# Bird's Eye View of the Monsoon

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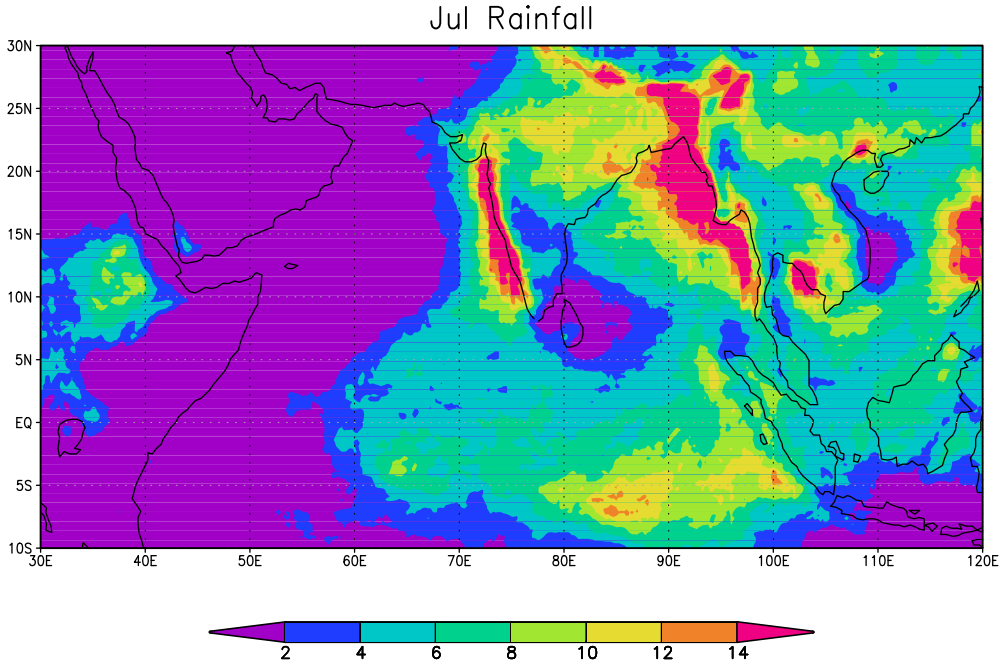
Summer School 2016

# Outline



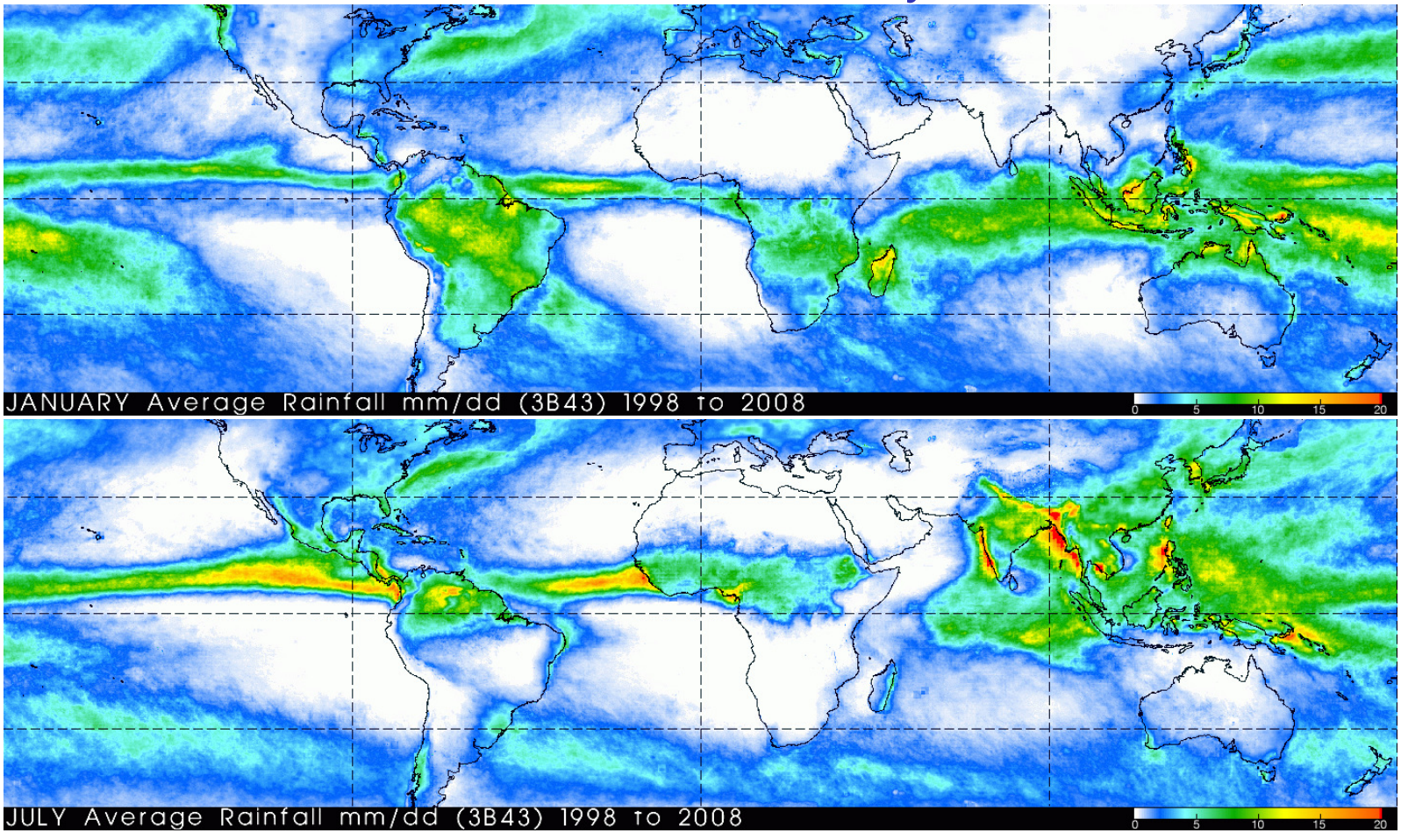
# The Mean Monsoon




- High Rain:Northern Part of Bay of Bengal and adjoining Mynmar
- High Rain: Foothills of Himalayas and NE India (where is the highest rainfall?)
- High Rain: Western Ghats

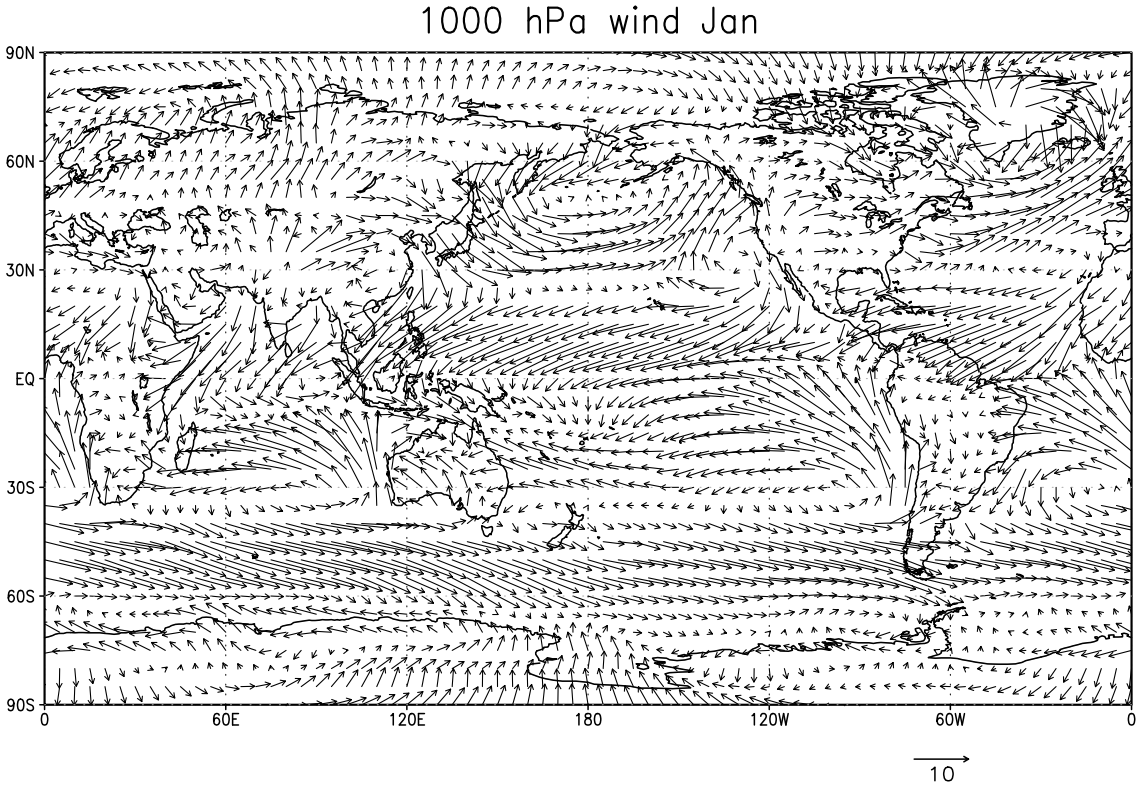
- High Rain:Equatorial Indian Ocean
- We notice a east-west gradient in rainfall
- Contrast the high rain over Head Bay with Red Sea (same latitude)
- Low rain over Tamil Nadu

# Part of the Global System




- Indian Monsoon - part of the Asian Monsoon system
- The monsoon is manifestation of ITCZ in our region

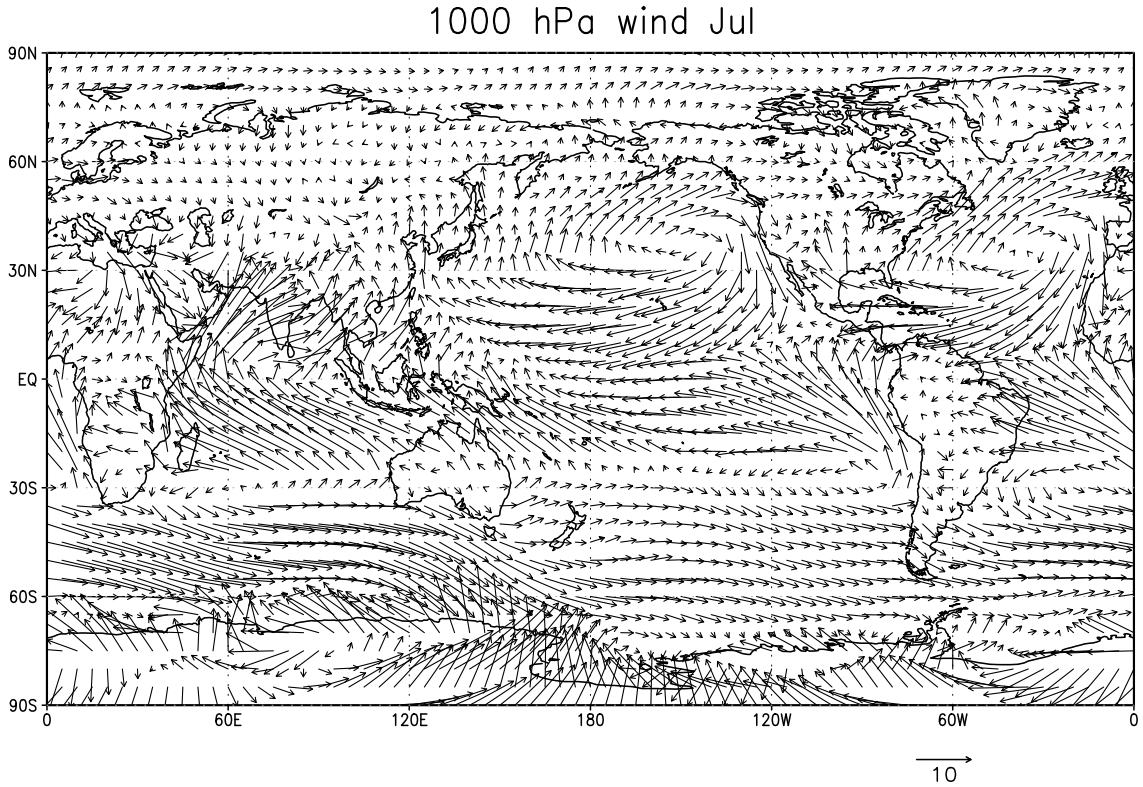
# Surface Winds




- Notice the winds converging near the equator
- The winds from both hemispheres converge here hence: Inter-Tropical Convergence Zone (ITCZ)

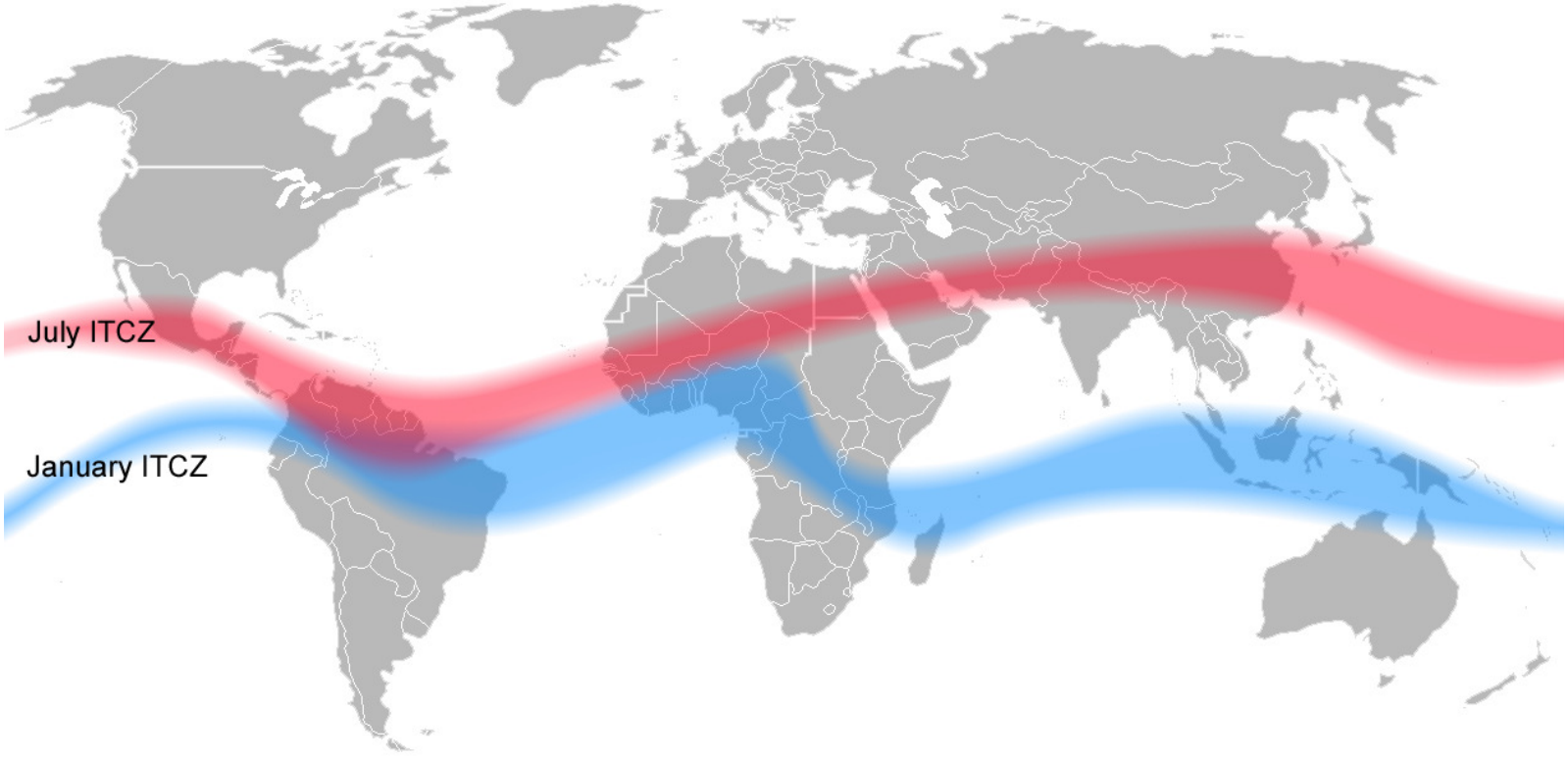
- Note that near ITCZ the zonal winds are easterly *'Easterly Trades'*
- In January the mean position of ITCZ is south of equator

# Surface Winds



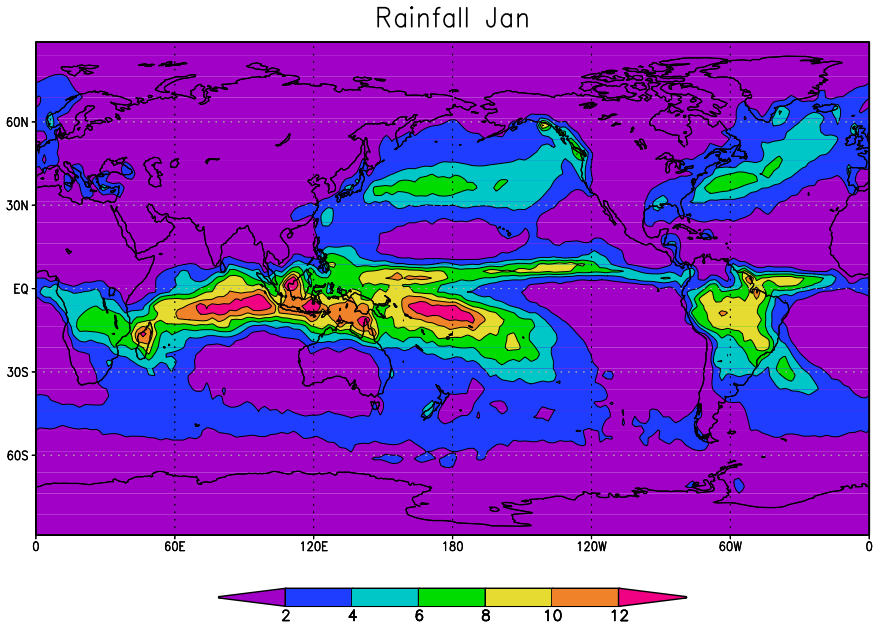

- In July the position is north of equator
- Where do you think the largest excursion of ITCZ occurs?

