

The Monsoon and Its Variability
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Lecture - 01
Preamble and Introduction to the Indian Monsoon

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The monsoon and its variability

- **It gives me immense pleasure to give these set of lectures on a phenomenon I have studied for several years at the Centre for Atmospheric and Oceanic Sciences at the Indian Institute of Science.**
- **Over a billion people residing in the monsoonal regions of the world associate the monsoon with joy and love.**

Well, an alternative name for this series of lectures could be “monsoon for bird watchers”. It gives me immense pleasure to give these set of lectures on a phenomenon I have studied for several years at the Centre for Atmospheric and Oceanic Sciences at the Indian Institute of Science. Over a billion people residing in the monsoonal regions of the world associate the monsoon with joy and love.

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- **However, every year, they await the forthcoming monsoon season with some trepidation, as a deficit monsoon can have a disastrous impact on the well being of the people, the flora and fauna.**
- **Scientists of different hues as well as lay people are, therefore, curious about the monsoon and its vagaries.**

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- **In this lecture series on the Monsoon and its variability I have tried to elucidate important facets of this fascinating phenomenon, what we understand about the mechanisms leading to its variation in space and time, adaptation to monsoon variability and finally problems and prospects of monsoon prediction.**
- **I have adopted an approach which should make the lectures comprehensible to anybody with a desire to know the nature of this phenomenon.**

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- **I have assumed no prior knowledge of meteorology, and defined the jargon as and when required. I have attempted to elucidate the physical processes involved generally without using equations.**
- **At the same time I have dealt with each topic in some depth and included recent advances in the field. This should make it useful for students of atmospheric and oceanic sciences, particularly those interested in the tropical atmosphere and oceans.**

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- **Monsoon is one of the most challenging problems in atmospheric science today. It has a rich history with great minds having contributed to our understanding of the Indian monsoon from the 1880s onwards.**
- **I have talked about how ideas have evolved, discussed the present understanding of the monsoon and its variability and also brought out the scientific challenges that remain in modelling and prediction.**

Monsoon is one of the most challenging problems in atmospheric science today. It has a rich history with great minds having contributed to our understanding of the Indian monsoon from 1880s onwards. I have talked about how ideas have evolved, discussed the present understanding of the monsoon and its variability and also brought out the scientific challenges that remain in modelling and prediction.

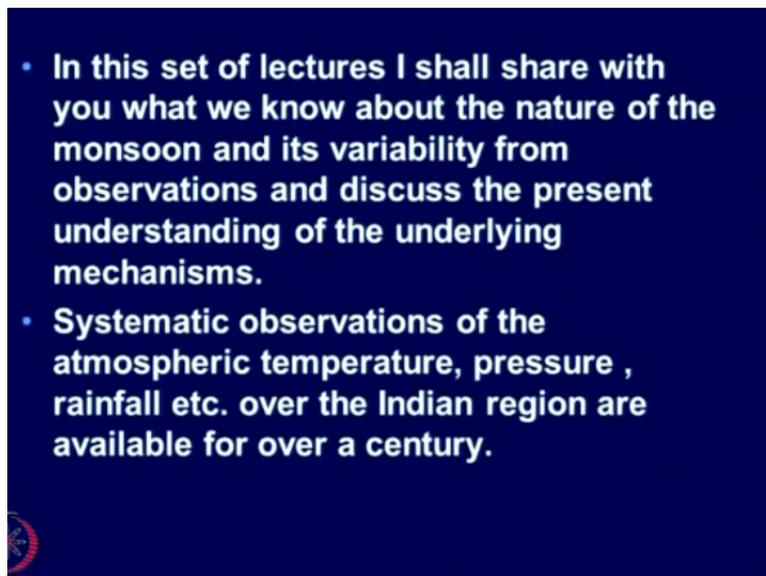
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- **I have considered quantitative assessments of the impact of the monsoon on agriculture and economy.**
- **Given the large socio-economic impacts, I have also discussed at some length the adaptation of farming strategies to the variability of the monsoon.**
- **I hope that by the end of the lecture series, at least a few amongst you come under the spell of this fascinating complex system and take up the challenge of understanding, modeling and predicting the monsoon and its variability.**

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Namaskar and Good afternoon! I am Sulochana Gadgil. My passion over 4 decades has been the monsoon. I have been working on the monsoon from 1973 in the Indian Institute of Science and so it is a great pleasure for me to give this course under NPTEL on “The Monsoon and Its Variability”.

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Now, in this set of lectures I shall share with you what we know about the nature of the monsoon and its variability from observations and discuss the present understanding of the underlying mechanisms. Now, systematic observations of the monsoon of the atmosphere over India actually of temperature, pressure, rainfall etc. are available for over a century.

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- With the analysis of the data of the first few years, a lucid account of the nature of rainfall and its variability by Blanford was published in 1886.
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With the analysis of the data of the first few years, a very lucid account of the nature of rainfall and its variability over the Indian region by Blanford was published in 1886. Of course, since then our knowledge about the weather and climate of India has increased continuously with the efforts of many monsoon meteorologists.

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With the advent of meteorological satellites in the mid-sixties, there was a quantum jump in our understanding of the nature of the system responsible for the monsoon and of the links of the Indian monsoon to events over the surrounding seas and the other parts of the tropical belt.

Now, with the advent of meteorological satellites in the mid-sixties, there was a quantum jump in our understanding of the monsoon, the nature of the system responsible for the monsoon and of the links of the Indian monsoon to events over the surrounding seas meaning the Bay of Bengal, Arabian Sea, Equatorial Indian Ocean as well as other parts of tropical belt like the Pacific.

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- **Observations of the tropical oceans and the atmosphere above with ocean based platforms (buoys) established in the 90s have further added to our knowledge of the monsoon and its ‘teleconnections’**
- **Thus much of our continuously growing knowledge of the monsoon has been gained empirically. Such an in depth knowledge of the nature of the system is essential for modeling and hence predicting the monsoon.**

Now, observations over the tropical oceans and the atmosphere above the ocean with special ocean based platforms called the buoys established in the 90s particularly over the Equatorial Pacific have further added to our knowledge of the monsoon and its ‘teleconnections’. Thus much of our continuously growing knowledge of the monsoon has been gained empirically. Such an in depth knowledge of the nature of the system is essential for modelling and hence predicting the monsoon.

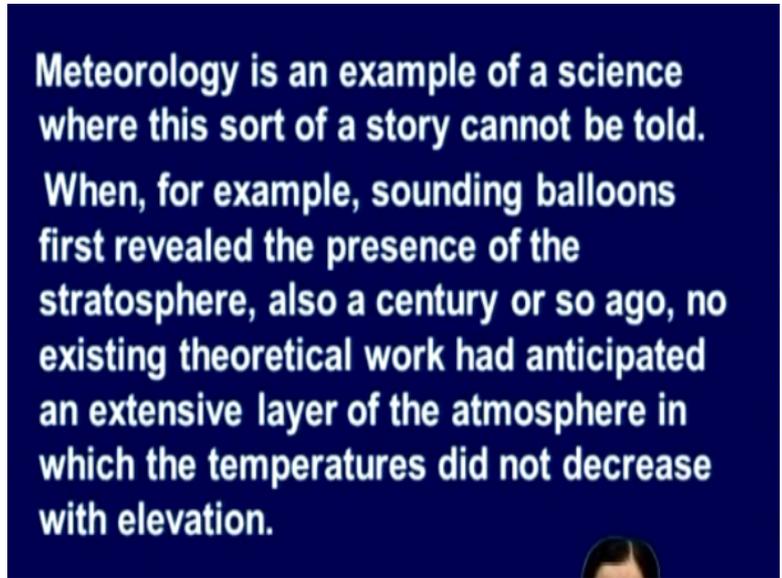
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The important role of empirical knowledge in advances in atmospheric science was pointed out by E N Lorenz. “A full century has passed since Albert Einstein announced his famous theory of relativity. Among the previously unobserved and unsuspected phenomena demanded by it was the bending of light rays that passed close to the Sun. Subsequent careful measurements confirmed that the theory was correct in this respect.

Now, the important role of empirical knowledge in advances in atmospheric science was pointed out by E N Lorenz, a genius, one of the most brilliant meteorologists, who, is perhaps better known to you all as “The Father of Predictability and Chaos”. Well, he remarks, “a full century has passed since Albert Einstein announced his famous theory of relativity and among the previously unobserved and unsuspected phenomena demanded by this theory was the bending of light rays that passed the Sun.

Now, subsequent careful measurements confirmed that the theory was correct in this respect so the prediction of the theory was (()) (06:13) out by observation subsequent to its publication.

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Meteorology is an example of a science where this sort of a story cannot be told. When, for example, sounding balloons first revealed the presence of the stratosphere, also a century or so ago, no existing theoretical work had anticipated an extensive layer of the atmosphere in which the temperatures did not decrease with elevation.

Now, Meteorology is an example of a science where this sort of a story cannot be told. When, for example, sounding balloons first revealed the presence of the stratosphere, you know that we are used to living in an atmosphere in which temperature decreases with height, this is why hill stations are cool and sea level stations are rather warm.

So when sounding balloons first revealed the presence of the stratosphere in which temperatures increases with height, okay. So the presence of a stratosphere also a century or so ago, no theoretical framework had anticipated an extensive layer of the atmosphere in which the temperature did not decrease with elevation.

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More recently, the earliest reports of Ozone depletion during the Antarctic spring (the 'Ozone hole') were attributed to instrumental error; no existing theory could account for them.'

in the forward to
"Empirical methods in short term climate prediction" by Huug van den Dool, Oxford university Press, 2007

Another example of new phenomena being discovered in the atmosphere which were not anticipated by theory at the time is more recently, the earliest report of Ozone depletion during the Antarctic spring known as the 'Ozone hole', were attributed to instrumental error; and the very first observations were thrown off, no existing theory could account for them'. So this is the remark made by Lorenz in a forward to a very interesting book called "Empirical methods" in short term climate prediction.

We will allude to this later in the course of our lectures.

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Overview

- I begin with what the monsoon means to the life in a monsoonal region such as ours and why I consider a study of the monsoon, the most enjoyable and worthwhile of our scientific endeavors.
- Then, I elucidate the important facets of the monsoon and its variability i.e. what is it that we are trying to understand and hence predict.

Now, let me first give you an overview of the lecture series, in what way I hope to cover the topic. I begin with what the monsoon means to the life in a monsoonal region such as ours

and why I consider the study of monsoon, the most enjoyable and worthwhile of our scientific endeavors.

