第五章:

大气环流中的纬向环流系统

5.2 Monsoon Circulation

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Outline

- Introduction
- Features of monsoon circulation:

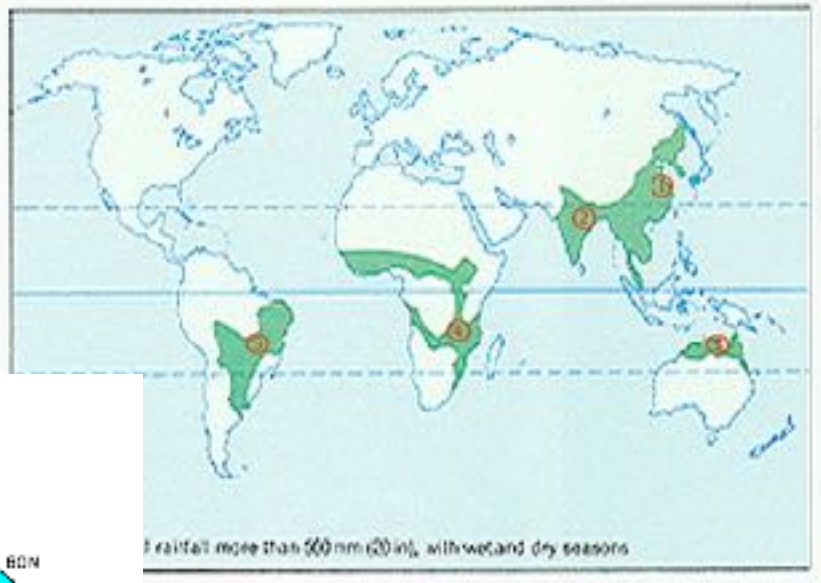
  an Indian monsoon example
- Monsoon dynamics
  - The land-sea contrast
  - The role of Orography, Tibet Plateau
  - Some GCM results
- On the East Asian monsoon

Introduction

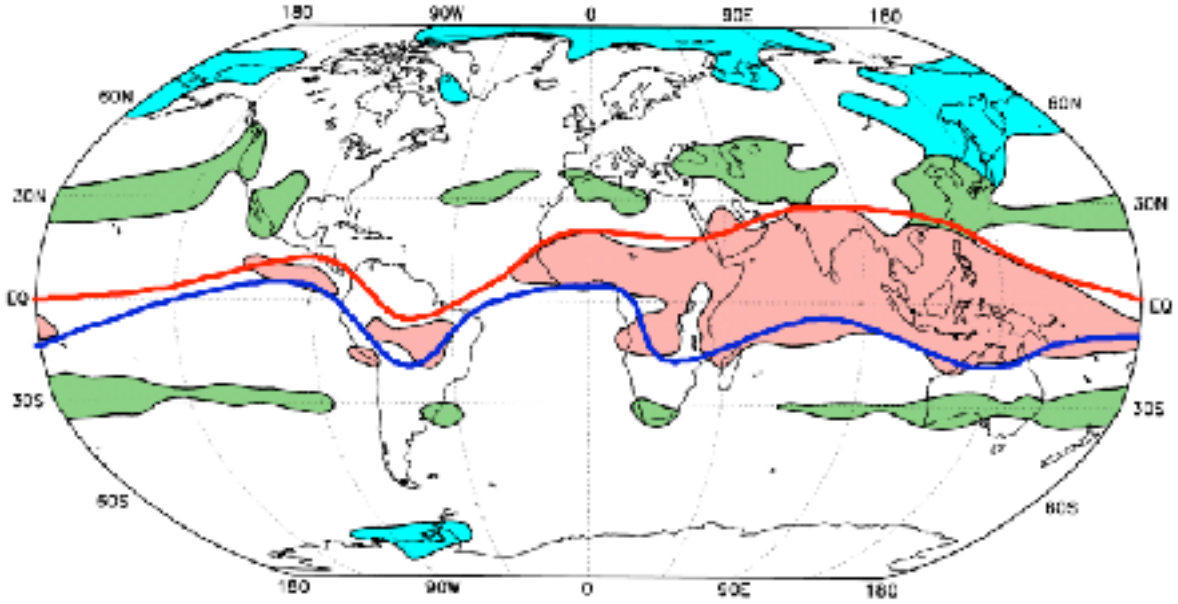
- The definition of monsoon: a dramatic **seasonal reversal** of the low-level prevailing winds, precipitation and atmospheric circulation.

- The major monsoon systems of the world:
  - Asian monsoon
    - South Asian monsoon
    - East Asian monsoon
  - Australian (Indo-Australian) monsoon
  - West African monsoon
  - North and South American monsoon (controversial)

Introduction



Geographical Extent of the Global Surface Monsoons

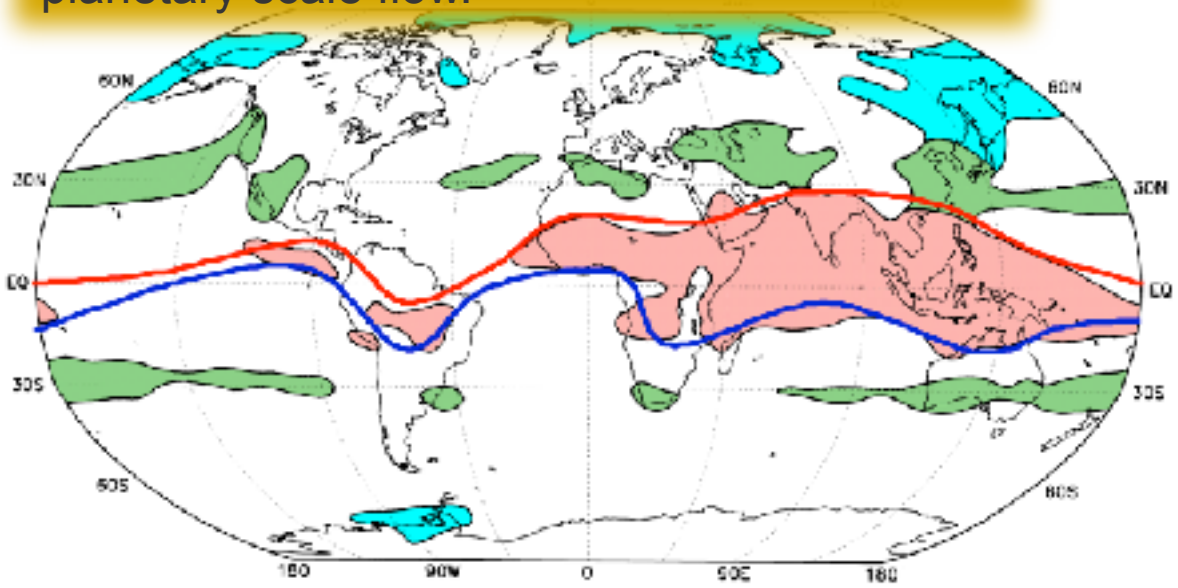


The red, green, and blue areas indicate the tropical, subtropical, and temperate-frigid monsoons, respectively. The red and blue thick lines represent the ITCZ in summer and winter, respectively. (Li, J., and Q. Zeng, 2005)

- 65% of world's population lives within monsoon;
- Monsoon precipitation is crucial to the life, food production, economy et al in these regions;
- Proper forecasting of location and quantity of precipitation is crucial to theses regions.

Introduction

The formation of monsoon climate is closely related to the seasonal variation of the solar forcing and the seasonal migration of the planetary scale flow.



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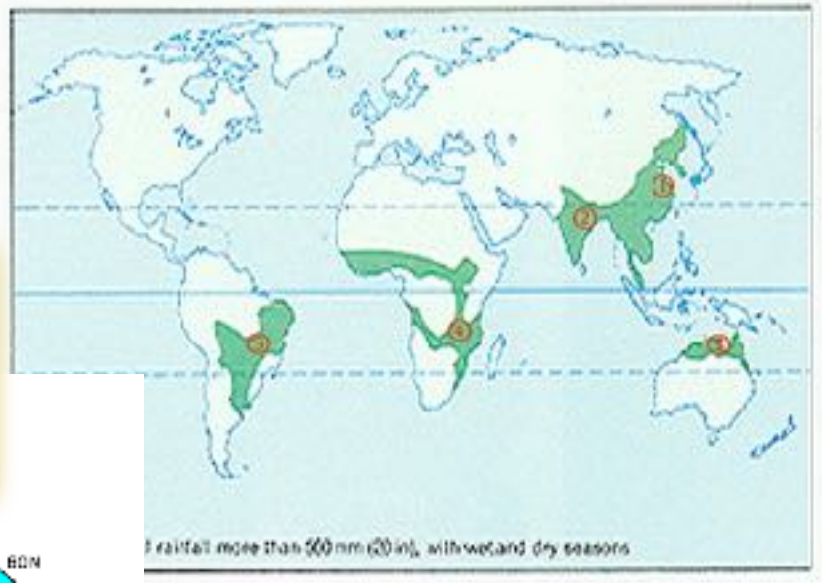