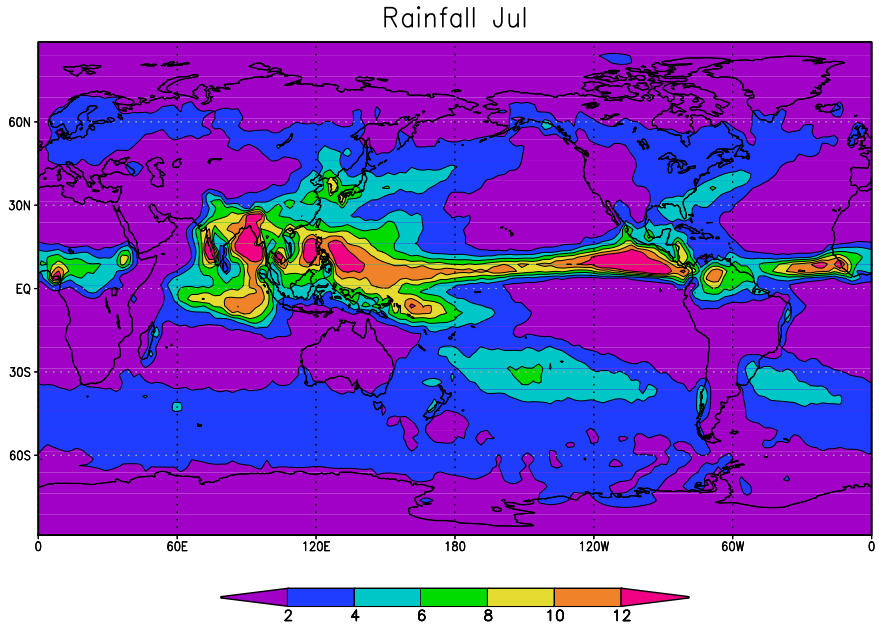
# ITCZ




- We notice that maximum excursion occurs over the Asian region during northern summer (boreal summer)
- During southern summer (austral summer) the ITCZ remains closer to equator

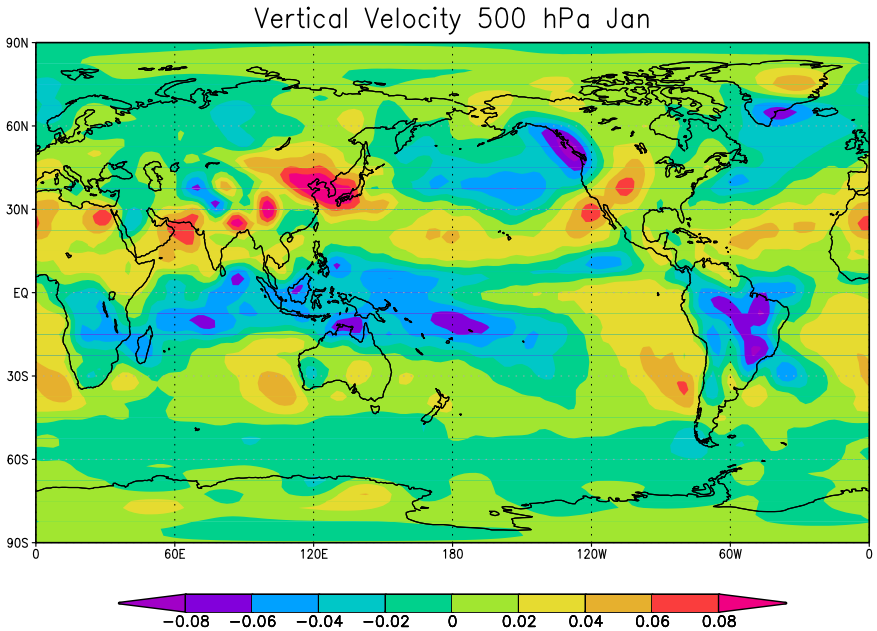
# Rainfall Pattern in January and July

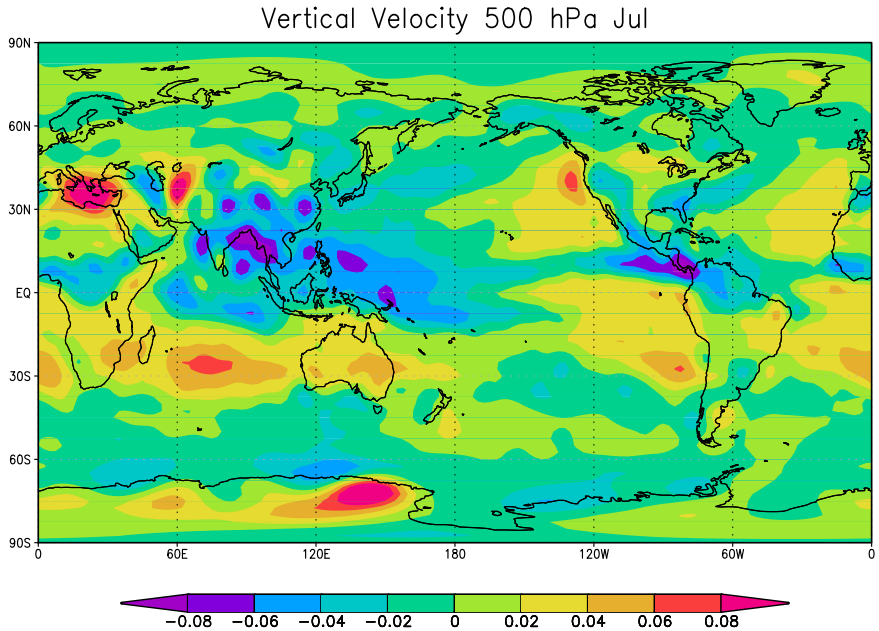



- We notice that ITCZ is related to high rainfall
- Rainbands shift with ITCZ

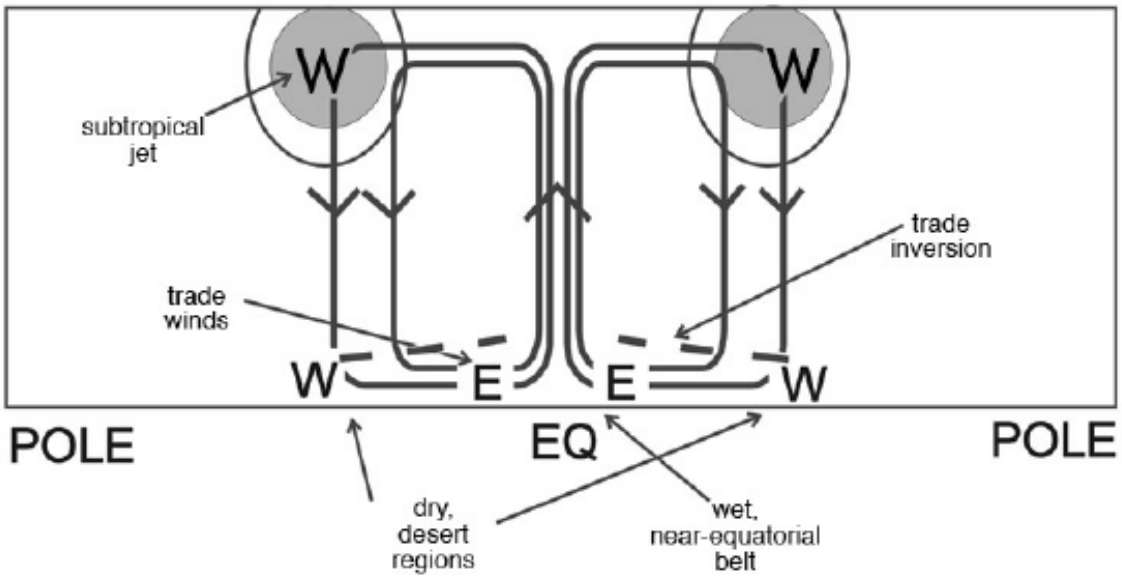
# Vertical Velocity Pattern in January and July



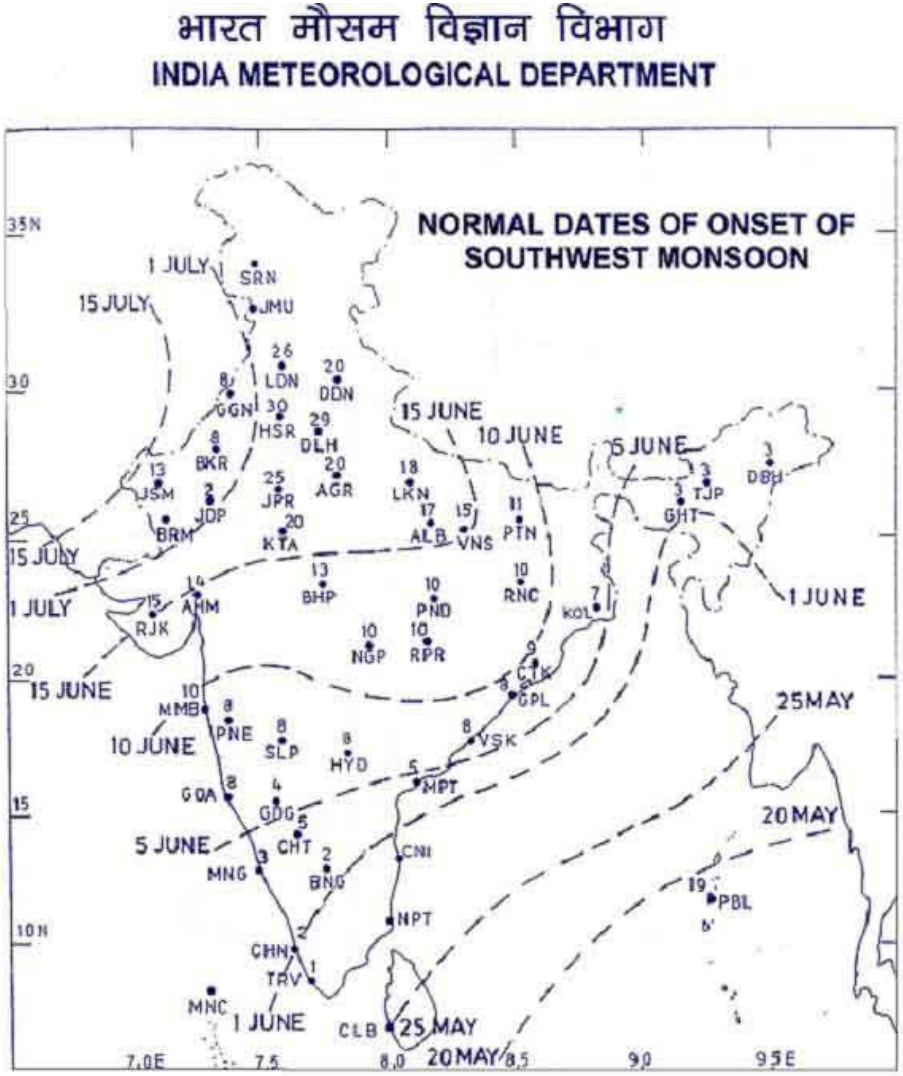

- We notice that ITCZ is related to high upward velocities related to deep convection
- Regions of descent more diffuse and descent occurs over larger region
- In short ITCZ related to convergence of winds, heavy rainfall and large upward velocity.

# Cross-Section of Hadley



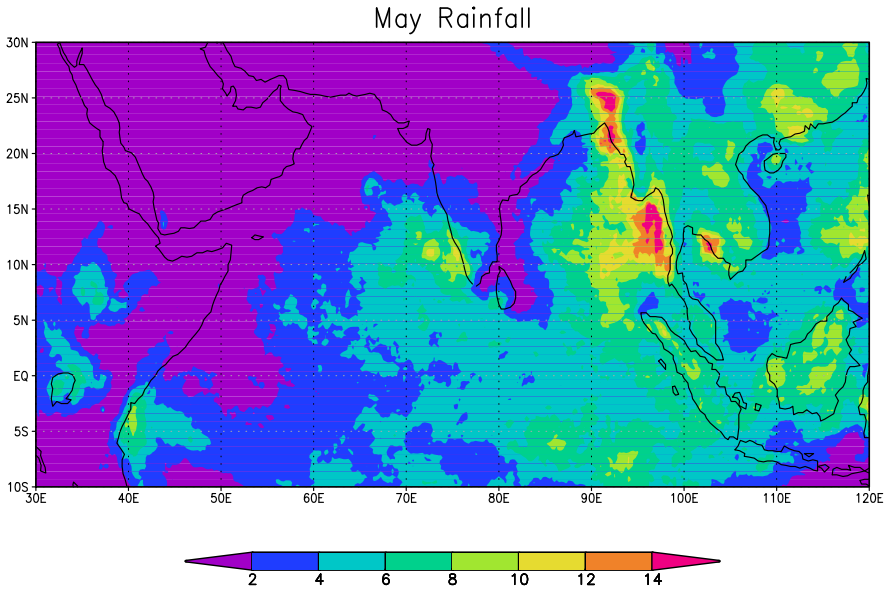

- We can summarize the behaviour of Hadley cell as
  1. Upward motion at ITCZ which coincides with the upward limb of Hadley Cell
  2. This region is associated with heavy rainfall and high cloudiness
  3. Descent occurs over mid-latitudes
  4. In short, observations show that the overturning due to Hadley cell is limited between equator and around $30^o$ latitude
- In higher latitudes transport of momentum and energy is due to eddies