Then, I elucidate the important facets of the monsoon and its variability because that is what we are trying to understand and eventually predict. There are great demands on prediction of the monsoon, so, we should know what are the facets of the monsoon that we should try and understand and predict.

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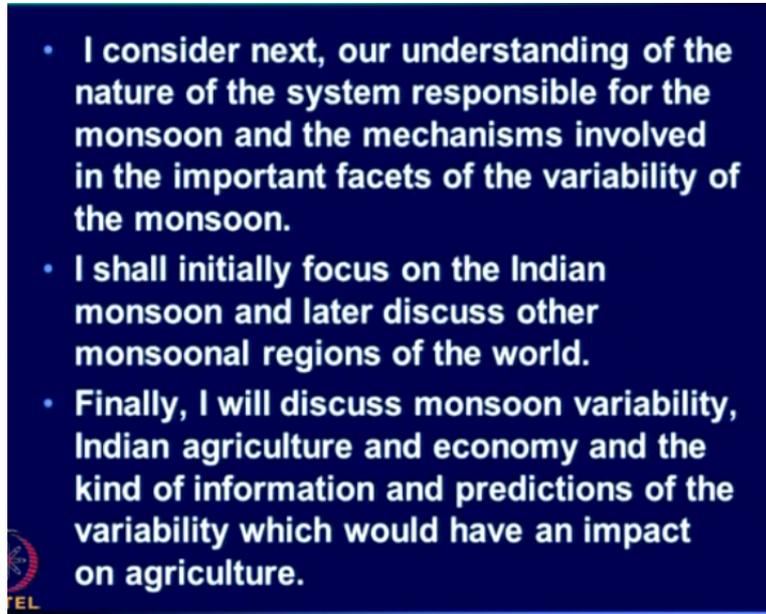
- **This is followed by a discussion of the background that is necessary to understand the physics of the monsoon and the proposed theories for the mechanisms governing its variability in terms of the nature of our atmosphere, important concepts and results from fluid dynamics and geophysical fluid dynamics.**
- **I have attempted to define all the terms used and explain all the basic concepts without introducing too many equations.**

Now after describing what we know from observations, as the important facets of the monsoon and its variability, I will discuss the background necessary to understand the physics of the monsoon and the proposed theories for mechanisms governing the variability. So I will develop some discussion on the background that we need and the background I do not assume too much of a background from the students.

So the background will involve the nature of our atmosphere, important concepts and results from fluid dynamics because you must remember that the atmosphere is a fluid after all and atmospheric circulation is flow of this fluid, as well as geophysical fluid dynamics. Now, why geophysical fluid dynamics, because the atmosphere is on a rotating earth and we measure winds or currents in the ocean relative to this rotating earth, so geophysical fluid dynamics concepts also are important.

Now, I have attempted to define the terms used and explain all the basic concepts without introducing too many equations. So I do hope that some naturalists and biologists who are also interested in the monsoon will come along at least for the first part of this course.

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- I consider next, our understanding of the nature of the system responsible for the monsoon and the mechanisms involved in the important facets of the variability of the monsoon.
 - I shall initially focus on the Indian monsoon and later discuss other monsoonal regions of the world.
 - Finally, I will discuss monsoon variability, Indian agriculture and economy and the kind of information and predictions of the variability which would have an impact on agriculture.

Now after developing the background necessary then I consider our understanding of the nature of the system responsible for the monsoon and the mechanisms involved in the important facets of the variability of the monsoon. Now, I shall initially focus on the Indian monsoon because I worked a great deal on the Indian monsoon, but, extend the discussion also to the other monsoonal regions of the world.

Finally, I would discuss another topic of great interest and great possibilities for application to society namely; the relationship between monsoon variability and agriculture and also economy, what is the kind of information about monsoon variability which would be useful for enhancing our agricultural production, what are the kind of predictions which would be useful and would contribute to the decision making of farmers to enhance the agricultural production.

And what is the impact assessment quantitatively of what is the impact of the monsoon on our agriculture and an important measure of the economy, the GDP.

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Lecture 1

- **Introduction to the Indian Monsoon: what is the monsoon, why study it?**
- **Response of the nature around us and the humans to the seasonal cycle**
- **Onset and retreat of the monsoon**
- **Rainfall over the Indian region in different seasons: the summer monsoon, pre-monsoon, post-monsoon and winter seasons**

Okay, so with this overview you will get a feel for how I am going to go about discussing the monsoon. Now let us begin with lecture 1. In lecture 1, the kind of topics I want to cover is; first of all, I will define what we mean by the monsoon, then try and share with you the response of nature around us and the humans to the seasonal cycle because those of us who live in the monsoonal regions of the world have a very strong link with this monsoon system.

Then I talk about the important phenomena of onset and retreat of the monsoon that is the seasonal variation and then talk to you about the climate in other words what is the mean rainfall in the major seasons of the year. So they would be the pre-monsoon season, the summer monsoon season, the post-monsoon season and the winter season. So this is the outline.

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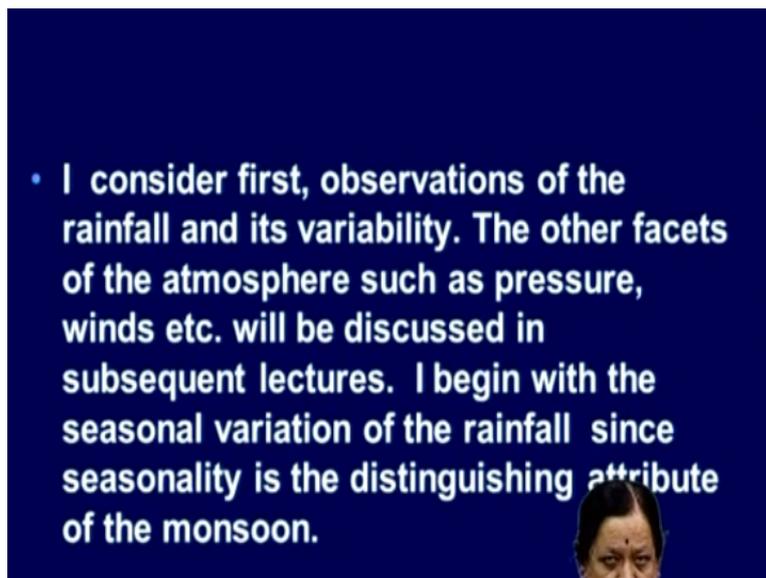
What is the Monsoon?

- **The term 'Monsoon' is derived from the Arabic/Hindi word 'Mausam' for season. The term was first used by Arab sailors for the large variation in the direction of the winds with season, observed over the Arabian Sea.**
- **However, for the billions inhabiting the monsoonal regions of the world, the marked variation of the rainfall with the season is of far greater interest than the seasonal variation of the wind.**

So let us begin with what is the monsoon. Now the term 'Monsoon' is derived from the word 'Mausam' in Arabic, which is also the word in Hindi for season and this term was first used by Arab sailors for the large variation in the direction of winds with season, observed over the Arabian Sea. So to come from where the Arabs live to India in one season the winds were very favourable right, they had a component which was going from the west to the east but in another season the winds would change direction and would be against them.

So this is something that the Arab sailors observed and called this seasonality of the direction of winds 'Mausam' or the 'Monsoon'. Now for many of us living in the monsoonal regions of the world wind really is not that important, it does not have much bearing on our life but what we care about is the variation of rainfall with season so the market variation of rainfall with season is of far greater interest to us than the seasonal variation of the wind which was of interest to the Arab sailors.

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Now I consider first, the observations of the rainfall and its variability. The other facets of the atmosphere such as pressure etc. will be discussed in subsequent lectures.

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Why study the monsoon?

- Understanding and predicting the monsoon and its variability is one of the most challenging problems in atmospheric science today.
- The monsoon governs the pulse of life for the millions of humans as well as the flora and fauna living on the Indian subcontinent.

Now, why study the monsoon? Why is it of such interest? First and foremost, for a scientist to get excited about it, must be on the cutting edge of science and indeed understanding and predicting the monsoon and its variability is one of the most challenging problems in atmospheric science today. So it is very exciting for us to work on this problem.

Also as I mentioned before, the monsoon governs the pulse of life for millions of humans as well as the rich flora and fauna living on the Indian subcontinent and also the other monsoonal regions of the world.

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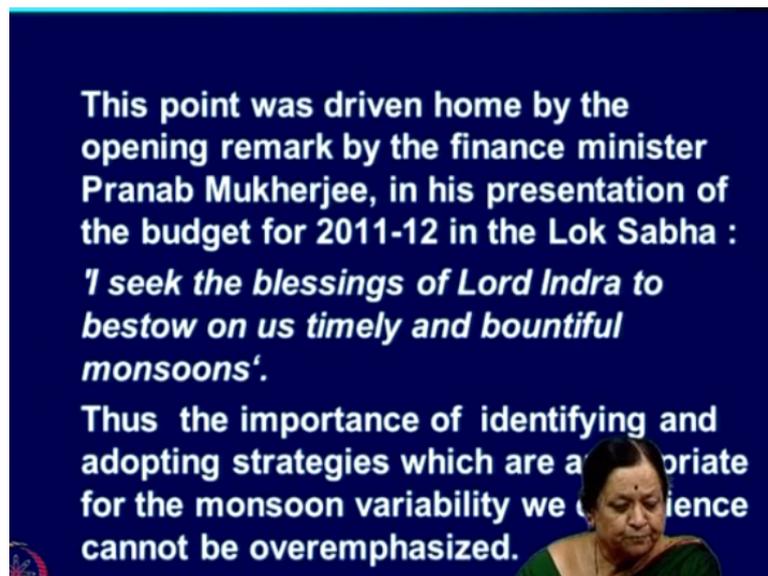
- Understanding and predicting the variability of the Indian monsoon is very important because it has a large impact on the agriculture and economy of the country. In the colonial era, the Indian economy was described as a gamble on the monsoon rains.
- Even after more than six decades of development, the monsoon continues to have a large impact on our economy.

So this is the second reason. Then understanding and predicting the variability of the monsoon, Indian monsoon is very important because it has a large impact on agriculture and economy of the country. In fact, in the colonial era, a Britisher is supposed to have remarked

that the Indian economy was described as a gamble on the monsoon rains, so dependent was our economy on the monsoon rains.

