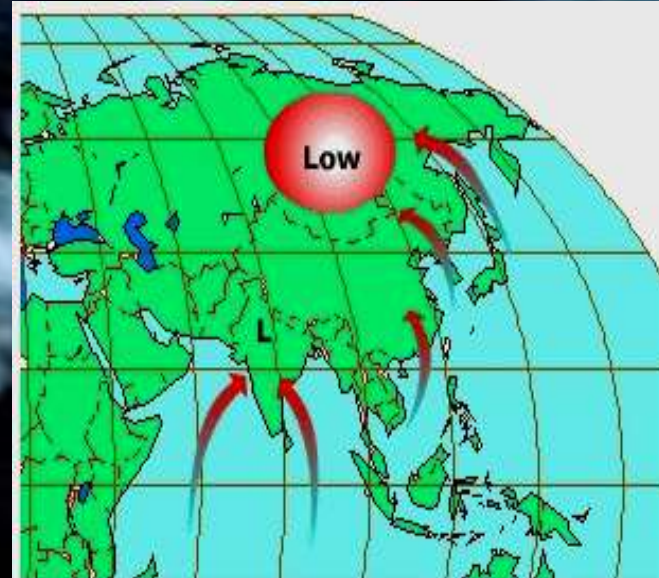
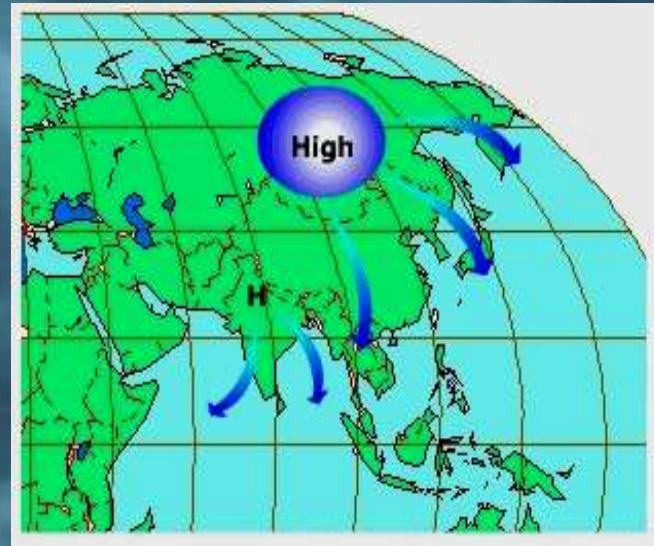




# Indian Monsoon

DR.K.K.MISHRA

- India's climate is dominated by monsoons.
- Monsoons are strong, often violent winds that change direction with the season.
- The term technically describes seasonal reversals of wind direction caused by temperature differences between the land and sea breeze, creating zones of high and low pressure over land in different seasons.



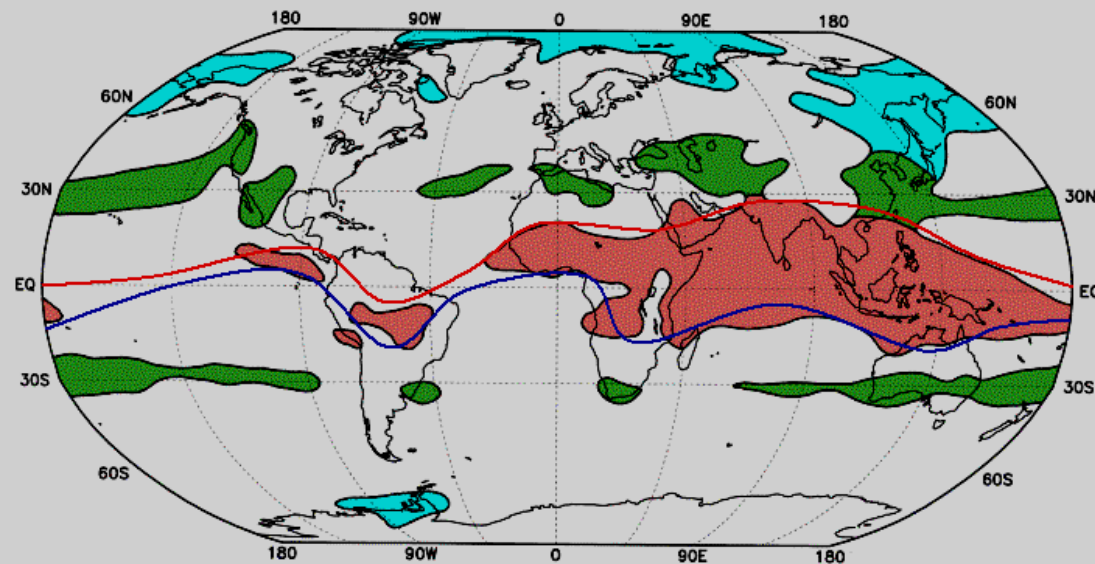


Monsoons occur due to changes in atmospheric pressure which are caused by different rates of heating and cooling of continents and oceans.

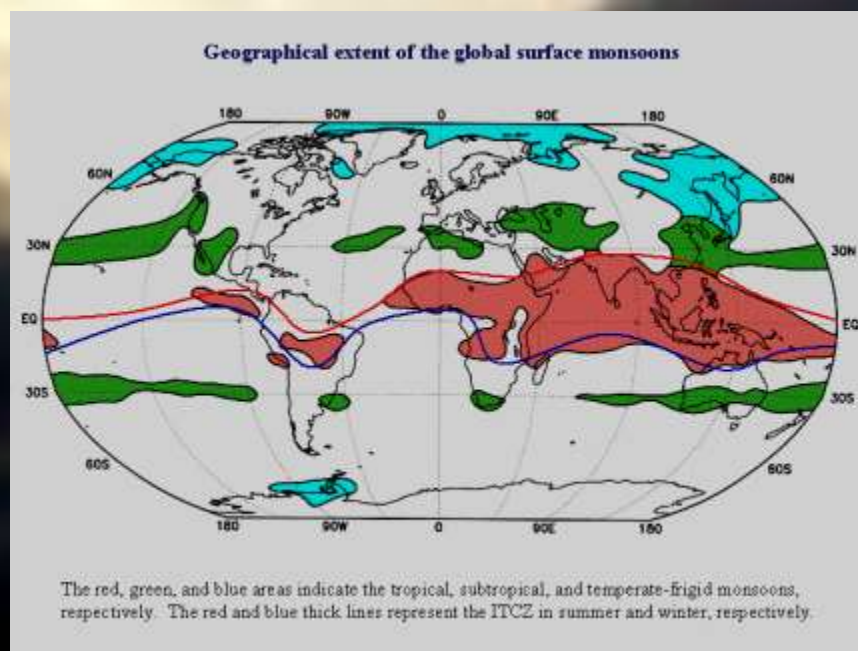
Monsoons occur every year in many countries around the world other than South Asia - northern Australia, Africa, South America and the US are also affected.

The geographical extent of the global surface monsoons (the figure below) can be outlined by the normalized seasonality

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.