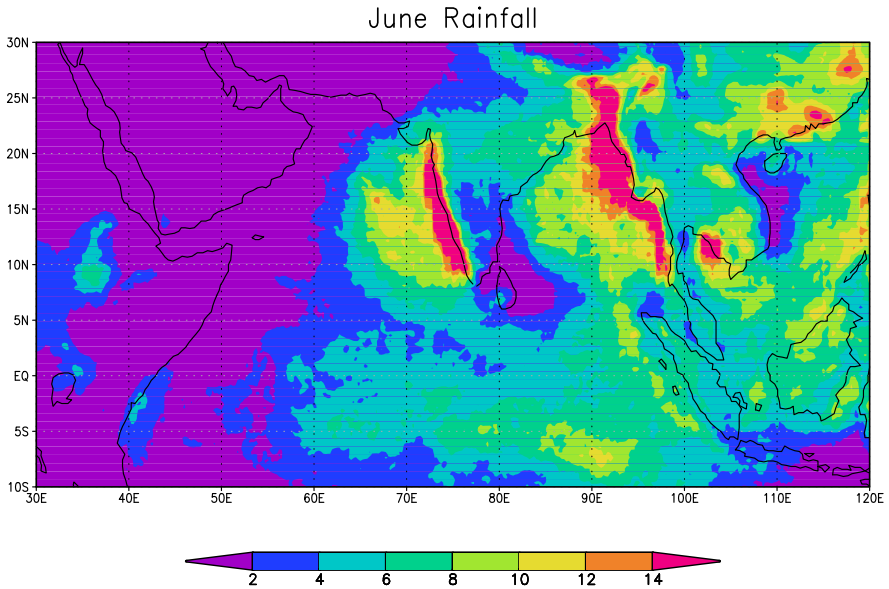
# Onset of Monsoons




- Monsoon onset over the Indian subcontinent starts in May
- Earliest onset is around 20 May around Andaman and Thailand
- A little later the onset occurs over Myanmar around 25$^{th}$ May
- Onset over mainland India occurs around 1$^{st}$ June over Kerala.
- This has a standard deviation of about 7 days.
- Around this time onset also occurs Bangladesh
- A little later around 6$^{th}$ June onset occurs over souther Karnataka
- Onset over Mumbai occurs about 10 days after over Kerala
- Over Delhi monsoon arrives around 1$^{st}$ July
- By mid-July monsoon covers the entire country

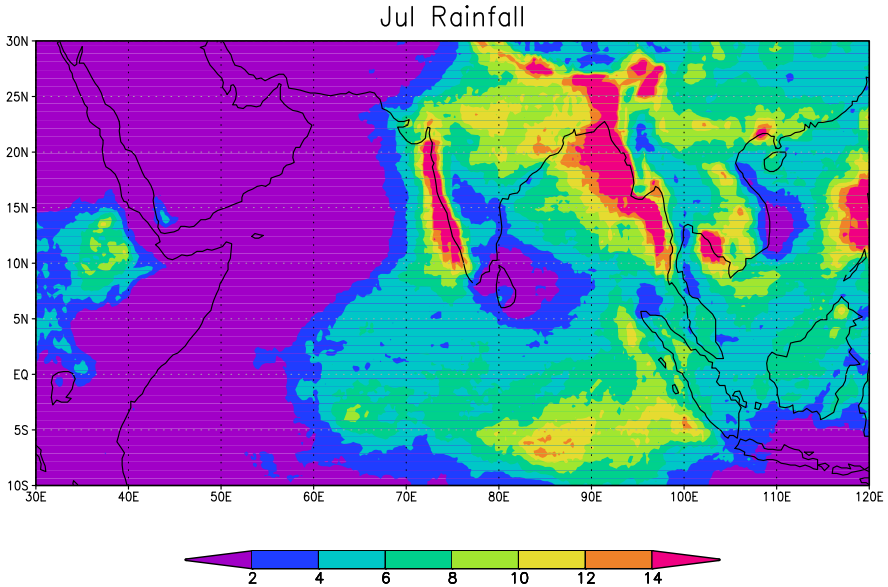
# Rainfall During May & June

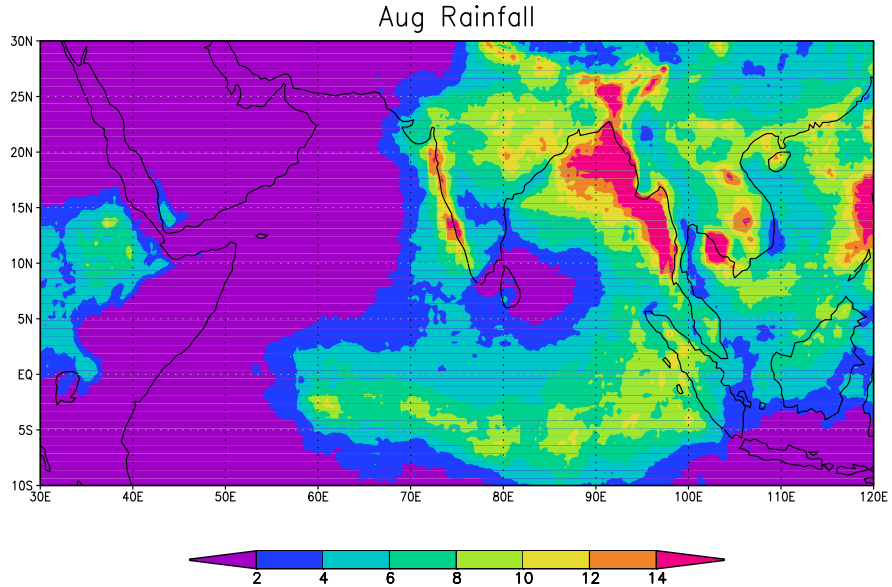



- During May rainfall is confined to essentially Arabian Sea near Kerala and off Myanmar
- During June the primary rainband is still predominantly over southern part of Peninsula and over Northern Bay of Bengal
- Northern parts such as Punjab/Rajasthan still do not have much rain.

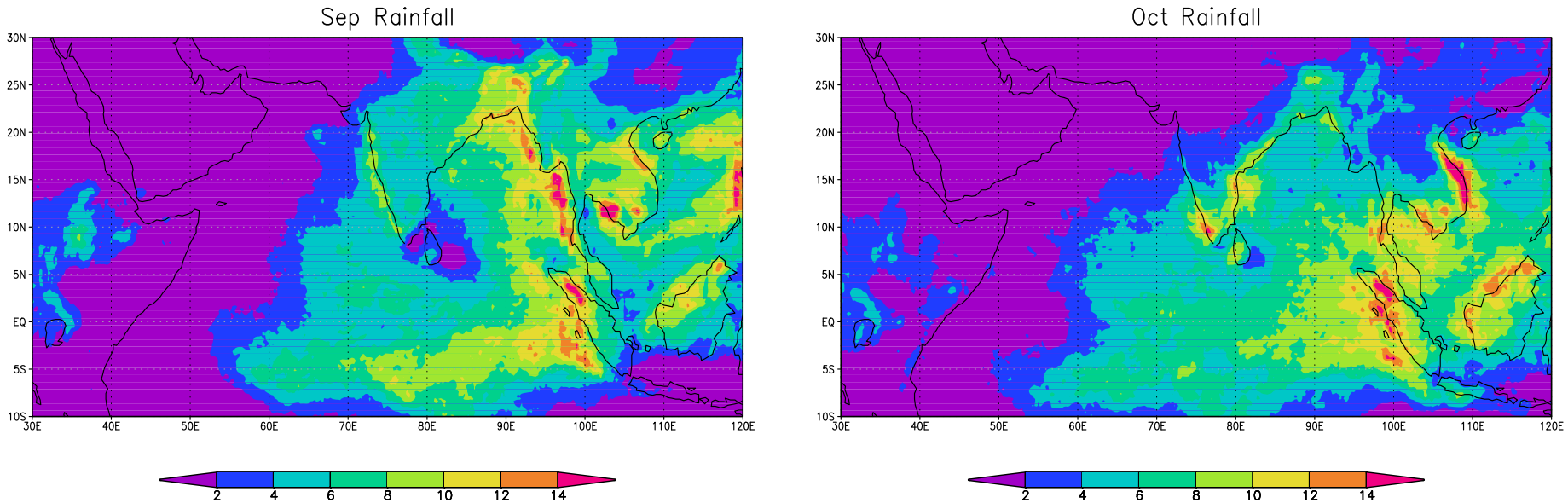
# Peak Monsoon Period : July & August



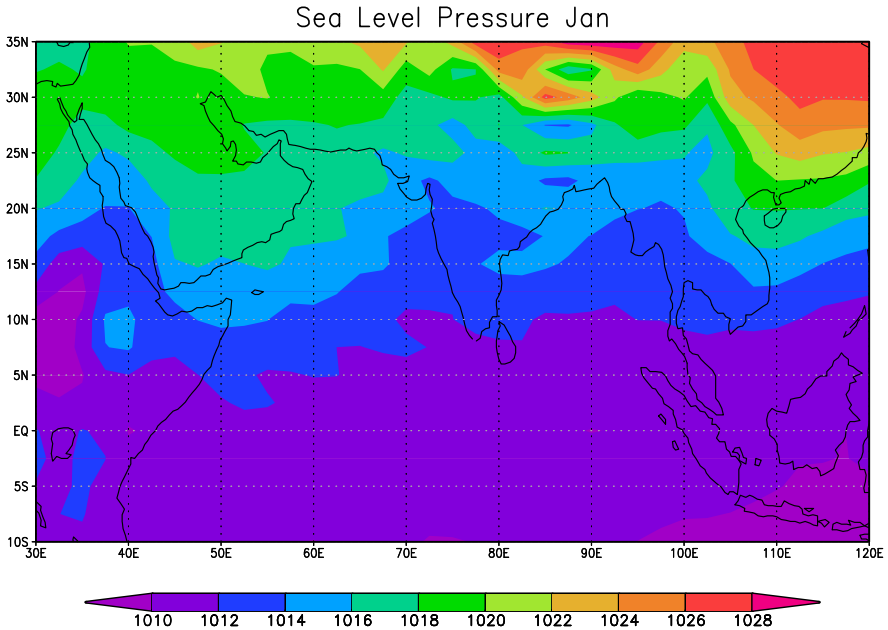

- Rain covers most of the country.
- Significant rainfall over the monsoon trough region
- Secondary rainband over Equatorial Indian Ocean also prominent
- Low rainfall over Sri Lanka and Tamil Nadu can be seen.
- Note the sharp gradient of rainfall over Arabian Sea (why?)

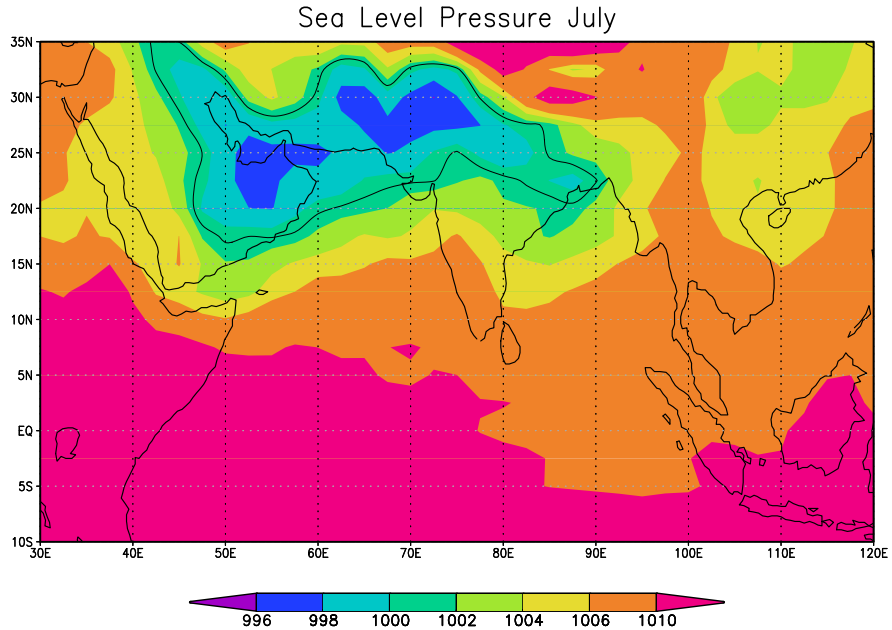
# Withdrawl Phase : Sept & Oct




- In Sept rainfall is widespread over most of the country though the magnitude is less than in July/August
- Rainfall over equatorial IO and head Bay are comparable
- During October rainfall is confined to the southern part of peninsula.

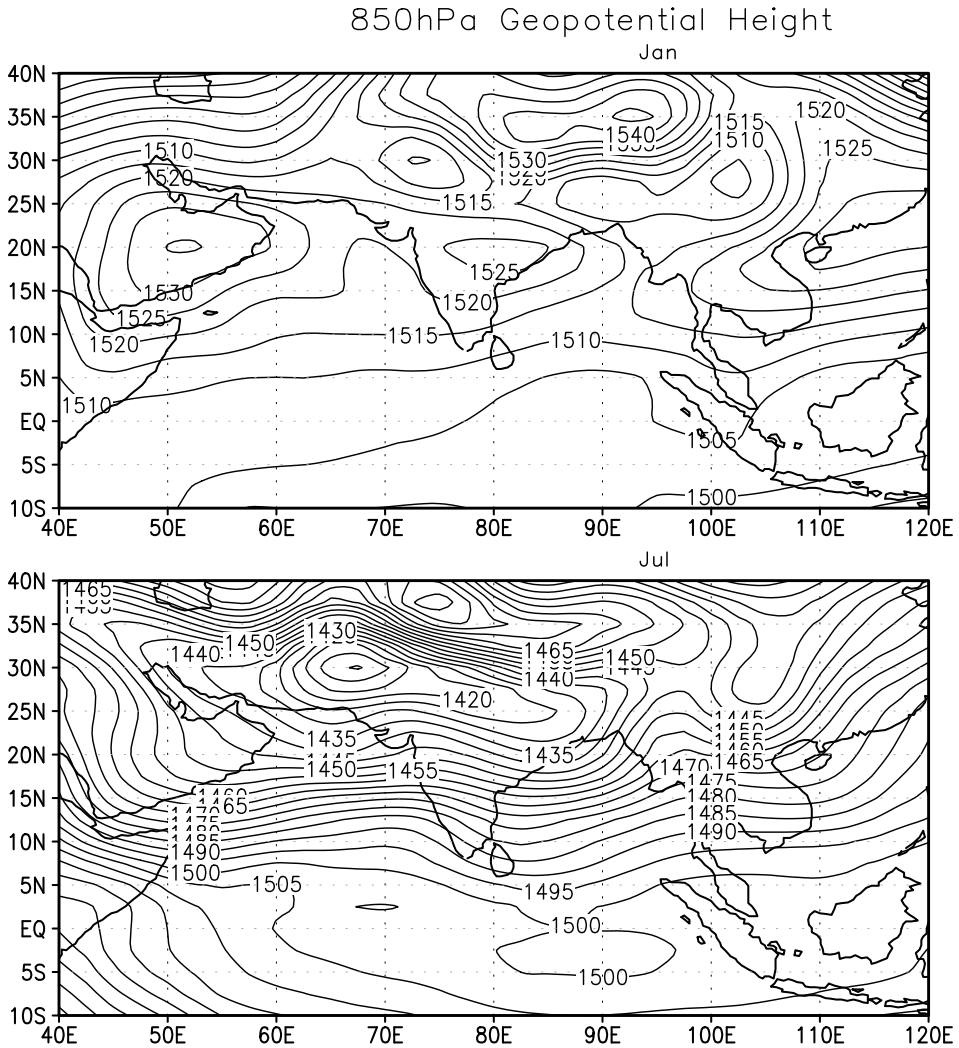
# Sea Level Pressure



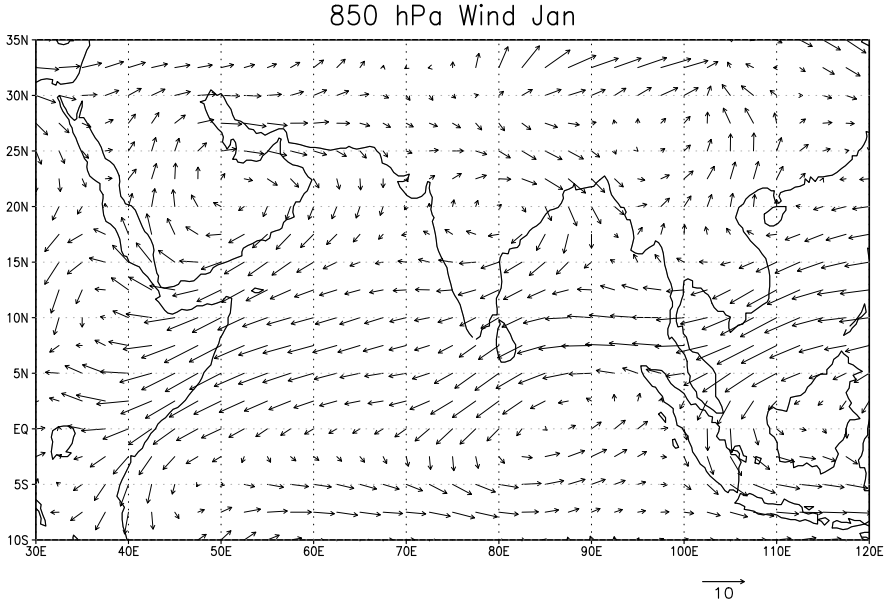

- There is a flip in sea-level pressure between Jan and July
- Over most of India the pressure is higher over land than over ocean in Jan (note the scales are not same)
- The opposite is true in July
- The eastern part of the low-pressure zone is monsoon trough
- It merges into the heat-low or surface low in the western end

