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Component-I (B) - Description of Module

Items	Description of Module
Subject Name	**Geography**
Paper Name	Climatology
Module Name/Title	**MONSOON: DEFINITION, THEORIES AND CONTROLLING FACTORS**
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Pre-requisites	
Objectives	
Keywords	

MONSOON: DEFINITION, THEORIES AND CONTROLLING FACTORS

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MONSOON: DEFINITION, THEORIES AND CONTROLLING FACTORS

Dr. Kanchan Singh

Introduction

The term monsoon is derived from Arabic word 'mausim' meaning 'season'. Arabians were known to general pattern of winds in different seasons. As such, Arabians used to sail their ships for the movement of goods and people. It is believed that seamen used to describe alternating winds in Arabian Sea where they appear to blow from north east for six months and from southwest for another six months. Seasonal alternating of wind direction and speed was used by early seamen to trade from India to Arab and African countries during winter and return trade from African and Arab countries to India during summer.

In addition to this, economy and society in the tropical world depends directly on the success of the monsoon. The failure of monsoon upsets the socio-economic balance in the region. Behavior of the monsoon is erratic. Because of heavy rains in some parts of the region, the areas are flooded while in other parts there are severe drought conditions. Since monsoon plays a pivotal role in socio –economic life of the region, it is embedded in socio-cultural milieu of the people in monsoon lands.

Objectives

After studying this module, you will be able to:

- define the monsoon,
- discuss the major characteristics of monsoon,
- differentiate between summer and winter conditions of temperature, air pressure and wind direction,
- examine the factors favoring the occurrence of monsoon,
- explain different theories related to the origin of monsoon,
- analyze the role of surface and upper air circulation in the mechanism of monsoon and
- explain the significance of monsoon on the socio-economic conditions of people in the monsoon lands.

Historical context of Monsoon

The term monsoon appears in early writings of Greek, Indian, Buddhists, and Arab scholars. However, credit for first scientific studies of monsoon winds goes to the Arabs. Al Masudi, Baghdad based Arab Scholar, gave an account of the reversal of ocean currents and the monsoon winds over north Indian Ocean. Sidi Ali, another Arab Scholar, could calculate the precise dates of the commencement of monsoon at several places.

Sir Edmond Halley, an English scholar, opined in 1686 that monsoons are the result of thermal contrasts between continents and oceanic areas due to differential heating. Accordingly, Halley conceived the idea of summer and winter monsoon depending upon the season. The idea of Halley prevailed for about three centuries. Although Hailey's idea is not out rightly rejected, recent studies after 1950 have thrown significant light on the genesis of monsoon. During these years contributions of Flohn, Thompson, Stephenson, Frost, Yin, Hwang, Takahashi, Palmen, Newton and Indian meteorologists including Koteshwaram, Krishnan, Raman, Ramnathan, Krishnamurti, Rama Rattan, Ramaswami, Anant Krishnan, etc. have contributed significantly to the study of monsoon winds.

Definition

Scholars engaged in studies of climatology and meteorology have defined monsoon from different angles. Some of the commonly used definitions have been given below to explain the wider context of monsoon.

> "Monsoons are large scale seasonal wind systems blowing over vast areas of the globe persistently in the same direction, only to be reversed with change of season." **Rama Shastry.**

> "That the monsoon represents simply a land and sea breeze on a large scale, and that the annual period of the monsoon corresponds to diurnal period of breezes." **Angot, Hann and Koppen.**

> "Whereas monsoon climates appear to be very complex in detail, their fundamental principle that of land and sea breezes on a large scale remains simple and straightforward." **Miller**

According to **Nieuwolt**, "The word monsoon is used only for wind systems where the seasonal reversal is pronounced and exceeds a minimum number of degrees." The term has been applied to wind system which shows at least 120 degrees of change of wind direction with the change of a season. These winds are characterized by constancy higher than 40 percent and a mean resultant speed of more than 3 meters /second.

According to **Chang-Chia-Ch'eng** "Monsoon is a flow pattern of the general atmospheric circulation over a wide geographical area, in which there is a clearly dominant wind in one direction in every part of the region concerned, but in which this prevailing direction of wind is reversed (or almost reversed) from winter to summer and from summer to winter".

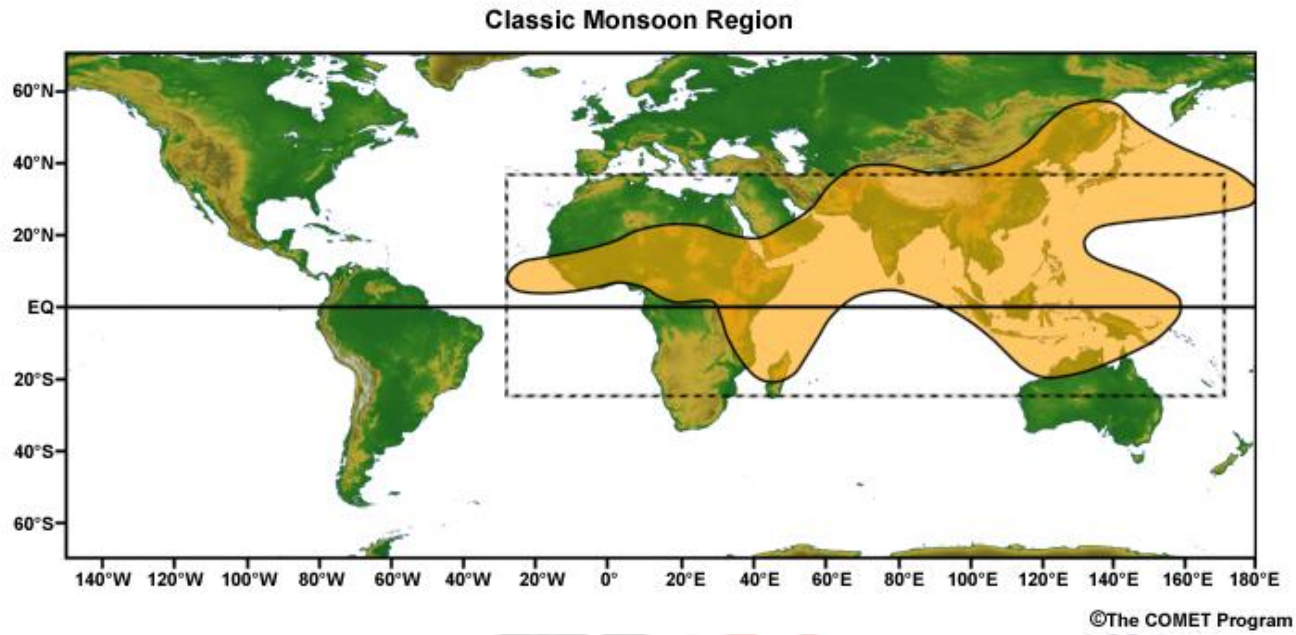
The term 'monsoon' is broadly used to denote the cyclic reversal of pressure and wind systems in a year. Such a seasonal reversal of pressure and wind system is associated with sequential changes in the cloud and weather patterns mainly in the tropics. Monsoon as a system of winds has the following features:

- **i)** A system of winds, with marked seasonal shifts, caused by differential heating of land and sea in response to incoming solar radiation on the earth's surface.
- **ii)** A system of wind that is largely confined to the tropics, a region between 20^0 N and 20^0S on both the sides of equator.
- **iii)** Monsoons over northern hemisphere are the trade winds of southern hemisphere. On crossing the equator, the winds are deflected to the right due to earth's rotation. Consequently winds blow in south westerly direction. In the same way, on southern hemisphere, monsoons are the trade winds of northern hemisphere which, on crossing equator, are deflected to the left due to earth's rotation. Consequently, winds blow in north westerly direction.