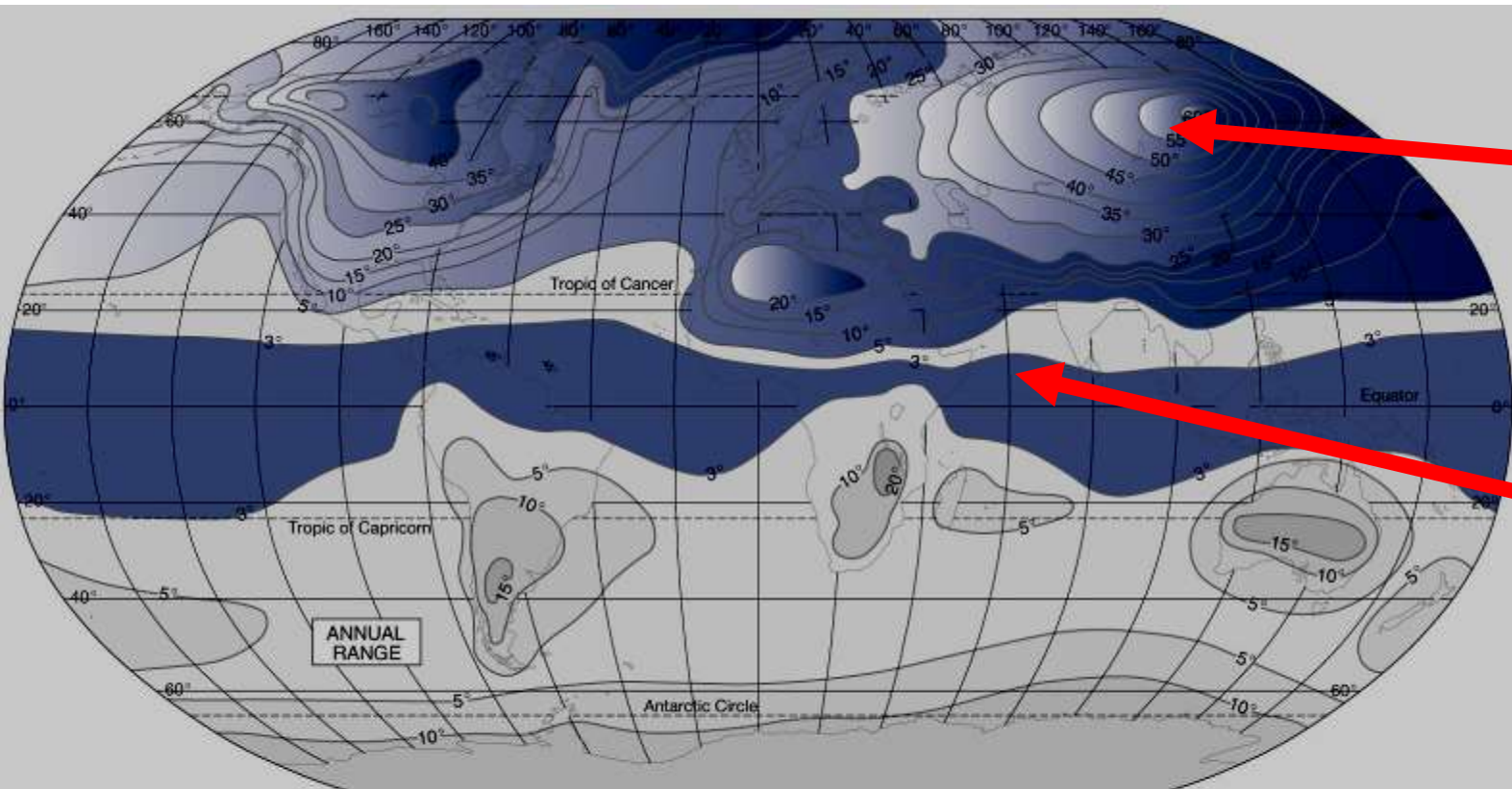
**The global surface monsoons contains three kinds of monsoons: the tropical, subtropical, and temperate-frigid monsoons, respectively.**

**The extent of the classical tropical monsoons is surrounded by the positions of the Inter Tropical Convergence Zone (ITCZ) in summer and winter, which is the result of the two driving forcings of the tropical monsoon, the seasonal variation of the planetary thermal convection and the seasonal variation of the semi-permanent planetary waves due to the thermal contrast between ocean and continent. (Li and Zeng, 2000, 2003, 2005).**



# Surface temperature range that results in the monsoon

Sea surface temperature variations are much smaller than land surface temperature variations. (Mainly the seasonal cycle)



Tibetan plateau

Ocean:  
range of  
3 to 5°C



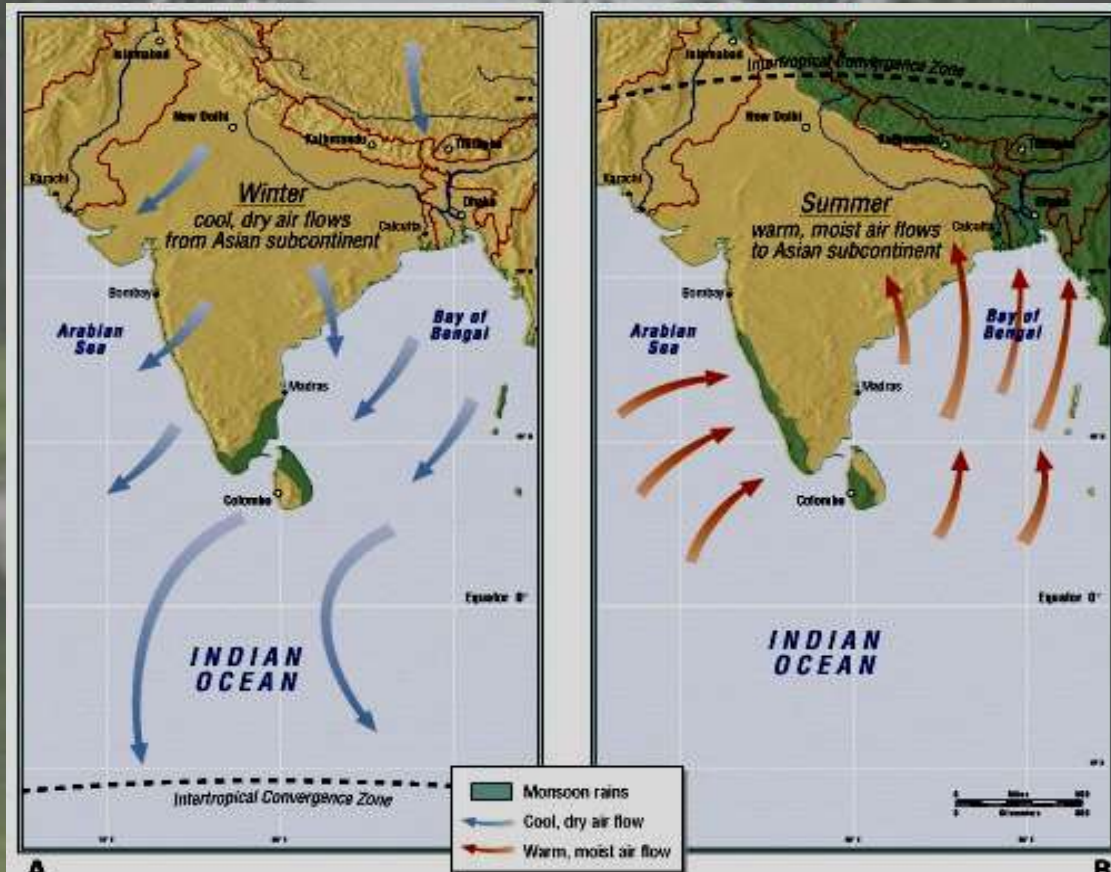
F°	5	9	18	27	36	45	54	63	72	81	90	99	108	F°
C°	3	5	10	15	20	25	30	35	40	45	50	55	60	C°

(c)

Monsoon is a term derived from the Arabic word "*Mausim*", meaning season. It was first used by Arabic navigators to describe the seasonal winds of the Arabian Sea.

These winds blow from the north-east for one half of the year and from the south-west for the other half.

