) Lag one autocorrelation values of soil moisture for the months of June, July and August(JJA) for SMI. At each grid point, deviations of monthly mean soil moisture from the long-term mean for that month were correlated with data from the same grid point, but lagged one month. Coefficients greater than 0.16(0.3) are significantly different from zero at the 95%(99.9%) confidence level (see Chatfield, 1984, p.63). Values greater than 0.6 are densely stippled, while value less than 0.4 are lightly stippled. Permanently ice-covered region are black. (b)Potential evaporation (cm d^{-1}) for JJA in SMI. (Delworth and Manabe, 1989)



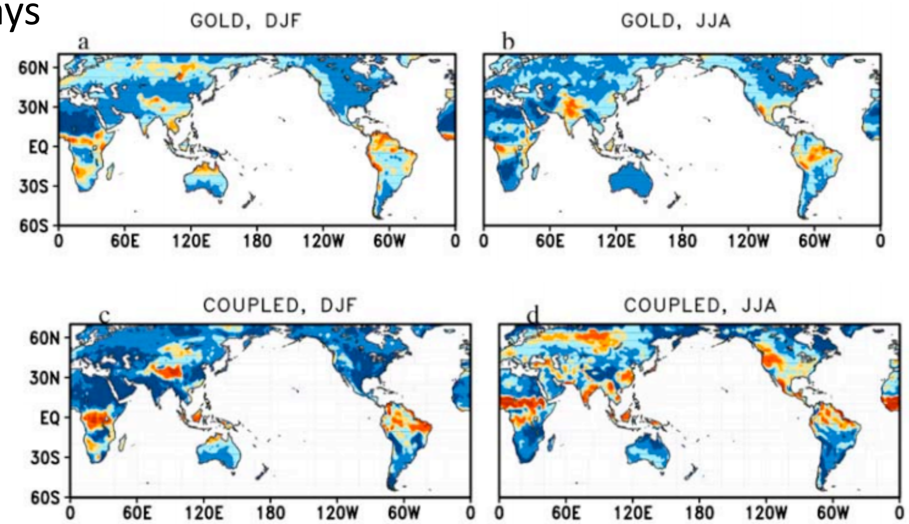
From Koster et al. (2009)

In more recent studies (left), it is clearly seen that Delworth and Manabe (1989) results continue to be upheld on the lack of significance of soil moisture anomaly to climate memory in the most humid tropic regions. Impact of soil moisture is important in relatively dry monsoons like the Indian monsoon and northeast Asia but not in the moist southeast Asia because of already saturated soil conditions.



Put together, these figures display that local recycling of precipitation in summer monsoons is significant.

Decorrelation time of daily rainfall in days



Misra (2009)

Total number of days when significant correlation (at 90% confidence interval according to t-test) exists over land when evaporation leads precipitation.

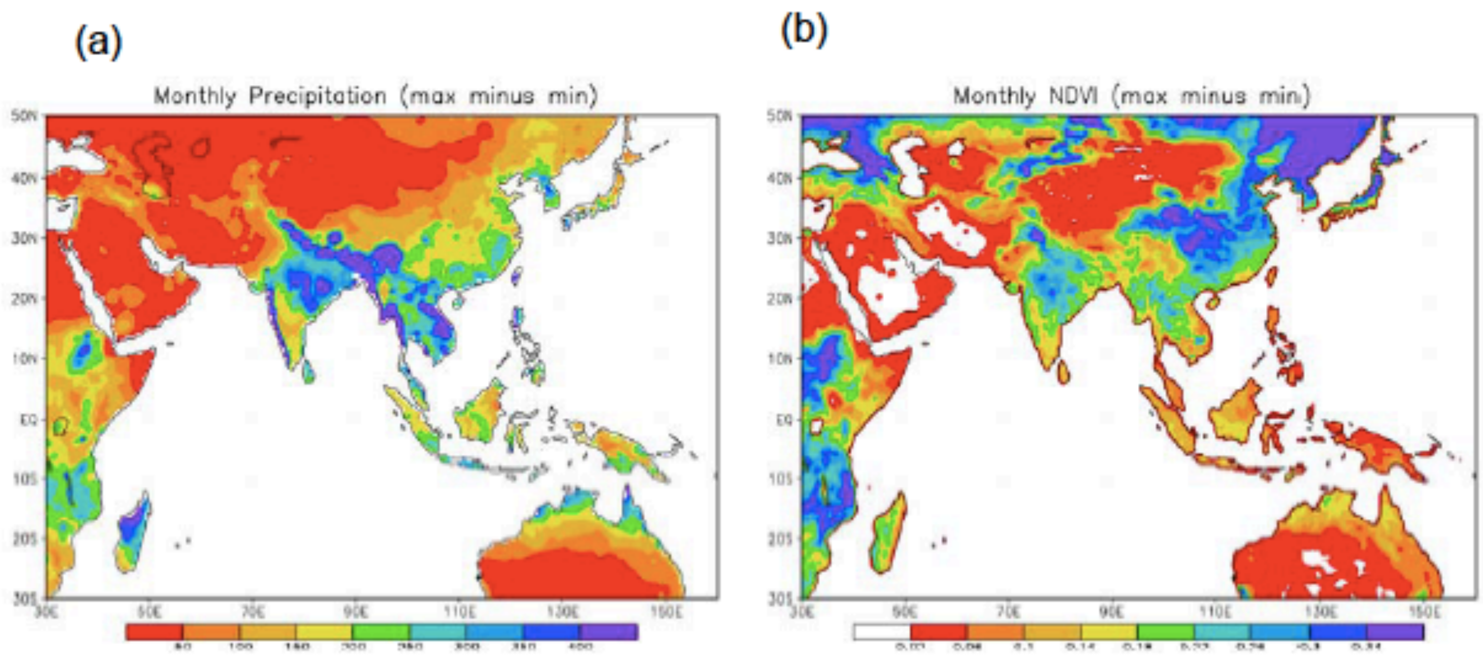


Fig. 5 (a) Difference in climatological monthly precipitation between its maximum and minimum values in annual cycle. The data used are the monthly total precipitation series (Version 1.02) produced by Cort J. Willmott and Kenji Matsuura. Unit is mm. (b) As in (a) but for normalized difference vegetation index (NDVI).

Only a part of northern Australia has over 300mm difference compared to southeast Asia, west coast and northeast of India. Australian monsoon does not penetrate deep into the inland as compared to southAsian monsoon. Likewise Normalized Difference Vegetation Index (NDVI) difference is large in southeast Asia than in northern Australia➔seasonal changes of vegetation in Australia is small. So land-surface process more sensitive in SouthAsian monsoon compared to the narrow continental extent of the Australian monsoon.

From Yasunari et al. (2009)

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