Monsoon winds are more pronounced in the months of July and August in the tropics of northern hemisphere and in January and February in the tropics of southern hemisphere. Thus, the summer season in the tropics of both the hemispheres coincide with the monsoonal winds and rains.

Monsoon winds with other continental masses of the earth are not so well marked as the Indian monsoon. Seasonal wind changes have been known to occur in north-east Australia, Africa, South America (Brazil), southern USA and in Latin America. Figure -1presents the classic monsoon region. It is obvious from the map that monsoon regions develop in the tropical belt. They are, however, well developed in and around Indian Ocean.

Figure 1: Classic Monsoon Region of the World



Source: http://www.goes-r.gov/users/comet/tropical/textbook_2nd_edition/media/graphics/monsoon_regions_classic.jpg

Theories of the origin of monsoon

The origin of monsoon is a complex meteorological and climatological phenomenon. Scientists have developed theories to solve the mystery of the origin of monsoon. These are broadly grouped under the following three:

- Classical Theory
- Dynamic Theory
- Modern Theory

A brief description about each theory is given below:

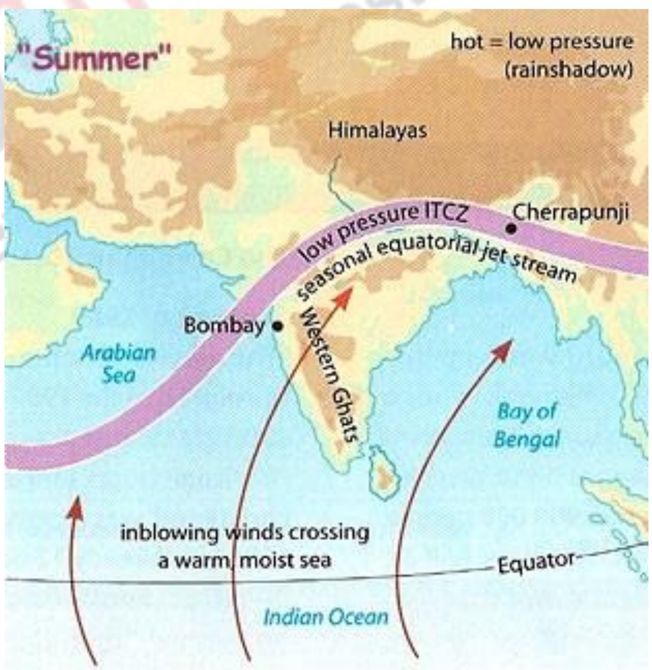
Classical Theory: The theory was propounded by Sir Admond Halley in 1686. It was further extended and supported by Hann, Koeppen and Miller.As per theory, monsoons are the extended land breeze and sea breeze on a large scale, produced by the differential heating of continents and oceans.The response of continents and oceans to solar energy creates striking difference in surface pressure conditions and movement of local winds. Most of the solar energy received at the ground by the continents is used up in heating the air. Only a shallow layer of a few meters of soil are heated by energy received at the ground by the continents.Contrary to this, solar energy is able to penetrate much greater depths of oceans because water being a good conductor of heat.Consequently, a smaller part of solar heat is available for heating the air in oceanic areas. The overall result is that rise in temperature in summer is much less over the oceans as compared to the continents. It has been observed that the mean summer temperatures over the continents often exceed those of the oceans by 5^0 to 10^0 C acrossthe same latitude. The situation in winter is reversed and greater heat storage of oceans leads to higher temperatures as compared to the continents.

During summer season, in northern hemisphere, a thermally induced low pressure centers develop in the Thar, Arabia and Sahara. An elongated low pressure belt over a large area from Sahara to Thar develops to the north of tropic of Cancer. Conditions of marked thermal contrast between continents and oceanic areas cause a sea to land air pressure gradient during summer season. As a consequence, the normal wind systemfrom north east is reversed to south west. The air moving from oceans towards continents is warm and moist.

Land barriers such as mountains and plateaus obstruct the air motion and lead them to ascend. Warm moist air ascends along the land barriers and causes precipitation. Land barriers such as Western Ghats obstruct south west warm and moist winds and cause rainfall along the west coast of India. Contrary to the above, Aravali Hills, despite having north- south orientation similar to that of Western Ghats, fail to cause rainfall because of its location north of tropics and the absence of oceanic proximity. As such, moisture laden winds from Arabian Sea weaken by the time they approach Aravali areas and hence cause scanty rainfall.

The situation of south west monsoon in July is depicted in Figure 2 when sun is over head at tropic of cancer and two low pressure areas develop one in central India and another in the highlands of central Asia. Because of relatively low temperature (southern winter) a high pressure belt develops in central Australia and southern part of Indian Ocean.

Figure 2: Position of ITCZ and Southwest Monsoon in July

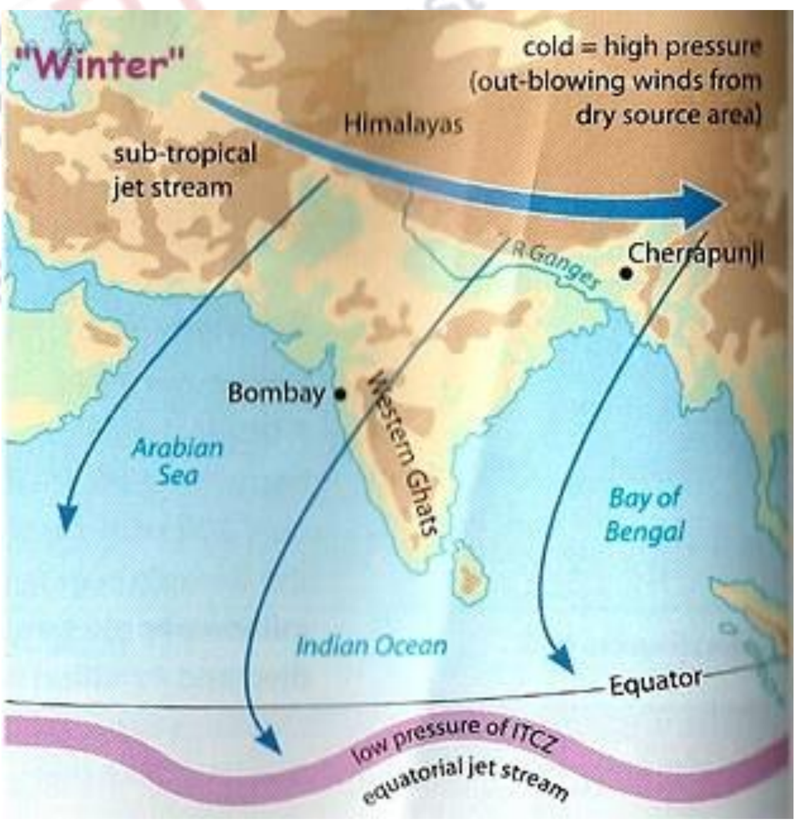


Source: http://rossway.net/wp/wp-content/uploads/2015/10/6-monsoon1.jpg

Similarly, conditions of thermal contrasts during winter season cause a land to sea air pressure gradient. The change in pressure pattern begins by September in northern hemisphere. With the apparent movement of sun towards Tropic of Capricorn, temperature begins to decrease while air pressure starts increasing in northern hemisphere. By December – January a high air pressure gets fully established in northern hemisphere with its center near Lake Baikal (1035 mb) and in north Indian plains. Compared to the continental areas which are cold and zones of high air pressure, heat storage of oceans leads to record a higher temperature and low air pressure during winter season. As a consequence,winds blow from continents to oceanic areas in northern tropics. Since air moving from land is cold and dry, it is incapable of giving precipitation unless it comes in contact with large water bodies like sea and ocean. But in case of Tamil Nadu region of India and in Sri Lanka, north-east trades cause sufficient rainfall because they pick up moisture from Bay of Bengal on their way from northeast to southwest.