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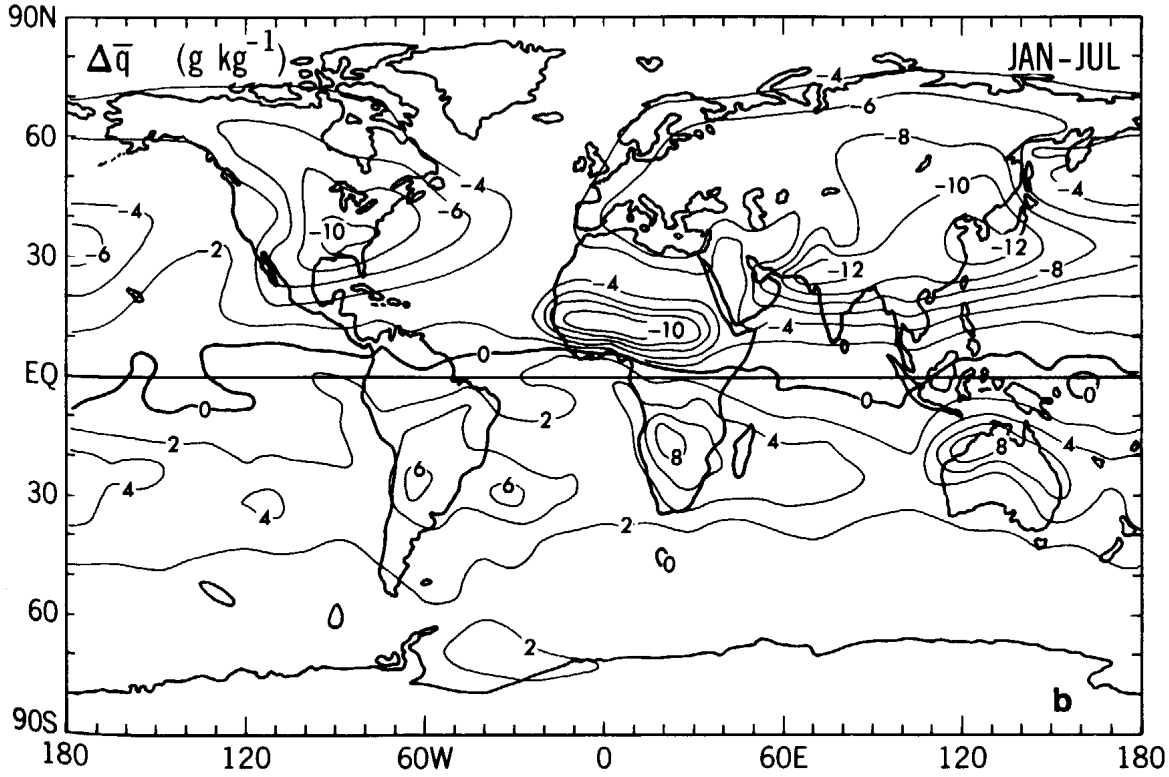
Latent heat and water vapor

- Seasonal variation: strongest in the subtropics, monsoon regions

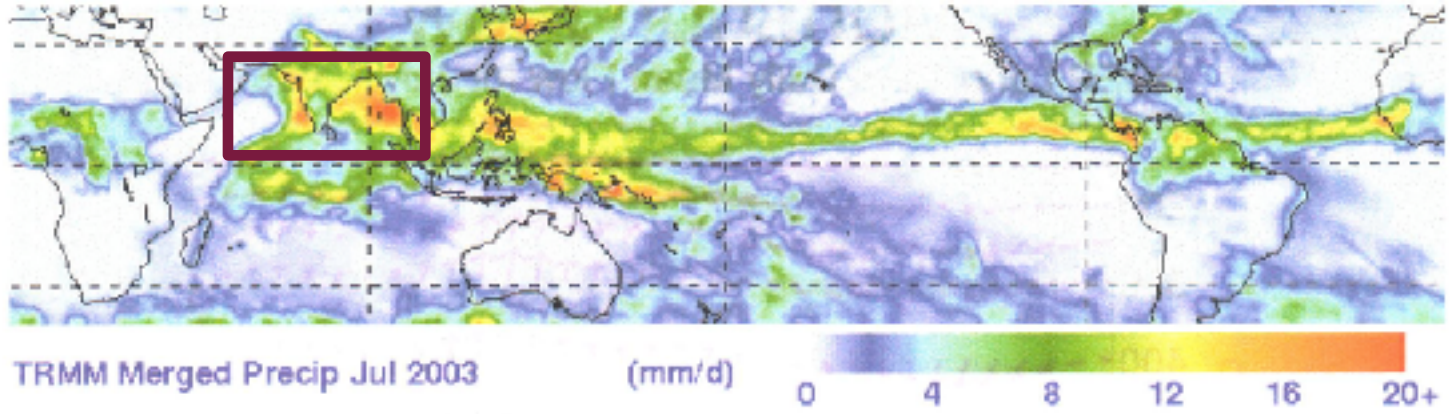


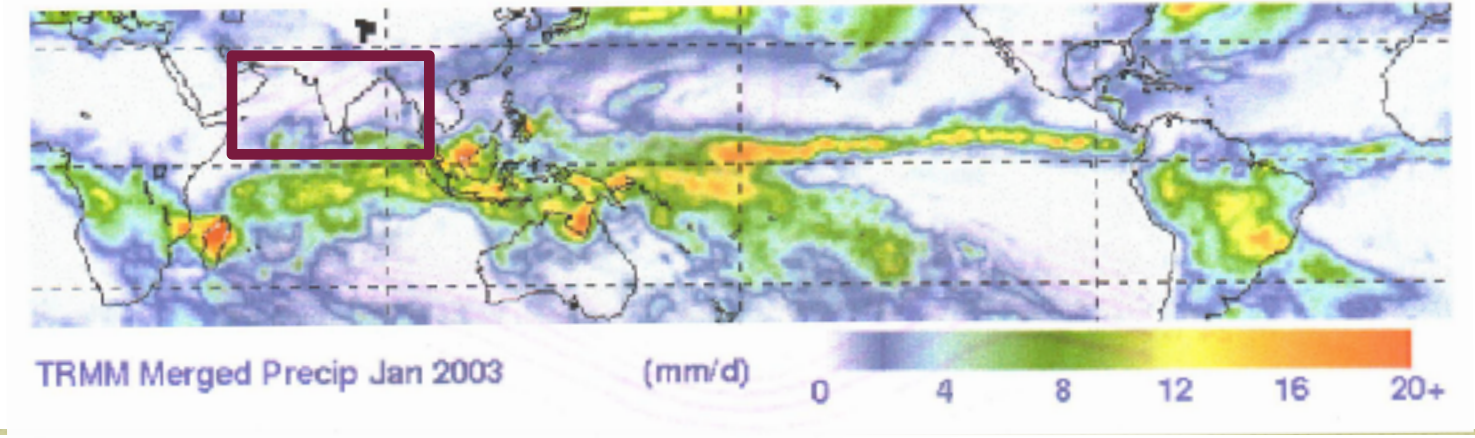
$$e_s \cong 6.11 \times e^{\frac{L}{R_v}\left(\frac{1}{273}-\frac{1}{T}\right)}$$

$$\mathrm{LH} = Lq$$

$$q = \mathrm{RH} \times q^*$$

Features of monsoonal circulation:
-an Indian monsoon example





Features of monsoonal circulation: -an Indian monsoon example

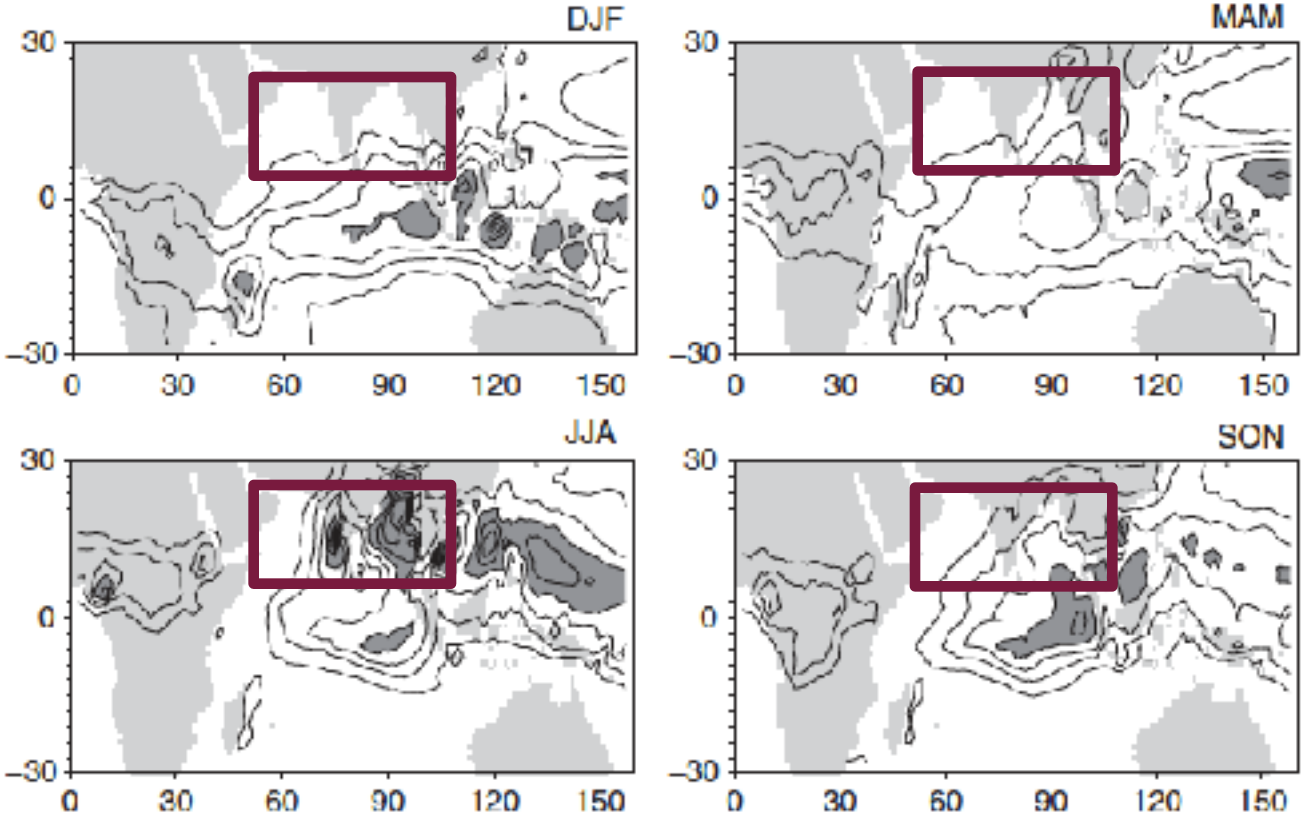


Figure 1.11 Climatological mean rainfall rate for the four seasons. The contour interval is 2.5 mm day^{-1}; heavy shading denotes rainfall greater than 5–10 mm day^{-1}. (from Clift and Plumb, 2008)

The seasons of winter and summer might be better described as **dry** and **moist** seasons.