Monsoon winds blow from cold to warm regions because cold air takes up more space than warm air



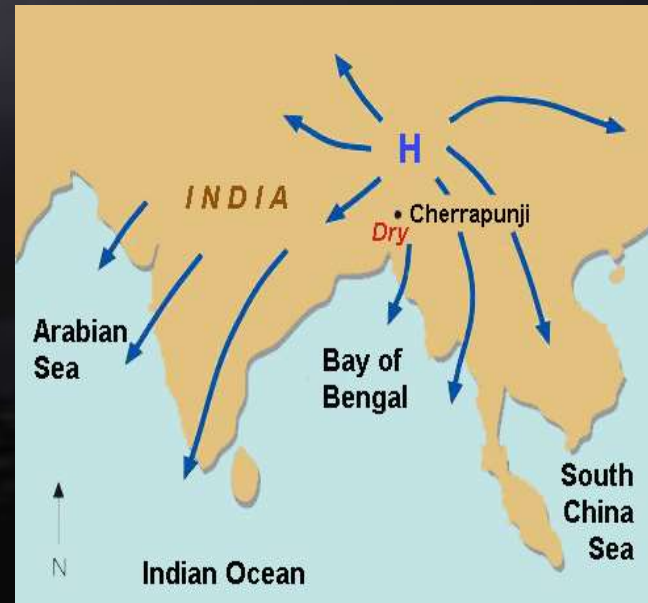
❖ Being a tropical monsoon country there are two monsoon seasons.

❖ **The South -West (summer)** monsoon has warm winds blowing from Indian Ocean. Its span is June to September, with 75 % of the annual rainfall in India. It varies from 10 cm in western Rajasthan to over 900 cm in Meghalaya.

❖ **North- East (winter) monsoon** is characterized by a dry continental air mass blowing from the vast Siberian high pressure area from December to March. The rainfall includes snowfall during winter monsoon which is of the order of 1000 km<sup>2</sup> in India. This is also known as Retreating monsoon.



**Summer monsoon**



**Winter monsoon**



- The mountains of southern India split the summer winds. The western arm of the monsoon is deflected northwards, by the western Ghats, to Mumbai and then on to Pakistan.
- The eastern arm travels up through the Bay of Bengal to Kolkata and Assam, and is deflected north-westwards by the Himalayas.
- On average, the winds arrive in southern India about six weeks before they arrive in north-west India.

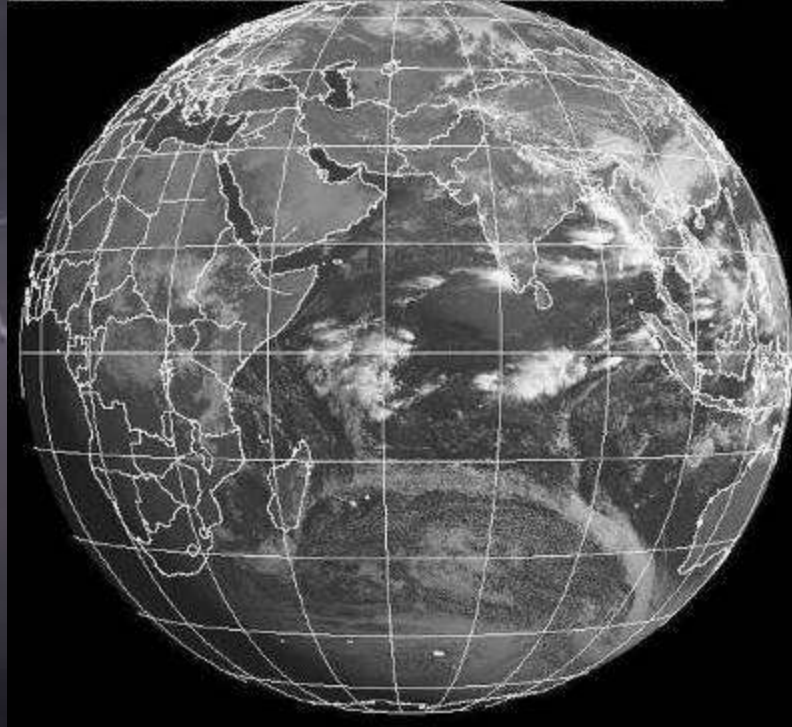




➤ Thar desert and adjoining areas of the northern and central Indian Subcontinent heats up too much during summer. This causes a low pressure area over the northern and central Indian subcontinent. To fill up this void, the moisture-laden winds from the Indian Ocean rush in to the subcontinent.

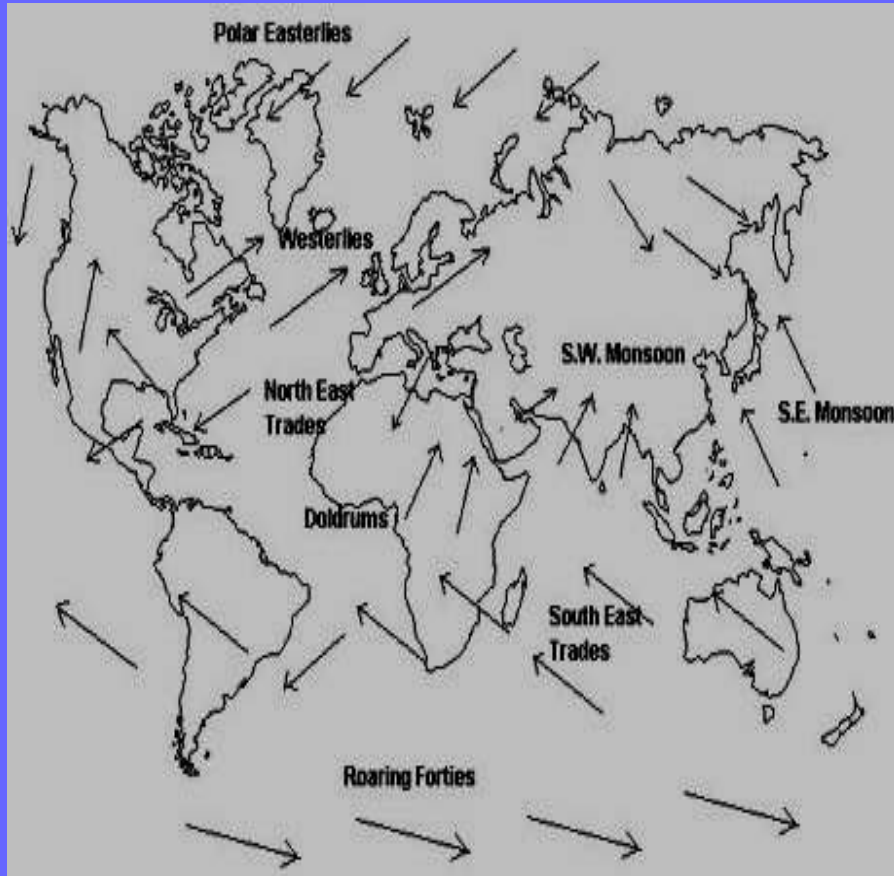
➤ These winds, rich in moisture, are drawn towards the Himalayas, creating winds blowing storm clouds towards the subcontinent. The southwest monsoon is generally expected to begin around the middle of June and dies down by September.

METEO-5 VIS 06/21/2001 0600Z Naval Research Laboratory

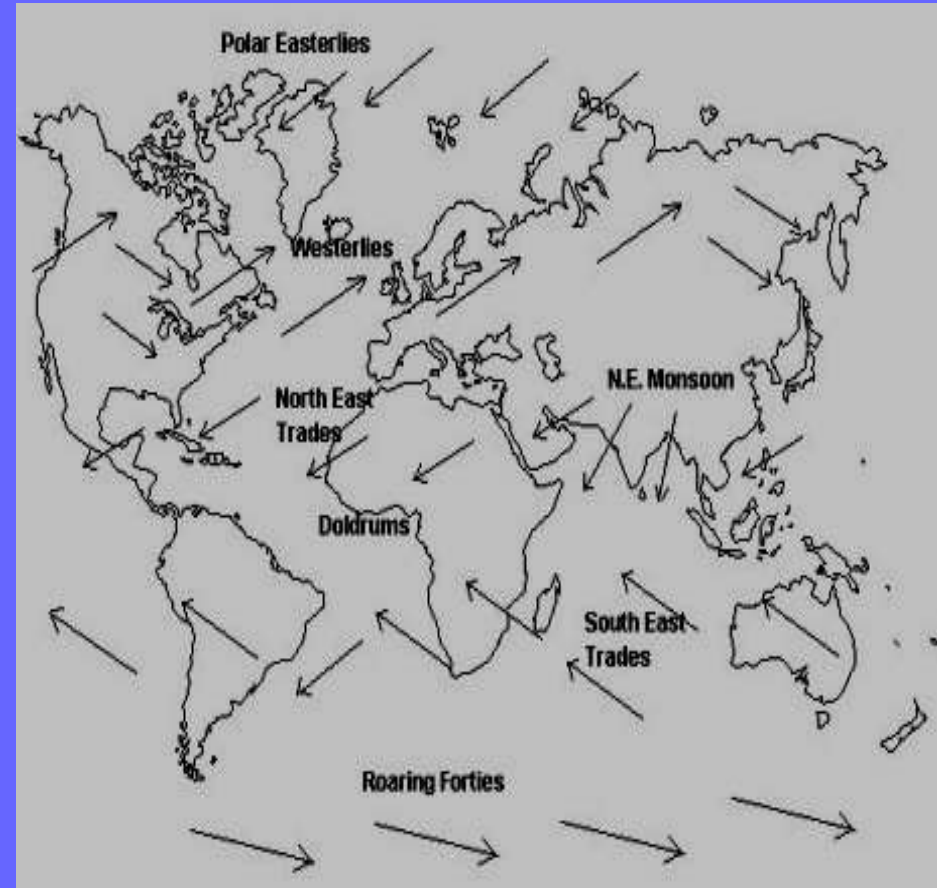


a fully illuminated view of the Indian Ocean region shortly after the onset of the SW Monsoon.

# Indian ocean winds - monsoon



June-August (SW monsoon)



December-March (NE monsoon)

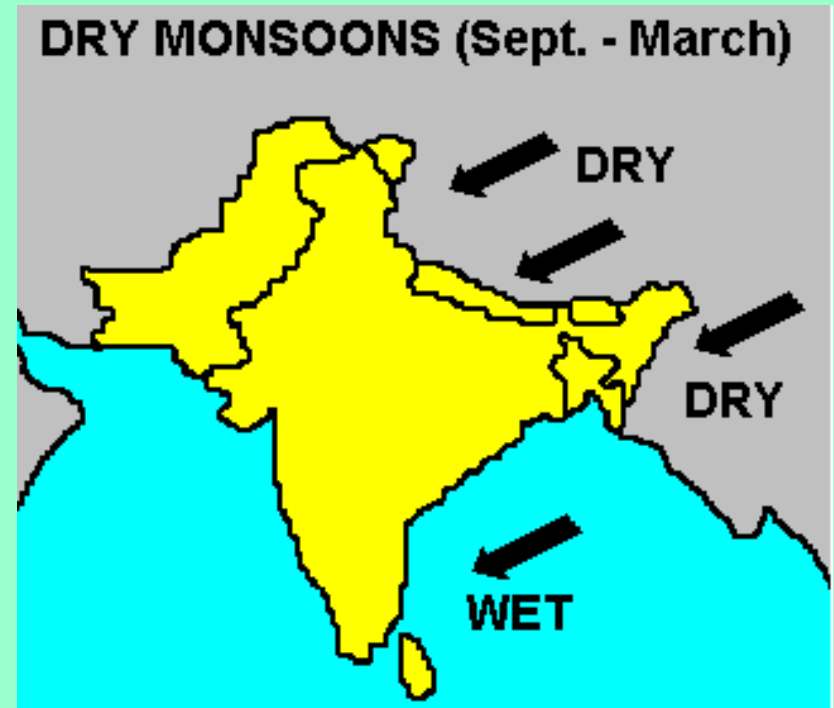


# Onset of South West Monsoon



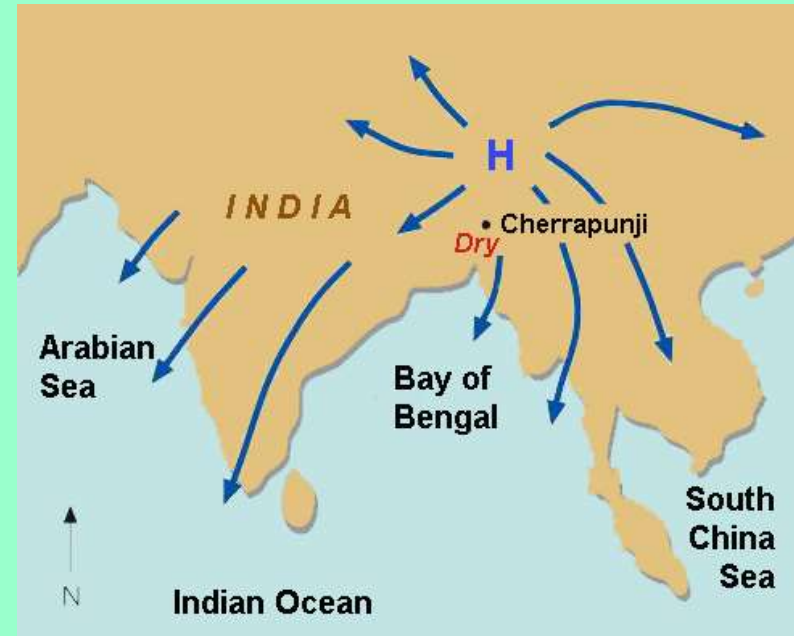
## Retreating Monsoons ( North East Monsoon )

- Much of India experiences infrequent and relatively feeble precipitation during the retreating monsoon.
- An exception to this rule occurs along the southeastern coast of India and for some distance inland.
- When the retreating monsoon blows from the northeast across the Bay of Bengal, it picks up a significant amount of moisture, which is subsequently released after moving back onto the peninsula.
- .





- Thus, from October to December the coast of Tamil Nadu state receives at least half of its roughly 1,000 mm of annual precipitation
- This rainy extension of the generally dry retreating monsoon is called the northeast, or winter, monsoon.
- Another type of winter precipitation occurs in northern India, which receives weak cyclonic storms originating in the Mediterranean basin.
- In the Himalayas these storms bring weeks of drizzling rain and cloudiness and are followed by waves of cold temperatures and snowfall. The state of Jammu and Kashmir in particular receives much of its precipitation from these storms.



Retreating Monsoon

- **The heaviest monsoon rainfalls occur where the winds blow side-on to the hills. The higher the hills and more moist the air, then the greater the amount of rainfall.**
- **These factors give Cherrapunji, in Assam, one of the highest rainfalls in the world. On average, Cherrapunji has an annual rainfall total of nearly 11 metres, the maximum monthly amount occurring in June.**
- **Mumbai receives about 1.8 metres with the maximum monthly total in July.**
- **In comparison, Delhi registers only 64 cm of rainfall each year with the maximum monthly total occurring in both July and August.**
- **At Chennai the pattern of rainfall is different because the monsoon winds blow along the coast. Here, the rainfall increases gradually through the summer months with larger amounts falling in October and November, owing to tropical cyclones traveling westwards across the Bay of Bengal.**



- The torrential rainstorms often cause violent landslides and widespread floods. Entire villages have been swept away during monsoon rains. Despite the potential for destruction, the summer monsoons are welcomed in India.
- Farmers depend on the rains to irrigate their land.
- Additionally, a great deal of India's electricity is generated by water power provided by the monsoon rains.