The position of Sun is overhead close to tropic of Capricorn in December-January. The low pressure develops to the south of equator, along tropic of Capricorn and in central Australia. As a consequence, there is an outflow of air from oceans towards continental areas. North-west monsoon is active in southern hemisphere causing heavy rains in Australia and areas close to tropic of Capricorn (Figure 3).

Figure 3: Position of ITCZ and Southwest Monsoon in January



Source: http://rossway.net/wp/wp-content/uploads/2015/10/6-monsoon1.jpg

Criticisms/ Limitations

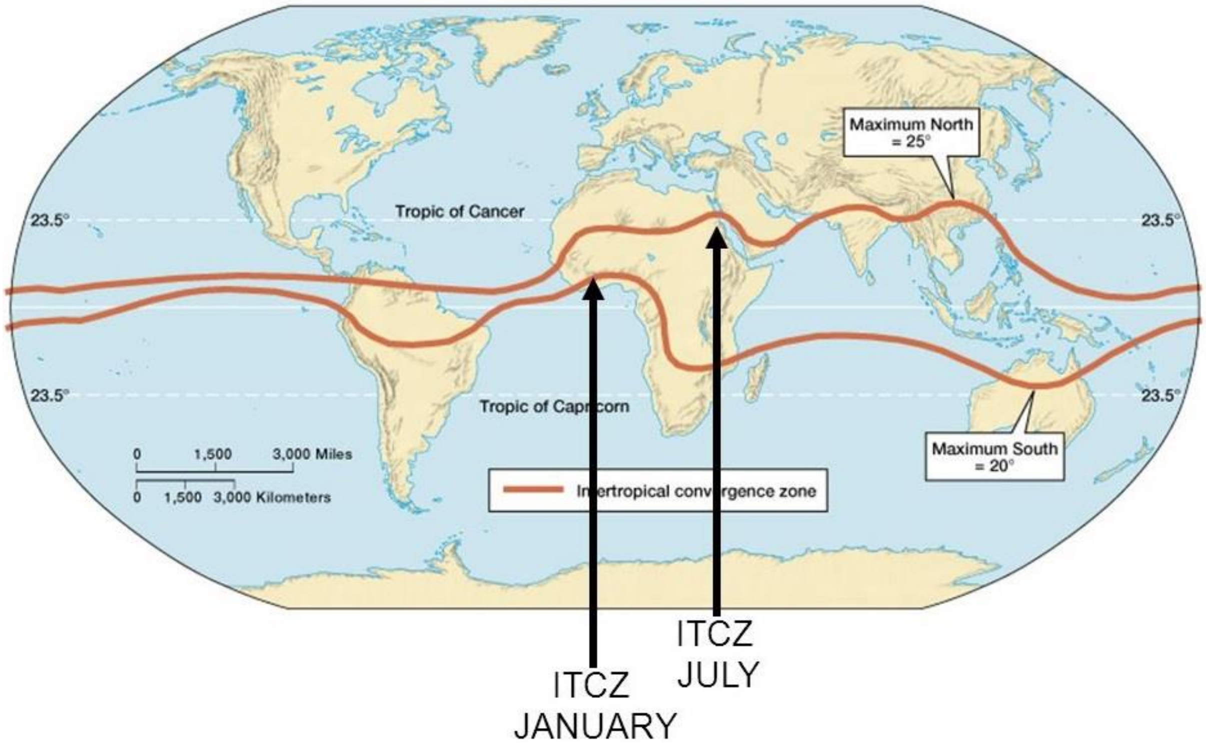
The theory of thermal contrasts about the origin of monsoon suffers from certain limitations which are briefly discussed below:

- The basic premise that high thermal conditions over land cause low atmospheric conditions resulting in air movements from oceans which are related to low thermal conditions during summer season. It does not seem to explain the origin of monsoon fully as the highest temperature in land areas are usually associated with the months of April and May when there is a complete absence of rainfall.
- Monsoonal rainfall are not solely orographic, rather they are a jointly produced phenomenon with convectional and cyclonic situations.
- The surface and upper air circulations are usually opposite in their orientation. Had the origin of monsoons been thermally induced, there need to be an anti – monsoon air – circulation in upper air which is not so in some of the cases.
- The theory does not take into account circulation of oceanic water which is a major cause of thermal contrast among the oceans.
- The theory also ignores upper air circulation which serves as the base for the intensity and extension of summer rainfall in tropics.

Dynamic Theory: It was propounded by Flohn, a German Meteorologist, in 1951. The theory was further enriched by the research works of Krishna Rao (1952). It is also known as theory of shifting pressure and wind belts. According to Flohn, monsoon is the result of seasonal migration of planetary winds and pressure belts. The trade winds from both the hemispheres converge near equator and form Inter Tropical Convergence (ITC) zone. The northern and southern limits of ITC are known as NITC and SITC respectively. A narrow belt of doldrums lies in between NITC and SITC and is characterized by 'equatorial westerly's.

During summer solstice, trade winds of southern hemisphere (south-east trade winds) extend and shift northward while during winter solstice trade winds of northern hemisphere (north-east trade winds) extend and shift southward from their normal position. The south-east trades in association with equatorial westerly's produce south-west or summer monsoon around summer solstice when sun is overhead at tropic of Cancer. Similarly, around winter solstice when sun is overhead at tropic of Capricorn, north-east trades in association with equatorialwesterly's produce north- west or winter monsoon. Thus, shifting position of pressure and wind belts due to dynamic motion of the earth is responsible for the origin of monsoon and reversal of wind patterns in the tropics. Obviously, the shifting of the ITCZ is responsible for the reorientation of pressure and wind conditions in tropics. The Figure 4 represents the location extent of ITCZ in January and July.

Figure 4: Average Position of ITCZ in January and July



Source: http://slideplayer.com/slide/7741637/25/images/8/ITCZ+JULY+ITCZ+JANUARY.jpg

Criticisms/ Limitations: The apparent change in the position of sun causes northand southward shift of ITCZ. There is an associated change in the pressure conditions over land and sea in the tropical belt. The directional change of winds is more pronounced around Indian Ocean which has alternating distribution of land and sea.Thetheory has a scientific significance in explaining the origin of south-west and north-west monsoon in association with the movements of planetary trade winds. However, theory carries some limitations. They are briefly explained below:

- Theory does not take into account the role of upper air circulation which remains significant in maintaining the rhythm of monsoon for a fairly long period and over extensive areas in tropics.
- Theory also seems to have ignored the oceanic circulation and temperature gradient in oceanic waters.
- The position of air masses (warm/cold) and their gradual shift from tropics is one of the potent factors that affect the origin of monsoon. Theory does not seem to include these vital elements.