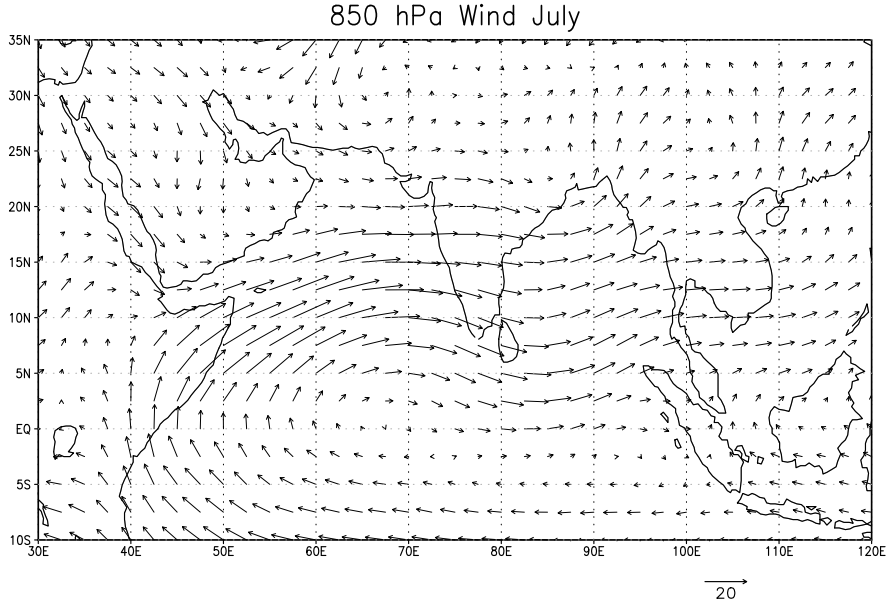
# 850 hPa geopotential during Jan & July




- Reversal of geopotential gradients

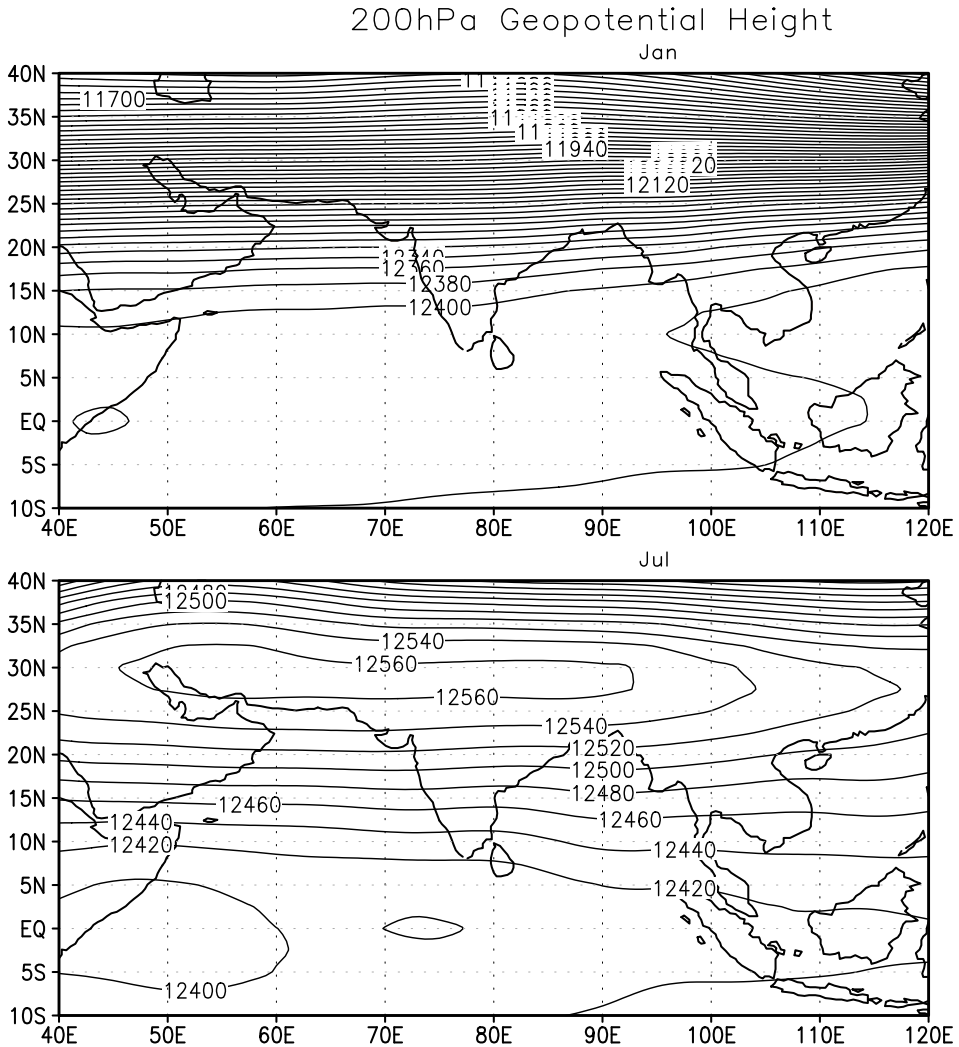
# Low Level Winds



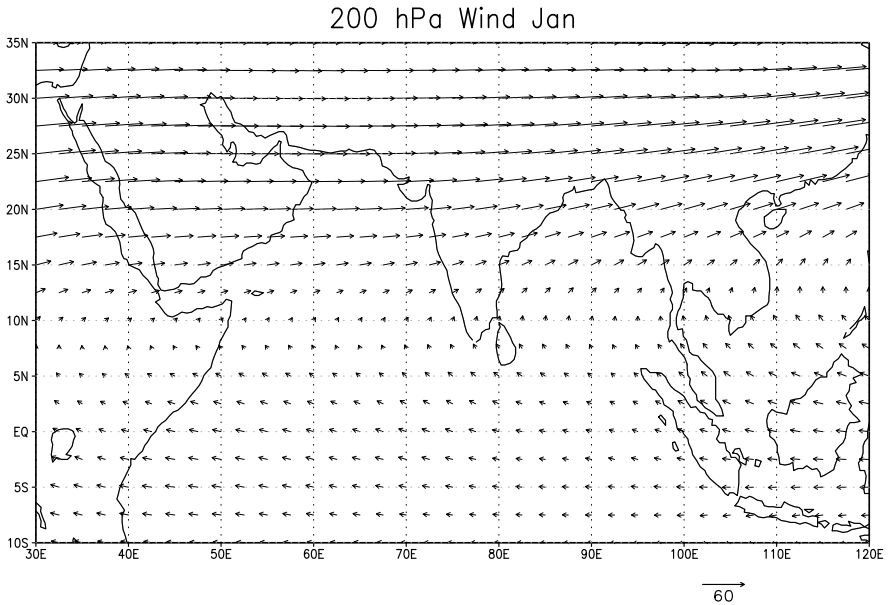

- There is a reversal wind at the 850 hPa level between Jan and July
- There is a strong jet during July.
- South of equator it is easterly, near the equator this crosses near the Somali coast, hence Somali Jet
- Over India this jet is westerly, called the 'Low-Level Jet'
- This happens as a response to monsoonal heating
- Monsoonal heating causes lower pressure to the north and higher pressures to the south. Hence the geostrophic response
- Low level Jet plays an important role in transporting moisture into the Indian sub-continent.
- Also causes cooling over Arabian Sea.

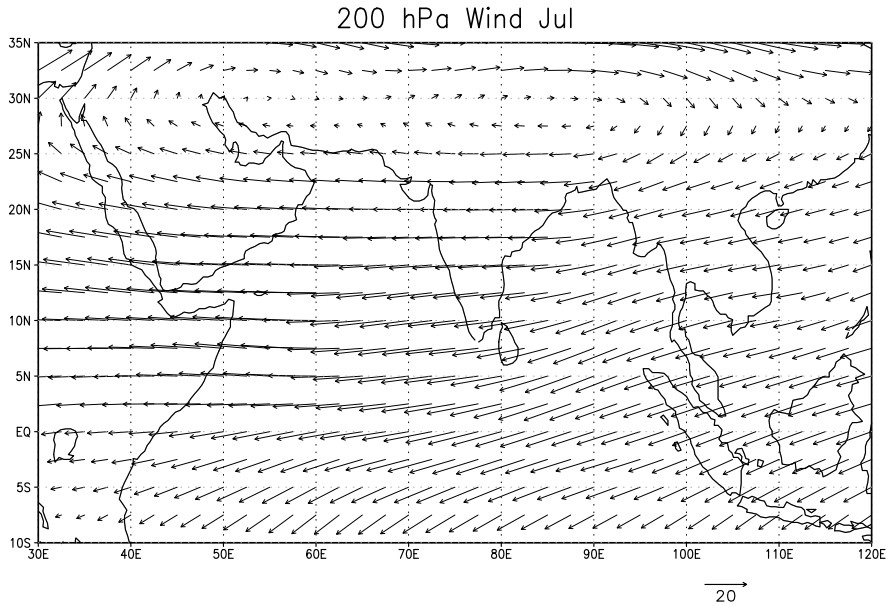
# 200 hPa geopotential during Jan & July




- Reversal of geopotential gradients
- Opposite to that at 850 hPa

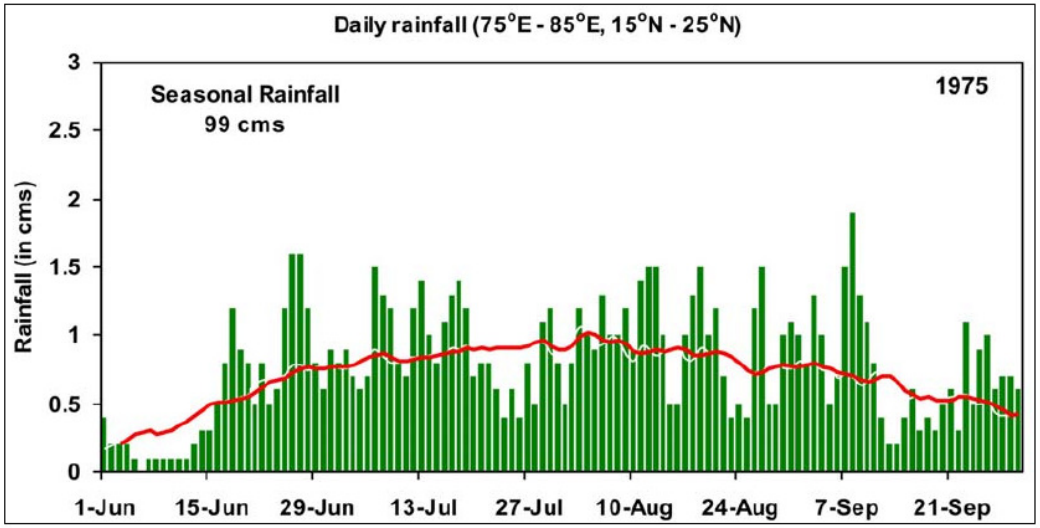
# High Level Winds

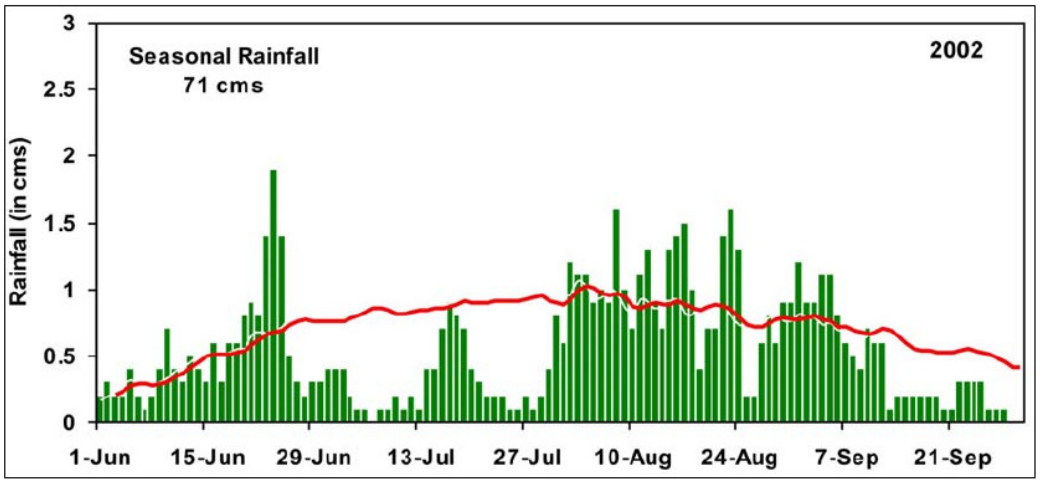



- Note that winds are much more zonal at 200 hPa than at 850. Why?
- During January the upper levels have westerlies (why?)
- During July there are Easterlies south of Himalayas, Westerlies to the north of it
- The strong winds found around $10^{o}$N-$15^{o}$N are called the 'Tropical Easterly Jet'
- Over Tibet there is an anti-cyclone called the 'Tibetan Anti-Cyclone'

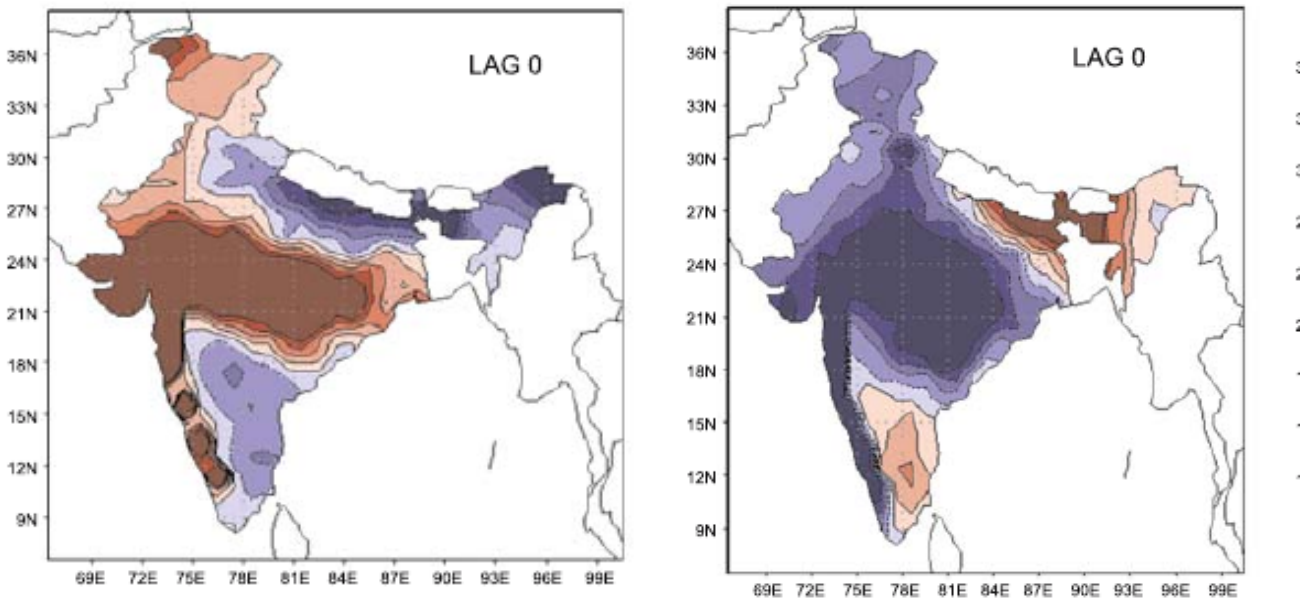
# Active & Break Spells




- We know that it does not rain continously over the entire seasonal
- Some days it rains more and some days it doesn't rain at all.
- Long periods (generally >3) when there is no rain is called a break, long periods when monsoon is vigorous is called active spell
- During Active spells rainfall is widespread over most of monsoon trough
- During breaks, rainfall is limited to Himalayan foothills and NE India and peninsula
- Long and persistent breaks can lead to droughts