Features of monsoonal circulation: -an Indian monsoon example

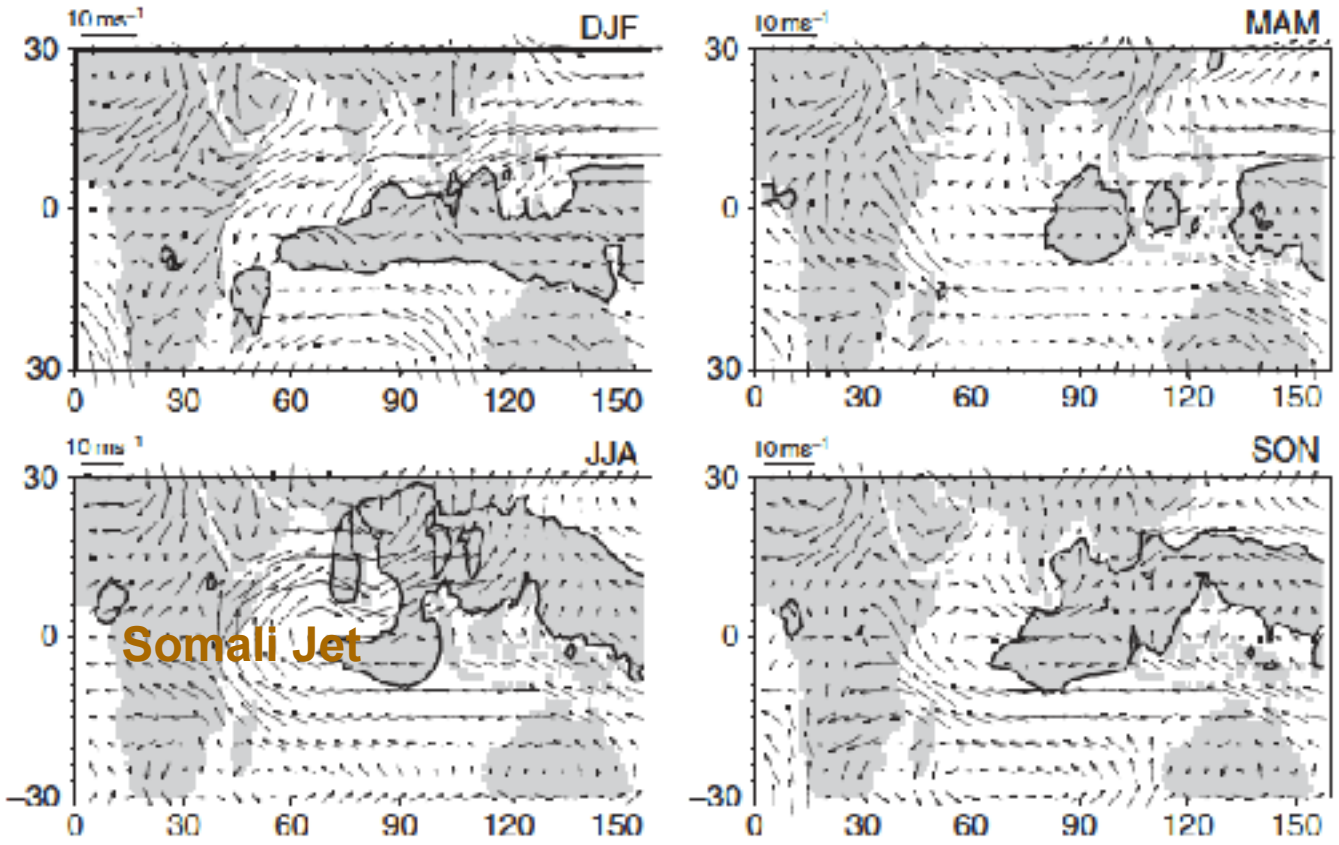


Figure 1.12 Climatological mean low level (850 hPa) winds for the four seasons. The scale for the wind arrows is shown at the top left of each plot. The heavy lines mark regions of seasonal mean rainfall in excess of 7.5 mm day $^{-1}$.

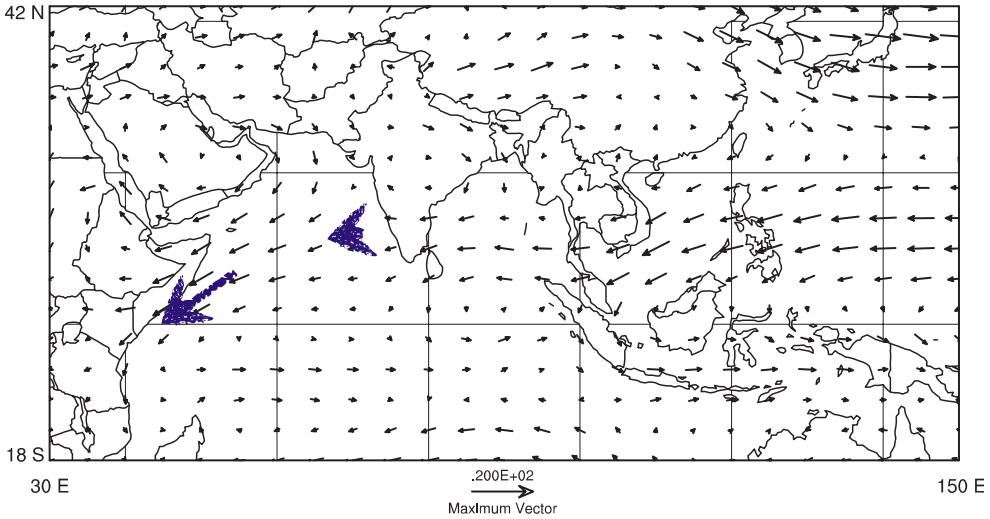
(from Clift and Plumb, 2008)

An obvious reverse of the prevailing winds

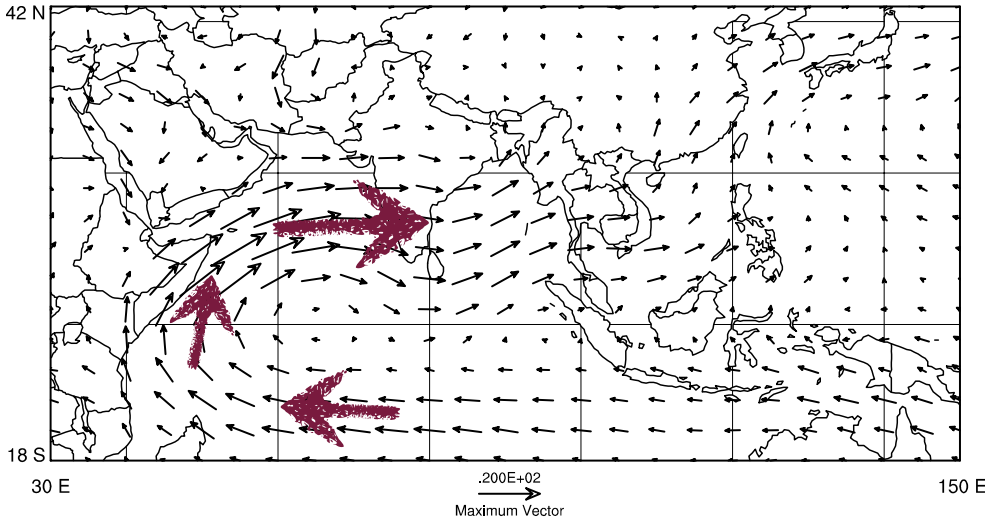
Features of monsoonal circulation:

xample

a



b



Accompanied is the reverse of whole atmospheric circulation.

Cross equator meridional overturning circulation.