Now it was felt that with the kind of development we have had after the independence from the colonial rule one would have expected and many people predicted that we would not be so sensitive to the vagaries of the monsoon, okay. However, even after more than 6 decades of development, the monsoon continues to have a large impact on our economy.

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Now this point was driven home by the opening remark of the finance minister Pranab Mukherjee, in his presentation of the budget for 2011-12 in the Indian Parliament, the Lok Sabha. He began this budget speech saying, ‘I seek the blessings of Lord Indra to bestow on us timely and bountiful monsoons’.

You see, so thus the importance and remember he was the finance minister, thus the importance of identifying and adopting strategies which are appropriate for the monsoon variability we experience cannot be overemphasized, it is an extremely important problem. Okay.

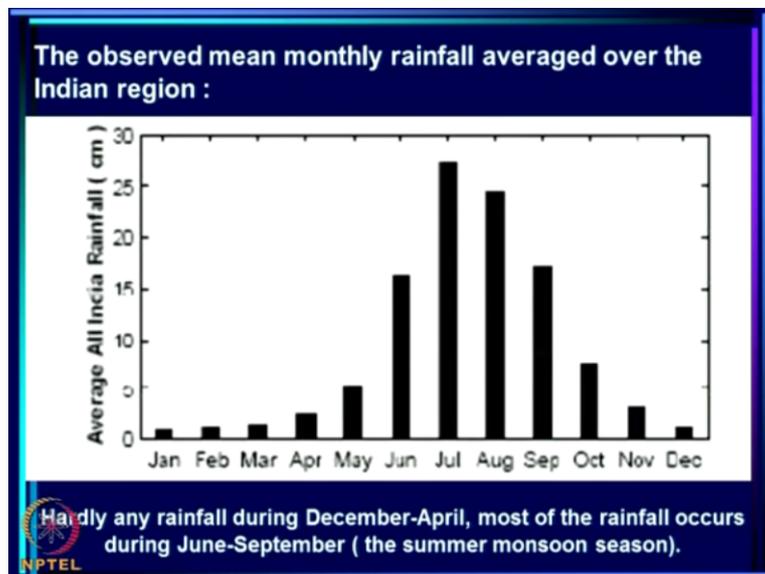
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The mean rainfall over the Indian region

- Consider first, the variation of the observed mean (averaged over about a hundred years) monthly rainfall averaged over the Indian region :
- Over the Indian region, there is hardly any rainfall during December to April and most of the rainfall occurs during June-September which is the summer monsoon season.

Now, having talked about the monsoon and seasonality. Let us see how the rainfall varies over our region. So first we are going to consider the mean or what is called climatology by meteorologists, this is average over many years typically 50 or more years. Okay. And furthermore we are also going to average over spatial scales. So we are going to look at rainfall averaged over the entire Indian region, okay, to begin with and we are going to see how monthly rainfall averaged over the entire country varies from month to month. Okay.

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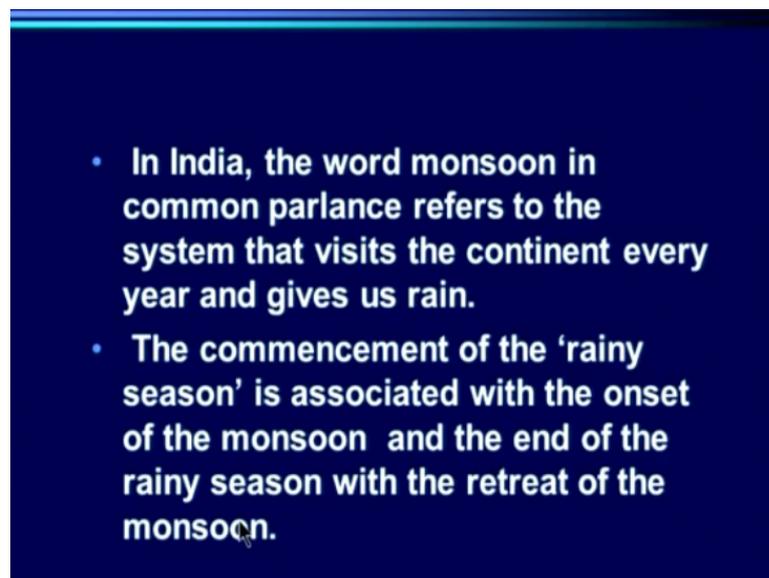


Now what you see here is plotted the variation of all-India Rainfall from January to December, as I mentioned this is average rainfall. This is not the rainfall of any specific year but it is the average rainfall over many years. So you can see that there is hardly any rain January, February, March and hardly any rain in December. So December to March hardly

any rain, April it has picked up a little, May it is still higher and June to September are the major rainy months as for us all-India Average Rainfall is concerned. Okay.

Then it decreases in October but is still significant, decreases further in November and becomes very small from December to March. Okay. So over the Indian region, there is hardly any rainfall between December to April and most of the rainfall occurs as you saw during the 4 months June, July, August and September. Now this June to September period, this season is called the summer monsoon season.

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- In India, the word monsoon in common parlance refers to the system that visits the continent every year and gives us rain.
 - The commencement of the 'rainy season' is associated with the onset of the monsoon and the end of the rainy season with the retreat of the monsoon.

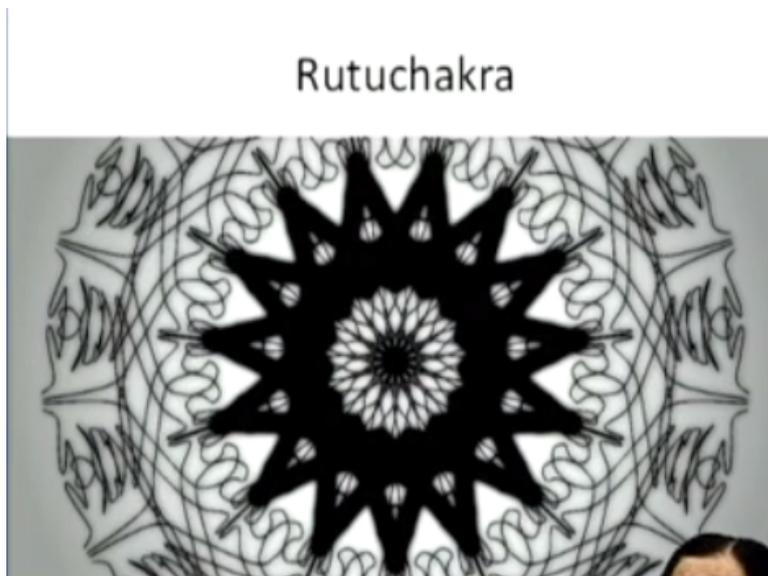
Now in fact, in India the word monsoon in common parlance refers to the system that visits us every year and gives us rain. So monsoon to us is the rain giving system or that comes and visits us every year and the commencement of the 'rainy season' is associated with the onset of the monsoon or the first arrival of the monsoon on the Indian region. Now end of the rainy season coincides with the retreat of the monsoon from our region.

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- In Indian poetry and films, the monsoon is associated with abundant joy and love.
- The life of plants, animals as well as human beings on the Indian subcontinent, is tuned to the seasonal cycle (Rutuchakra) of the rainfall associated with the annual visit of the monsoon

Now for those of us who live in this country know very well that in Indian poetry and films, the monsoon is associated with abundant joy and love. Life of plants, animals as well as human beings on the Indian subcontinent, is tuned to the seasonal cycle which we call Rutuchakra, 'Rutu' as you know in Sanskrit means the 'Season' and 'Chakra' is the 'Cycle'. So this Rutuchakra of the rainfall associated with the annual visit of the monsoon is what most of our plants and animals, birds and bees are tuned to.

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So let us just have a glimpse of how nature around us response to this seasonal cycle of the monsoon.

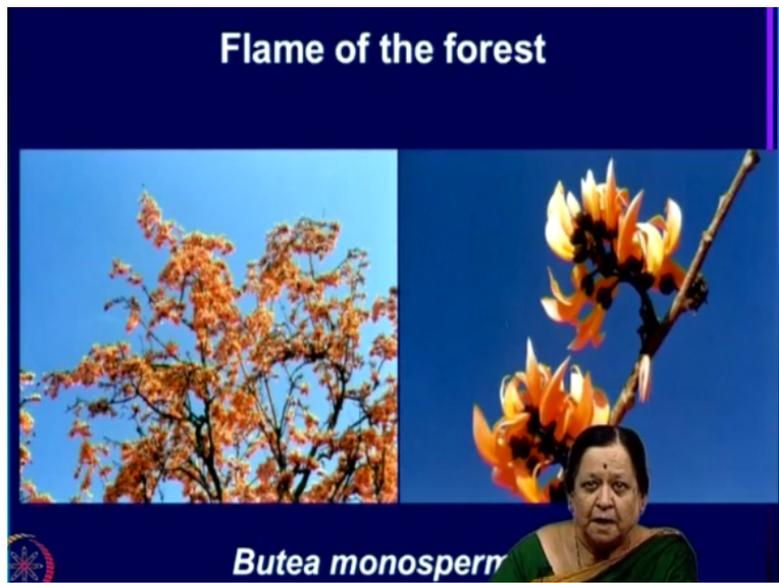
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The new year according to the Indian calendar, is around the spring equinox, which heralds the beginning of the hot dry summer preceding the monsoon rains.

At the height of the long dry season, many trees burst forth into bloom, as their seeds must be ripe and ready to sprout with the arrival of the rains. e.g. the flame of the forest (*Butea monosperma*),

Now the New Year according to the Indian calendar is around the spring equinox, right, 21st of March, which heralds the beginning of the hot dry summer preceding the monsoon. Now at the height of this long dry season, well it is solace, what give us solace are many trees burst forth into bloom, as their seeds must be ripe and ready to sprout with the arrival of the rains.

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Among some most beautiful of these trees is the “Flame of the forest” which you see in this slide and this again has inspired many a poet to write beautiful poems.

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Another spectacular tree that blooms in the hot dry season before the monsoon is the Indian Laburnum, 'Cassia fistula' and in fact there is an interesting story about this tree. People in Kerala believe that the onset of the monsoon in Kerala, the date of onset of the monsoon in Kerala is linked to the date when this tree first blooms before the monsoon season.

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Of course, in this hot season we have Koels which are Cuckoos, singing in the mango trees in fruit and they lend magic to the Vasanta Ritu, or spring, that just follows the spring equinox.