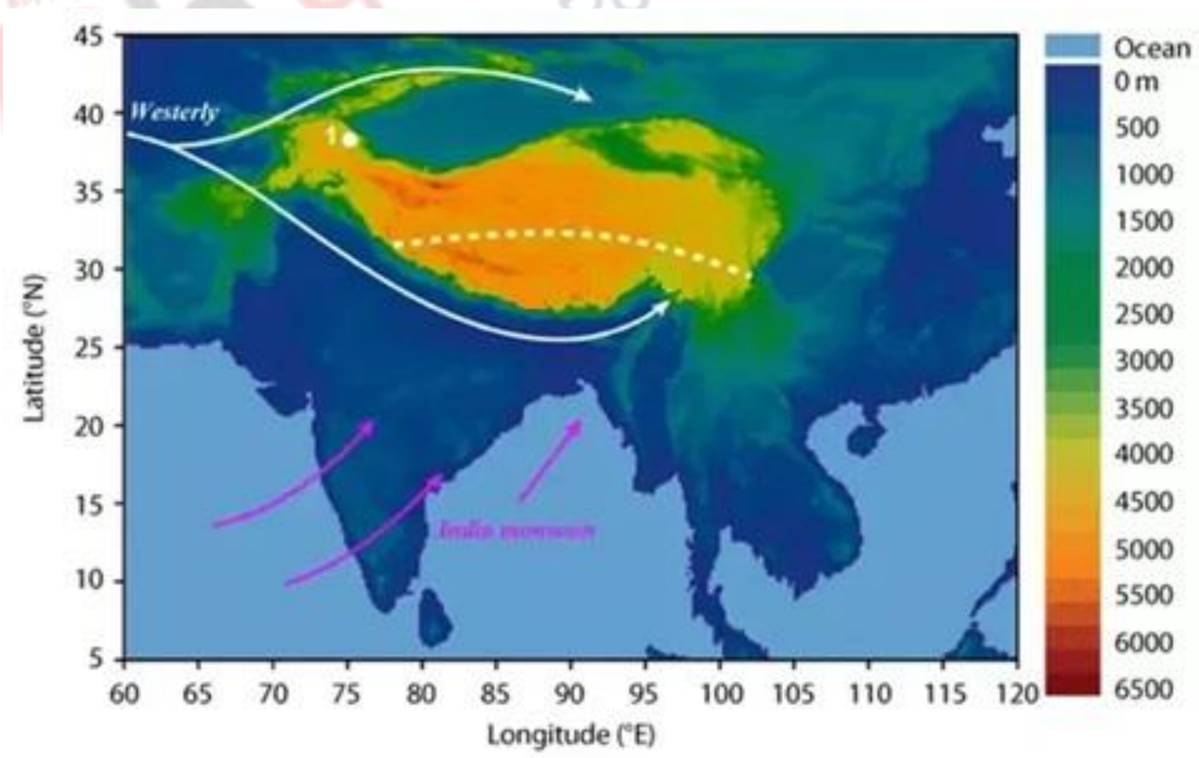
Recent Theory

With the advancement in satellite technologies, précised weather recording instruments and global network of meteorological observations, a large and varied data is now available to process through computers, develop models and arrive at very precise results about weather and climate. The recent theory related to the origin of monsoon is based on observations concerning upper air circulation, temperature conditions over Tibetan Plateau, jet streams, Oceanic water circulation, the occurrence of El- Nino and La Nina and Southern Oscillations. A brief discussion on these elements is given below:

The Monsoon Expedition: To understand the causes and the mechanism of monsoon an Indo-Soviet joint expedition was carried out in 1973. The Monsoon expedition, popularly known as Monex, was jointly organized in May – July 1973. Four Soviet and Two Indian Ships equipped with scientific tools of meteorological observations were used to take precise observations in Indian Ocean, Bay of Bengal and Arabian Sea.

Dr. P. Koteswaram and Professor H. Flohn suggest that the Tibetan Plateau is a source of heat for the upper atmosphere. The rising temperature in higher altitudes generates an area of rising air motion. During summer, Tibetan plateau remains warmer by 2^0 - 3^0 C than the adjoining areas. The low pressure created in Tibetan Plateau pushes westerly Jet further northward. It coincides with the arrival of Indian summer monsoon. The southward blow of air from Tibet helps to strengthen the prevailing easterly winds over south India. It explains the appearance of easterly Jet at about the same time as appearance of Indian monsoon. The facts have been shown by a diagram given below (Figure 5).

Figure 5: Tibetan Plateau Heating and Westerly Jet Stream Shift



Source: http://www.geographynotes.com/essay/indian-monsoons-significance-and-peculiar-features/938

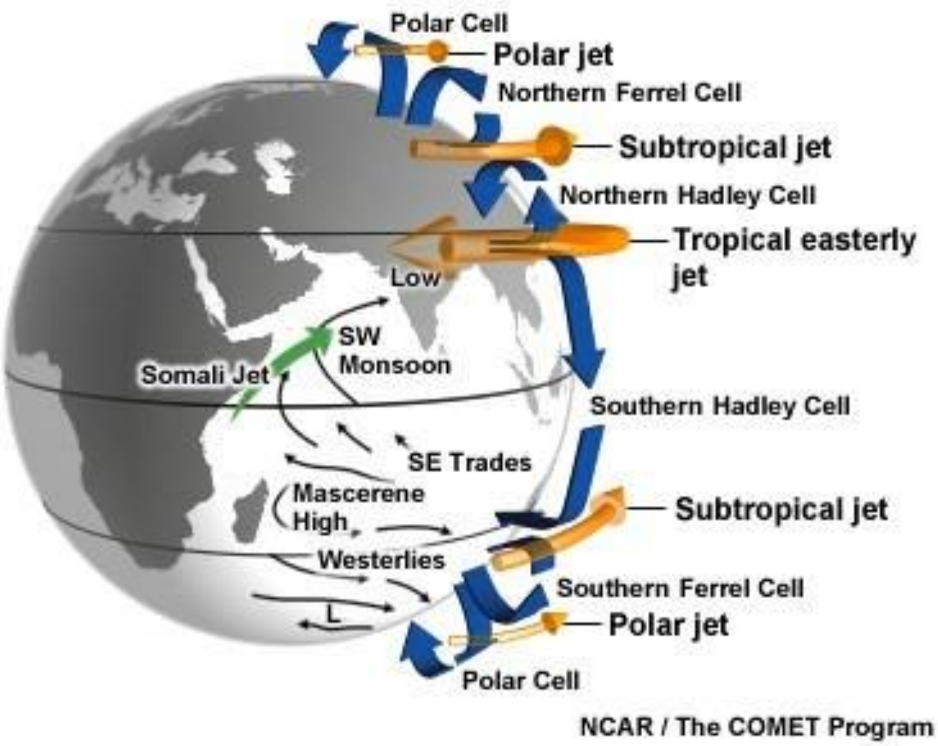
According to Maung Tun Yin, there is a correspondence between shifting of the Jet and slowing down of the westerly jet over whole of Eurasia. As against this, Plateau of Tibet becomes very cold during winter and serves as the most important factor in advancing the westerly Jet to the south by mid of October. It helps in establishing cold wave and western disturbances over north Indian plains resulting in high pressure over land surface and low pressure over Indian Ocean. These meteorological conditions help in causing favorable monsoon.

Jet Streams and the Monsoon: Jet Streams are prominent movements in upper level wind flows. These streams are concentrated, meandering bands of geostrophic winds, travelling at a speed of 300 – 400 km/hour. Jet streams are the general circulation of upper atmosphere similar to planetary wind system in the surface of the earth. Between equator and about 30^0N, in which there are easterlies (Trade winds) at lower levels and westerly winds aloft. In middle zone between 30^0 and 60^0N,in which there are westerly winds at the earth surface and easterly winds aloft. Finally between 60^0N and the North Pole where surface winds are easterly and upper winds are from a westerly direction (Figure-7). The easterly Jet Stream was first inferred by Koteshwaram and Krishna in 1952. The core of easterly jet is at 13 km (150 mb) while that of westerly jet at 9 km. The axis of strongest winds in the easterly jet may extend from the southern tip of the Indian peninsula up to Tropic of Cancer.

Jet streams, particularly westerly jet plays a decisive role in the origin of Indian summer monsoon. Observations reveal that northward push of westerly jet, due to heating of Tibetan Plateau, marks the onset of Indian summer monsoon. As against this, westerly jet stream is located to the south of the Himalayas during winter season. The winds tend to descend along northwestern part of India which coincides with the occurrence of western disturbances in the region, common during winter season (October – March). These disturbances result in occasional rains which is highly beneficial for standing winter (Rabi) crops.