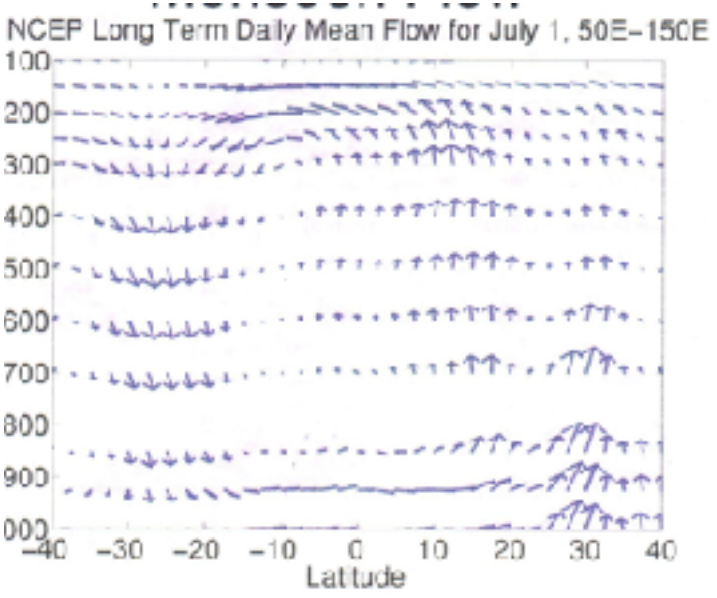
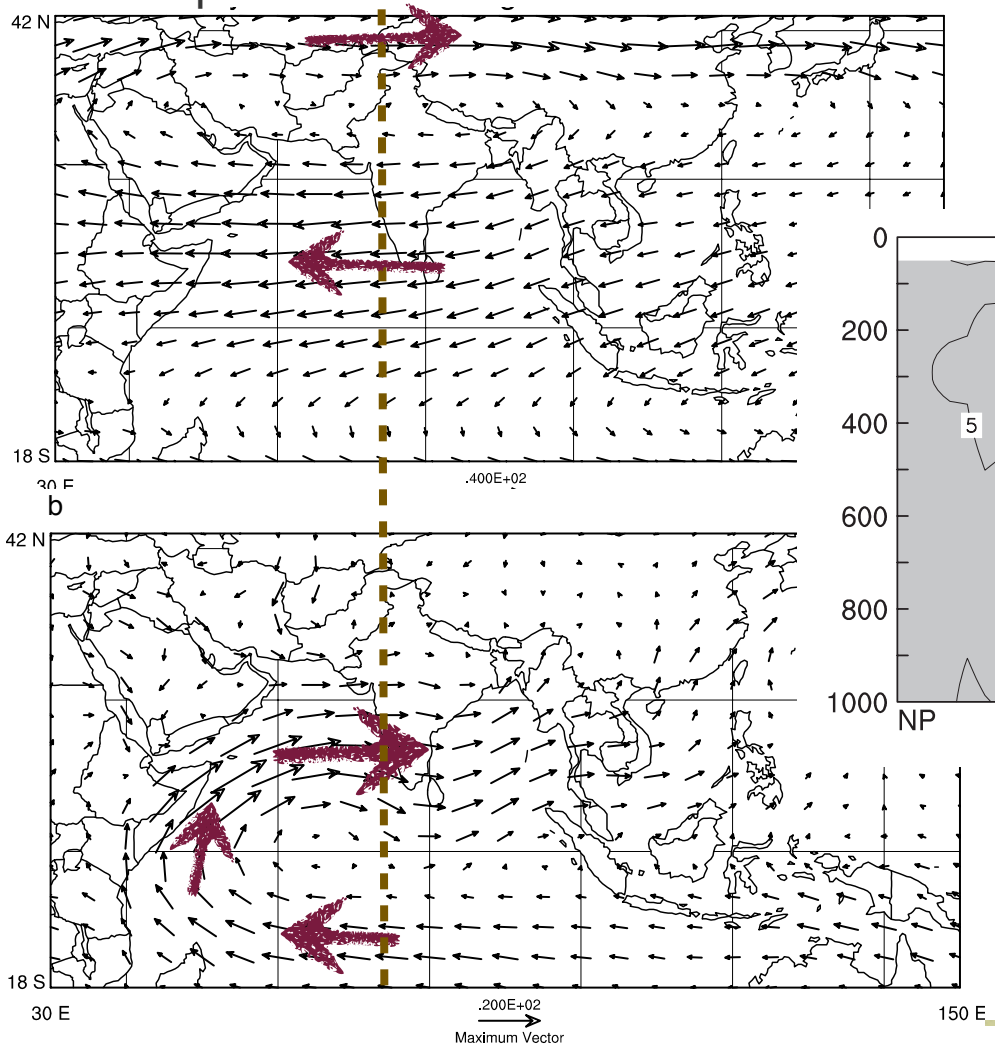


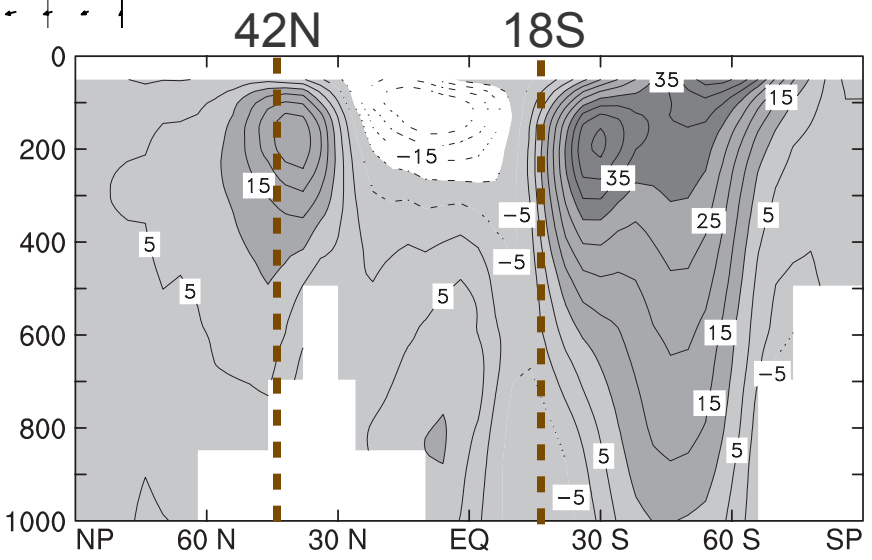
Figure 8.29: Observed 850 mb wind vectors for a) January, and b) July.

Features of monsoonal circulation:

-an Indian monsoon example

250 hpa





Strong vertical shear of zonal wind

(from Randall 2009)

Features of monsoonal circulation: -an Indian monsoon example

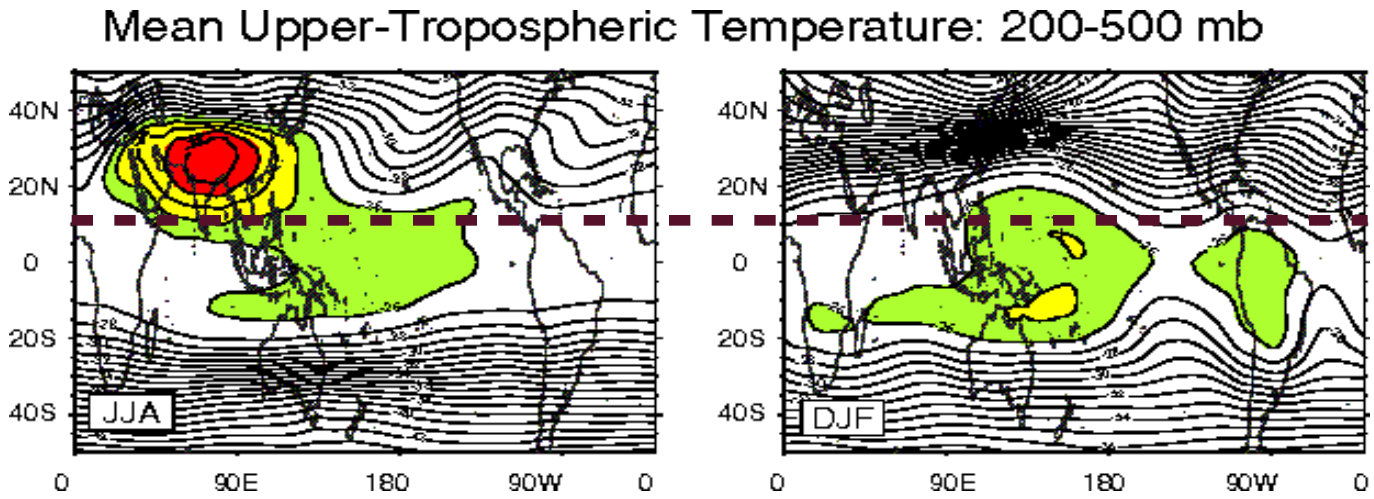
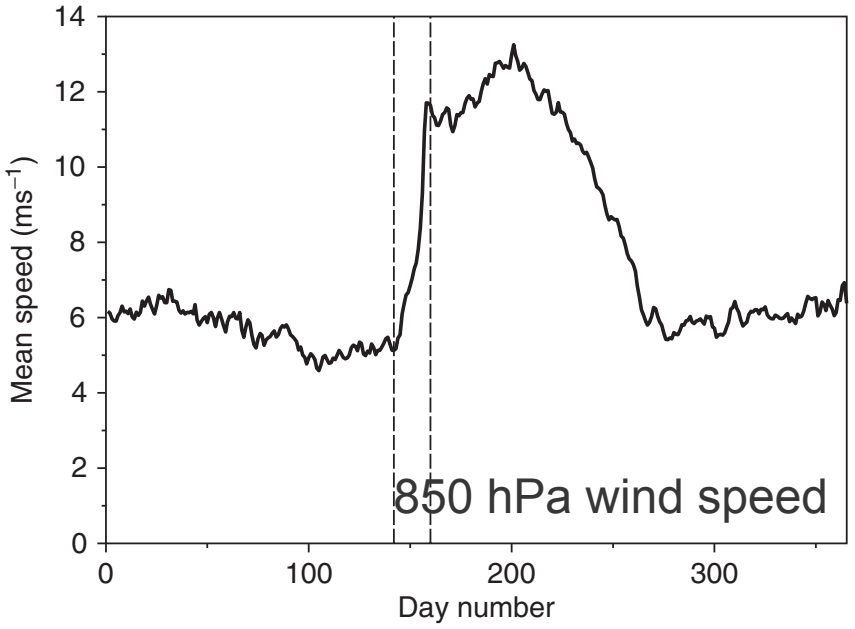


Figure 6a. Mean upper tropospheric (200--500 mbar) temperature (degrees Celsius) for the boreal summer (JJA), and boreal winter (DJF), averaged between 1979 and 1992. The boreal summer plot is based on calculations first made by Li and Yanai [1996]. Mean columnar temperatures warmer than --25C are shaded.