- The monsoon delivers most of India's rainfall and has a key impact on the economy. Only a third of India's crops grow on irrigated land and a weak monsoon can wipe out many incomes and shrink demand for farm equipment and consumer goods.
- Monsoon rainfalls are unreliable in that the amount varies considerably from year to year. Low rainfalls cause great problems for agriculture and water supplies in general.
- In the Indus river the flood problem is often made worse because the monsoon rainfalls can coincide with high river levels in its tributaries, caused by water from the melting mountain snows of the Himalayas





## **Interannual variations of Indian summer monsoon**

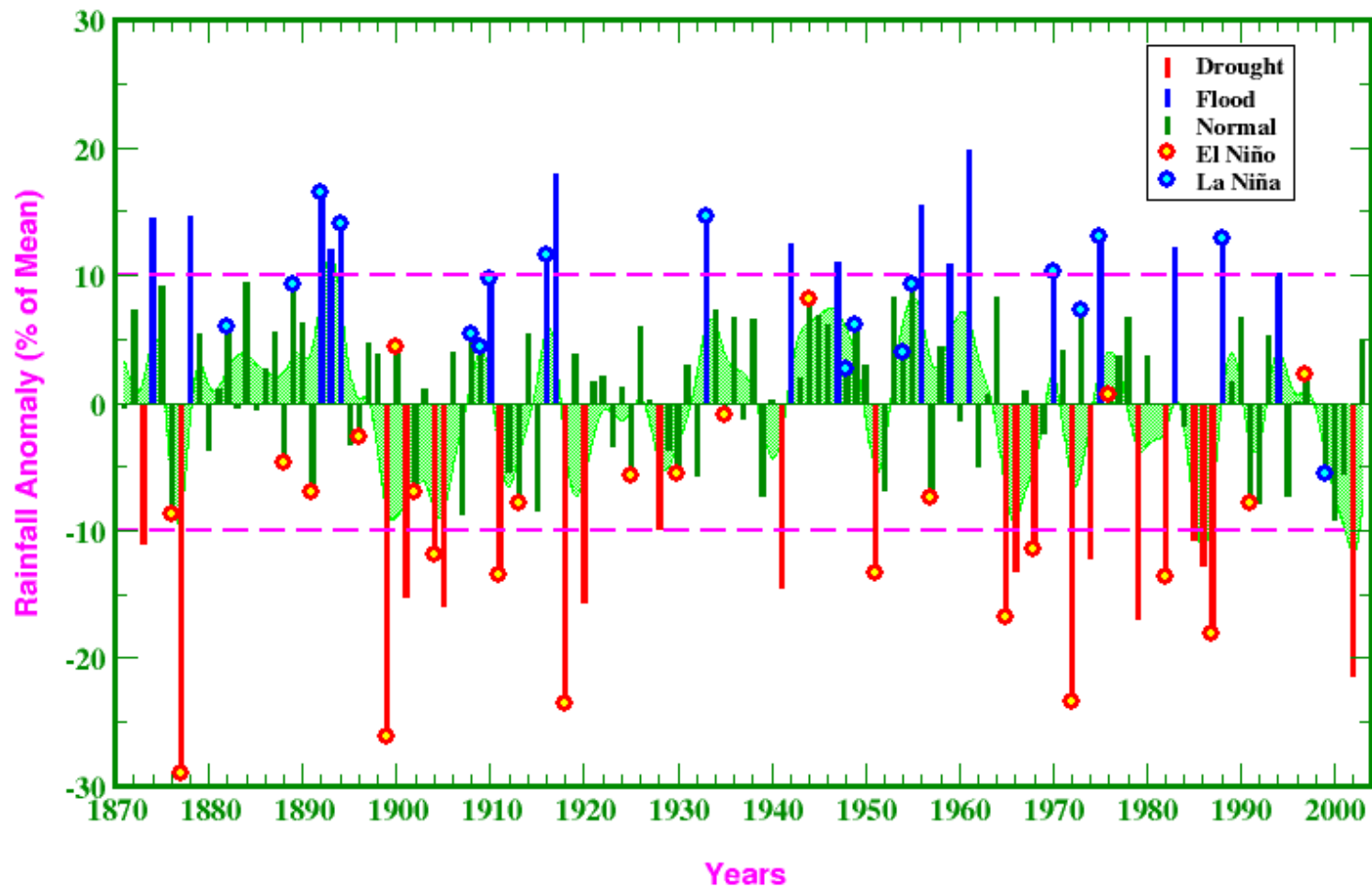
- The rainfall during the Indian summer monsoon season (June, July, August and September) show considerable inter-annual and interseasonal variability.
- Over any part of India, Some years a lot of rainfall occurs causing flood, while some other years rainfall amount received is much less causing drought like situations. This year to year variation of rainfall over a region during monsoon seasons is termed as Interannual variability of monsoon rainfall.
- This inter-annual variability in the summer monsoon rainfall has a profound effect on the socioeconomic well being of India. Hence, the ability to forecast such events became the focus of various meteorological studies.

# Monsoon Rainfall Variability

## All-India mean Rainfall

### All-India Summer Monsoon Rainfall, 1871-2003

(Based on IITM Homogeneous Indian Monthly Rainfall Data Set)



# Predictability of the Indian Monsoon Rainfall

- Short range (1-2 days in advance) and medium (3-10 days in advance) predictions of rainfall over any region including that over the Indian region during the monsoon season depend on how well the initial state of the atmosphere has been defined with large number of very good quality observed data and the quality dynamic model used for predictions. The better the initial data, better is the forecast.
- In the tropical region, it is believed that the predictability of day-to-day weather patterns is restricted to 3-4 days.
- Observational studies show that the Indian Monsoon's seasonal rainfall is linked with several surface boundary conditions like sea surface temperature (SST) of the east Pacific, Indian ocean, land surface temperature, Eurasian and Himalayan snow cover etc.



# Prediction of Indian summer monsoon

**Since 1988, the Indian Meteorological Department has been issuing forecast based on 16-parameter power regression and parametric models.**

## **List of 16 parameters**

- El Nino (same year) (Nino 1 + 2)
- El Nino (previous year) (Nino 1 + 2)
- South Indian Ocean SST (Feb. + March)
- East Coast India temperature (March)
- Arabian Sea SST (Nov. + Dec. + Jan.)
- Central India temperature (May)
- N H Temperature (Jan. + Feb.)
- Darwin pressure tendency (April–Jan)
- N H Pressure (Jan. to April)
- Southern Oscillation Index (Mar to May)
- Indian Ocean Equatorial Pressure (Jan to May)
- Europe Pressure Gradient (January)
- Argentina pressure (April)
- 50 hPa East–West Ridge Extension (Jan. + Feb.)
- Himalayan Snow Cover (Jan. to Mar.)
- Eurasian Snow Cover (Dec.)

# Methods of Predicting Indian Monsoon Rainfall

- IMD utilizes statistical method for making seasonal predication of the Indian monsoon rainfall.
- Studies of historical data sets, over the years, have brought out several predictors for the monsoon rainfall forecasting.
- The most commonly used statistical technique for seasonal predication is the linear regression analysis.
- IMD has also started using dynamic model forecasts for proving southwest monsoon rainfall.

# The Hadley Circulation

- The Hadley circulation spans half of the surface area of the globe, and variability within this system affects the lives of billions of people.
- Our understanding of this variability is limited to the last century of instrumental measurements, to the even shorter record of satellite-derived observations, or to associated modeling studies aimed at simulating variability in the tropics associated with the Hadley circulation.
- Only by bringing together climatologists and paleoclimatologists on the current understanding of the Hadley circulation, by examining paleoclimatic records that provide evidence of past variability in this system, and model simulations of expected future changes, a proper prediction on monsoons can be made.

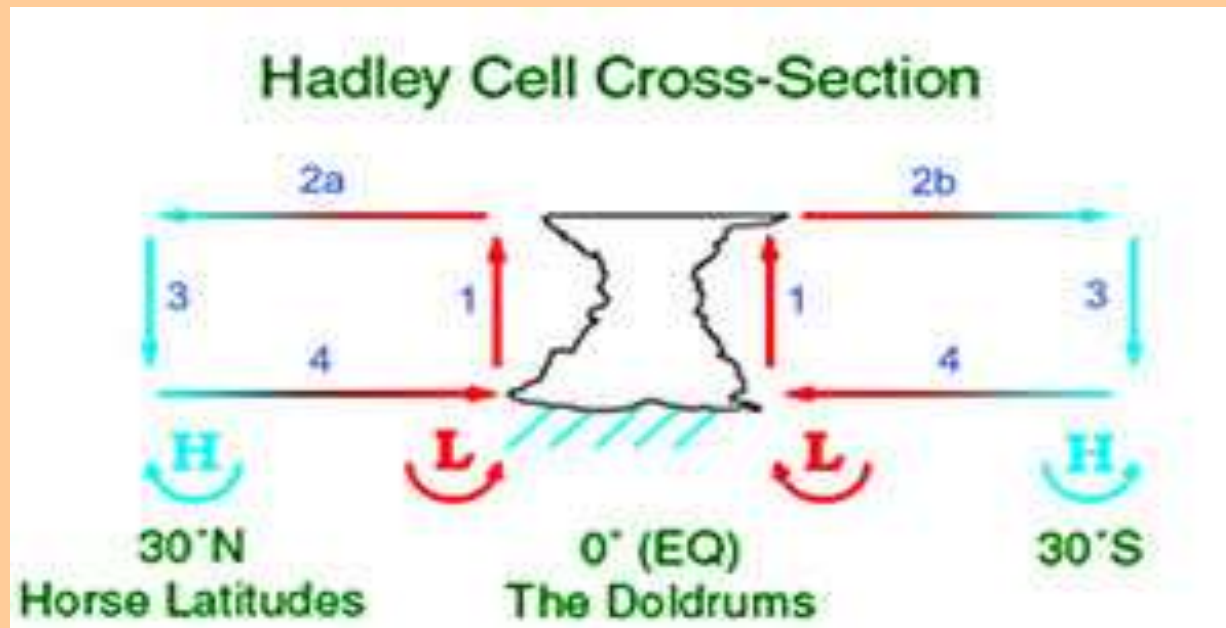




# Monsoon Circulation

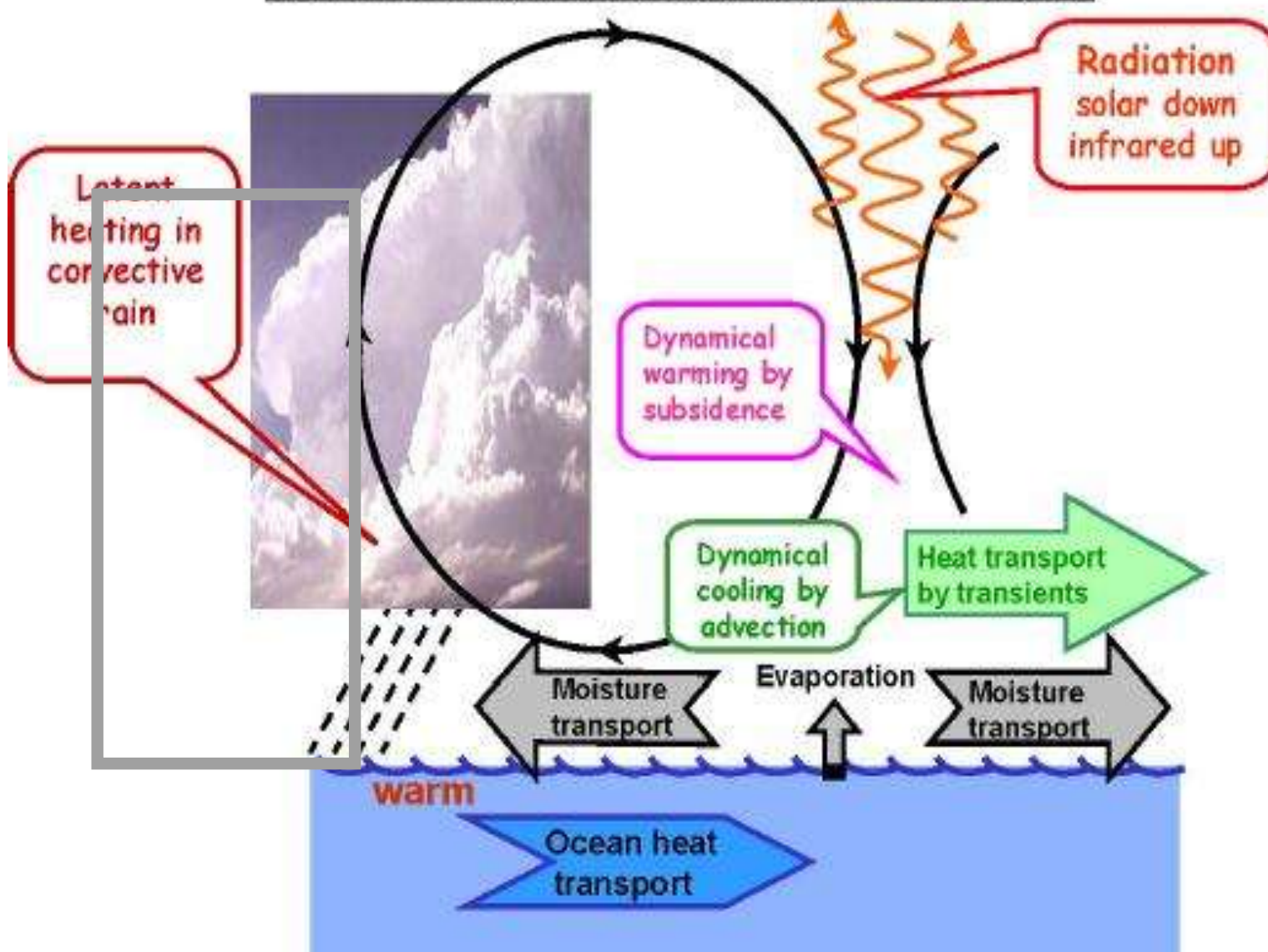
## Hadley cell

The Hadley cell is a circulation pattern that dominates the tropical atmosphere, with rising motion near the equator, pole ward flow 10-15 kilometers above the surface, descending motion in the subtropics, and equator ward flow near the surface. This circulation is intimately related to the trade winds, tropical rain belts, subtropical deserts and the jet streams.



The Hadley cell carries heat and moisture from the tropics to the northern and southern mid-latitudes

## Hadley circulation and heat budget in subtropics



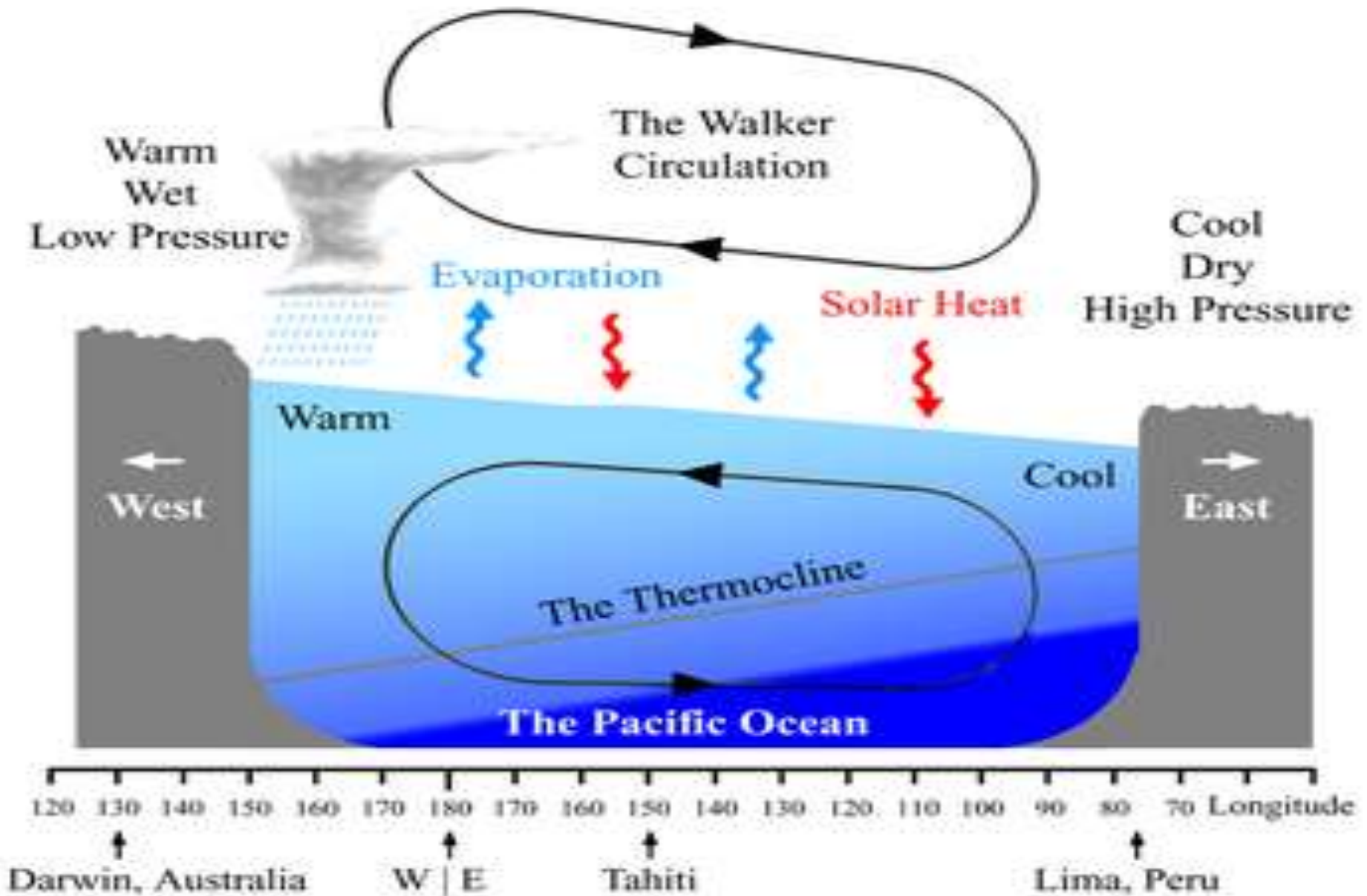
**During Monsoon season, rising limb of Hadley cell is over the Indian continent and the sinking limb is over the equatorial Indian ocean.**

**Therefore the monsoons circulation is opposite to conventional Hadley circulation.**

## Walker circulation

- The **Walker circulation** is an atmospheric circulation of air at the equatorial Pacific Ocean, responsible for creating ocean upwelling off the coasts of Peru and Ecuador.
- This brings nutrient-rich cold water to the surface, increasing fishing stocks. It was discovered by Jacob Bjerknes in 1969 and was named after the English physicist Sir Gilbert Walker who discovered the Southern Oscillation .
- The Walker circulation is caused by the pressure gradient force that results from a high pressure system over the eastern pacific ocean, and a low pressure system over Indonesia.





*It is seen at the surface as easterly trade winds which move water and air warmed by the sun towards the west.*

## **HADLEY circulation is intimately related to the trade winds, tropical rain belts, subtropical deserts and the jet streams.**

- ❖ The **trade winds** are a pattern of wind that are found in bands around the Earth's equatorial region. The trade winds are the prevailing winds in the tropics, blowing from the high-pressure area in the horse latitudes towards the low-pressure area around the equator. The trade winds blow predominantly from the northeast in the northern hemisphere and from the southeast in the southern hemisphere.
- ❖ **Jet streams** are fast flowing, relatively narrow air currents found in the atmosphere at around 11 kilometres (36,000 ft) above the surface of the Earth, just under the tropopause. They form at the boundaries of adjacent air masses with significant differences in temperature, such as of the polar region and the warmer air to the south. The jet stream is mainly found in the Stratosphere.

## **El Niño and La Niña relation to Indian Monsoons**

El Niño and La Niña are defined as sustained sea surface temperature anomalies of magnitude greater than  $0.5^{\circ}\text{C}$  across the central tropical Pacific Ocean.

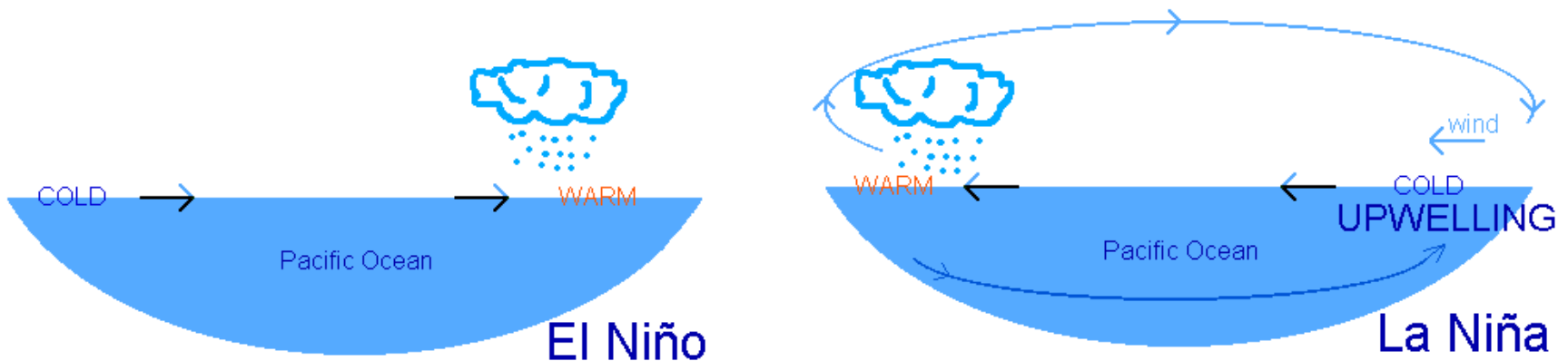
When the condition is met for a period of less than five months, it is classified as El Niño or La Niña conditions; if the anomaly persists for five months or longer, it is classified as an El Niño or La Niña episode. Historically, it has occurred at irregular intervals of 2-7 years and has usually lasted one or two years.

The first signs of an El Niño are:

- ✓ Rise in air pressure over the Indian Ocean, Indonesia, and Australia
- ✓ Fall in air pressure over Tahiti and the rest of the central and eastern Pacific Ocean
- ✓ Trade winds in the south Pacific weaken or head east



- ✓ Warm air rises near Peru, causing rain in the deserts there
- ✓ Warm water spreads from the west Pacific and the Indian Ocean to the east Pacific. It takes the rain with it, causing rainfall in normally dry areas and extensive drought in eastern areas.



- ✓ For India a continuous and homogeneous record is available since 1871.
- ✓ Monsoon rainfall is increasing (+10 to +12 % per century) along the west coast, north Andhra Pradesh and in northwest India. It is decreasing (-6 to -8% per century) over east Madhya Pradesh and adjoining areas, northeast India and parts of Gujarat and Kerala.
- ✓ A weak monsoon, is a result of a large negative Southern Oscillation Index (SOI) and El Nino event.
- ✓ A strong monsoon, is a result of a large positive SOI and the absence of El Nino event.
- ✓ During the period 1871—1999, 11 of 21 drought years were El Nino years.
- ✓ The periods 1895-1932 and 1965-1987 were characterized by frequent droughts.
- ✓ The periods 1872-1894 and 1933-1964 were practically drought free

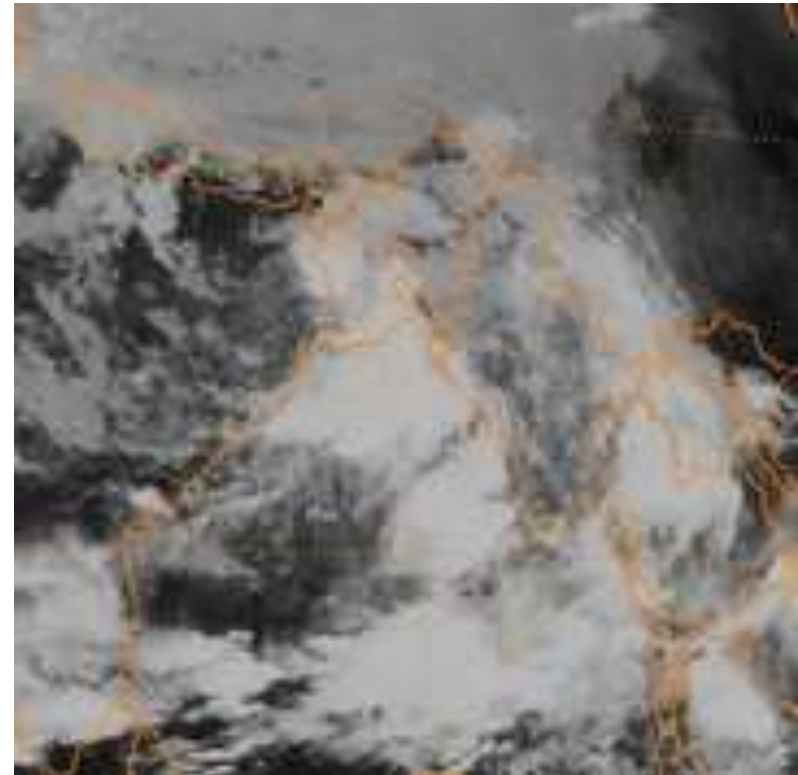
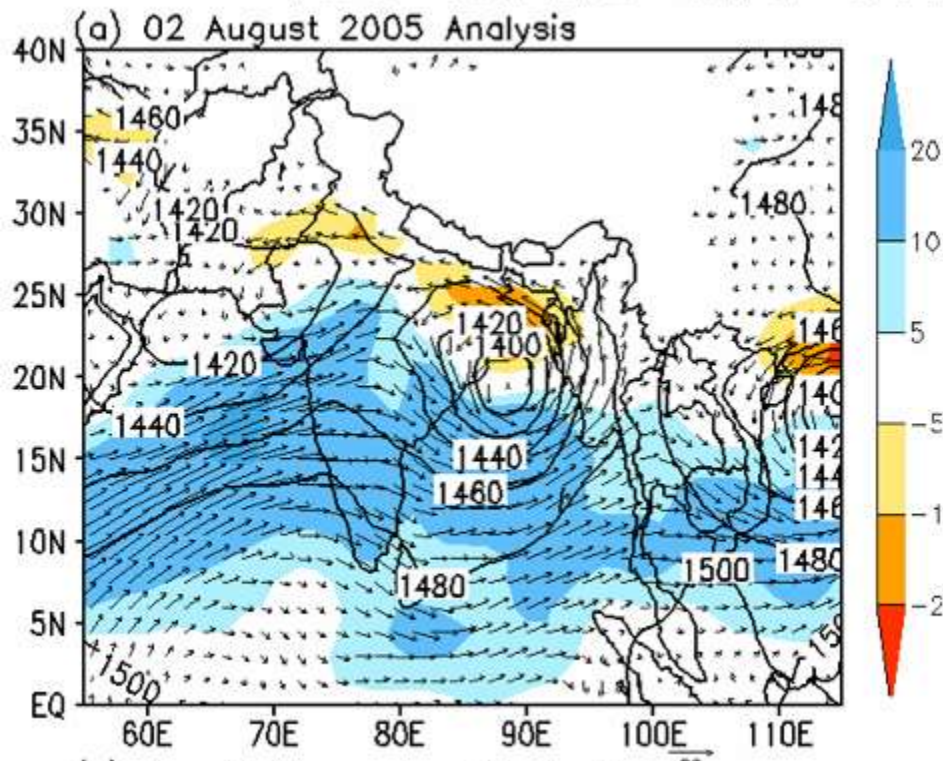
## Relationship of EQUINO and ENSO over Indian Monsoon

- Comparison of the evolution of the normal summer monsoon of 2003 with the unanticipated drought of 2002 led to this investigation of the role of the deep convection in the atmosphere (deep cloud systems) over the equatorial Indian Ocean.
- The link of the Indian monsoon to events over the equatorial Indian Ocean is as important as the well-known link to the dramatic events over the Pacific (El Niño Southern Oscillation; ENSO).
- Over the equatorial Indian Ocean, enhancement of deep convection in the atmosphere over the western part is generally associated with suppression over the eastern part and vice versa. This oscillation between these two states, which is reflected in the pressure gradients and the wind along the equator, the Equatorial Indian Ocean Oscillation (EQUINOO).



## Monsoon depression

A depression that forms within the monsoon trough. The term is most frequently used to describe weak cyclonic disturbances that form over the Bay of Bengal and generally track northwestward over the Indian subcontinent. These occasionally intensify into tropical cyclones if they remain over warm ocean water long enough.



The criteria followed by the Meteorological Department of India to classify the low pressure systems in the Bay of Bengal and in the Arabian Sea as adopted by the World Meteorological Organisation (W.M.O.) are:

### **Types of Disturbances**

### **Associated wind speed in the Circulation**

1. Low Pressure Area	Less than 17 knots ( < 31 kmph)
2. Depression	17 to 27 knots ( 31 to 49 kmph)
3. Deep Depression	28 to 33 knots ( 50 to 61 kmph)
4. Cyclonic Storm	34 to 47 knots ( 62 to 88 kmph)
5. Severe Cyclonic Storm	48 to 63 knots ( 89 to 118 kmph)
6. Very Severe Cyclonic Storm	64 to 119 knots ( 119 to 221 kmph)
7. Super Cyclonic Storm	120 knots and above ( 222 kmph and above)

1 knot - 1.85 km per hour



# Indian Monsoon can be affected by pollution over Indian Ocean

- ❖ A dense brownish haze of microscopic pollutant particles suspended in air (aerosols) in the Indian Ocean, discovered by an international team of researchers, could "affect monsoon parameters in the long run," referred as Atmospheric Brown cloud.
- ❖ Widespread pollution observed recently over an area as large as the United States in the Indian Ocean including the Bay of Bengal and the Arabian Sea could affect monsoon in the Indian subcontinent.
- ❖ The extent of the effect, which depends on other factors like how aerosols react with clouds, is being studied.



## Monsoons and Climate Change

- There is a competition between zonal circulation and monsoon winds. We have to find which will be favoured by global warming.
- Overall, global warming will change conditions in the sea more slowly than conditions on land, because of the difference in the rate of response to heating, a concept familiar from the sea breeze.
- Thus, we would expect the summer monsoons to be amplified by stronger warming in summer. In addition, with more moisture in the air, extracted from a warming ocean, rainfall (and flooding) might be expected to increase.
- Conversely, in winter, we should expect less of a difference, as the land refuses to get quite as cold as previously. So, the winter monsoons should weaken, as should any of the nutrient-supplying coastal upwelling associated with winter monsoons.



# Will Climate Change Affect India's Monsoon Season?

- Changes to India's annual monsoon are expected to result in severe droughts and intense flooding in parts of India.
- Scientists predict that by the end of the century the country will experience a 3 to 5 degree C temperature increase and a 20% rise in all summer monsoon rainfall.
- Climate change studies undertaken so far reveal that action is essential in order to prevent long term damage to India's water cycle.
- The livelihood of a vast population in India depends on agriculture, forestry, wetlands and fisheries and land use in these areas is strongly influenced by water-based ecosystems that depend on monsoon rains.



**Warmer temperature appear to bring heavier rainfall**

## **Future changes in monsoon variability**

- **India is already vulnerable to variations in the monsoon, both from year-to-year and within the season.**
- **One of the key questions in climate change is whether the remarkable stability of the monsoon rains will continue, or whether the monsoon will become more volatile.**
- **Most models predict a modest increase in interannual variability but to differing degrees. At the heart of this are the projections of what will happen to El Nino - whether it will become stronger and/or more frequent - since El Nino has dominant influence on monsoon variability.**
- **Monsoon is important and scientists are engaged in understanding the variability of monsoon using observed data and numerical models.**
- **Hope that in future we will have more accurate prediction of Indian monsoon rainfall.**

# End of Slide Show



[Back to Index Page](#)

[Back to Home Page](#)