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As the dry season drags on, the lakes begin to dry and fish become easy picking for the pelicans. When the monsoon sets in, their chicks fly away and the Pelicans close shop.



Now, as the dry season drags on, the lakes begin to dry and the fish become very easy picking for the Pelicans. Now, when the monsoon sets in, their chicks fly away and the Pelicans close shop.

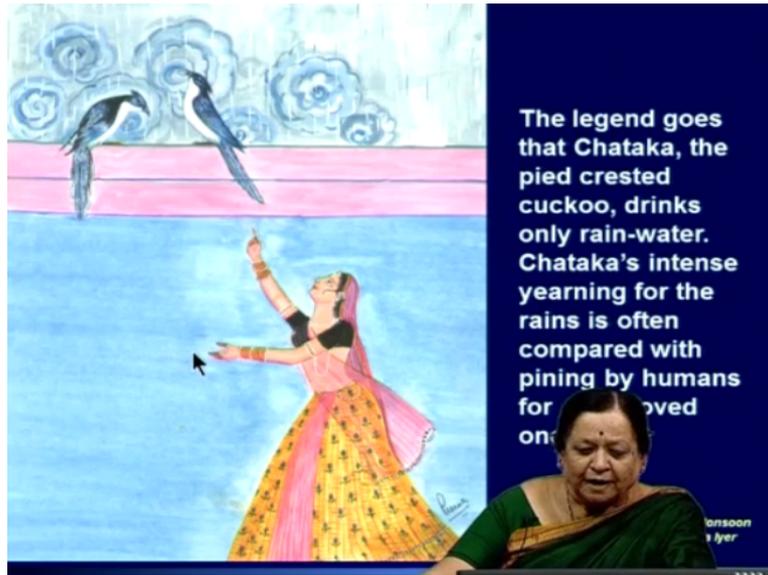
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As the rains approach, nomadic shepherds head back towards their monsoon settlements in the semi-arid tracts of the Peninsula



As the rains approach, nomadic shepherds head back towards their monsoon settlements in the semi-arid tracts of the Peninsula. Obviously, they want to go to regions where there is much less rains. So they start moving towards the semi-arid tracts of the Peninsula.

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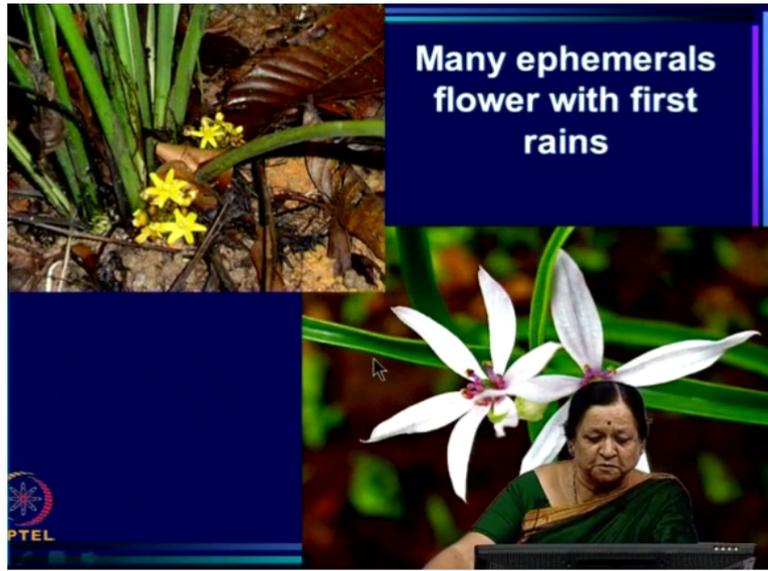
Now, this is a very famous bird called Chataka and the legend goes that Chataka, which is actually a pied crested cuckoo, drinks only rain-water, no other water would do, so Chataka's intense pining for rain is often compared with the pining by humans for their loved ones, again a source of lot of poetry in Indian literature.

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Now, at the end of the hot dry season or what marks the end of the hot dry season, certainly, in some parts of India is the burst of the monsoon and you see here these black clouds, Cumulonimbus, we will meet them again when we talk of clouds occurring over coast of Kerala which herald the burst of the monsoon.

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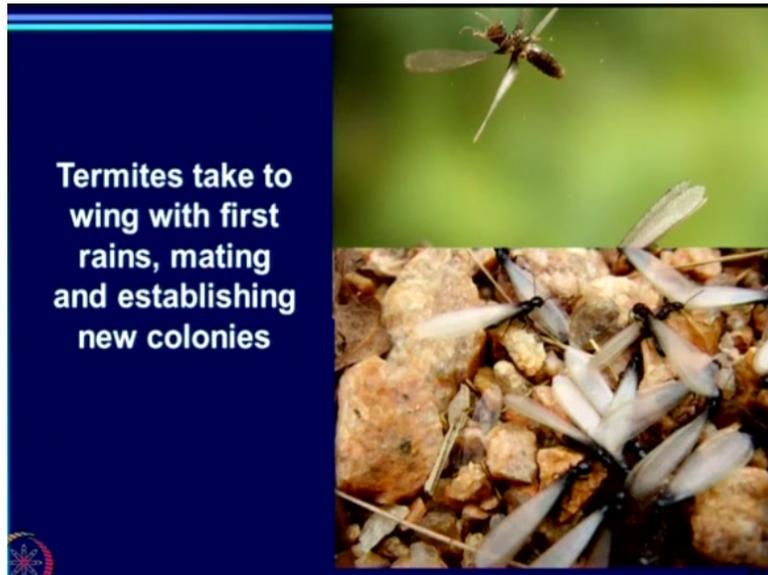
Now, as soon as the burst of the monsoon occurs, the mother earth changes. We immediately see these flowers around. Many ephemerals flower with the first rains; these are two of them.

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Then many medicinal herbs like Shatavari which is Asparagus sprout soon after the first rains.

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Termites take to wing with the first rains, mating and establishing new colonies. In fact, as soon as, we here the thunder and rain appear; very often termites invade our houses also because they come out in large numbers at this time.

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And with this large numbers of termites on wing Skillful fliers like Drongos hawk this bounty nature on wing, enjoying a feast of a lifetime.

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The spectacular dance of the peacock characterizes the monsoon season. Peafowl breed at the height of the monsoon, feeding on the reptiles that thrive during the rains.



Of course, during the monsoon, the spectacular dance of the Peacock is what we all enjoy seeing, it characterizes the monsoon season. Peafowl breed at the height of the monsoon, feeding on the reptiles that thrive during the rains.

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As rivers and streams swell with the monsoon rains, many fish swim up the current to spawn in pools near river origins.



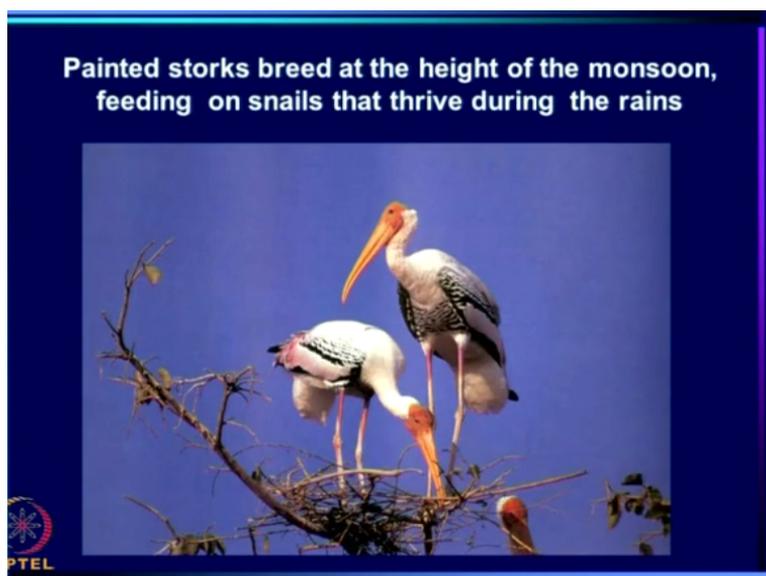
Now, as the rivers and streams swell with the monsoon rains, many Fish swim up the current to spawn in pools near the river origins.

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And you see one beautiful one here. Now, these are nests built by Baya Weaver birds. Now, Baya Weaver birds take advantage of the abundance of insects that feed on the monsoon vegetation to raise their Chicks.

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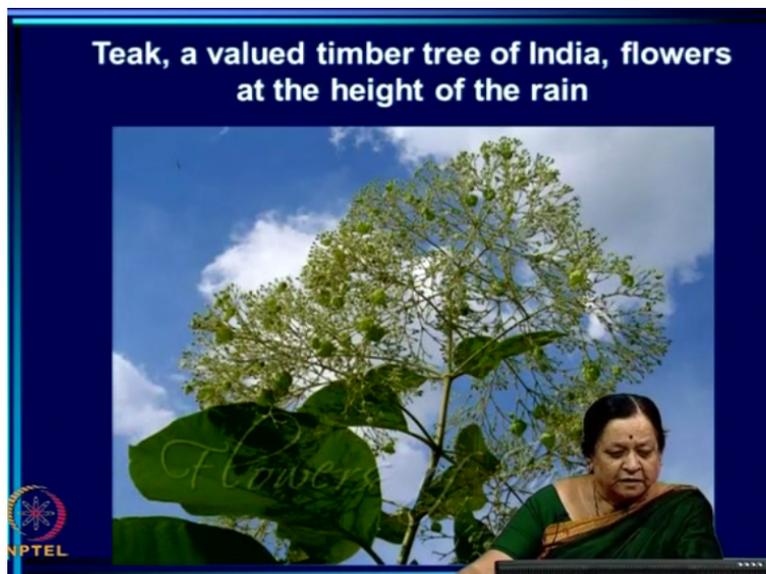
Painted storks breed at the height of the monsoon, feeding on Snails that thrive during the rains.

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Humans also have festivals which are connected with the monsoon and the one that attracts lot of attention during the monsoon is the famous Dahi handi festival. This takes place in Gokul Ashtami day and the one in Mumbai is very famous. It involves a pyramid of children, human pyramid, trying to break an earthen pot full of yogurt by eventually reaching, which is hung way above where they can reach. So this is the celebration, ritual celebration of the young called Dahi handi.