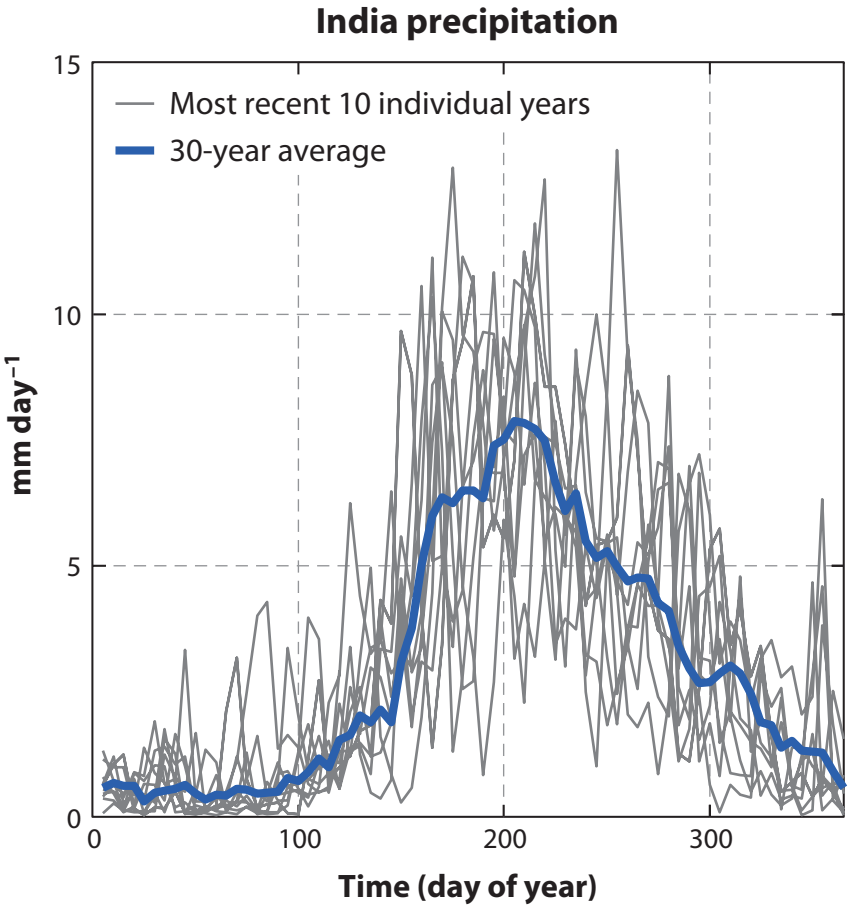
(from Webster 1998)

Features of monsoonal circulation: -an Indian monsoon example



The sudden onset of south asian monsoon occurs between Julian day 146-160.

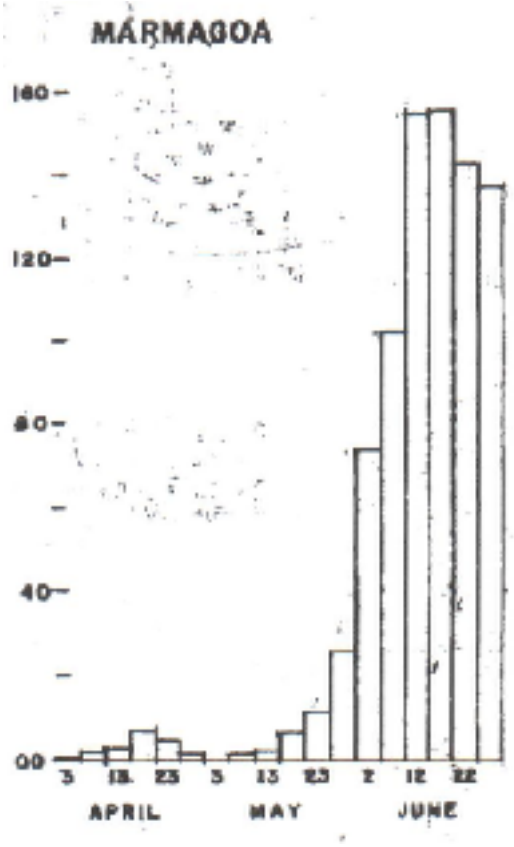
(from Clift and Plumb, 2008)

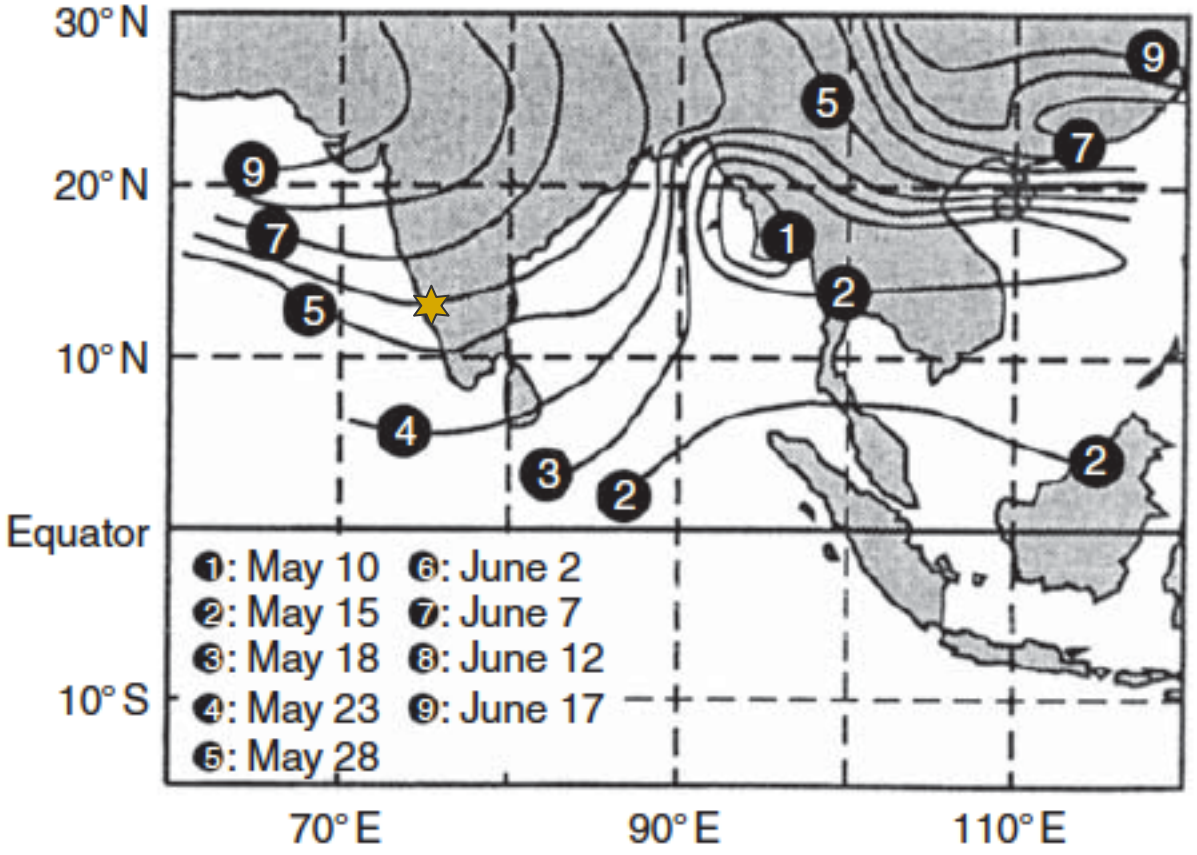


(from Molnar et al, 2010)

Features of monsoonal circulation: -an Indian monsoon example

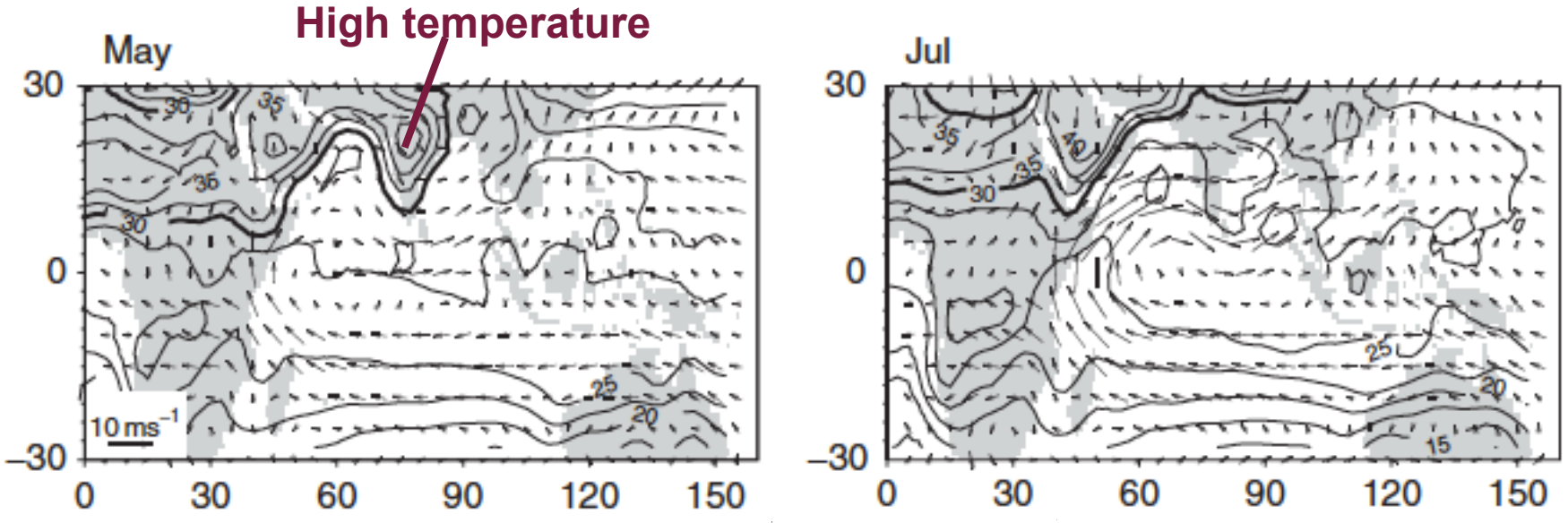
The sudden onset of south asian monsoon.