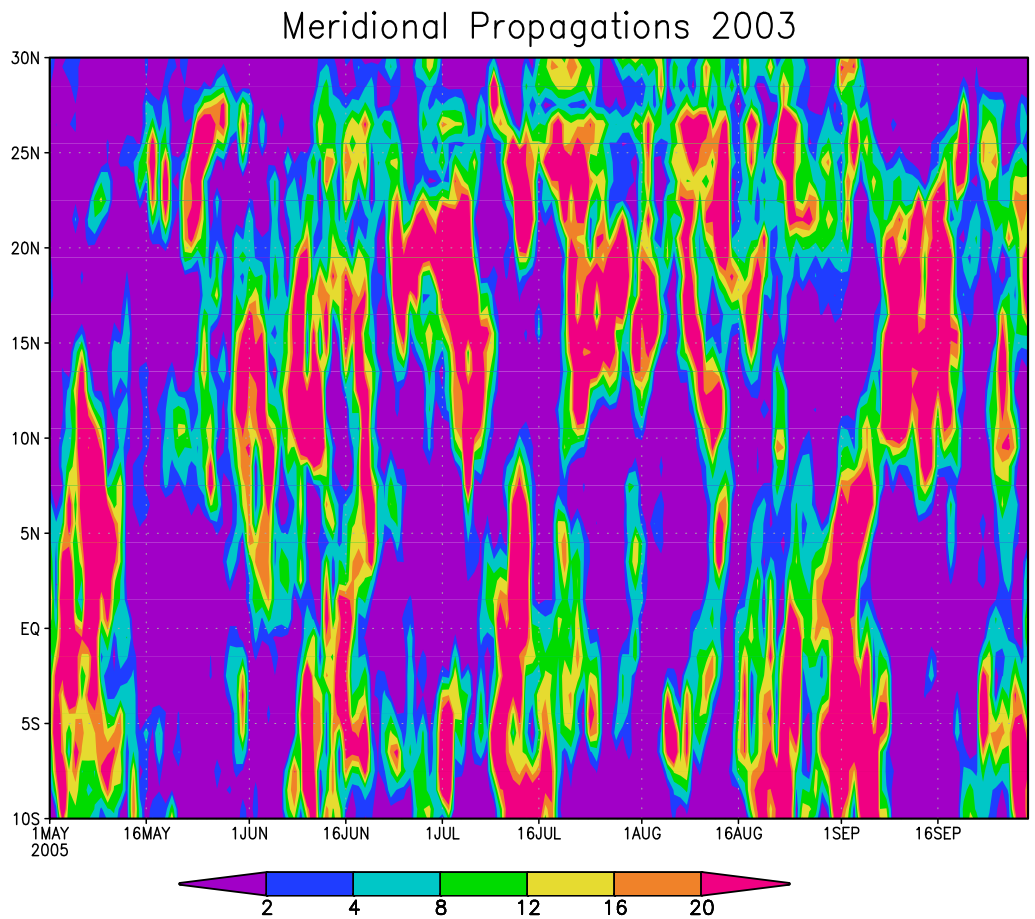
# Active and Break Spell




Rajeevan et al, 2010

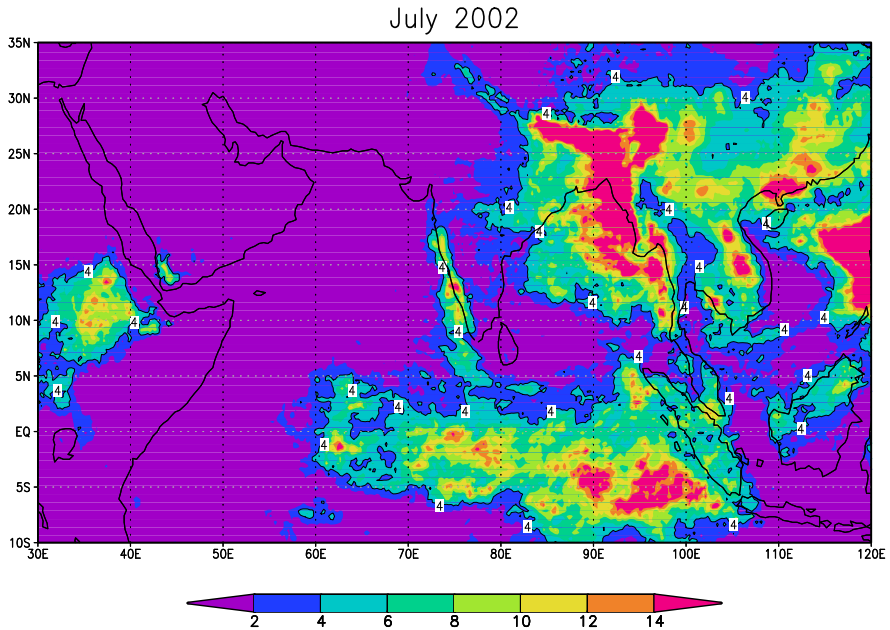
- Rainfall widespread over most of continental trough zone during active phase
- Rainfall confined Himalayan foothills and NE India during break spells
- Peninsular India gets higher rainfall during weakspells
- How does rainfall vary in space and time within a season?

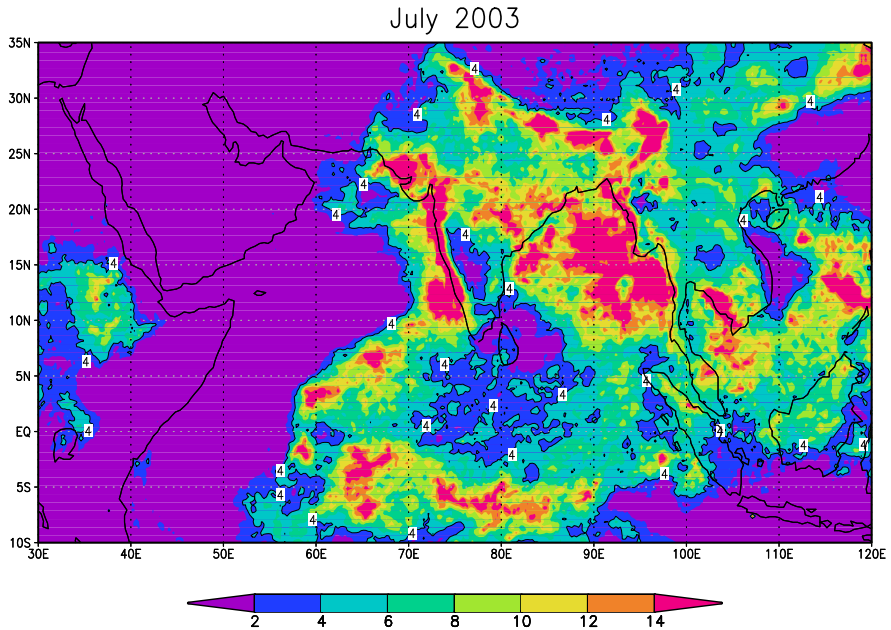
# Intraseasonal Variations




- A characteristic feature of Indian Summer Monsoon is the northward movement of rainbands
- Rainbands originate near equator ($5^oS$) and move northwards
- They culminate in the monsoon trough zone
- Typical time between these poleward movements is about 25-30 days
- Only over Western Pacific ($150^oE$) does one find such poleward movements
- The mechanism of poleward propagations are still a matter of research
- They play a major role in reviving active spells after a break

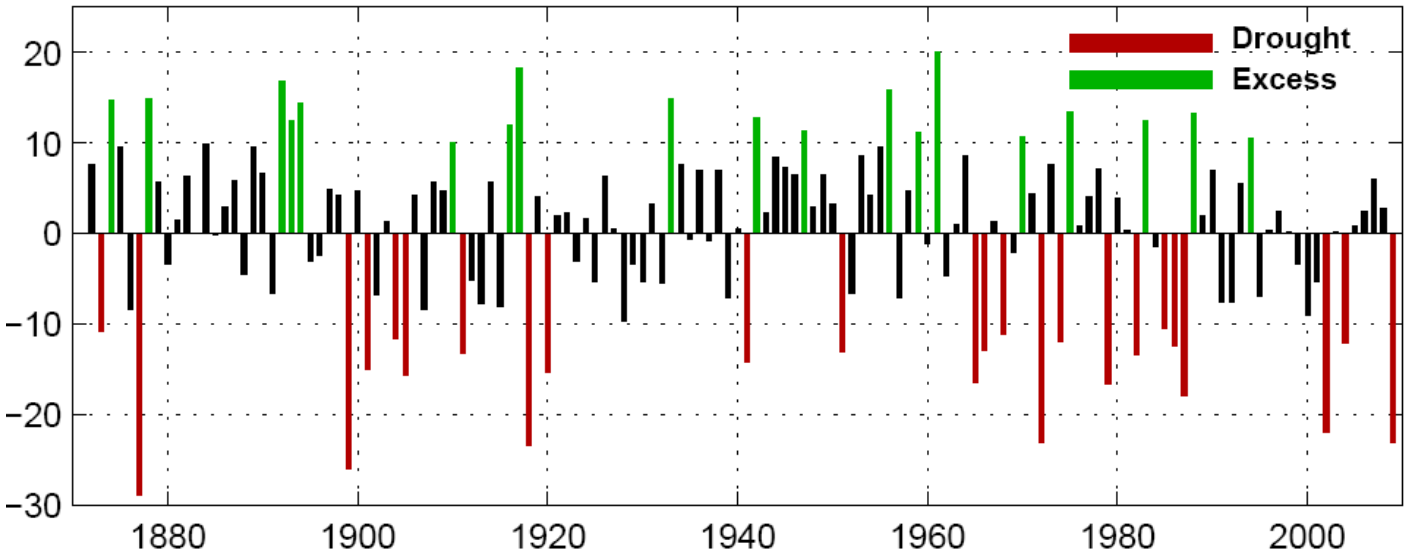
# Droughts



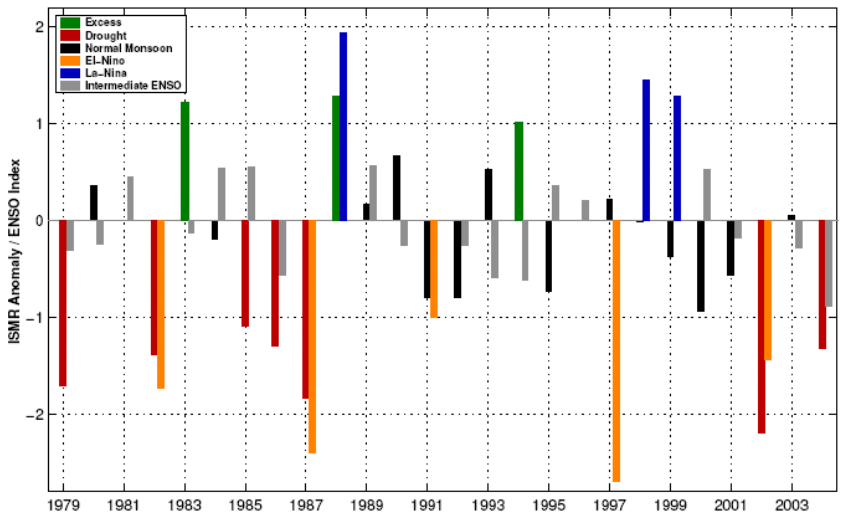

- 2002 was a major drought with rainfall about 20% below its long term mean
- 2003 was a near normal monsoon

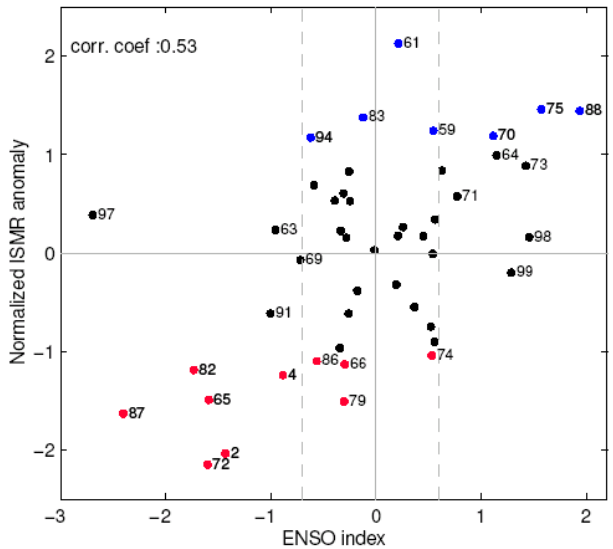
# Interannual Variability




- We note that not all years have the same monsoon strength
- Some years with strong monsoon, some with weak monsoons
- Typical the standard deviation of ISMR is 10%. Mean value is about 860mm (JJAS)
- Some years have severe drought, some have excesses rainfall
- What are these interannual variations related to?

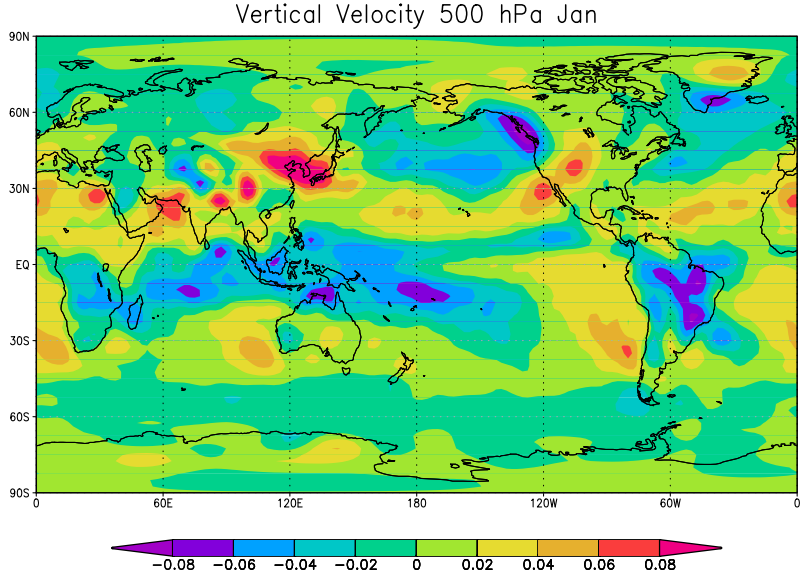
# EnSO-ISMR Relationship

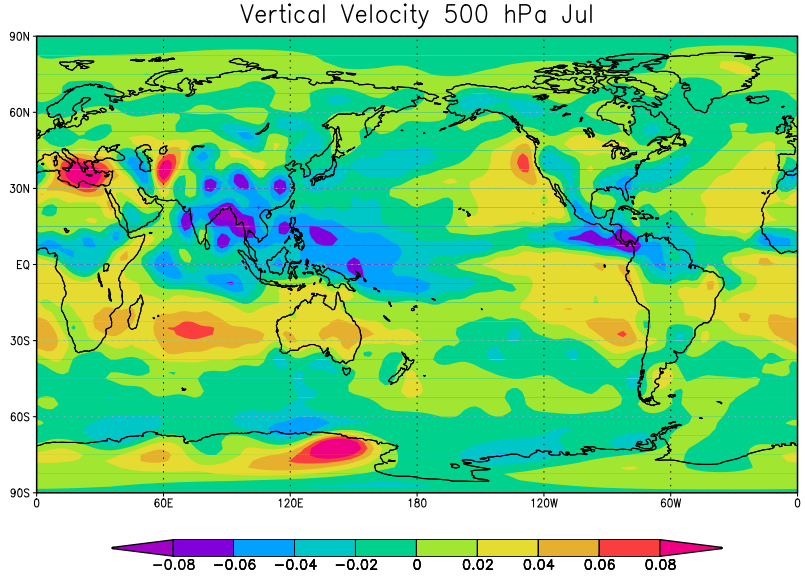



- We note that quite a few droughts are related to the occurrence of El-Nino
- Some of the excess rainfall years are associated with La-Nina
- The correlation between EnSO and ISMR is about -0.53
- Occurrence of EnSO disrupts the Walker circulation
- In turn modifies the Hadley cell- has an impact on the monsoon.
- What is Walker Circulation?
- What is El-Nino?

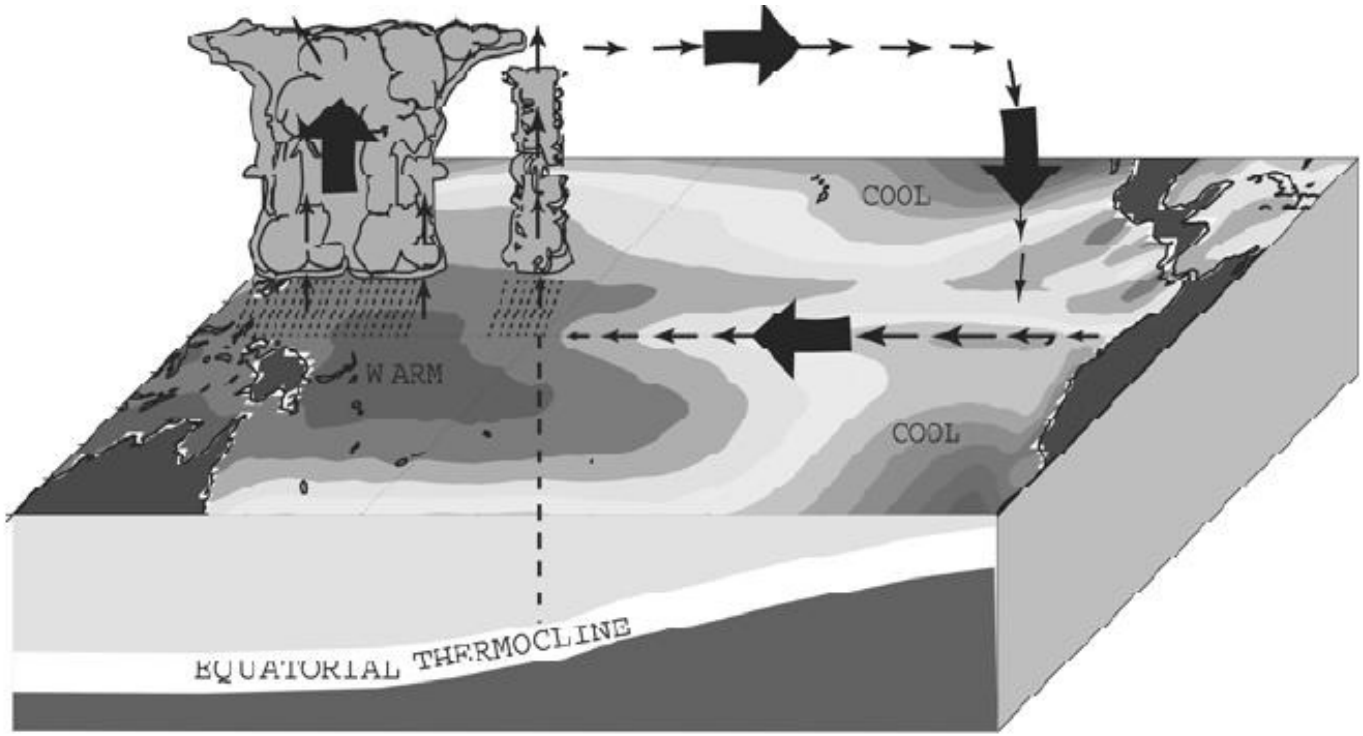
# The Walker Circulation



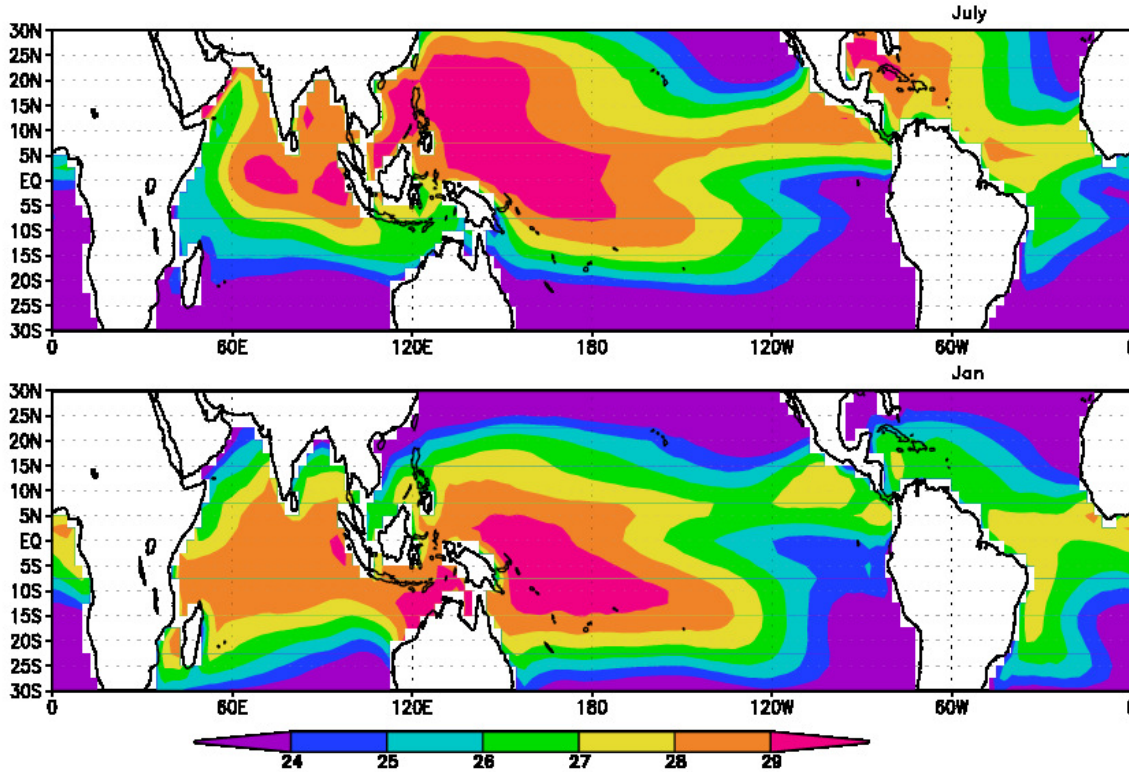

- We have considered zonally averaged circulation in the north-south direction
- Is this zonally symmetric view completely correct?
- Near the equator we find significant differences in upward velocities over the two parts of the Pacific.
- Over Western Pacific (close to Indonesia) there is intense ascent
- Over Eastern Pacific (close to American coast) there is descent
- Does this signify a circulation in the East-West Direction?
- This east-west circulation is the Walker Circulation – after Sir Gilber Walker.

# The Walker Circulation



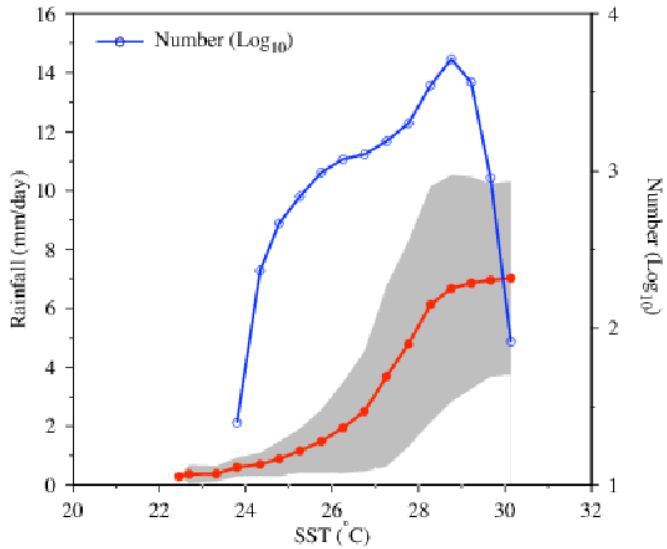

- There is rising motion off the Indonesian coast (Western Pacific)
- Descending motion off the American coast
- This circulation along the equator is called Walker Circulation
- What causes this zonal circulaition?

# SST pattern



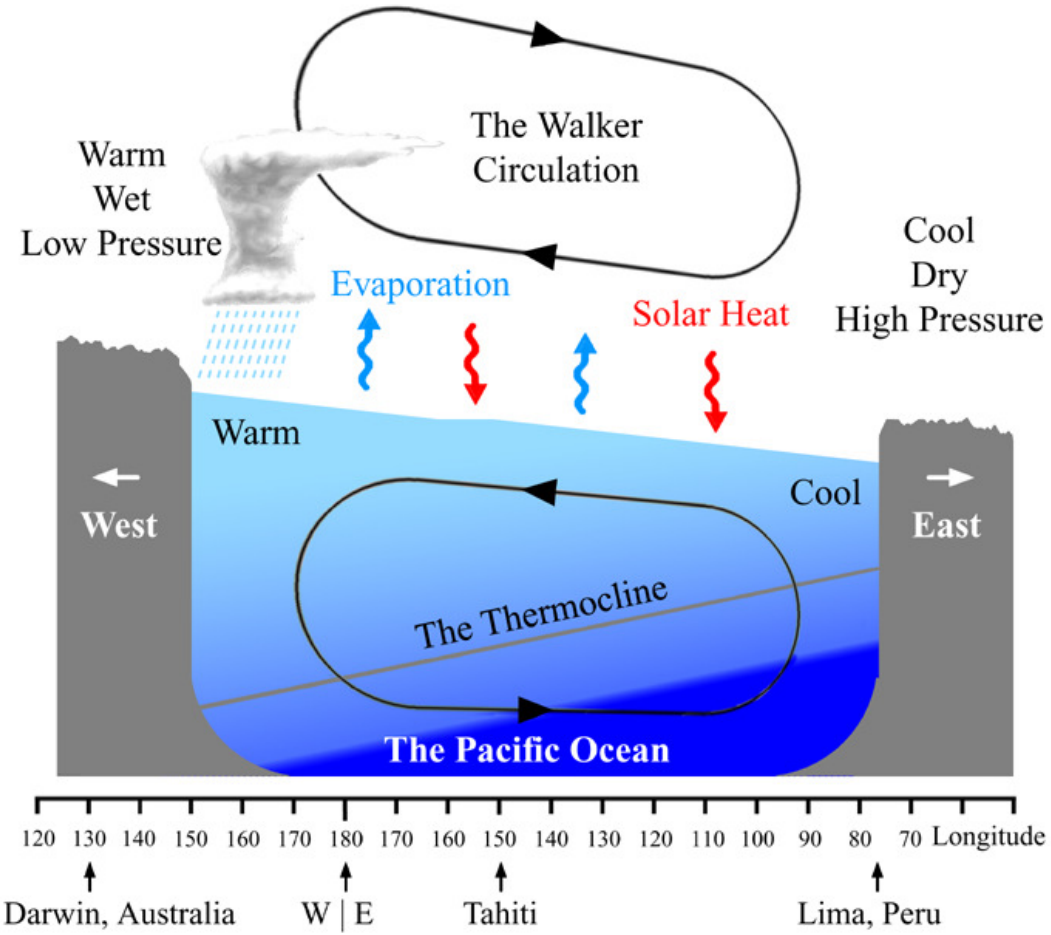

- We find that SSTs are higher over Western Pacific (Indonesian coast)
- SSTs are lower over Eastern Pacific (American coast)
- This coincides with regions of high rainfall/ascent and low rainfall/descent
- How do SSTs affect rainfall and ascent?

# SST-Rainfall Relationship




- Examining the SST rainfall relationship we find
  1. Rainfall is low and increases slowly below SST of $27^oC$.
  2. Above $27^oC$, there is a rapid increase in rainfall
  3. We generally find that organized convection is sustained only above $27^oC$
  4. West Pacific is well above $27^oC$ while East Pacific is below the threshold
  5. What causes SST to have this structure?

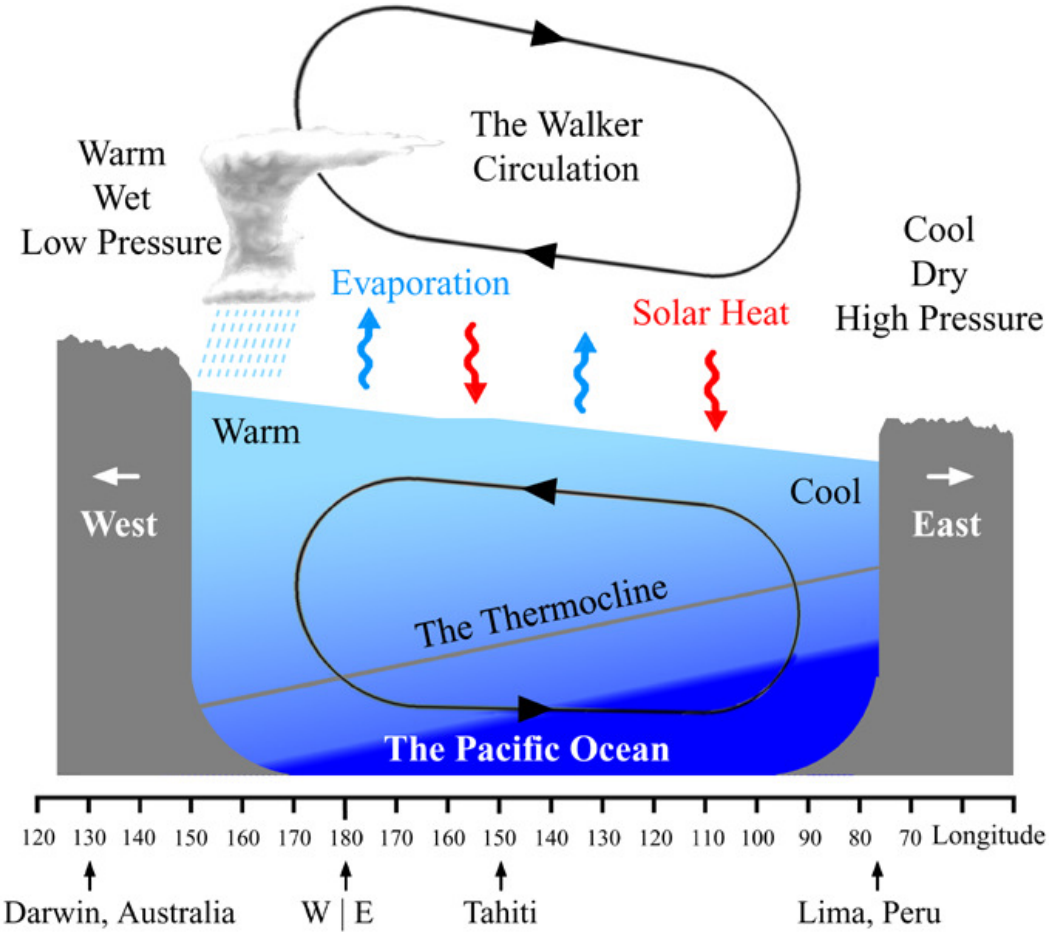
# A Coupled System




- Looking at the surface wind pattern we notice that the winds are generally westward (easterlies, the trade winds)
- Near the coast of Peru, winds are northward cause upwelling at the eastern end of a basin and easterlies along the equator - causes the thermocline (the interface across which there is cold water below and warmer water above) to be shallow.

- At the western end there is a 'piling up of water' – the thermocline is deep

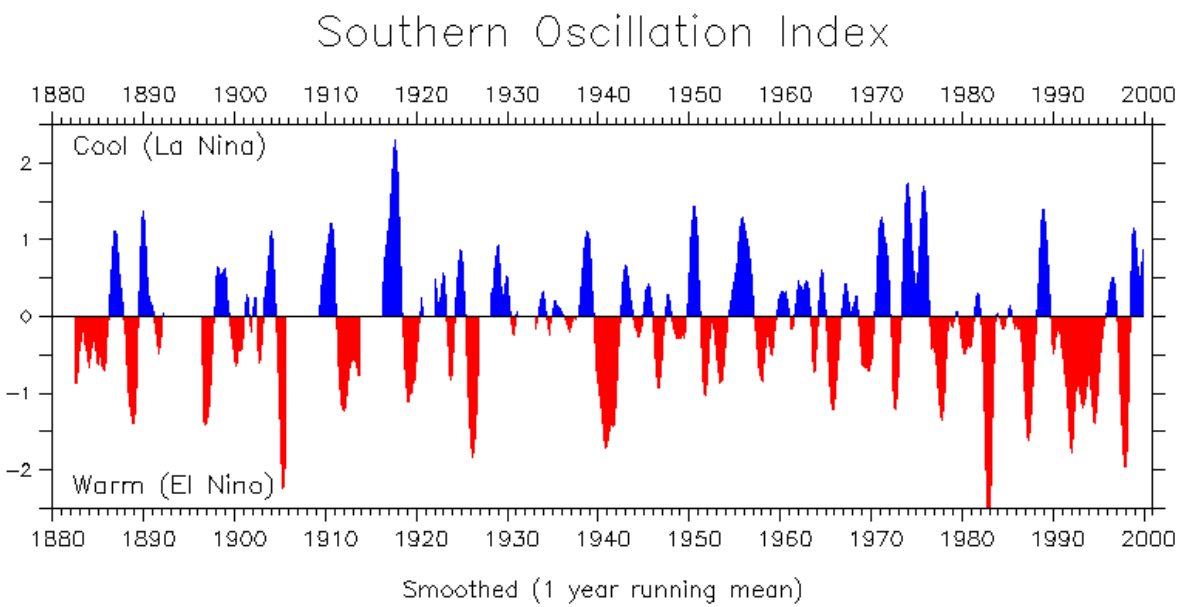
# A Coupled System . . .




- With deeper thermocline even if there is upwelling, colder water does not affect the SST
- With a shallow thermocline cold water comes up to the surface cold SSTs –> unable to sustain convection.
- So in a nutshell – we have low pressure at the western end, high pressure at the easter end

- We measure the strength of the Walker circulation by the difference in surface pressure anomalies between Tahiti and Darwin – called the Southern Oscillation Index (SOI)

# El-Nino, La-Nina & SOI



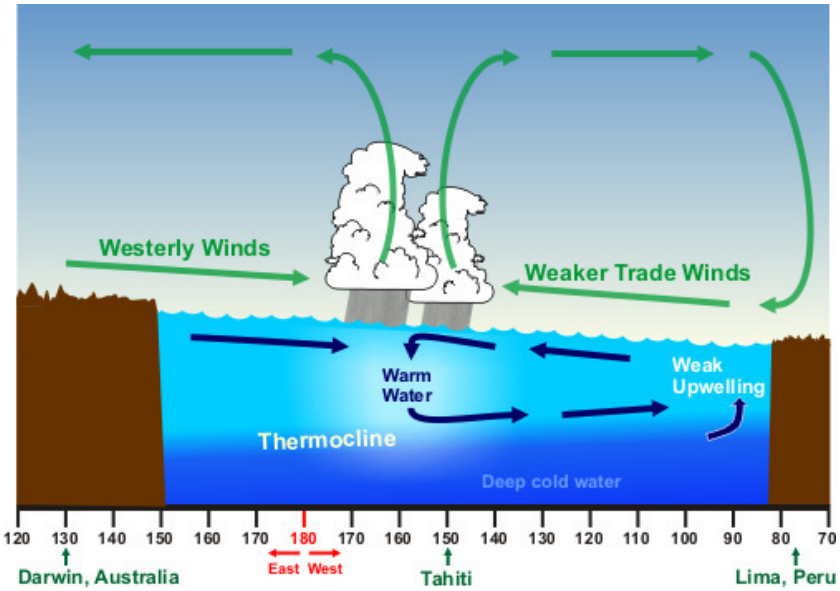

- We define SOI as:

$$SOI = 10\frac{P_{diff} - P_{diffav}}{\sigma_{Pdiff}}$$

- Here $P_{diff}$ is the difference in surface pressure between Tahiti and Darwin, $P_{diffav}$ is longterm average (for that month) of difference in pressure. $\sigma_{Pdiff}$ is the standard deviation of timeseries of pressure difference

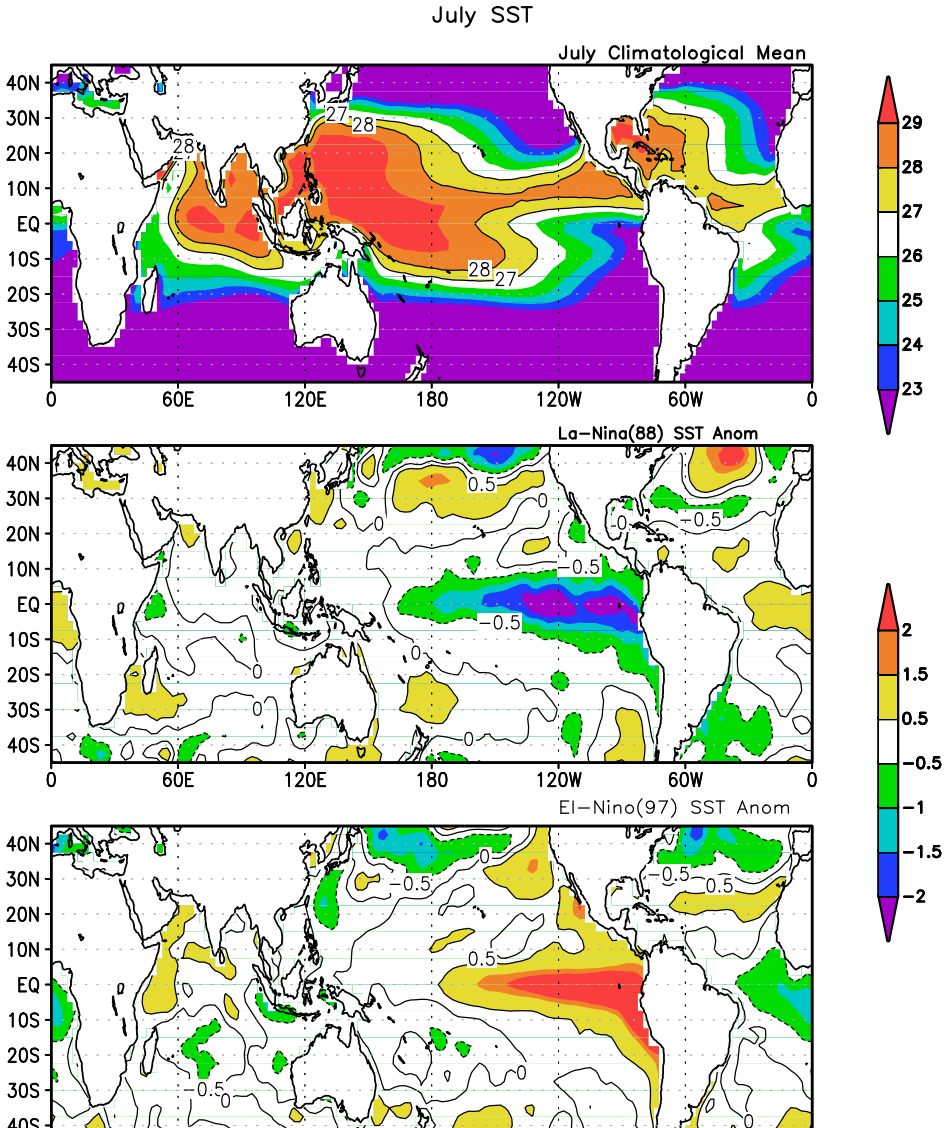
- Positive Values indicate strong Walker circulation. Negative values indicate weaker circulation
- We note that SOI is quasi-periodic
- Sometimes the Walker circulation is very strong and sometimes weak
- Negative SOI occurs with El-Nino, Positive with La-Nina.
- Why does the Walker Circulation weaken?

# EI-Nino



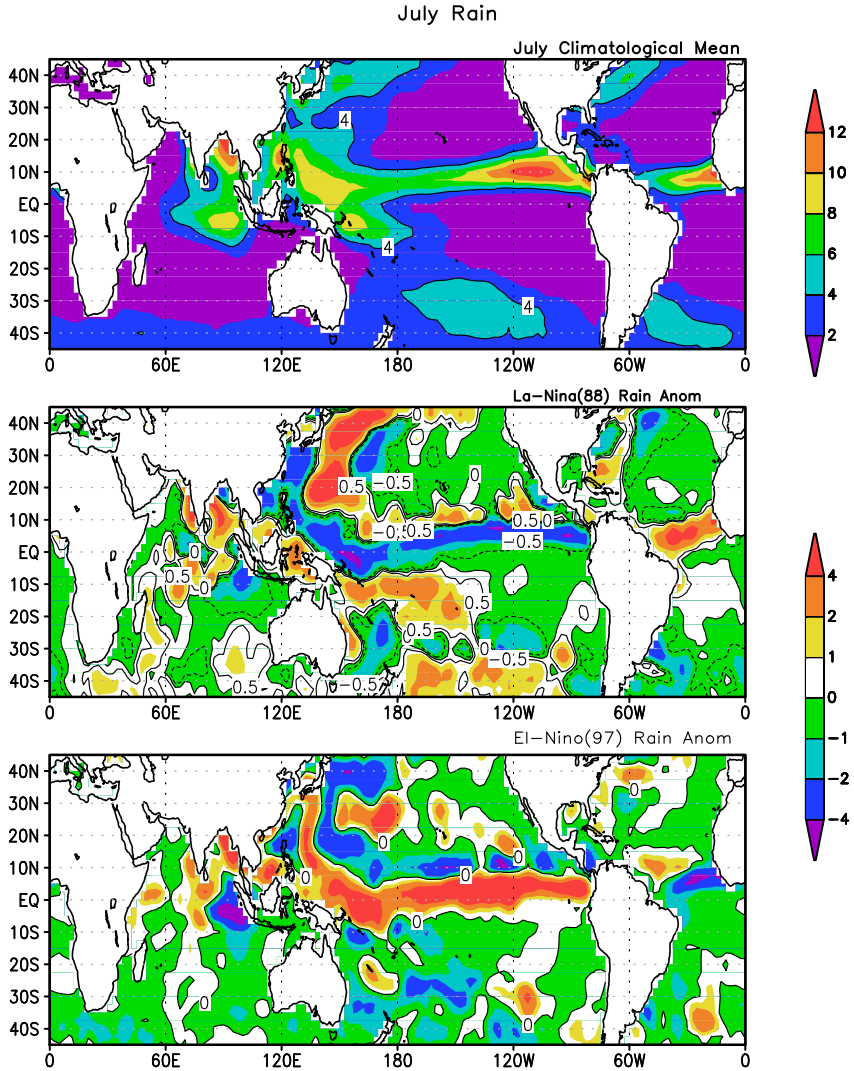

- In some years the easterly trades weaken
- Many theories about the cause of this: one of the more prevalent ones is about westerly wind bursts related to rainfall activity on intraseasonal scale
- The weakening of easterlies reduces upwelling and the thermocline deepens over Central and Eastern Pacific
- These two regions warm and can sustain convection

# SSTs during La-Nina and El-Nino



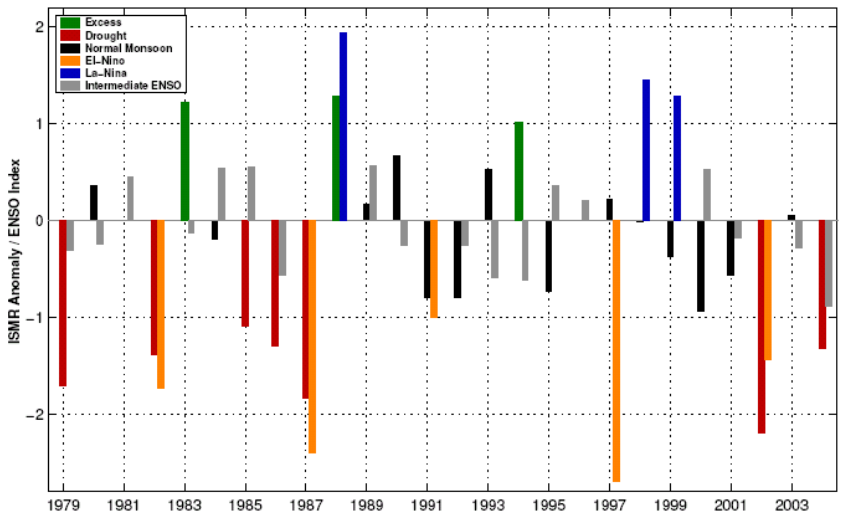

- Shown are SSTs for July 1997 (El-Nino), July 1988 (La-Nina) and climatological July
- We notice that SSTs in central and Pacific show large fluctuations
- How does this translate to rainfall?

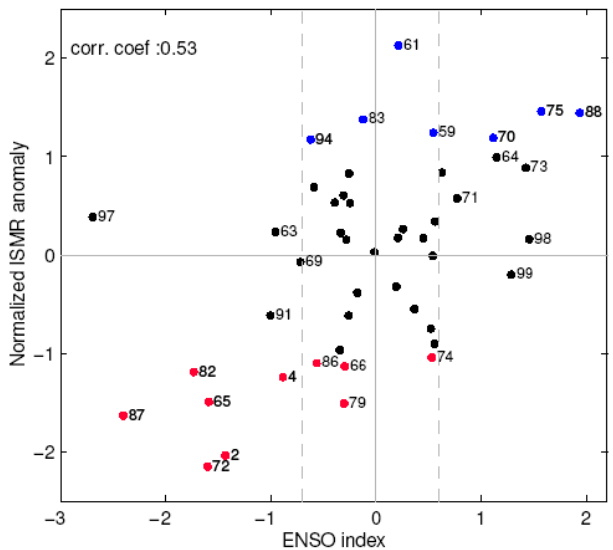
# Rainfall during La-Nina and El-Nino




- Shown are oceanic rainfall for July 1997 (El-Nino), July 1988 (La-Nina) and climatological July
- Rainfall over central and Eastern Pacific is higher during an El-Nino than during La-Nina

# EnSO-ISMR Relationship

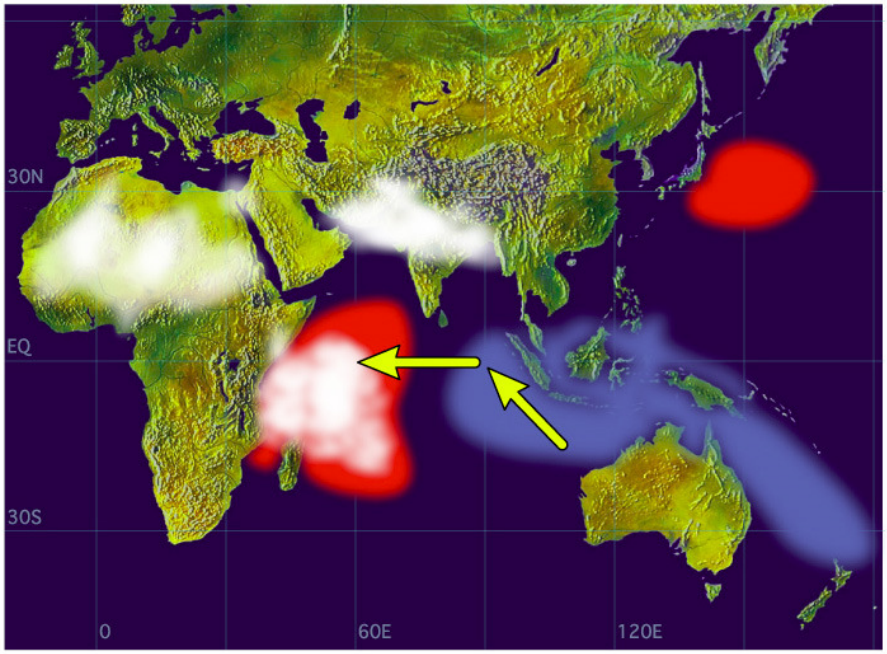


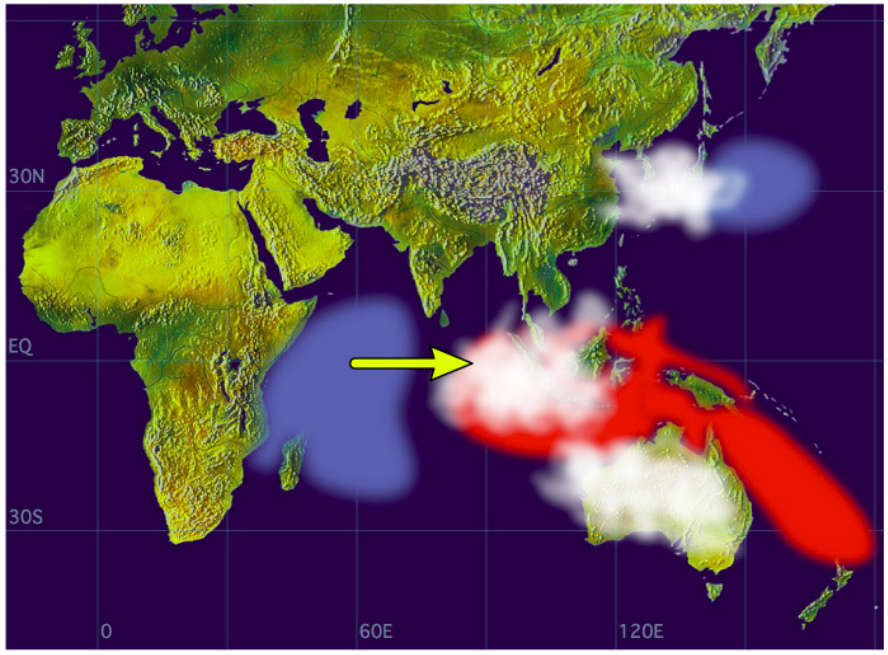

- EnSO itself does not explain all the droughts
- Is there any other player?

# EQUINOO & DIPOLE

Positive Dipole Mode

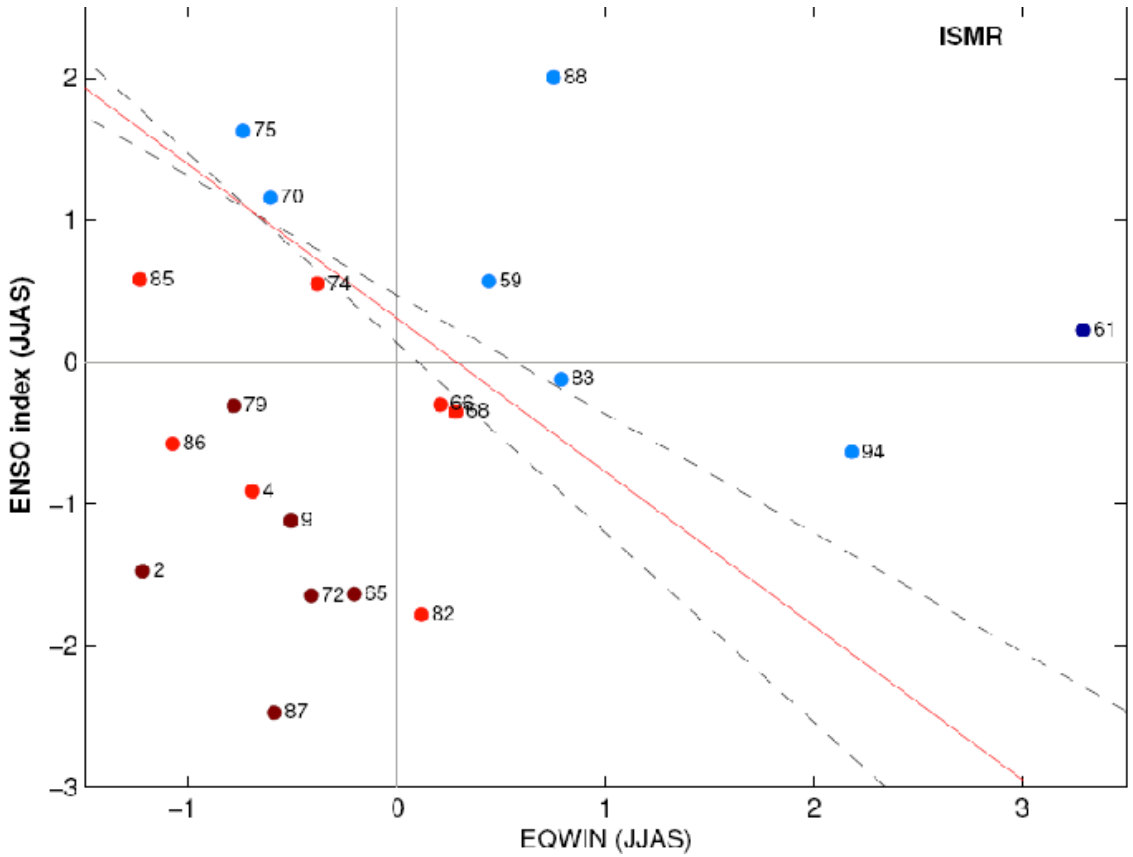



Negative Dipole Mode




- Convection over Indian Ocean oscillates between higher convection over Western part and Eastern Part (Equatorial Indian Ocean Oscillation - EQUINOO)
- A similar flip-flop occurs in the ocean – Indian Ocean Dipole
- Also a coupled event
- Positive EQUINOO favourable for good Indian Monsoon and vice-versa.

# Droughts EnSO & EQUINOO

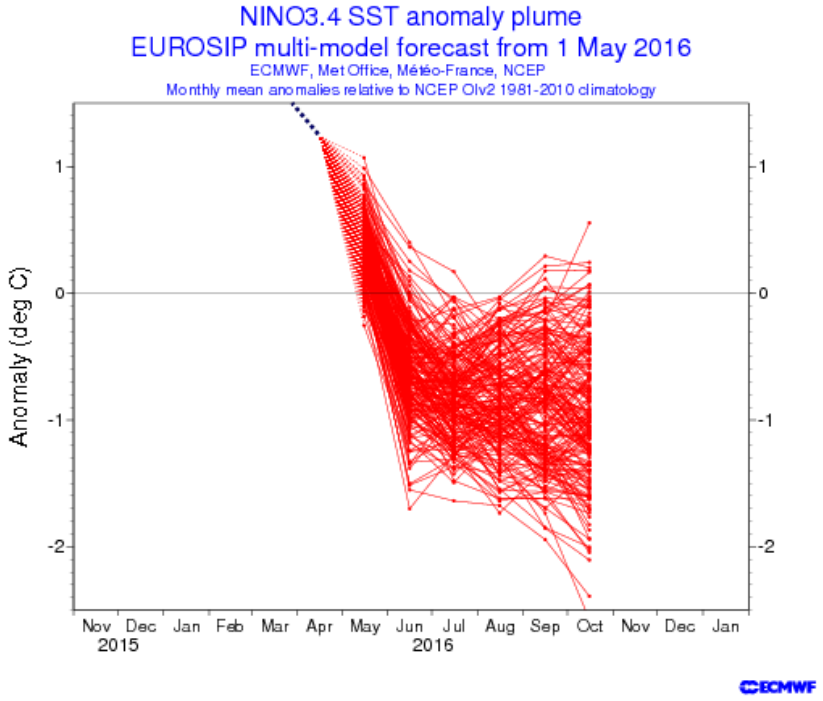



- Most of the extreme events of Monsoons can be explained due to either occurrence of an EnSO event or an EQUINOO event.
- Extreme droughts have occurred when both EnSO and EQUINOO were unfavourable – 2002
- 1997 when EnSO was unfavourable but EQUINOO favourable rainfall was near normal
- 1994 when EnSO was near normal and EQUINOO favourable rainfall was excess
- Exact Mechanism of the linkages is a topic of research

# IMD's Seasonal Forecast for 2016

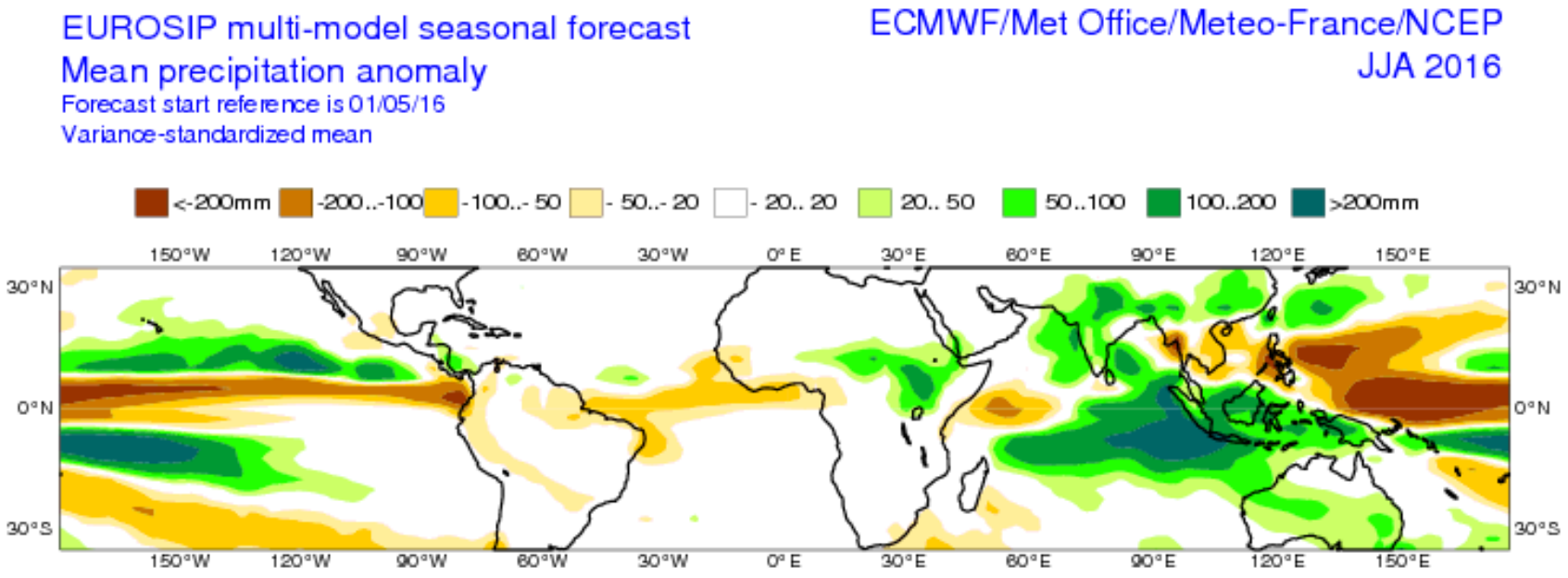
| Category | Rainfall Range (% of LPA) | Forecast Probability (%) | Climatological Probability (%) |
|---|---|---|---|
| Deficient | < 90 | **1** | 16 |
| Below Normal | 90 - 96 | **5** | 17 |
| Normal | 96 -104 | **30** | 33 |
| Above Normal | 104 -110 | **34** | 16 |
| Excess | > 110 | **30** | 17 |

# El-Nino Forecast



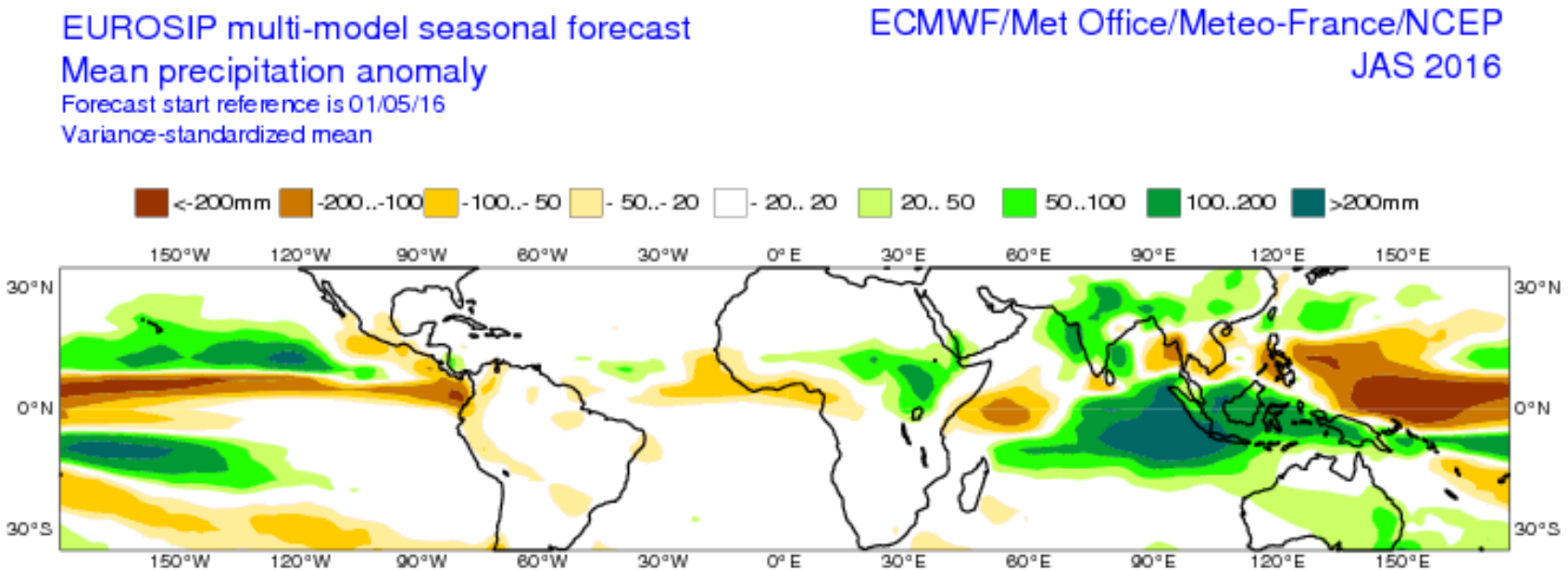

- Shows forecast of SST over mid-equatorial Pacific (Nino3.4) region
- Most likely to move into La-Nina mode
- La-Nina generally good for monsoon

# Rainfall Forecast for JJA



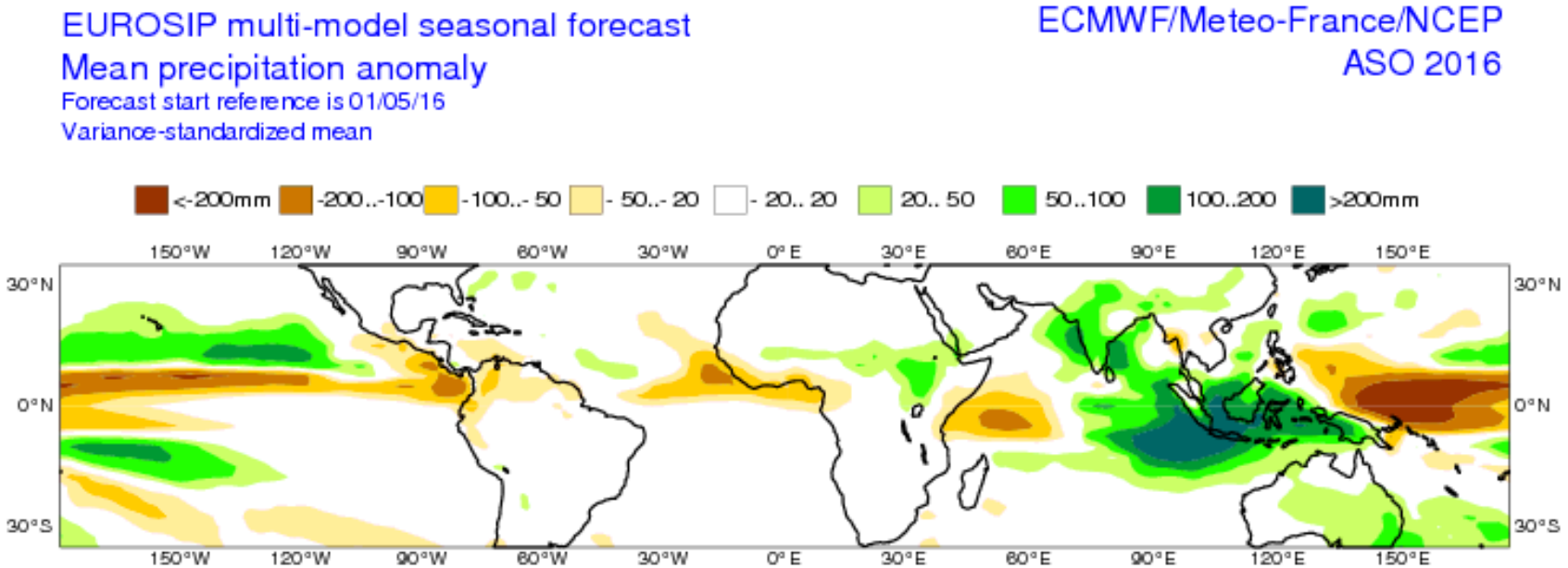

- Near Normal Rainfall for June July August

# Rainfall Forecast JAS




- Good Rainfall over Indian region during July August September

# Forecast for Aug-Sep-Oct



# Summary

- Indian Monsoon is part of the global climate system – manifestation of ITCZ over the Indian region
- Shows significant fluctuation within a season – active & break spells
- Also northward propagation of cloud bands – unique to this region
- Monsoon also shows year-to-year fluctuation
- El-Nino and Indian Ocean can influence the Indian monsoon rainfall
- Monsoon of 2016 should be good

# Further Suggested Reading

Some useful articles/books


- Sulochana Gadgil, 2003: Monsoons and Its Variability. Annual Reviews in Earth and Planetary Science, **31**, 429-467.
- Y P Rao: Monsoons. A Monograph available from IMD website www.imd.gov.in