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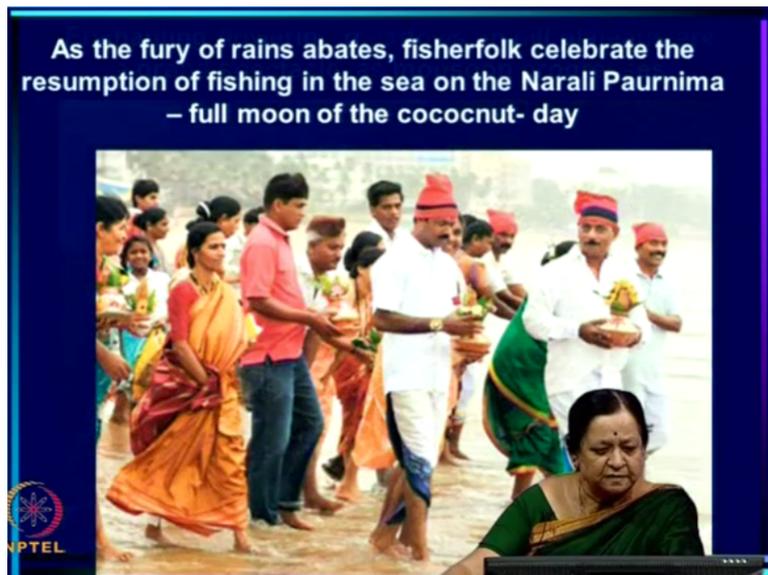
Now, Teak, a valued timber tree of India, flowers at the height of the rain.

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These are enchanting flowering meadows on hill plateaus which are a grand spectacle as monsoon progresses.

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And as the fury of rains abates, fisher folk, who had given up fishing during the monsoon season, celebrate the resumption of fishing in the sea on a full moon day, the Narali Purnima and this is called the coconut-day and they are going out to with coconuts to celebrate this.

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As the monsoon season draws to a close, elephants begin to head back to the rain forests of the Western Ghats, which they had left for the deciduous forests just before the onset of the monsoon.



As the monsoon season draws to a close, these gorgeous beasts of the forests, the elephants begin to head back to the rain forests of the Western Ghats, which they had left for the deciduous forests just before the onset of the monsoon.

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As rains abate, nomadic cattle keepers of Kutch move towards forested tracts of Central India



Now, as the rains abate, nomadic cattle keepers of Kutch which is on the west coast, to the north of the west coast move towards the forested tracks of central India.

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Seeding of grasses marks the end of the monsoon. You see them all in seed there.

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And you know in India we have typically 2 harvest seasons the Kharif season, the sowing occurs with the onset of the monsoon and harvest occur at the end of the monsoon. Now, Kharif harvests following the summer monsoon are celebrated by Deepavali, again another very famous festival in India called the festival of lamps, with fireworks, seen here on top of the beautiful Golden temple of Amritsar.

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Many Birds of Prey breed in the dry season that follows the monsoon, taking advantage of the abundance of rats and mice that have fattened on grass seeds



Now, many birds of prey breed in the dry season that follows the monsoon and you can see them here in this picture, taking advantage of the abundance of rats and mice that have fattened on the grass seeds.

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The final retreat of the monsoon from the south eastern parts of the Indian Peninsula is celebrated with the Pongal festival



The final retreat of the monsoon from the Indian region that is from the south eastern parts of the Indian Peninsula is celebrated with another very colourful festival called Pongal in south India, Maharasankranti in the north and what you see here is people very colourful clothes, wearing very colourful clothes and (()) (27:10) and dancing to the tune of the music.

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Holi, the festival of colours, is celebrated towards the end of the Indian calendar year, during the leisure following Rabi harvests and before the preparation for farming in the upcoming monsoon must begin



Then comes Holi, again it is a festival of colours and it is celebrated towards the end of the Indian calendar year and in fact it is celebrated in the interim when there is some leisure following the Rabi harvests, as I said there are 2 harvests. Rabi is planted soon after the monsoon is over and in fact the crops grow on stored water in the soil.

After Rabi harvests and before they have to start preparing for the Kharif season, there is some leisure and it is in this leisure that Holi, the festival of colours is celebrated.

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Soon after celebrating Holi shepherds move up Himalayan slopes to high altitude pastures, or, Bugyals



Soon after celebrating Holi shepherds move up the Himalayan slopes to high altitude pastures or, Bugyals.

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The seasonal cycle

- So far we have seen how life on the subcontinent revolves around the mean seasonal cycle. The seasonal cycle itself is not the same over different parts of the country. Thus there is a spatial variation in the dates of the onset of the monsoon as well as its retreat.

So, you see, life for humans and other creatures, plants, animals, bees, birds actually are tuned to the seasonal cycle which is what we called the monsoon. Now, so far we have seen how this life on the subcontinent revolves around the mean seasonal cycle. The seasonal cycle itself is not the same over different parts of the country.

We have to realize that, because the only picture we have seen is the all-India Average, but the average does not reflect the experience of different parts of the country. So in fact, there is a great deal of spatial variation in the rainfall from place to place. I must say one of the great advantages we have in studying the monsoon is the rich data sets that we have.

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The seasonal cycle

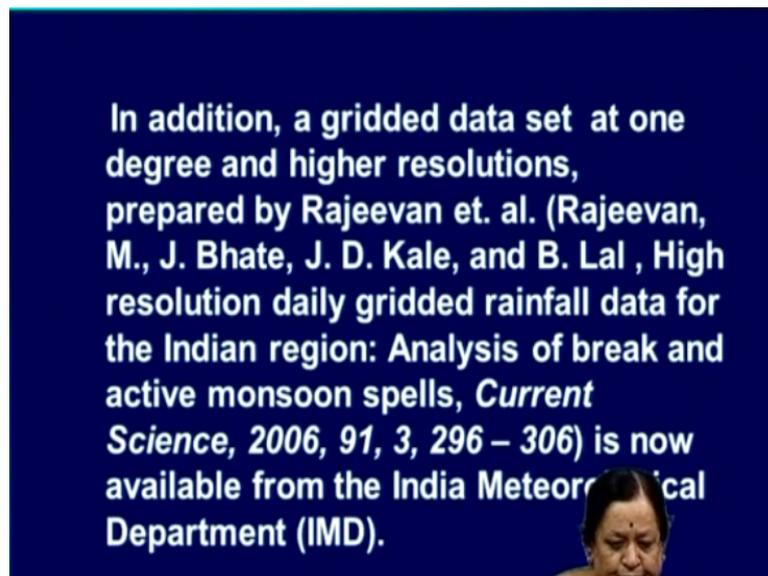
- So far we have seen how life on the subcontinent revolves around the mean seasonal cycle. The seasonal cycle itself is not the same over different parts of the country. Thus there is a spatial variation in the dates of the onset of the monsoon as well as its retreat.

In fact, data on observed rainfall and its variability are available at a large number of stations with modern rain gauges for the Indian region, right from 1876 onwards, okay. Now these

have been extensively analyzed, I said to begin with Blanford and then by many meteorologists after that.

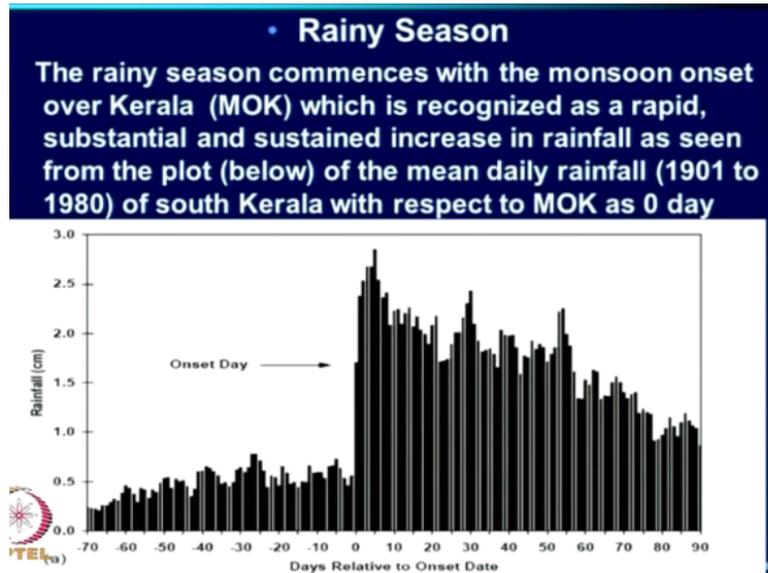
And actually some kind of analyzed data namely, monthly data for averages over the entire Indian region or what we call meteorological subdivisions to which again I will come to later in the lectures, are available actually to anybody who is interested from the website of the Indian Institute of Tropical Meteorology at Pune.

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Now, in addition to these rainfall data which are averaged over met subdivisions or over the entire country a gridded data set has been prepared recently, in fact, it was published on 2006 by Rajeevan and others from India Met Department and these data are available from the website of the India Met Department. Okay.

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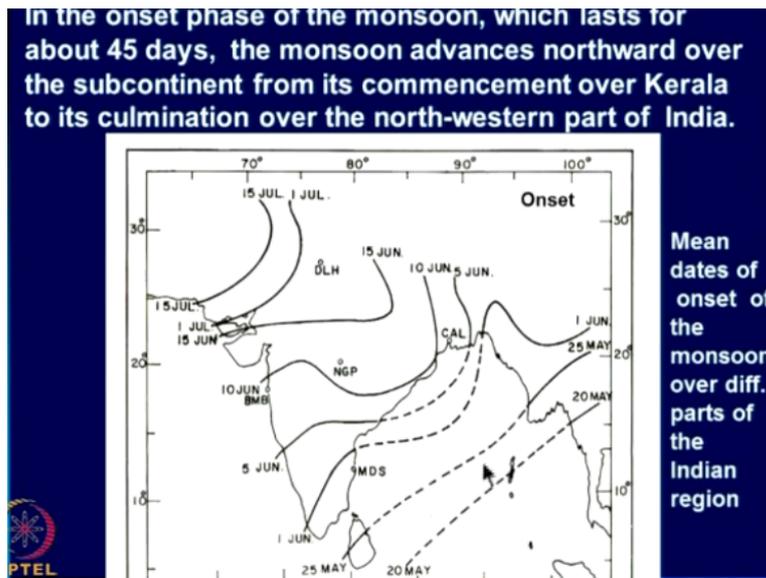
So, now let us see, what are the major facets of the monsoon or the rainy season? Okay. Now, the rainy season commences rather dramatically with the burst of the monsoon or what we call the onset of the monsoon and the first onset of the monsoon over the Indian region first occurs over Kerala, okay.