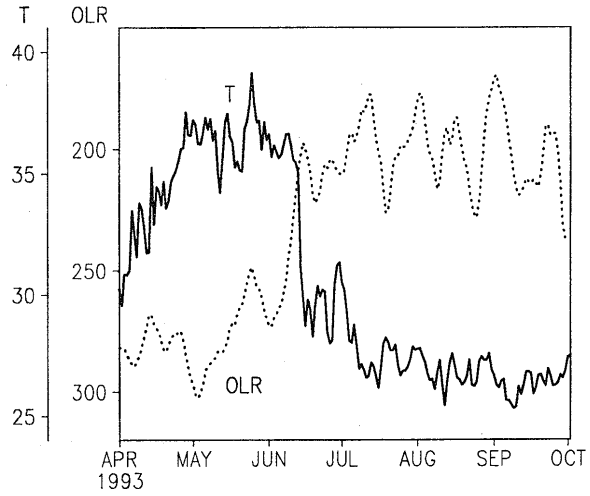




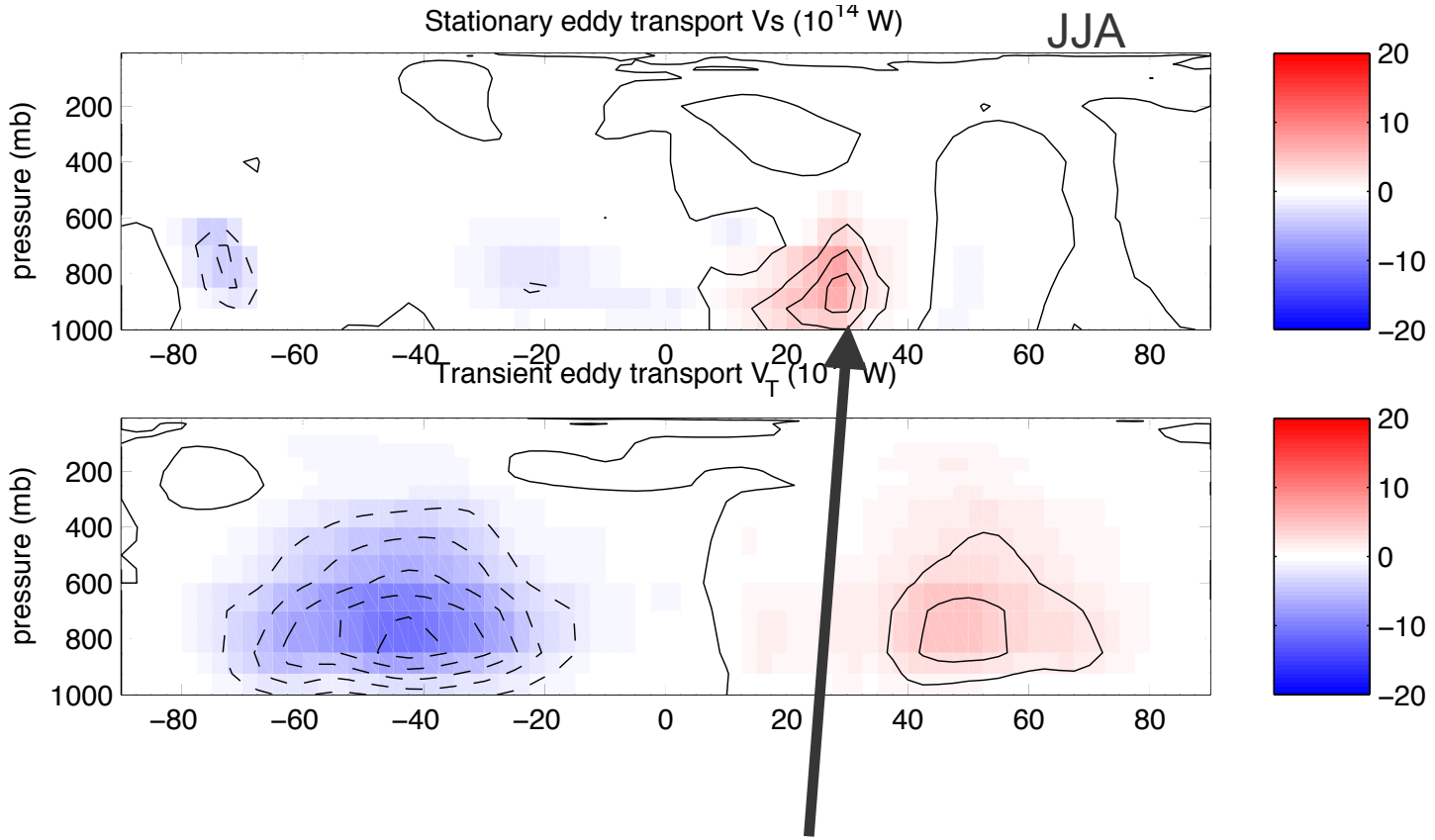
(from Webster 1998)

Features of monsoonal circulation:
-an Indian monsoon example





Features of monsoonal circulation: -an Indian monsoon example



Features of monsoonal circulation:
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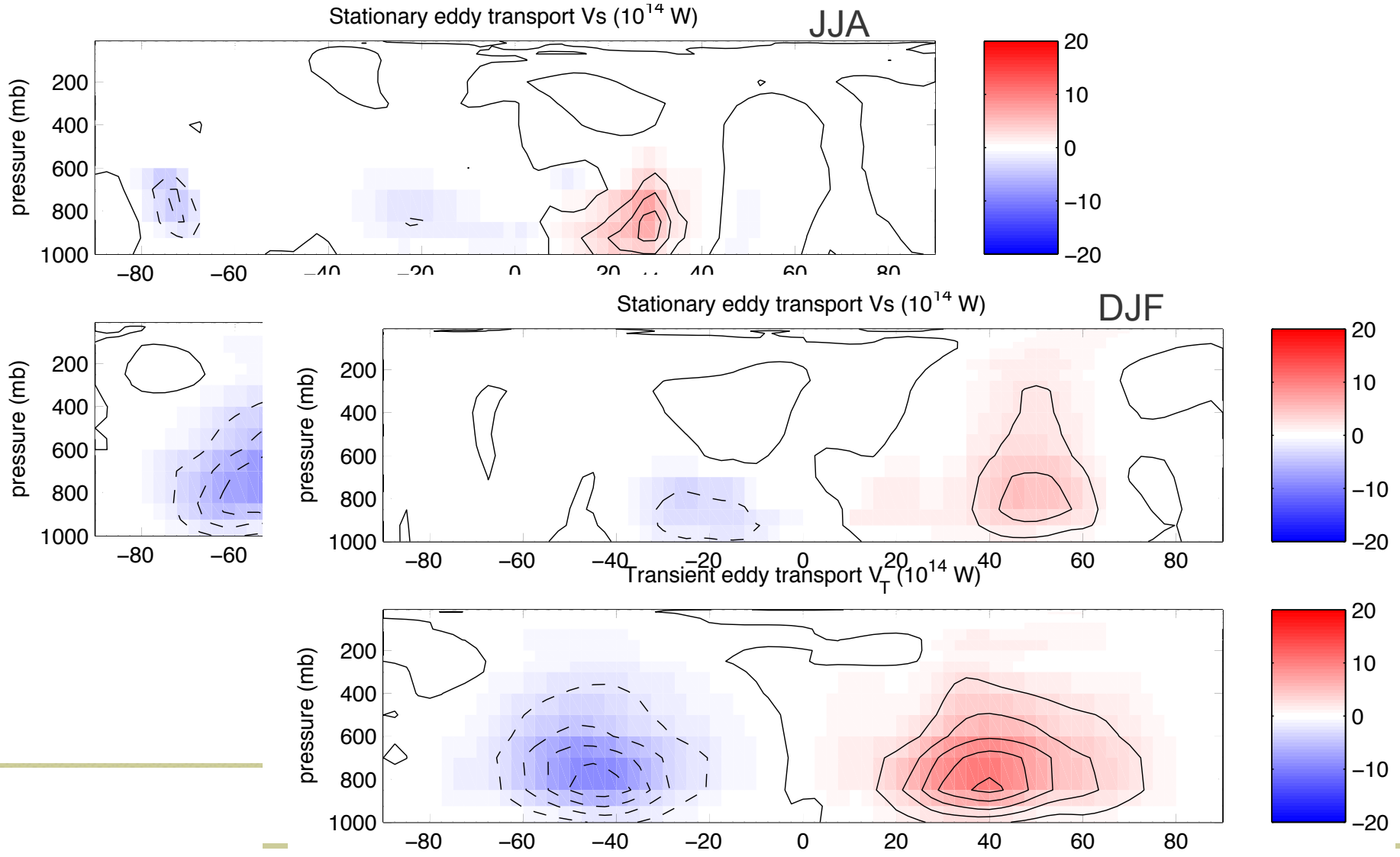
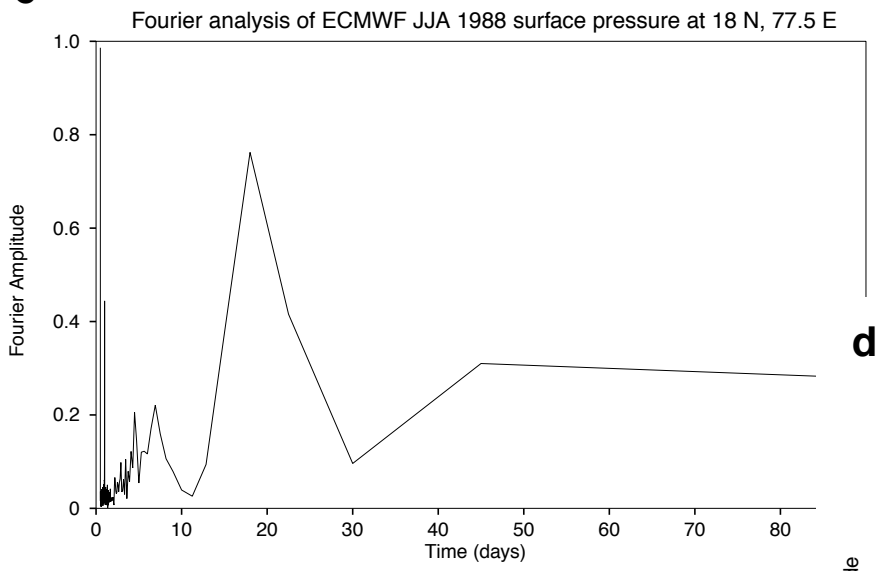