The tropical easterly jet descends in permanent high pressure area formed over the south Indian Ocean. With further intensification of high pressure gradient over Indian Ocean, the vigor of summer monsoon increases sharply. The facts related toair pressure, wind pattern, upper air cell, jet streams, Indian Ocean dipole and summer monsoon have been displayed through Figure-6.

Figure 6: Pressure, Wind Pattern, Jet Streams and Indian Ocean Dipole

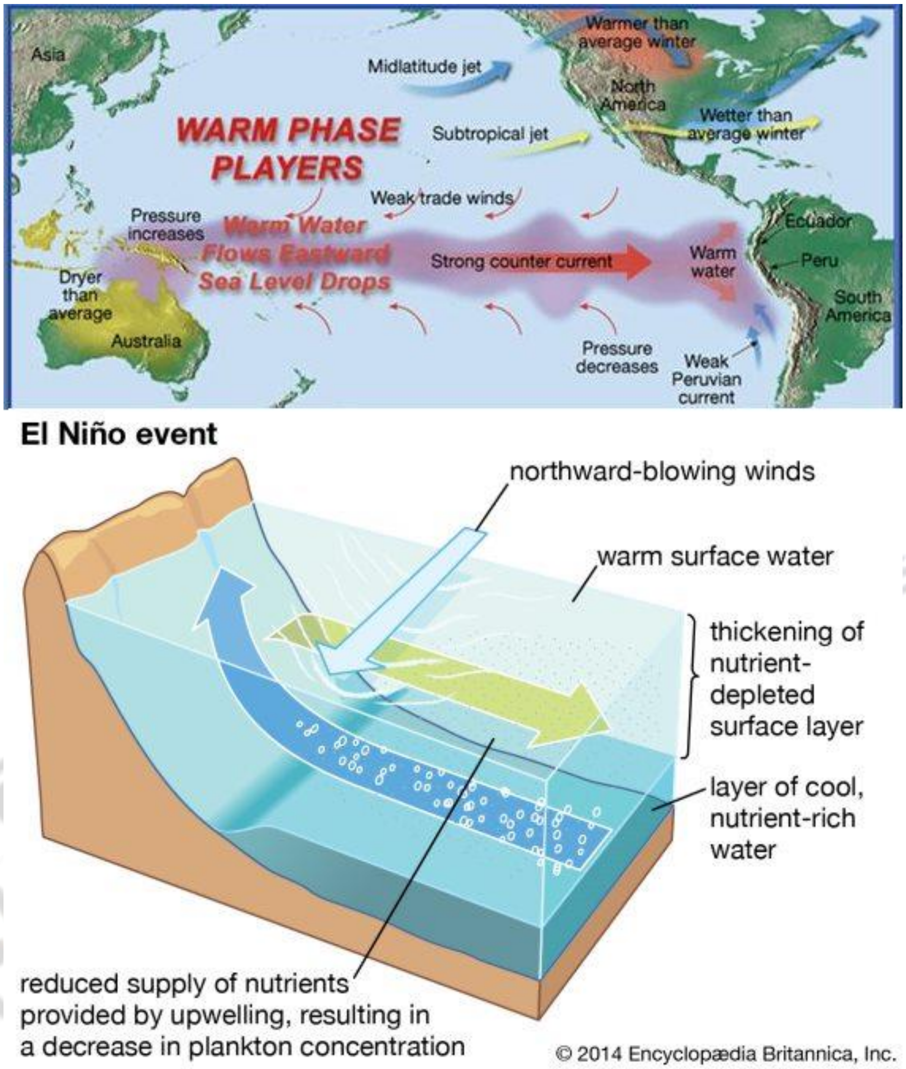


Source: https://www.pmfias.com/indian-monsoons-tropical-easterly-jet-tibet-somali-jet-indian-ocean-dipole/

Tele-connections, the Southern Oscillation and the El Nino: Meteorological observations reveal that there are tele-connections between occurrences of weather phenomena at one place and its effects over time at another place. Based on the premise of tele-connections, origin of monsoon has been explained with reference to El- Nino, La Nina and Indian Ocean Dipole.

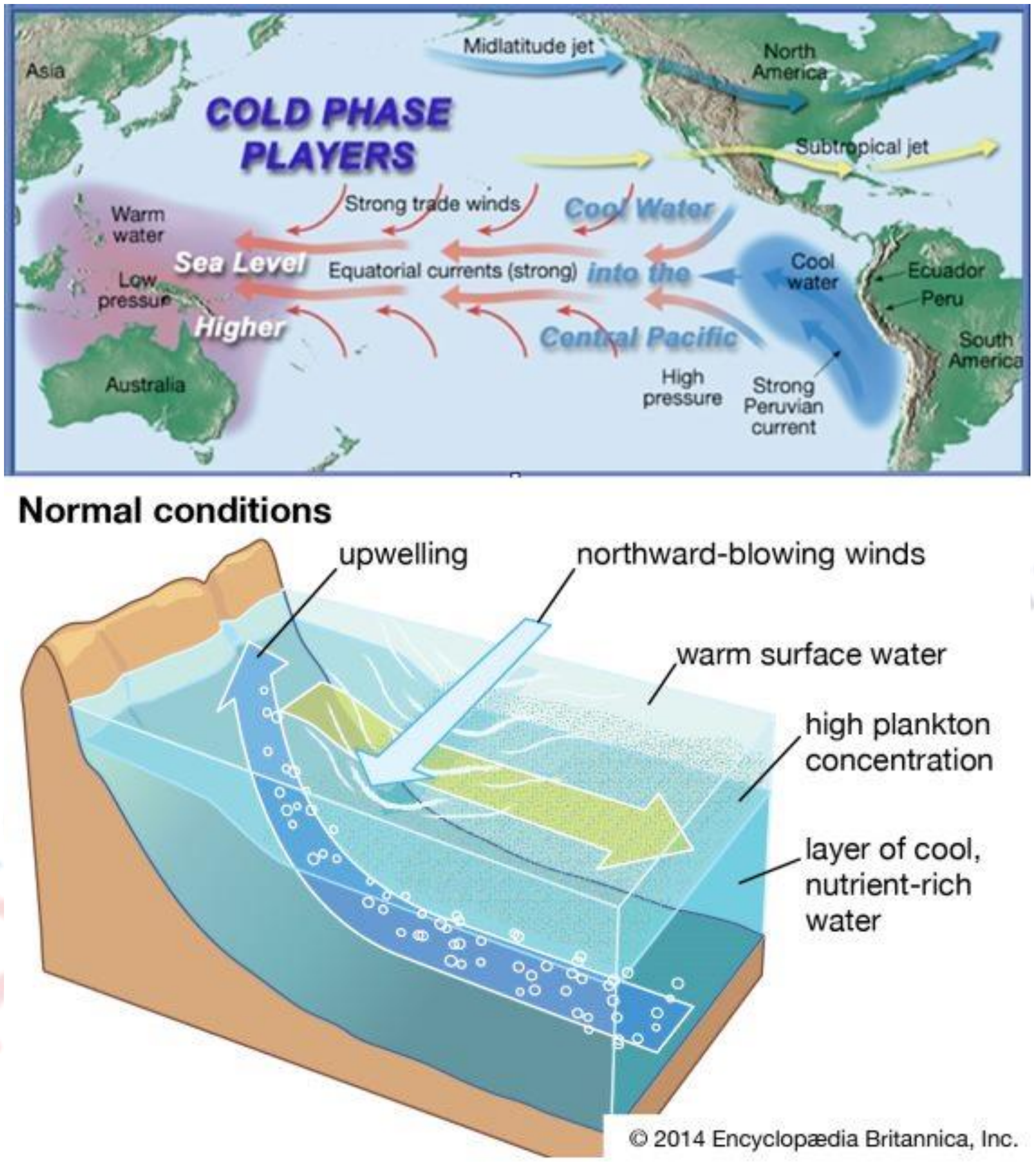
El-Nino and Monsoon: The effect of El-Nino on summer monsoon is significant. El-Nino is a warm ocean current appearing along the coast of Peru. The literal meaning of El-Nino is Child Christ or little boy and it develops generally in December. Peru or Humboldt is a cold current flowing along the coast of Peru. The appearance of El-Nino reverts the condition of Peru current by developing a warm water and moist air conditions over eastern Pacific (Peru coast) and cold conditions in western Pacific coast (eastern Australia and Indonesia). As a result, eastern Pacific along Peruvian coast in South America records high rain fall while western Pacific along Australian and Indonesian coast record drought conditions. El-Nino results in weakening of the monsoon causing drought conditions and crop failures in Monsoon regions of South and South East Asia (Figure-7). The warming of Indian Ocean, under the influence of El-Nino weakens the intensity of Monsoon.