So, rainy season for the Indian region commences with the monsoon onset over Kerala (MOK) which is recognized as a rapid, substantial and sustained increase in rainfall. Now you can see that in the picture on your screen very clearly. You see what is done here is this is what we call the composite picture.

So you know the onset date varies from year to year but what is done is every year the date on which the MOK or the monsoon onset over Kerala actually occur is taken as 0 and then you count days from that, days after that in terms of positive numbers here, days before that in terms of negative numbers here. So what you see here is the rainfall before the onset and rainfall after the onset. This is obtained by averaging over all the years and the reason we see such a sharp peak is that we have not plotted calendar dates here.

With calendar dates you would not really see how abrupt the change is, but remember that in spite of the fact that it is an average over 80 years, 1901 to 1980, in spite of the fact that there is, it is averaged over such a long period you see such a spectacular sharp change, almost a step function change in the rainfall because we have adjusted the time and date such that all the onset dates fall on 0, this is what we call a composite.

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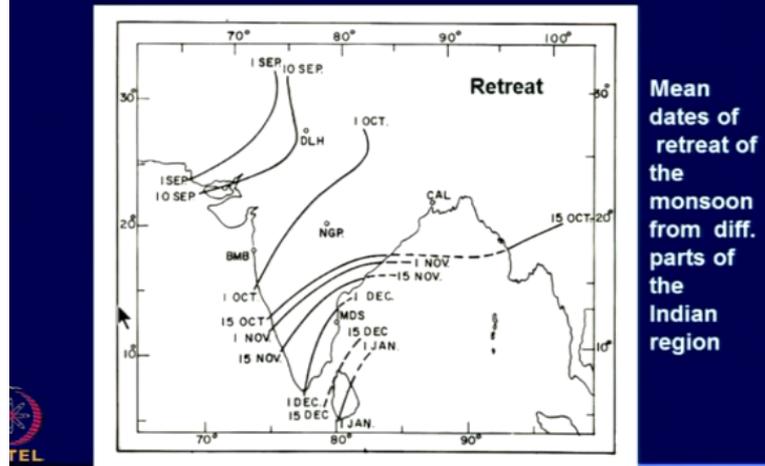
Okay, we have the spectacular onset over Kerala and the mean date is around 1st June. Now in the onset phase of the monsoon, which lasts for about 45 days, the monsoon moves northward, you see the monsoon moves northward in the onset phase. So having come to Kerala, it starts its journey northward in the onset phase and moves northward and north-westward to eventually reach, cover most of the country by 1st July.

But this is not the only track of the monsoon, onset of the monsoon over Andaman also occurs early and in fact in late May and from there again it starts moving here. So eventually around 1st June Gateway of Bengal also has had its onset and so then the monsoon moves from east to west towards Rajasthan and also from south to north towards the central parts of India.

So this is the onset phase of the monsoon and you can see that typically this onset phase takes about a month. By early July, in fact the almost the entire country has come under the sway of the monsoon. So this is the onset phase of the monsoon, which takes typically 45 days because if you go to the edge here, the Thar desert is somewhere here, if you go to the edge here, this is around 15 July and this is 1st July. Okay, but much of the country is already covered by 1st of July.

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The retreat of the monsoon commences in September from the north-western parts with the final phase over the south peninsula completed by mid-December.



Okay, so this is how the monsoon comes, this is the augma or the onset of the monsoon. The retreat of the monsoon commences in September, okay. And it in fact retraces its steps in (()) (34:15) so 1st September the retreats begin in the north-western part then it starts going slowly eastward. By 1st October it has gone beyond 80 degrees east or so and it has also moved south.

So it has gone south of Mumbai and it has come half way across the central plains by 1st October. So a large portion of India is no longer under the sway of the monsoon by the end of September, okay. Now by Mid-October actually, most of the region north of 15 degrees north is out of the sway of the monsoon. The monsoon is restricted to the southern Peninsula, to the peninsular region, south of about 15 degrees north.

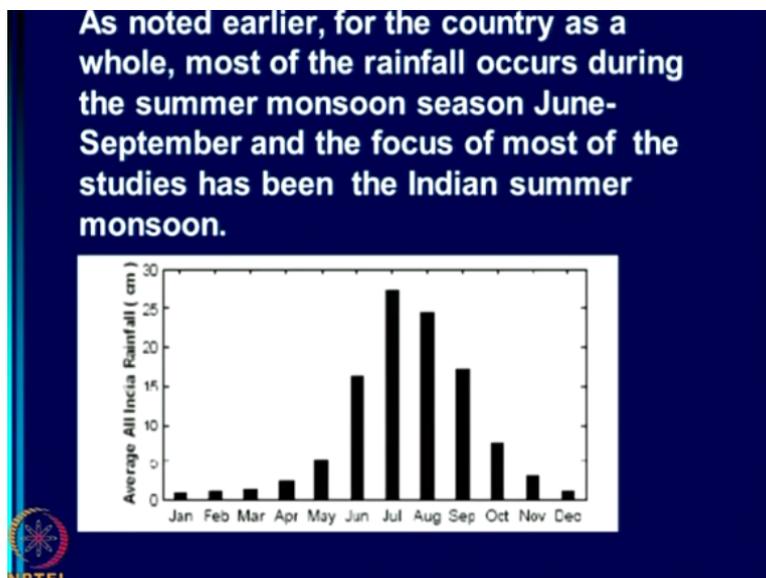
Now it keeps retreating from there and eventually completely retreats from our region only by about 15th of December. So this is the retreat phase of the monsoon and again.

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- It is seen that the entire country comes under the sway of the monsoon at the end of the onset phase, around the end of June. The monsoon begins its retreat from the northwestern parts around the beginning of September. July and August are, therefore, considered peak monsoon months. By the first half of October, the monsoon is restricted to the peninsula south of 15° N.

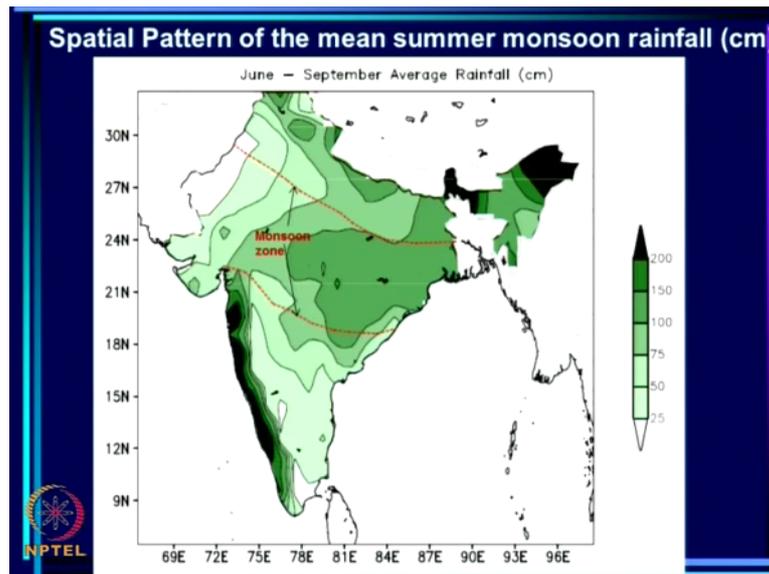
So what we have seen that the entire country comes under the sway of the monsoon at the end of the onset phase, around the end of June or beginning of July. The monsoon begins its retreat from the north-west region around 1st of September, right. So, July and August are, therefore, considered peak monsoon months, okay. And by the 1st half of October, the monsoon has gone south of 15 degrees north.

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As we have seen earlier, you know, if we consider the country as a whole, most of the rainfall comes during June to September; this is called the summer monsoon season and has been the focus of most of the studies on the monsoon.

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Let us look at what is the rainfall look like over the Indian region during June to September. So we are now looking at the average summer monsoon rainfall, okay, average over June to September at every place and what you see here is the rainfall pattern. And you can see, this stick tells you how much rain has occurred and please note that the units are centimetres.

So this very dark green, the darkest green here in the north-east and also part of Western Ghats and west coast actually correspond to more than 200 centimetres of rain in 4 months, okay. So it rains copiously in some parts. Then you can see that below 25 centimetres in 4 months, we have not even shown any colours.

Then this is 25 to 50 centimetres and there is actually a major rain belt that you see here, okay, in what we call the monsoon zone. Now that is marked by red here. So the monsoon zone has the major rain belt of the summer monsoon, okay and what is happening you can see is, that the rain is maximum near the gateway, near the east coast and as we go along the monsoon zone towards the north-west, the rainfall decreases from its maximum here to its minimum here, okay.

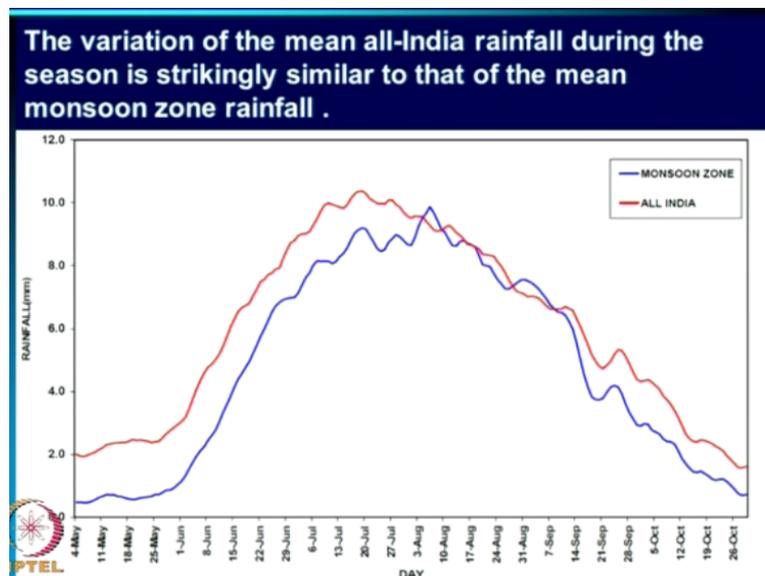
So this is the large rain belt which is the major rainy system of our summer monsoon. In addition to that lot of rain also occurs, heavy rain over west coast of the peninsula and the Western Ghats and the north-east region. This is the spatial pattern of the mean summer monsoon rainfall; please keep in the back of your mind that I am not talking of the rainfall of any year. This is the mean picture or what reflects the climate of the region.

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- It is seen that the mean rainfall pattern during the summer monsoon is characterized by a major rain-belt over the 'monsoon zone' (marked by the red-dashed line, in the last slide), with the rainfall decreasing northwestward from the maximum over the eastern part.
- In addition, heavy rainfall occurs along the west coast of the peninsula and over the northeastern region.

Now we have seen that the mean rainfall during the summer monsoon is characterized by the major rain belt over the 'monsoon zone' which we saw, with the rainfall decreasing northwestward from the maximum over the eastern part, okay. And in addition to this major rain belt, very large-scale rain belt, heavy rainfall also occurs along the west coast of the peninsula and over the north-eastern region. So these are the typical 3 rainy regions of the south-west monsoon.

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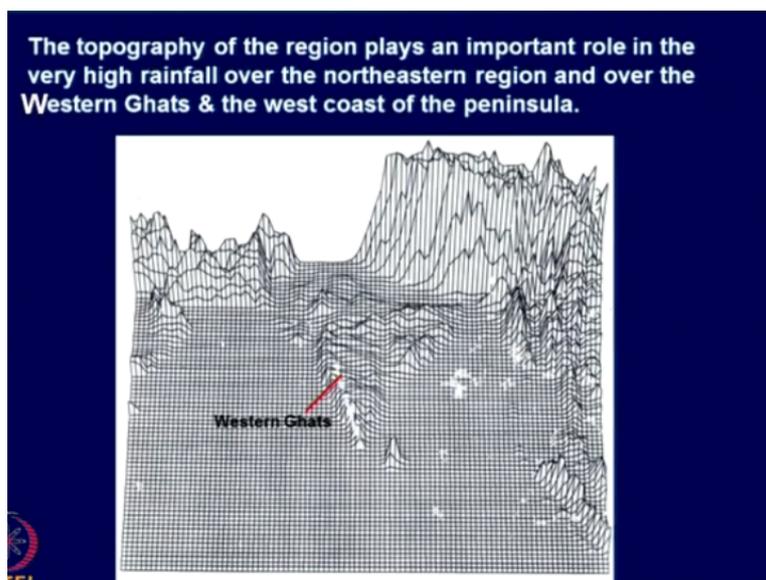


Now, this monsoon zone is very important because in a way that is the seat of the monsoon, during the peak monsoon months, okay. And what we have plotted here is again still the mean over many years and this is the rainfall and this is the date. So this will be the mean rainfall for 16th of May and red corresponds to the all-India rainfall and blue corresponds to monsoon zone.

So what you see is that the variation of both is very similar. Until the onset phase ends, in fact the monsoon zone rainfall is smaller than all-India rainfall because you must remember that monsoon has not made it yet to whole sway over the entire country. So in the onset phase it is less but you can see that the variation is still very similar.

Then during July, it comes closer to the all-India, August it is very close and then again once the retreat begins they part ways because Indian rainfall has contributions from other regions where as monsoon zone rainfall is decreasing. So you can see here that the pattern of variation, seasonal variation, now this is much, on a much smaller scale than month, this is on a weekly scale, is very similar for the monsoon zone rainfall and all-India rainfall or the Indian region average rainfall.

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Now there are many special features of the Indian region and one amongst them is our somewhat spectacular topography. Topography is mountain ranges and so on and so far topo features if you wish. So one important topography here is the Western Ghats, part of which is also called Sahyadri but it contains also many other mountain ranges.

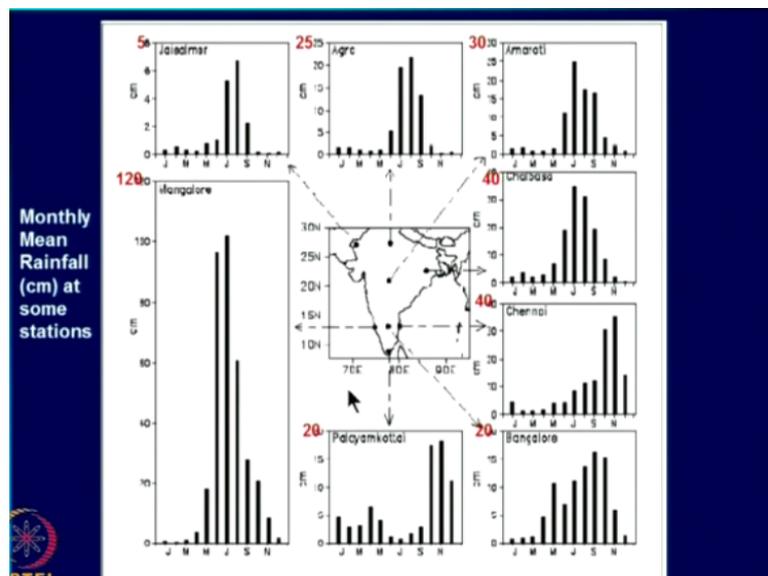
So these Western Ghats play a very important role and the other is the spectacular Tibetan plateau which actually extends to almost half the troposphere and it is the huge massive plateau which certainly has an impact on the regional climate and the monsoon, okay. Now, it is believed that the topography of the Western Ghats and the topography you see here, lot of hill ranges and so on of the north-east contribute to the rainfall over those regions.

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Although the focus of most of the studies of the Indian monsoon has been the Indian summer monsoon, the summer monsoon is not the major rainy season for the entire country. Consider the mean monthly (i.e. average over 30 or more years) rainfall at stations across the Indian region- next slide

So, this is the scenario, as far as the average rainfall during the summer monsoon period is concerned, okay. Now, although the focus of most of the studies of the Indian monsoon has been on the Indian summer monsoon, the summer monsoon is not the major rainy season for other, for all the, for the entire region it is not the major rainy season.

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In fact, let us see how the rainy season varies from place to place over India, okay. So what you see here is again mean monthly rainfall like we saw in the 1st slide. But this time it is not the average level for any spatial region, it is the mean monthly rainfall at different stations that represent different parts of the country, okay. So now let us begin here with the west coast, we already saw that west coast receives a lot of rainfall, okay.

And this is Mangalore on the west coast and the mean rainfall is shown here, mean monthly rainfall and you see the scale is such that the maximum here is 120 centimetres in a month (0) (42:16), okay. So this is 120 centimetres in a month and what you see here is that there is hardly any rain up to March or even in April there is not much rain, in May picks up somewhat. But June July are the very high rainfall months.

August it decreases on the west coast but is substantive and September also it gets rain, October also there is rain and November it starts petering out, by December there is not much rain. So this is the situation, this is our 13 degrees north; this is on the west coast. Now in the same latitude belt let us consider 2 other stations. One is Bangalore, from where actually this course is being recorded. This is Bangalore where the Indian Institute of Science is situated and let us see the monthly pattern for Bangalore.

Now for Bangalore, again you see, January, February, March and December there is hardly any rain, okay. It picks up by April and is quite substantive in May, decreases somewhat in June as the monsoon progresses northward of Bangalore, again July, August, September it keeps increasing, it is rather high in September and October, okay and then decreases in November, okay.

So it seems to get rain, like Mangalore does in June July, as well as the earlier part of the season, the pre-monsoon rain is also quite good here. It gets rain in June-July like Mangalore, continues to get rain in the latter part of the summer monsoon season as well and then gets quite a bit of rain in October and November, okay. So this is during the summer monsoon it gets rain, it also gets pre-monsoon rains, it also gets rain in October-November.

Now let us go to the east coast, same latitude 13 degrees north and this is of course, the ancient city of Chennai. Now Chennai as we went from Mangalore, sorry! As we went from Mangalore to Bangalore, in fact what happened was that the contribution of the October-November rainfall increase.

Now, as we go to Chennai, in fact, it is October-November rainfall that dominates, June, July, August, September there is hardly any rain, no pre-monsoon rain and October-November there is substantive rain which continues into December. You see there is considerable

variation in pattern of rainfall over the Peninsula but by in large the contribution of October-November rainfall is there for all the stations, okay.

Now, let us go to the southern tip of India, this is in Tamilnadu, Palayamkottai and this, a bit like Chennai, gets rain mainly in October-November continues to get rain in December, but gets much more rain during the winter months as well as the pre-monsoon and gets almost no rain at all from June to September, much less than Chennai actually.

Now we should note that that the rainfall involved is different. Here the maximum on the scale for Bangalore is only 20 centimetre, same for Palayamkottai and but for Chennai it is higher. So Chennai is getting more in these two months. So much now is the story for Peninsula and I find out dealt on a little bit because it is different in that it does not get rainfall only from the summer monsoon.

Now when we go to these stations, all these stations get rainfall, maximum rainfall during the summer monsoon. On the east coast you get rainfall again in June, July, August are the major months. This is again Amravati in central India again here July gets more than August and September, but all 4 months get rain.

Then this is in the north and again all 4 months get rain. And then we go finally to Jaisalmer and Jaisalmer where June rain is not much because monsoon has not made it yet and July and August get enough rain and by September it starts retreating. So there is considerable variation from place to place in the rainfall patterns.

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- The pattern of the variation of the mean monthly rainfall is not the same across the Indian region. Over the monsoon zone, most of the rainfall, occurs during the summer monsoon (June-September). This season is also called the southwest monsoon.
- On the other hand, over southeastern peninsula and the southern tip of the peninsula most of the rainfall occurs during October-December which is called the post-monsoon or the northeast monsoon.

So the pattern of the variation of the mean monthly rainfall is not the same across the Indian region, we have seen this. Over the monsoon zone, most of the rainfall, occurs during the summer monsoon and this season is also been called as the southwest monsoon. If you remember your Geography lessons in school, we were taught that this was the southwest monsoon season.

On the other hand, south-eastern Peninsula and the southern tip of Peninsula, most of the rainfall occur during October to December, which we called the post-monsoon season but which is also been called the north-east monsoon.

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- The west coast of the southern peninsula gets rain in the summer monsoon as well as post-monsoon seasons.
- The summer monsoon season (June-September) is also called the Southwest monsoon season. The post monsoon season (October-December) is also called the Northeast monsoon season.
- When I discuss the system responsible for the monsoon rains, I shall show that the names 'southwest' and 'northeast' for the seasons are misleading and inappropriate.

Now I will come back to this nomenclature. Now we have to note that the west coast of southern peninsula gets rain in the summer monsoon, as well as in the post monsoon. And

that the summer monsoon season is also called the Southwest monsoon season, as I mentioned earlier. And the post monsoon season is also called the north-east monsoon season, as we were taught.

Now when I discuss the system responsible for the monsoon rains, I will show that the names 'southwest' and 'northeast' for the seasons are misleading and inappropriate. But we will save that for the time when I talk about the system responsible for the monsoon.

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- The differences in the rainy season across the Indian region are manifested as differences in the spatial patterns for the mean rainfall for the different seasons. The mean rainfall for the for the different seasons viz.
- Pre-monsoon season – March-May
- Summer monsoon -June-September
- Post-monsoon : October-December and
- Winter- January –February

are depicted in the next set of slides.

Now the differences in the rainy season across the country are manifested as the differences in the spatial patterns for different seasons, obviously. So let us now quickly see what are the, what is the rainfall pattern like, for the pre-monsoon season which is March to May.

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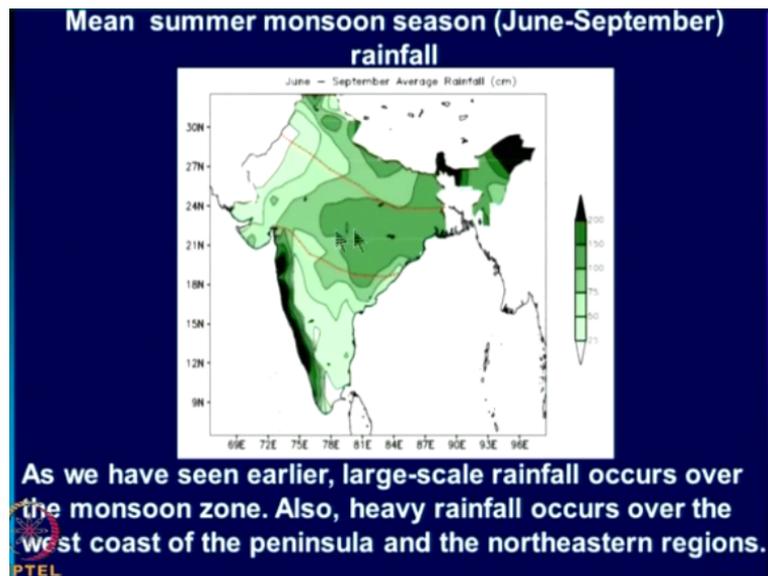
Mean pre-monsoon season (March-May) rainfall

March - May Average Rainfall (cm)

In the pre-monsoon season , rainfall occurs over the peninsula south of 15° N and parts of the east coast in tropical systems. In addition, some rainfall occurs in northern parts due to mid-latitude systems.

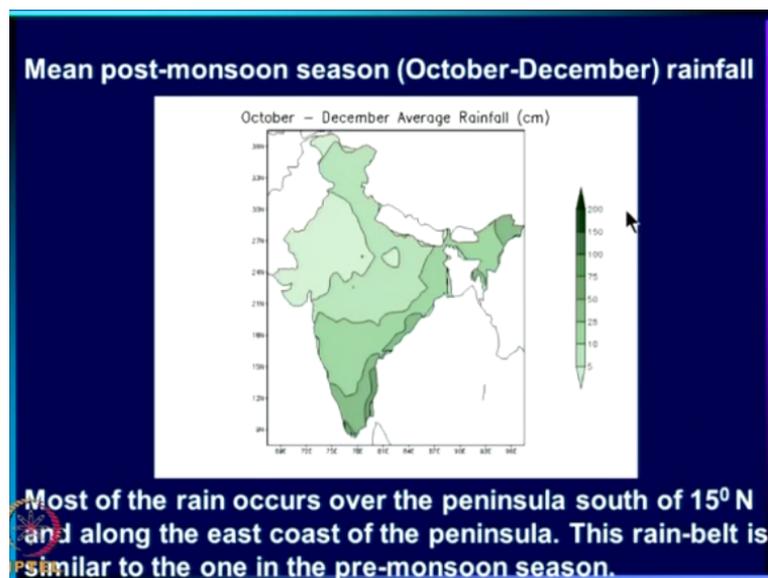
So March to May, you can see that most of the rainfall occurs in the Peninsula, south of 15 degrees north, this is where we could also see some pre-monsoon showers in places like Bangalore so on so far. It also extends to on the east coast, okay. So now there is also rain occurring at higher latitudes here. But this rain is not associated with tropical systems, rather northern parts of India come under the mid-latitude system in these months and so this is associated with mid-latitude systems.

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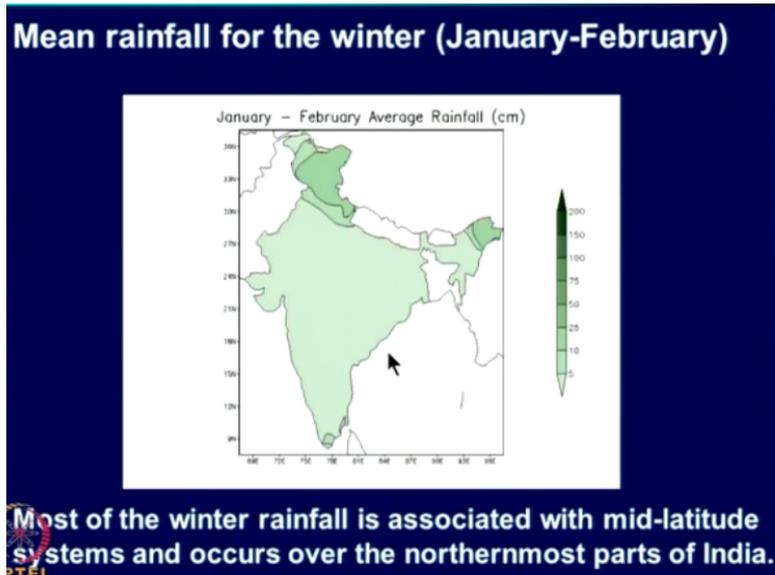
Now this is the 7 monsoon pattern from which we have seen already

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And then comes October to December pattern, this is very similar to the pre-monsoon pattern; again you have rain primarily over the Peninsula and over the east coast here, okay.

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And then, we come to the winter, which is January to February and this rainfall has nothing to do with tropics and you can see, it is restricted to the northern parts, which come under the sway of mid-latitude systems or higher latitude systems. So, this is something else, this is not monsoon rain, this is some other rain.

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- So far I have considered only features of the 'mean monsoon' or the average rainfall over a long period. Next, I will discuss the variability of some of the facets of the rainfall considered here as well as the nature of the variability revealed by analysis of satellite data, focusing on the major rainy season i.e. the summer monsoon (June-September).

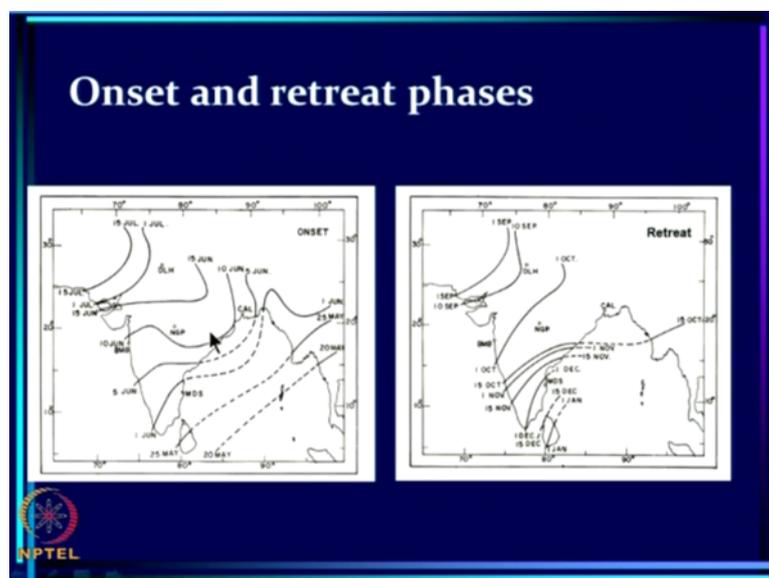
Okay, now, so far I have talked of only what we call the climate or what is the mean pattern, mean temporal pattern, we talked of average monthly rainfall both at stations as well as in all-India level, as well as mean spatial pattern, pattern associated with each of the seasons; the pre-monsoon, the post monsoon, so what is the mean rainfall expected over different parts of India for during this season, that is to say averaged over the season.

Now the whole point is, that in no year does the Indian average rainfall look like the all-India average mean rainfall that we have seen. Every year differs in all facets and so every year will be different and that is what makes the variability of the monsoon and it is the variability of the monsoon from climate which we are interested. So the next focus is going to be on the nature of variability of the important facets of the monsoon as revealed by analysis of conventional, as well as satellite data.

Now as far as this lecture is concerned let us just review briefly what we have learnt. We have learnt that this drama of the monsoon, the drama that occurs year after year with very similar events taking place but with considerable variability in the timing and distribution of these events, so thus it makes fun to study the monsoon variability.

But the same events take place year after year. So the first event of course in the drama is the monsoon onset over Kerala and you saw how spectacularly the monsoon change the rainfall increase and so it was called a sudden increase and this was sustained until the end of the season. So it is then sustained after that you know, it does not go back to what it was before the onset of the season.

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Then you recall we looked at what are the mean onset dates of the monsoon over different parts of the country, mean dates of the retreat of the monsoon from different parts of the country. We saw that the onset phase is about 45 days. Beginning with around 1st June with monsoon onset over Kerala, then the monsoon progresses northward as we go and also westward, at the same time the monsoon onset occurs over Kerala.

In fact, even before the onset of monsoon occurs over the Andaman and then it progresses in this direction with the gateway, already getting the onset by about 1st of June. And from there it progresses westward, you have the northward advance and the westward advance during the onset phase and the entire onset phase would start from here and go right up it takes about 45 days.

And also seen that the retreat of the monsoon is reversing the steps and by it starts in 1st of September and by the end of the summer monsoon season a large part of India has been left by the monsoon, only this is covered by the monsoon. By 15th of October, most of the entire monsoon zone is out of the sway of the monsoon and its only south of 15 and part of east coast that has rain and eventually after giving rain in the o called post monsoon season the monsoon retreats from our country side around December. So this is what we have seen.

This is the summer monsoon rainfall, which is really been the focus of most of the studies and which is something we understand most about and which I will also focus on. So in the next lecture then, what we will do is look at the variability of the monsoon by analysis of conventional and satellite data, what are the important facets, what are the things that we would like to understand and predict, what are the facets that is important to predict and that we would like to understand model and predict. Thank you.