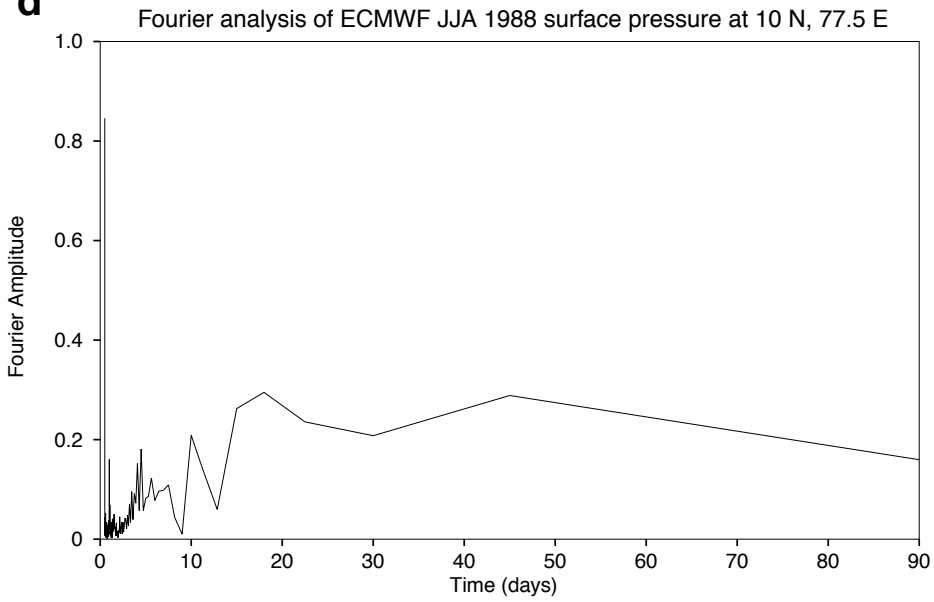
Features of monsoonal circulation: -an Indian monsoon example

e



Intra-seasonal variation: exhibits peaks on **4-5 days, 10-20 days and 40-50 days**

d



(from Randall 2009)

Features of monsoonal circulation: -an Indian monsoon example

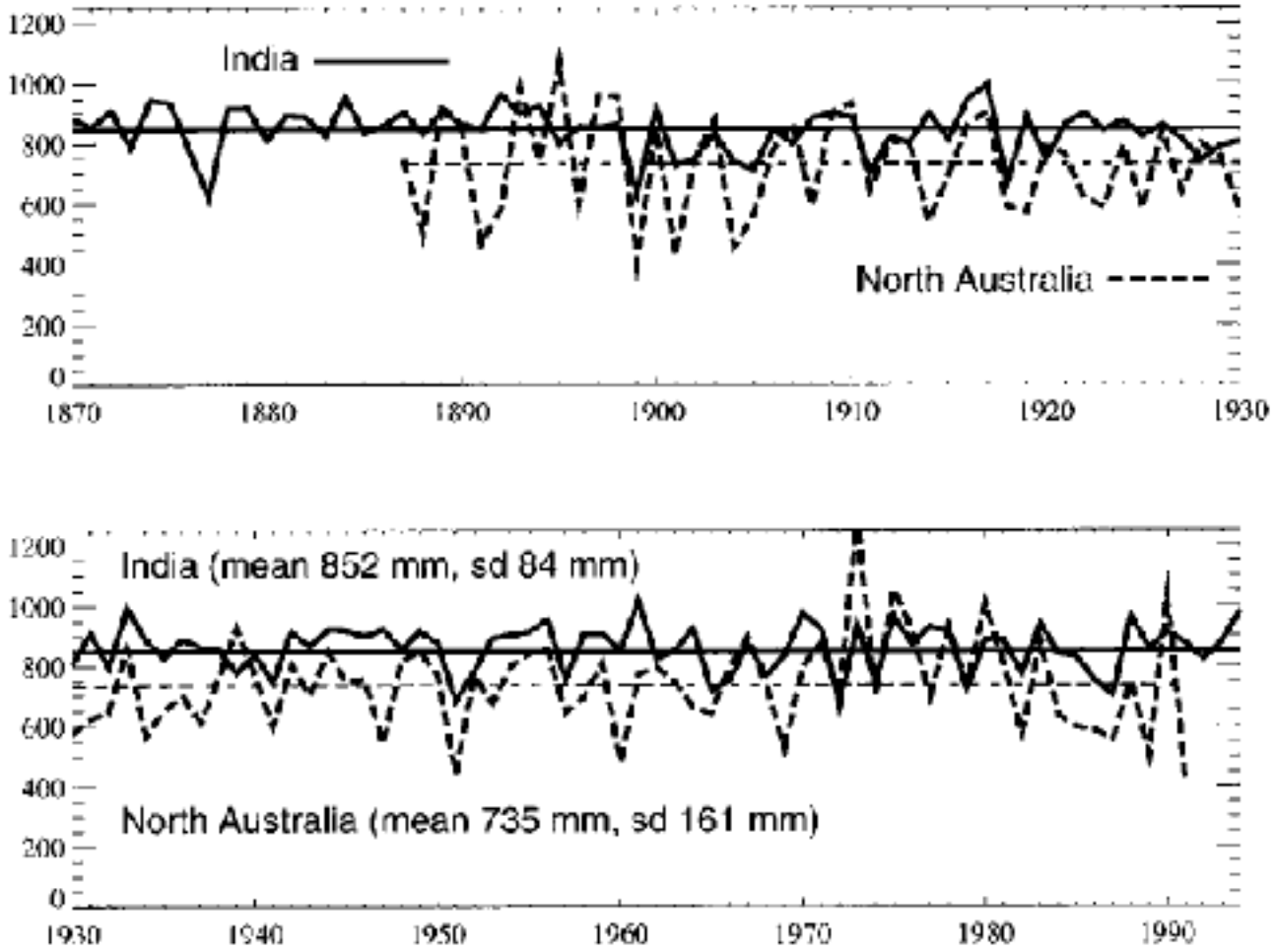
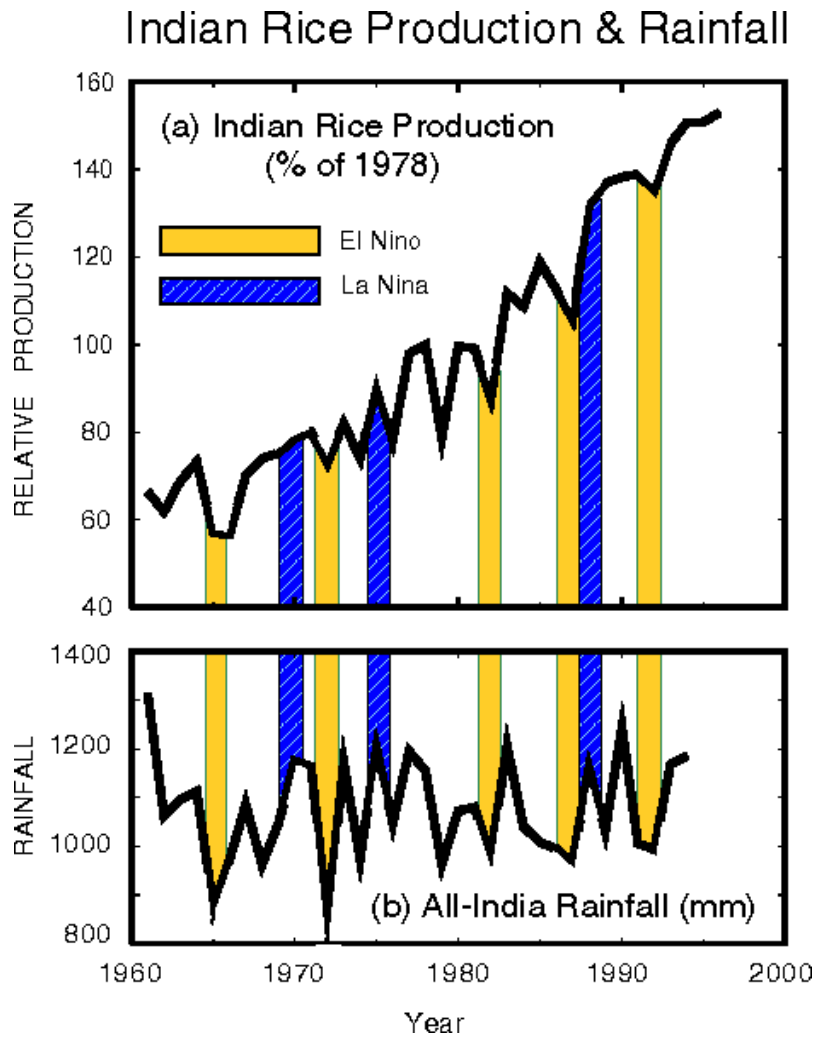


Figure 1.18 Annual-mean rainfall (mm) showing all-India rainfall (solid) and north Australia rainfall (dashed). (Webster *et al.*, 2005).

Obvious Inter-annual variation

Features of monsoonal circulation: -an Indian monsoon example



(from Webster 1998)

Inter-annual variation is related to the El Nino event and the pacific SST.

Relatively weaker precipitation over India is always found in the El Nino years;

Relatively stronger precipitation over india is found in La Nina years.