Figure-7: El Nino Event and Associated Drought Conditions in Monsoon Lands



Source: https://farm3.staticflickr.com/2902/14111875035_1dabdbb977_o.jpg

Figure 8: Normal Conditions and Favorable Monsoon



Source: https://farm6.staticflickr.com/5274/13925251440_1b95f2ae9d_o.jpg

La-Nina and Monsoon: La-Nina, the word originates from Spanish meaning "Little girl". It is characterized by unusually cold ocean temperatures in equatorial Pacific. During the period of La-Nina, sea surface temperature across Equatorial eastern central Pacific Ocean will be lower than normal by 3^0 to 5^0 C. It has extensive effect on the weather in North America, even affecting Atlantic hurricane season. La-Nina caused heavy rains over Malaysia and Philippines and Indonesia. Western side of the Equatorial Pacific is characterized by warm, wet low pressure weather as the collected moisture is dumped in the form of typhoons and thunderstorms (Figure-8). The ocean is some 60 centimeters higher in western Pacific compared to eastern as a result of this motion. The water and air is return to the east. Both of them are now much cooler and the air in the surface much drier.

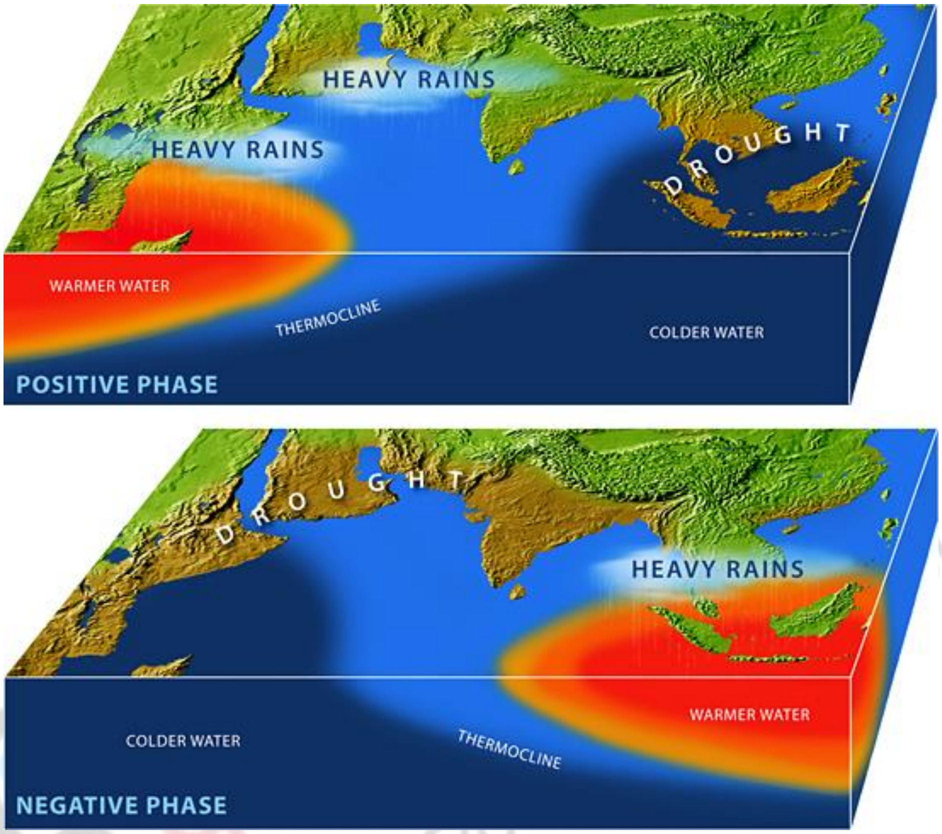
Southern Oscillations and Monsoon: The system of Southern Oscillations was worked out by Sir Gilbert Walker, the first Director General of Indian Meteorological service in 1924. It is a seesaw pattern of meteorological changes that are often observed between Pacific and Indian Ocean. It has been established that when surface pressure is high over the Pacific, air pressure over Indian Ocean tends to be low. Since surface air pressure over oceans during dry winter season is inversely related to summer rainfall; prevalence of low air pressure over Indian Ocean during winter season is a sign of 'positive southern oscillations'. The chances of favorable monsoon are generally linked with 'positive southern oscillations'. On the contrary, if air pressure is high over Indian Ocean during winter season, it denotes the 'negative southern oscillations' which means that coming monsoon will be weak. Southern Oscillations has a period ranging between 2 to 7 years.

The intensity of southern oscillations is worked out by the difference in sea level air pressures at Tahiti (18^0 South and 149^0 west), a station in mid Pacific and port Darwin (12^0 South 130^0 East), a representative station of Indian ocean. A negative value of 'southern oscillation index' (SOI) implies low pressure over Peru coast and high pressure over north Indian Ocean during winter season explaining a poor monsoon phase. There seems to be a close correlation between the appearance of El-Nino and the negative SOI (figure-7). The two adverse parameters (negative SOI and El-Nino) are the cause of a weak monsoon phase. Together these parameters are known as ENSO event.

Indian Ocean Dipole: It was in 1999 that phenomenon of Dipole in Indian Ocean was identified and was linked to the origin of monsoon. Scientists have concluded, based on their long term observations, that there are marked variations in thermal as well as atmospheric conditions of eastern and western part of Indian Ocean during winter months (December-January). These conditions are decisive for the significance of summer monsoon in Indian Ocean region.

Apparent changes in the thermal and atmospheric conditions of Tropical Pacific Ocean are known as El-Nino while development of similar conditions in Tropical Indian Ocean is known as 'Indian Nino'.

Figure 9: Positive and Negative Phases of Indian Ocean Dipole



Source: http://images.indianexpress.com/2015/03/iod.jpg

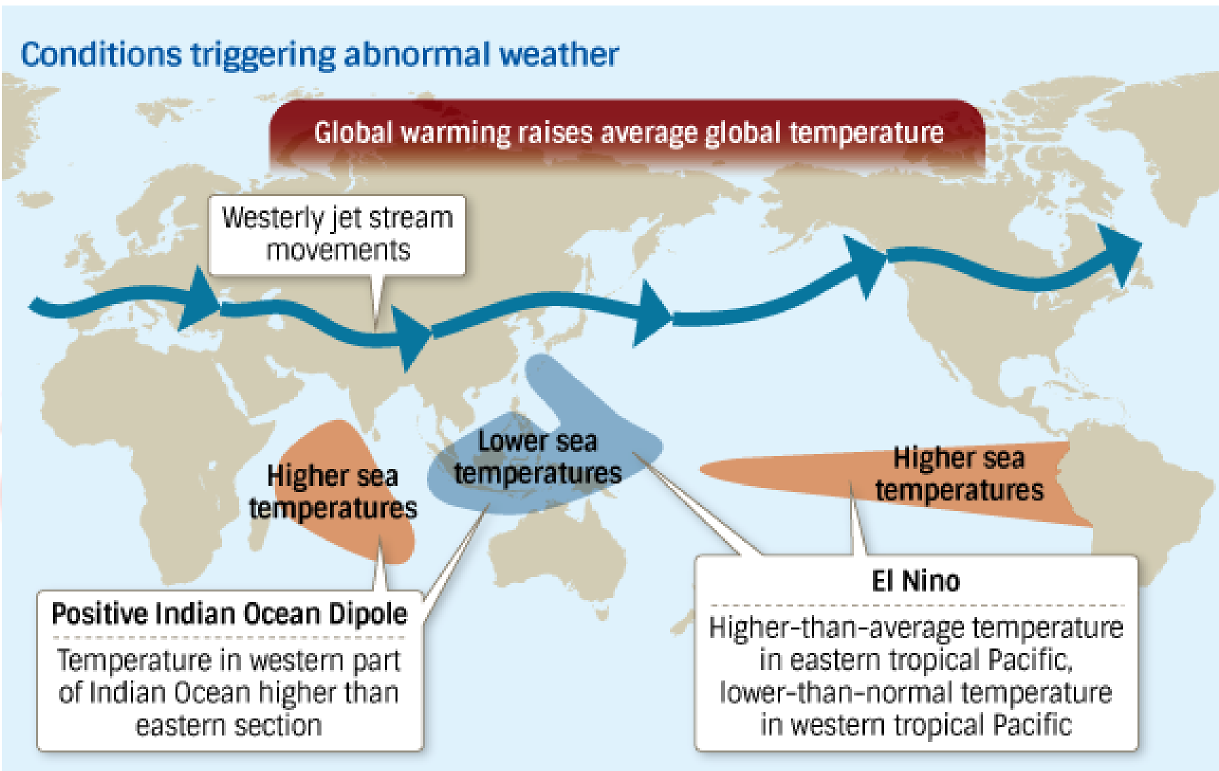
Indian Ocean Dipole (IOD) has three situations:

1. Positive IOD occurs when Sumatra in Indonesia remains colder than normal and western coast of Indian Ocean along Africa remains warmer than the normal. Such a situation is favorable for good monsoon. In such a situation, air pressure in eastern Indian Ocean is greater as compared to the western Indian Ocean. Presence of Agulhas warm current in western part of Indian Ocean and Western Australian cold current in eastern part of Indian Ocean are the major factors controlling for the development of such a situation (Table 1).
2. Negative IOD develops when Sumatra in Indonesia (eastern Indian Ocean) remains warmer than normal and Malagasy in East Africa (western Indian Ocean)remains colder than normal during winter season (December- January).The negative Indian Ocean Dipole results in weakening of the summer monsoon (Table 1).
3. Normal IOD refers to the normal thermal conditions over western and eastern coasts of Indian Ocean during winter season. Temperature and air pressure conditions do not vary significantly. Such a situation indicates about normal summer monsoon (Table 1).

Table 1: Indian Ocean Dipole

IOD Phase	**Air pressure of eastern coast**	**air pressure of western coast**	Difference
Positive IOD	1020 mb. (Sumatra)	1010 mb. (Malgasy- Somalia coast)	+10mb.
Negative IOD	1010mb. (Sumatra)	1015mb.(in Malgasy- Somalia coast)	- 05 mb.
Normal IOD	1005mb. (Sumatra)	1006 mb. (in Malgasy- Somalia coast)	≈ 01 mb.

Figure 10: Global Warming, El Nino and Positive IOD



Source: https://asia.nikkei.com/magazine/20150827-THE-GREAT-FALL/Tech-Science/Multiple-factors-lead-to-freak-weather

Limitation and Criticism

The recent theory of monsoon offers adequate insight into the origin of monsoon. It has a wide acceptance. However, there are some limitations of the theory which are explained below:

- Despite several merits to its credit, theory does not take into account spatial and temporal trends of weather and climate which are in the process of continuous change and are the cause of upsetting the normal conditions. As a consequence, there is an increase in the extreme weather conditions in the tropical world. Unless theory takes into account extreme situations into its ambit, mechanism of origin of monsoon remains partly explained.

- Periodicity and effectiveness of the monsoon seems to be more affected by human interventions in nature and degradation of ecological conditions. As such, parameters related to human activities such as emission of carbon and other CFC gases into environment and upsetting of ecological balance deserve to be considered while explaining the origin of monsoon. Prevalence of temperate conditions i.e. temperature, pressure, air mass during winter and its role in the origin of summer monsoon.
- Surface configuration such as land barriers and their orientation, extension of island groups in the oceans and proportion of oceanic expanse also play a decisive role in the advancement and intensification of monsoon.

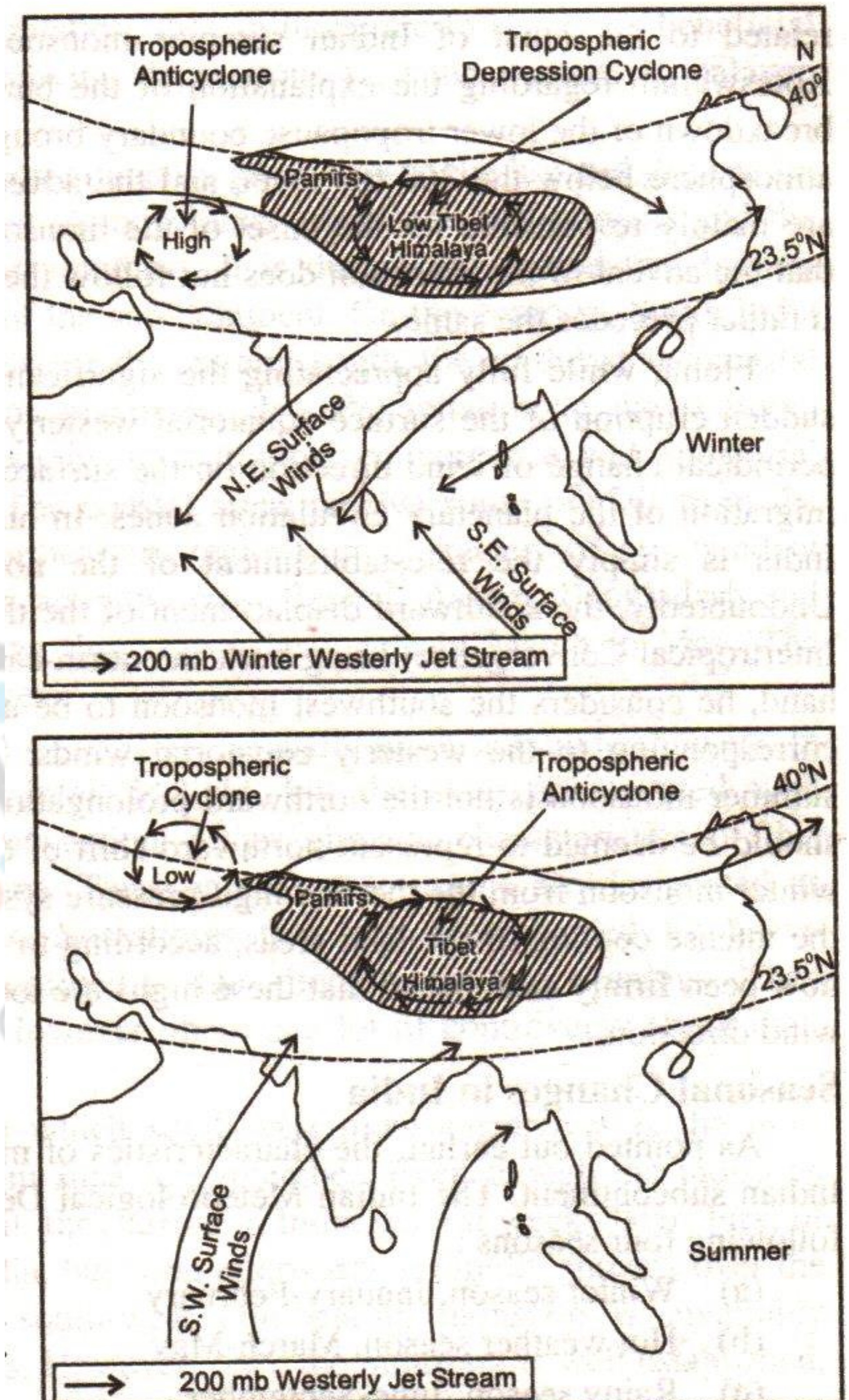
Controlling Factors of Monsoon

There are factors that exercise control over the origin and mechanism of monsoon. They are grouped into global and regional and locational factors that play a decisive role in the success or failures of monsoon**.**

Global Factors of Control: Among global factors of control, temperature and air pressure conditions on the earth surface and the upper air circulation in the higher altitude exercise effective control on monsoon. Recent researches have shown that global temperature rise has resulted in upsetting the trends of precipitation globally. Conditions of air pressure are partly controlled by temperature conditions and partly by the motions of oceanic waters and the mechanism of upper air circulation and descend of rising air to the ground. Meteorological conditions during winter, temperature and pressure gradient over oceans and continents, precipitation in temperate and tropical zones are some of the determinants of monsoon that operate globally and exercise their influence in the mechanism of monsoon.

Regional factors of control: Monsoons are largely considered to be a regional phenomenon. Topographic controls such as Himalayan Arch, Tibetan Plateau, Shillong plateau, Western Ghats, Arakan Yoma mountain chain, presence of hot deserts on the western margins of the continents in tropics and the location of island groups in proximity to equator exercise effective control on the origin of monsoon. It is well known that a large part of heavy rain that falls on the west coast of India is caused by the topographic barrier of Western Ghats. Regional meteorological observations such as floods in Nile, intensity of high rains in Abyssinian plateau and Zanzibar group of islands in tropical Africa during summer; persistence of cold wave in northern plains of India, extension of Siberian air mass up to Indian subcontinent and low air pressure conditions over Indian Ocean during winter are some of the regional factors that exercise influence in the mechanism of summer monsoon.

Figure 11: Physical Barriers and Control on Summer and Winter Monsoon



Source: Lal, D.S. (2009), **Physical Geography**, p. 365.

The locational and situational factors: Besides above, there are some locational and situational attributes that also exercise control over the effectiveness of the monsoon. The altitude, orientation and the extent of vegetal coverin a physical barrier augments the prospects of precipitation at a place. The west – east orientation of Himalayan arch serves as a factor of control for monsoon winds during summer. While there is a heavy rain to the south of Himalayas the areas north of Himalaya region remains dry and cold for most part of the year. Himalayas serve as a source of high altitude heat transfer towards north during summer and a facilitator for the transfer of cold wave towards North Indian Plains during winter. This characteristic plays a vital role in initiating the monsoon circulation over the South and South East Asia.

Tibetan Plateau, lying between Himalayan mountain system in the south and Altai mountain system in the north, acts as a factor in the origin and effectiveness of the monsoon. The Tibetan plateau remains warmer by 2^0 - 3^0 C than the adjoining areas during summer. The low pressure created in Tibetan Plateau pushes westerly Jet further northward and strengthens the easterly Jet which coincides with the appearance of the arrival of Indian Summer Monsoon.

Summary and Conclusions

The term 'monsoon' is broadly used to denote the cyclic reversal of pressure and wind systems in a year. Such a seasonal reversal of pressure and wind system is associated with sequential changes in the cloud and weather patterns mainly in the tropics. The monsoon plays a pivotal role in socio- economic life of the region. It is embedded in socio-cultural milieu of the people in monsoon lands. Thus, the economy and society in the tropical world depends directly on the success of the monsoon. The failure of monsoon upsets the socio-economic balance in the region. Behavior of the monsoon is erratic. Due to heavy rains in some parts of the region, the areas are flooded while in other parts there are severe drought conditions.

The classical theory of the origin of monsoon states that during summer solstice sun is overhead at tropic of Cancer. It results in high thermal conditions over the continents during summer causing low atmospheric pressure conditions. Consequently, air movements from oceans to continents takes place, as oceans are related to relatively low thermal conditions during summer season. The winds blowing from oceans are moisture laden and are the cause of monsoonal rains in tropics.

The dynamic theory states that the apparent change in the position of sun causes north and southward shift of ITCZ during summer and winter solstice. There is an associated change in the pressure conditions over land and sea in the tropical belt. The directional change of winds is more pronounced around Indian Ocean which has alternating distribution of land and sea. Consequently, winds from oceanic areas blow towards continents which are the source regions of high temperature and low air pressure during summer season. Thetheory has a scientific significance in explaining the origin of south-west and north-west monsoon in association with the movements of planetary trade winds.

The recent theory related to the origin of monsoon is based on observations concerning upper air circulation, temperature conditions over Tibetan Plateau, jet streams, oceanic water circulation, the occurrence of El Nino and La Nina, Southern Oscillations and Indian Ocean Dipole. Tibetan Plateau is a source of heat for the upper atmosphere. The rising temperature in higher altitudes generates an area of rising air motion. The low pressure created in Tibetan Plateau pushes westerly Jet further northward. It coincides with the arrival of Indian summer monsoon. The southward blow of air from Tibet helps to strengthen the prevailing easterly winds over south India. It explains the appearance of easterly Jet at about the same time as appearance of Indian monsoon. The effect of El Nino on summer monsoon is significant. The warming of Indian Ocean, under the influence of El Nino weakens the intensity of Monsoon. El Nino results in causing drought conditions and crop failures in Monsoon regions of South and South East Asia.

The system of Southern Oscillations is a seesaw pattern of meteorological changes that are often observed between Pacific and Indian Ocean. It has been established that when surface pressure is high over the Pacific, air pressure over Indian Ocean tends to be low. Since surface air pressure over oceans during dry winter season is inversely related to summer rainfall; prevalence of low air pressure over Indian Ocean during winter season is a sign of 'positive southern oscillations'. The chances of favorable monsoon are generally linked with 'positive southern oscillations'. On the contrary, if air pressure is high over Indian Ocean during winter season, it denotes the 'negative southern oscillations' which means that coming monsoon will be weak.

There are marked variations in thermal as well as atmospheric conditions of eastern and western part of Indian Ocean during winter months (December-January). These conditions are decisive for the significance of summer monsoon in Indian Ocean region. When western Indian Ocean remains warmer than eastern Indian Ocean during winter, it is said to be positive IOD which is indicative of favorable monsoon. Contrary to this, if situation is reversed it is said to be a negative IOD which is indicative of weak monsoon phase.

It is thus, obvious that mechanism of monsoon is a complex phenomenon and scientists are still engaged in decoding the mysteries of monsoon. Recent theory presents scientific explanation and is widely accepted.

In terms of controlling factors, there are global, regional and local elements that exercise influence on the mechanism of monsoon. Surface air circulation over continents and oceans and upper air circulation has a direct bearing on the intensity of monsoon. Rising temperature globally upsets the mechanism of monsoon and turns it erratic. Regional elements such as land barriers, distribution of ocean and continents and their orientation on the earth surface influences on the monsoon. Local elements such as forest cover, expanse of water bodies and wind ward orientation also influence the intensity of precipitation locally.

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