Observed features

- Summary:
  - A monsoon climate is characterized by the obvious **seasonal reversal** of wind, precipitation and atmospheric circulation.
  - From **a global view**: south asian monsoon is associated with the seasonal migration of ITCZ and Hadley circulation, which also plays an important role in the global meridional moisture and latent energy transport.
  - South asian monsoon exhibits obvious **sudden onset,** with the low-level winds and the whole monsoonal circulation built in two weeks.
  - **Intra-seasonal variation:** show periods in 4-5 days, 10-20 days and 40-50 days.
  - **Inter-annual variation:** Relatively weaker precipitation occurs during El Nino years.

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Monsoon dynamics:

-land-sea contrast

- Thermal contrast: different (equivalent) heat capacity

- Moisture advection: provide source of precipitable water

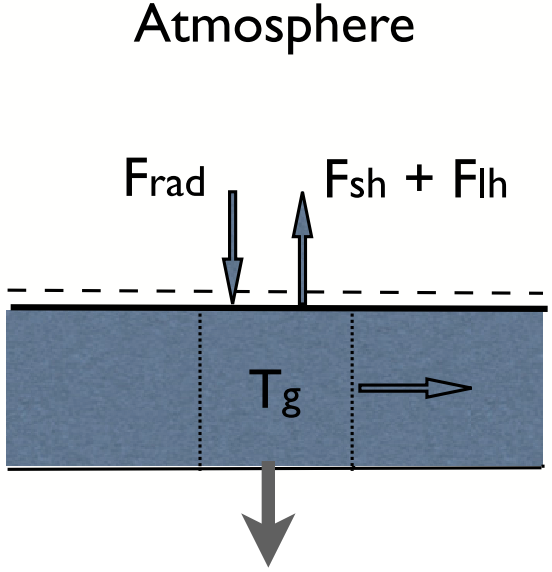
Monsoon dynamics:

-land-sea contrast

- Thermal contrast :

$$\rho_g C_{pg} H_{sur} \frac{\partial T_g}{\partial t} = F_{sur} + Q_{fx}$$

Determine the response time scale to surface heating



For ocean surface:

$\rho_g C_{pg} \sim 4 \times 10^6 \ Jm^{-3}K^{-1}$ $\quad H_{\text{sur}} \sim \text{O}(10m)$ to $\text{O}(100m)$

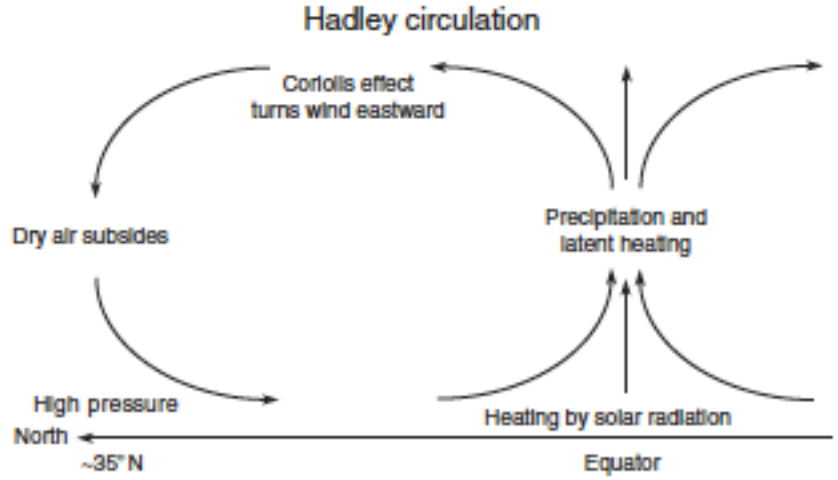
For land surface:

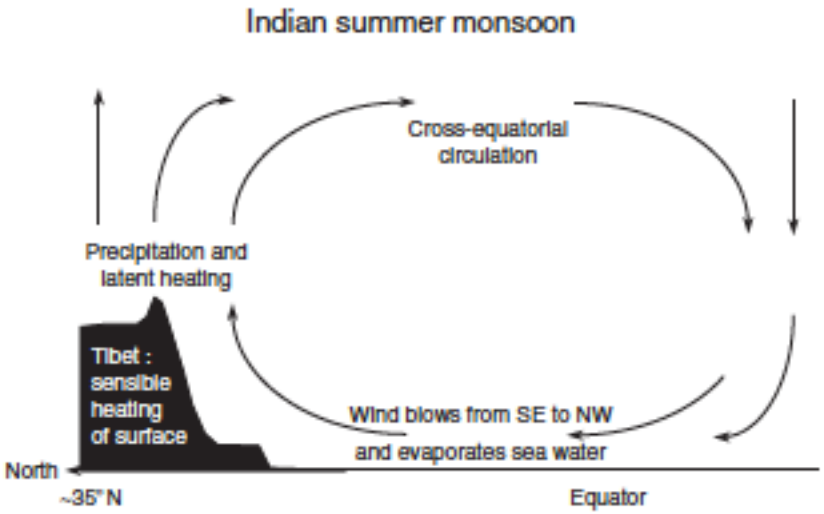
$\rho_g C_{pg} \sim 1 \times 10^6 \ Jm^{-3}K^{-1}$ $\quad H_{\text{sur}} \sim \text{O}(1m)$

fast response time scale

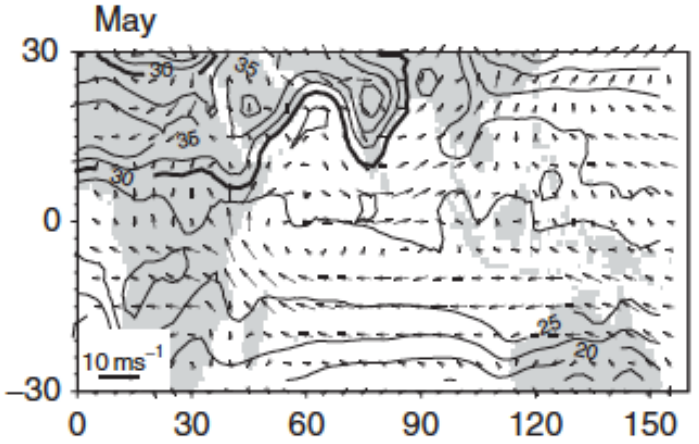
Monsoon dynamics:

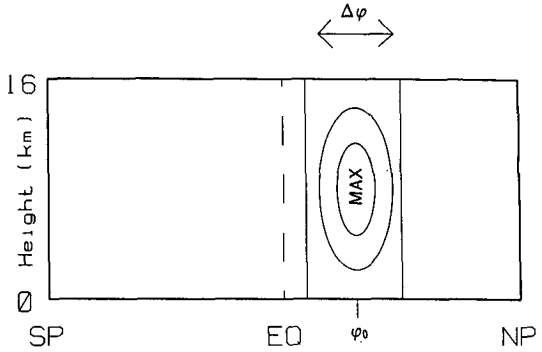
-land-sea contrast





- Thermal contrast :



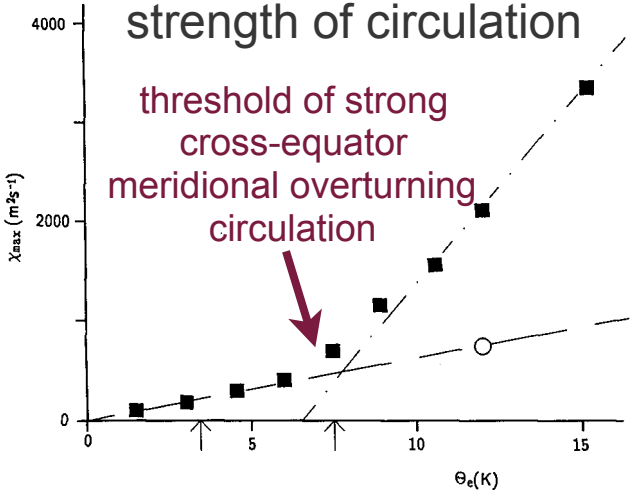


Plumb and Hou (1992)

Monsoon dynamics:

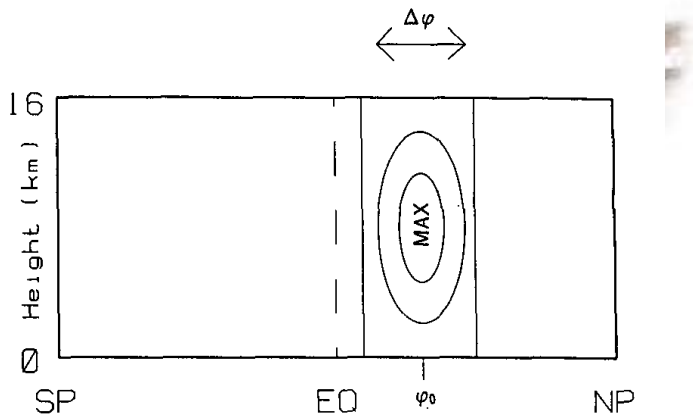
-land-se

- Thermal contrast:

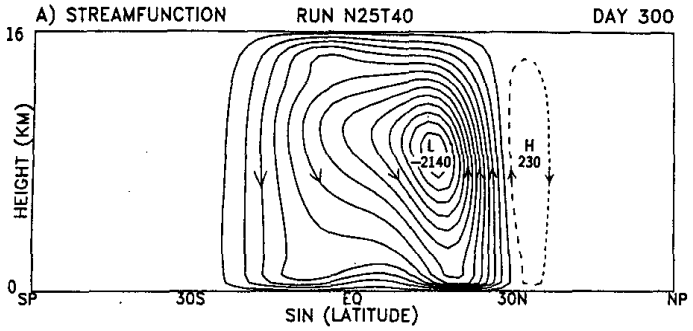


Plumb and Hou (1992)

Numerical results
for **axisymmetric** flow



strong heating:



weak heating: