**The Monsoon and Its Variability**
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**Lecture - 02**
**Nature of the variability of the Indian Monsoon**

Good afternoon, we have in the last lecture looked at what are the mean rainfall patterns like over the Indian region as well as the all-India rainfall. In this lecture, we look at the problem of nature of variability of the Indian monsoon by looking at what conventional as well as satellite data have shown us.

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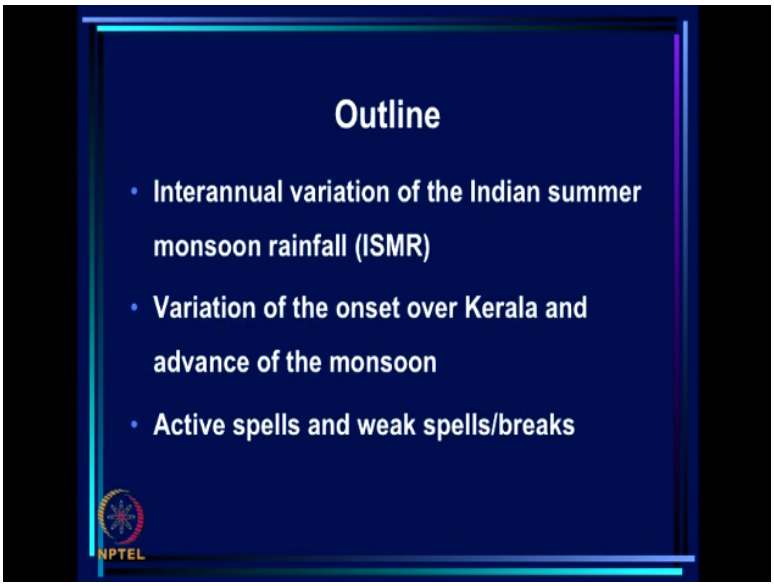


So, today's lecture, the outline is first we will consider the inter annual variation of the Indian summer monsoon rainfall that is to say the year to year variation of the all-India average of the summer monsoon that is to say June to September rainfall. Then we will talk of variation of the various facets of the monsoon we considered last time. We considered the mean date of onset over Kerala.

So now, we look at variation of the onset date over Kerala and variation in the advance of the monsoon. We will also look at active spells and weak spells or breaks.

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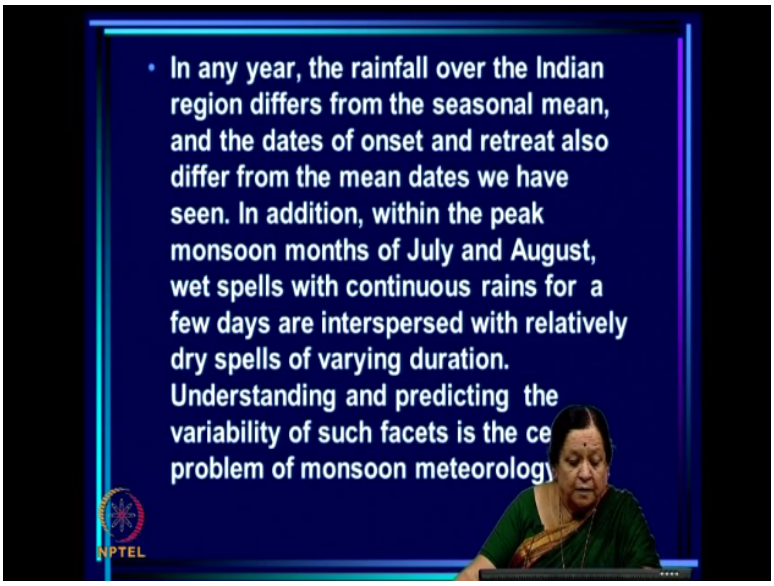


Now, in any year the rainfall over the Indian region differs from the seasonal mean which we have seen in the last lecture. And the dates of the onset, retreats also vary from year to year. In addition, within the peak monsoon months of July and August when the monsoon zone has the monsoon established over it. In fact, wet and dry spells occur.

Wet spells with continuous rain for several days interspersed with relatively dry spells with varying duration. Now, understanding and predicting the variability of such facets is the central problem of monsoon meteorology that is to say understanding and predicting. Year to year variation of the Indian rainfall average does the whole over the Indian region as well as average over difference spatial region.

As well as intra-seasonal or variation within the season between wet spells in which you have continuous rain for several days and dry spells, which may be relatively dry spell in which you have relatively less rain or it could be totally dry spells in which you have no rain at all okay.

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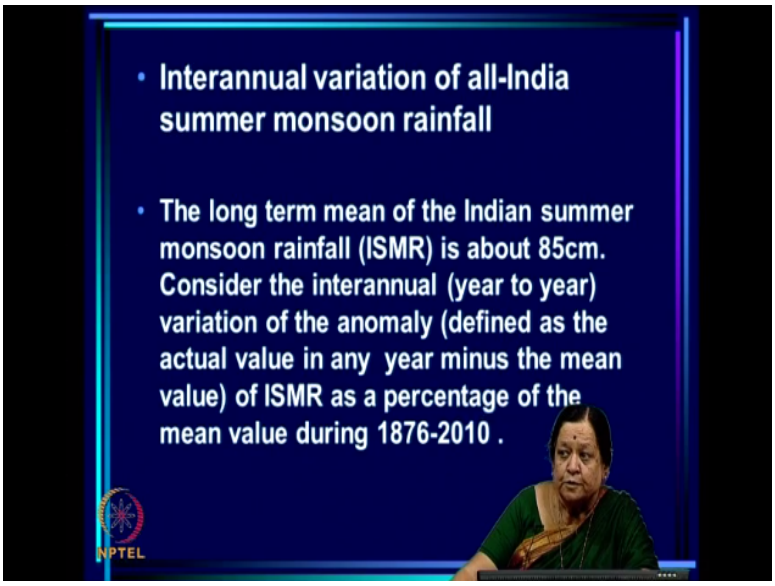


So, let us consider first the inter annual variation of all-India summer monsoon rainfall. Remember this is what our finance minister Pranab Mukherjee was concerned with when he talked about, praying to Indra for a bountiful monsoon. What he meant was that for India as a whole, the rainfall should be good during the summer monsoon that is June to September. Now, long term mean of the Indian summer monsoon rainfall is about 85 centimeters.

Now, consider first the variation from year to year of this and what we always look at in meteorology is so called departure from mean or the difference between the actual value and the average value. This is called also anomaly's. So an anomaly is defined as the actual value in any year of say in ISMR that is Indian summer monsoon rainfall - the mean which is about 85 centimeters.

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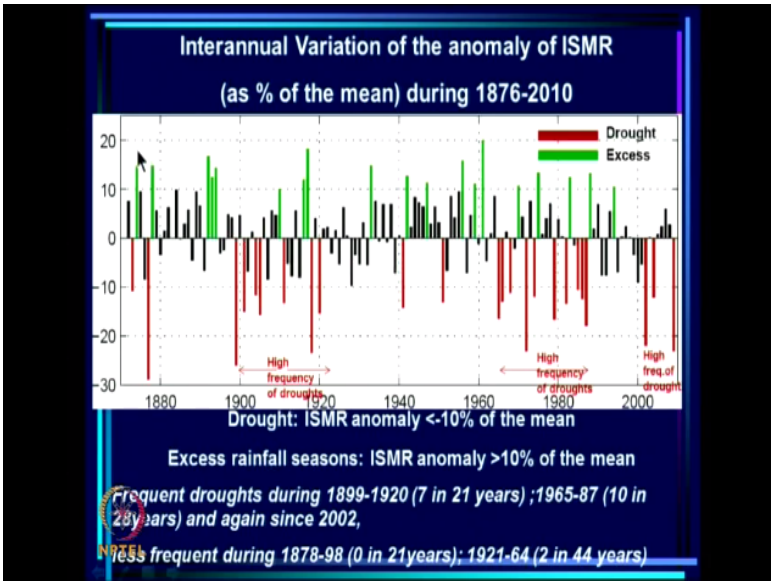


Now, what you will see in this slide is this anomaly of rainfall for each year is plotted as a percentage of the mean rainfall okay. So when the anomaly is positive, that means in that year say for example this year here, 1878, 1878 in fact the anomaly is about 15% or 14% or so and it is positive, which means than 1878 rather there rainfall received ISMR was above normal and above normal by about 14% of the mean or 14% of 85 okay.

So, when the sticks are above this line, that is positive values of anomaly that means rainfall was in excess of the average when the sticks are below this, this means rainfall was below the average. Now, it turns out 1 measure of course of variation of any quantity is the standard deviation right. You have a set of values in this case going all the way from 1876 to 2010 okay. So, 100 and odd years of values and these values will have a mean, which I said is about 85 or so and they would have a standard deviation.

So, a natural measure of variability is the standard deviation. Now, it turns out that for Indian summer monsoon rainfall, the standard deviation is about 8.5 centimeters or it is about 10% of the mean okay. So, whenever we have deficit rainfall that is to say rainfall is below the mean, below normal or below the average value and deficit is very much larger than the standard deviation, that is to say larger than 10% of the mean that is when we call it a drought.

So, a drought year in which ISMR anomaly is large and negative and larger than 10% of the mean or larger in magnitude then 1 standard deviation okay. Opposite end you will have excess monsoon years and for excess monsoon years like 1961, which is when the highest rainfall occurred so, in 1961, ISMR anomaly was positive and actually the rainfall was 20% in excess of the mean okay.

So, this is the largest excess that has occurred. So, now what do we see here that there are fluctuations in ISMR from year to year and in some years you have droughts, these are marked by big red lines and in some years, you have excess rain which are marked by green line okay. So, red line is drought and green line is excess. So, what you see here is how the ISMR or the all-India summer monsoon rainfall has varied from year to year okay from 1876 onwards.

It has fluctuated between above normal and below normal and between deficit, below normal is deficit and between droughts and excess seasons okay. Now, what is very interesting in this graph is if you see in fact, you see that, these droughts are sort of clustering around in some patches, that is to say if you consider this hipoc year between 1899 to 1920, there were many, many droughts okay and 1889 to 1920, is a 21 year hipoc.

So, in 7 out of these 21 years, there were droughts okay. Now, similarly you had very frequent droughts here, from 65 onwards we have been having very frequent droughts, 65 to 87, we had 10 droughts in 28 years okay. Again from 2002, we seem to have hit a bad patch, we had a drought in 2002, another in 2004, another in 2009 and 2012 has been close to a drought, though actually not a drought. In this year's monsoon, 2012 actually the deficit is about 8 %.

So, it is rather close to a drought but not actually a drought. So, what is interesting is that there seem to be what we call these decadal scale variations or hipocs. That is to say several decades in which we have a high frequency of drought interspersed with decades, in which the frequency of droughts is very, very low. So, in some sense the inter annual variation of anomaly of ISMR can be thought of as variation of frequency of what we call droughts or excess rainfall seasons or extremes of ISMR okay.

So, this is the story of the inter annual variation from the largest longest time series.

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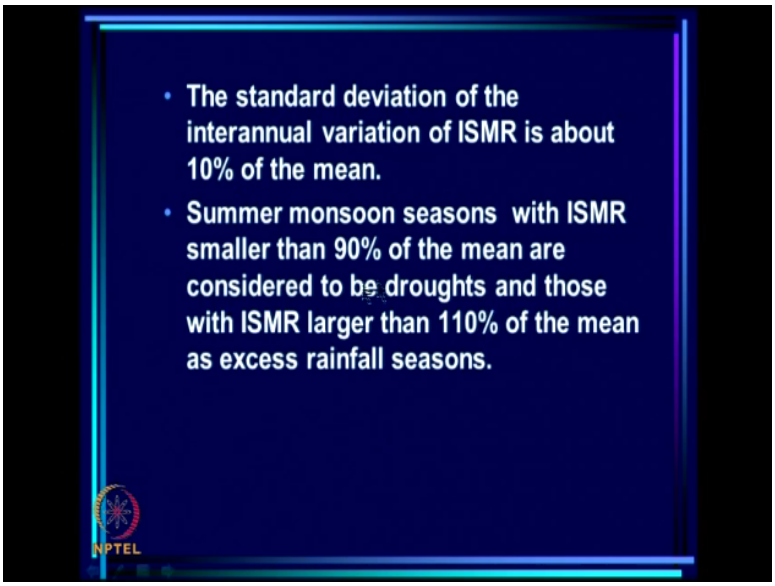


As I said before the standard deviation of the ISMR, all-India monsoon rainfall is 10% of the mean and so summer monsoon seasons with ISMR smaller than 90% of the mean that is deficit more than 10% in magnitude are called droughts and ISMR with anomaly's > 10% of the mean that is excess > 10% or rainfall > 110% are called excess rainfall seasons, these are the extremes. Now, in fact the Indian monsoon is rather reliable.

And we will go back to this slide and see how reliable it is. See the worst drought is < 30% deficit okay and the best rain is about 20%.

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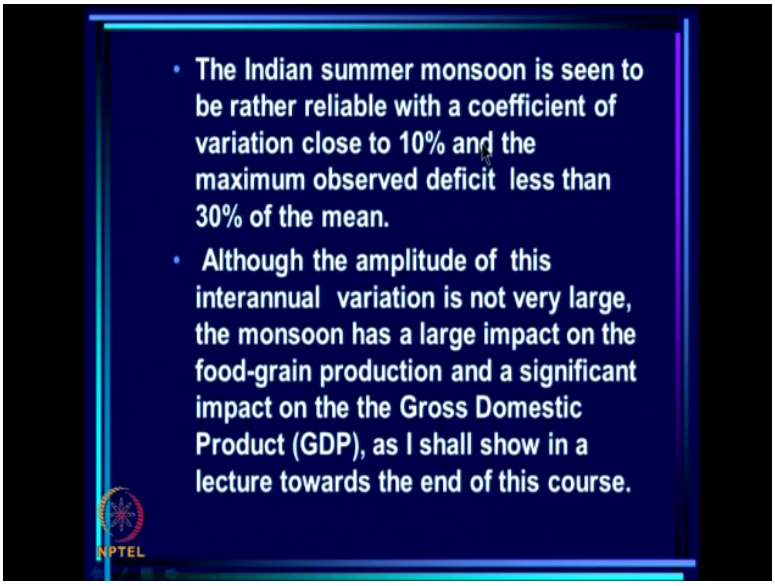


So, actually it is a fairly reliable thing, in many languages in India, there is a saying that every year we do have a rainy season, the monsoon does come every year and that is very true. Sometimes the strength is high and you know ISMR positive anomaly are excess rain, rain above normal up to 10 %, sometimes it very large in deficit but it is still only 30% of the mean. It is not as if there are years in which the monsoon never comes.

It is a very, very reliable feature but it is variable. This has to born in mind that it is 1 of the most reliable facets of tropical circulation. Now, although the amplitude of this inter annual variation is not very large, because the standard deviation is only about 10% and the maximum range of variation we have seen is about 40% of the mean. So the variation cannot be considered very large.

But even then it has a very large impact on the food grain production of the country and on the gross domestic product (GDP). Now, I will give a separate lecture in this series, on the impact of monsoon on agriculture and GDP and there we will see how large the impact is.

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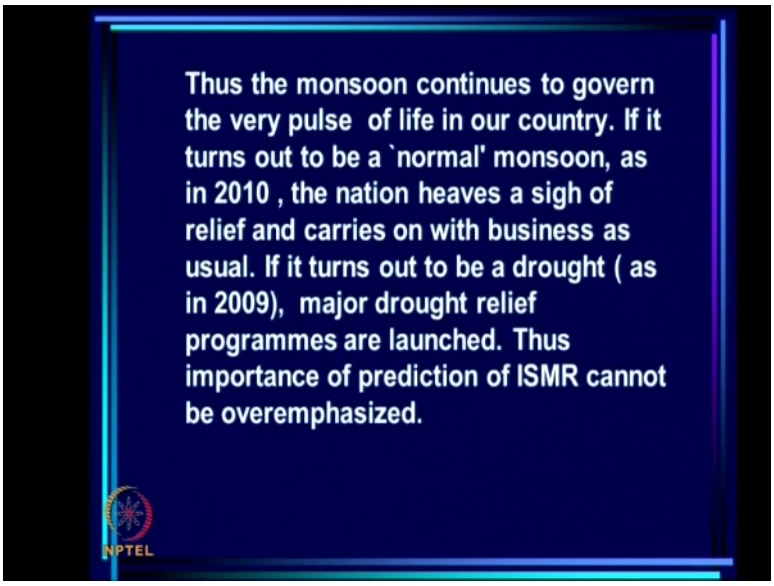


Even today, the monsoon continues to govern the very pulse of life in the country. If it turns out to be a normal monsoon like it did in 2010 and 2011, the nation heaves a sigh of relief and carries on with business as usual okay. But, if it turns out a drought like the last severe drought was 2009 and it took a long time for us to recover from the effects of that drought. Major drought relief programs are launched.

Thus the importance of prediction of ISMR cannot be overemphasized. This is why people are very keen to find out what the future holds for us. What is the next monsoon going to be like?

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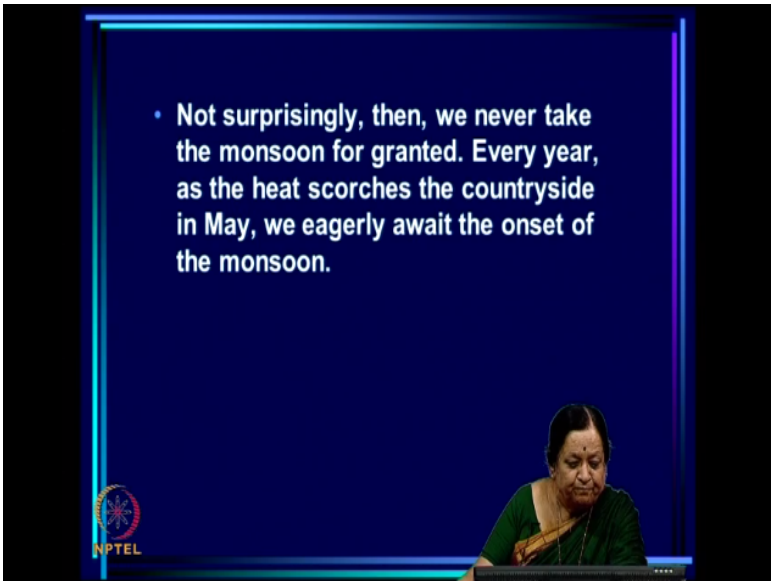

So, we never take the monsoon for granted, although it is a reliable facet and every year, as the heat scorches the countryside in May, we eagerly await the onset of the monsoon.

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Now, as I mentioned earlier the first important event of the drama which is repeated year after year of the monsoon is the onset of monsoon over Kerala, which is associated with a dramatic increase in rainfall of south Kerala. Now, in common parlance, the term monsoon onset in fact refers to the onset over Kerala okay.

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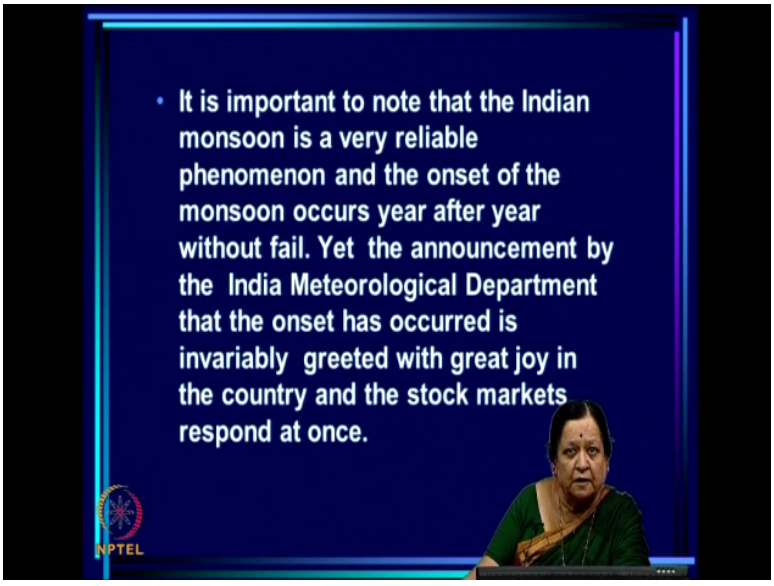


Now, just like we never have a year in which monsoon simply give any rain, obviously there is no year in which the onset did not occur. So, onset of the monsoon is also very reliable

phenomena and it occurs year after year without fail. There has never been a year in which the onset has not occurred.

Yet, the announcement by the India meteorological department that the onset has occurred over Kerala is invariably greeted with great joy in the country and even though stock markets respond at once.

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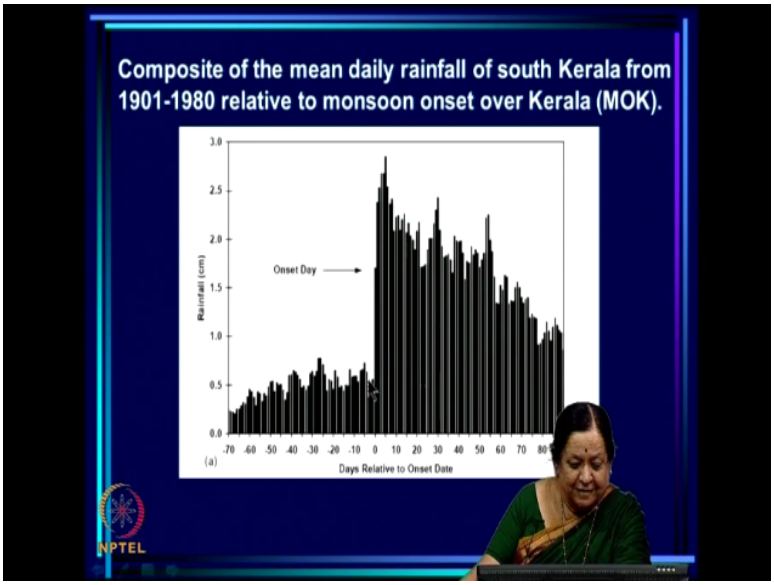


This is the really amusing that the monsoon seems so much impact on the pulse of the country. So, you remember this is what we saw last time, this is the monsoon onset over Kerala and this is what we are going to look for how, what is the variability of this onset over Kerala like?

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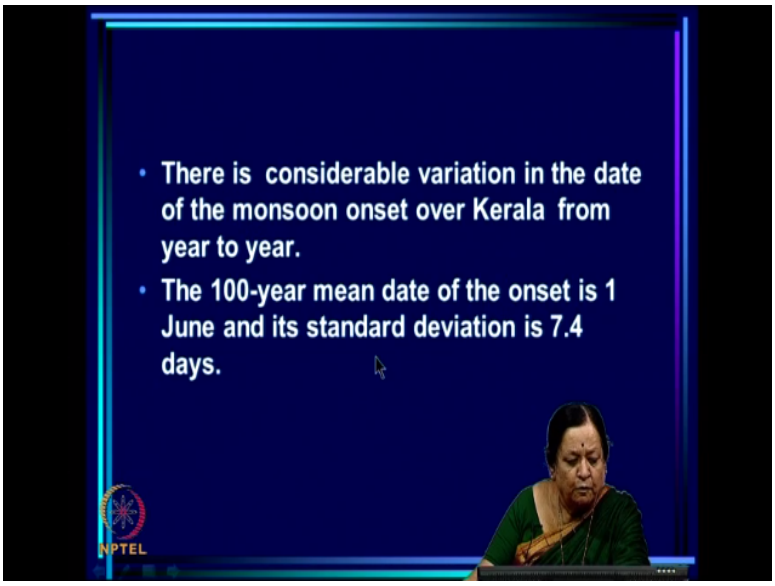


How does it vary from year to year? In fact, there is considerable variation as in this facet in every facet of the monsoon there is considerable variation from year to year okay. Now, if you look at the 100-year data, then 100 year mean of the onset date is first of June and in standard deviation is about a week, 7.4 days okay.

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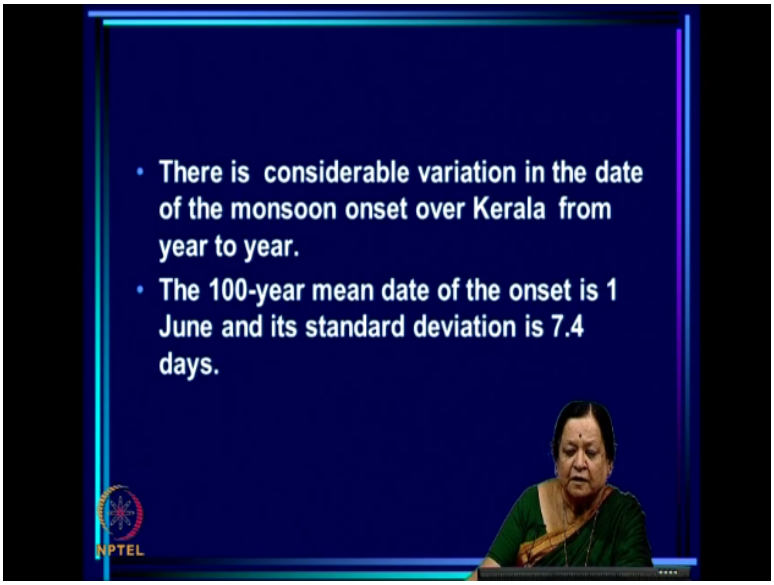


Now, this is the inter annual variation of the date of the monsoon onset over Kerala and you can see that it has varied all the way from mid-June to very, very early around mid-May. So, the range is quiet large but the fluctuations are not very high amplitude, they are close to the normal and you will see more about that, this as you see is the date of the onset and this is the year and this is plotted only up to 2000.

So, you can see for example from 1900 to 90 to 2000, it did not vary too much, it varied between end of May 20 something of May till about 6th of June above 2 standard deviations or so, < 2 standard deviations okay.

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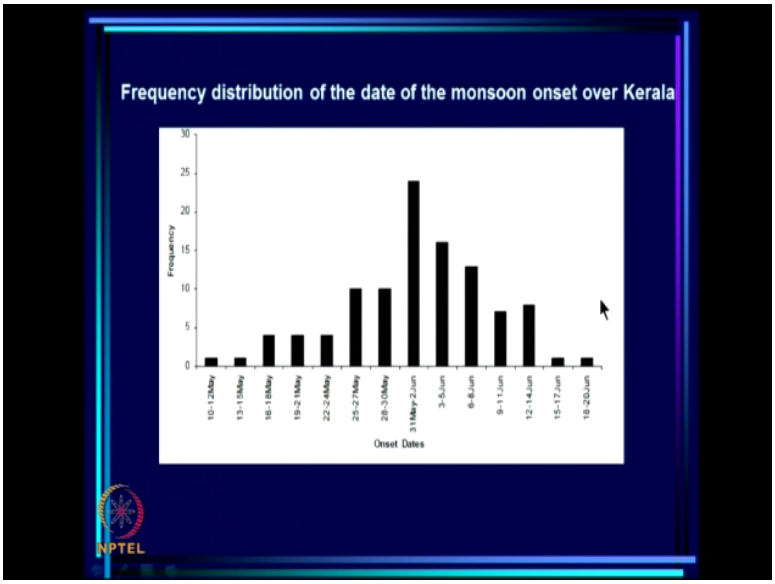


So, this is now the frequency distribution for the date of monsoon onset and this is from 30th May to 2nd June ok, this is 3rd June to 5th June. So how many years, what percentage of years had the onset date between this period, 31st May to 2nd June, this is where the mean is right, first June is the mean date. So, this is the frequency distribution of monsoon onset over Kerala and you see that the mode is actually close to the mean.

In other words, most likely it is going to occur between 31st May and 2nd June ok, that is most likely. But, there is quiet a spread and you have 1 year between 16th and 21st May and another between 18th and 20th June. So, this is the variation in the onset date of Kerala and this is what we are trying to predict. For a specific year, when will the onset be, here will the point lie in this frequency.

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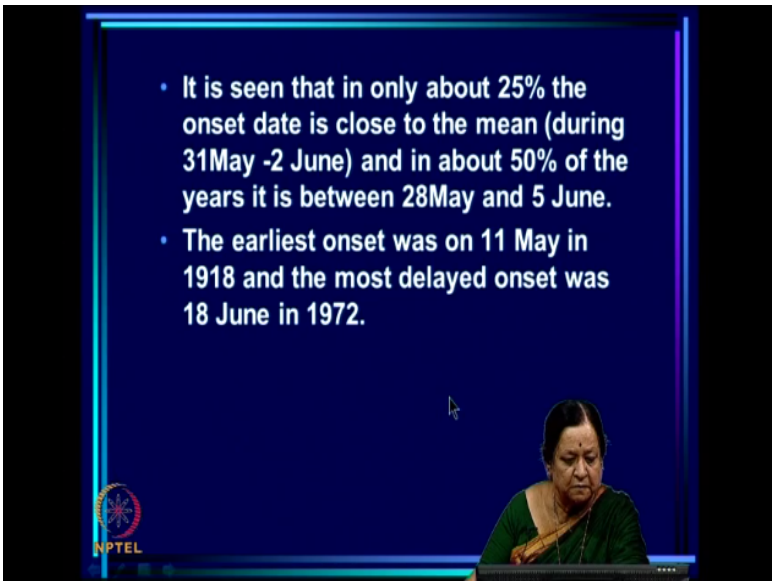


So, as I said in only about 25% of the years, onset date is close to the mean, that is during 31 st May to 2nd June, it is still the mode. So, the most probable date of monsoon onset is still within this 31st May to 2nd June. But, actually it occurs only on 25% of the occasion. In about 50% of the years, it is between 28th May and 5th June. So, that is a better window, if we see for about a week, that is few days before and few days after first of June.

Then almost half the years have onset date within this period okay. As I said the earliest onset was on 11th May in 1918 and the most delayed onset was 18th June in 1972.

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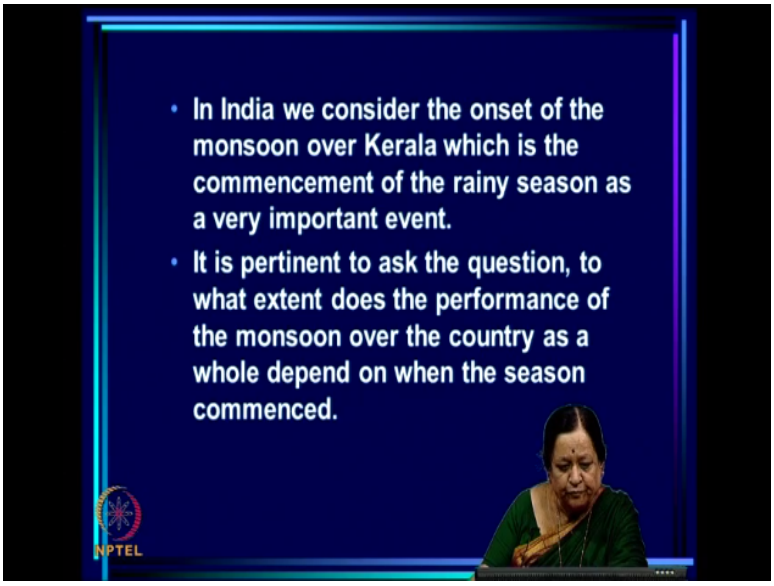

Now, in India we consider the onset of the monsoon over Kerala, which is the commencement of the rainy season as a very important event okay. Because, it is the first act of this play as I called it. So, many people are under the impression, that somehow when the monsoon onset occurs over Kerala holds the key to the future course of the monsoon for that season.

So, it is pertinent to ask the question to what extent does the performance of the monsoon in the season or what we called all-India monsoon rainfall ISMR to what extend does the ISMR depend on when the onset of the monsoon occurred over Kerala.

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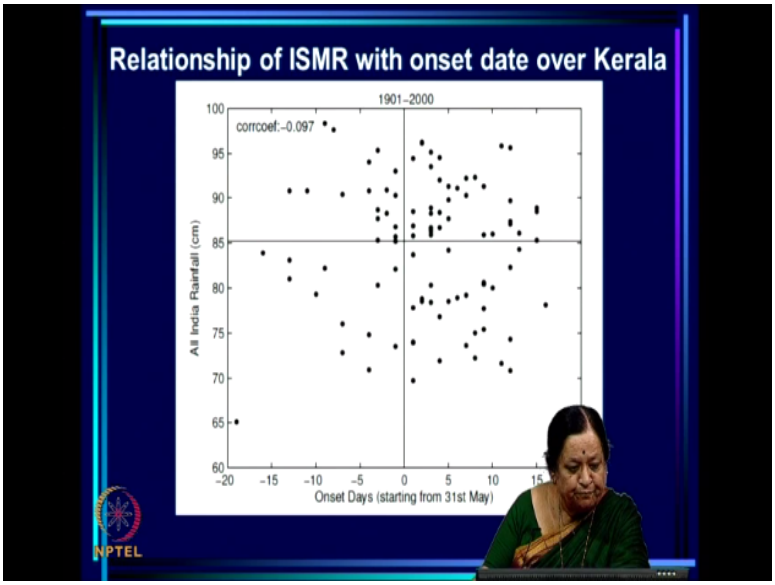


So, what you see here is plotted all-India rainfall which is the ISMR as we called it all-India summer monsoon rainfall and this is the onset days starting from 31st May. So, this is for all the years in the last century 1901 to 2000 okay. So, you have so many days in which the onset occurred after 31st May, so many years in which it occurred before 31st May and what you see here is that there is no relationship between what will happen to all-India rainfall for the season and the onset date, that is very clear because given any onset date, say here 5th of June.

You know the rainfall can be anywhere between 70 to 95, so it can be varied. This is the mean rainfall. So, it can be deficit and with equal probability it can be excess and this is true for any onset date that you take okay. There is a large spread of all-India monsoon rainfall values for

every date of onset and not surprisingly if you still want to compute a correlation of something like this, it comes out to be not at all significant. It is -0.097.

So, it is not significantly different from 0. In other words, what data I have shown us is, that even if the onset is delayed, one does not have to really worry too much about what will happen to be monsoon as a whole. So, ISMR is not related to the onset date over Kerala, in fact in the 2 cases, in which onset close to 20 days before and after the mean date ISMR was same. Let us go back and see that okay.

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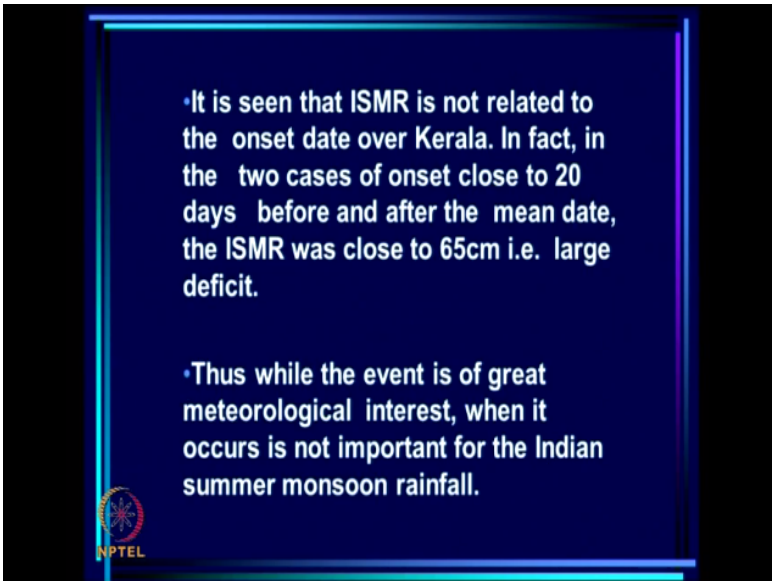


In the 2 cases in which, here you are, this is the spectacular thing. See this is a case, in which ISMR was almost close to 20 days before the 31st May and this is the case when it was almost 20 days later than 31st May and yet you see the all-India monsoon rainfall is the same for these 2 cases. Another manifestation of the fact that there is no relationship between all-India monsoon rainfall and the onset date okay.

So, while the event is of great meteorological interest, when it occurs is not important for the Indian summer monsoon rainfall okay.

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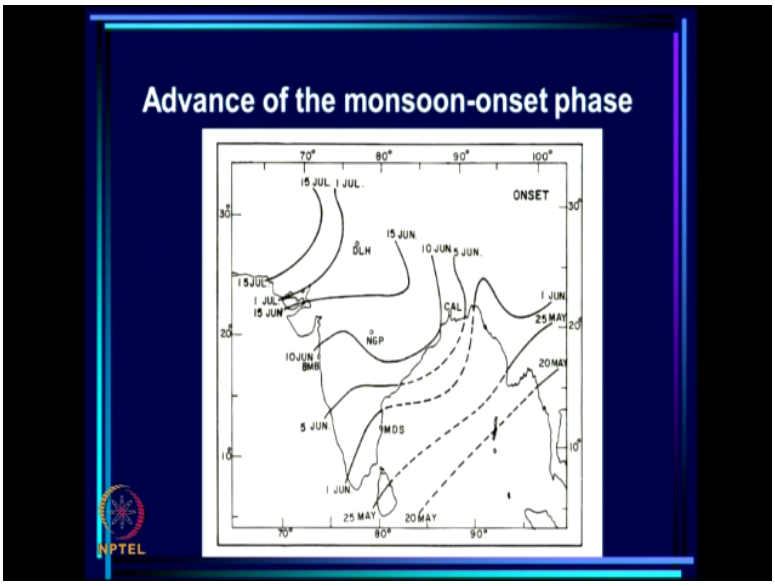


Then you remember we talked of after the onset over Kerala occurs the advance of the monsoon northward and westward propagation of the monsoon, northward advance and westward advance of the monsoon and by 15th July, it is set.

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Now, you may ask the question, these are mean dates of total. Mean date here is first June and mean date here is 15th July and therefore, in the mean, that is if you look at average over all years, it takes about 45 days for the advance of the monsoon from year to year okay. But, from year to year, the advance varies. When onset occurs on Kerala varies, how fast it progresses northward varies, how fast it progresses westward varies.

So, all these dates vary from year to year okay. So because of that, the total time taken for advance which in the mean case was just 45 days from first June to 15th July actually varies from year to year. Now, we have already seen that the all-India summer monsoon rainfall is not at all related to when the onset occurs over Kerala. There is no relationship. Next question is, is it at all related to how long the monsoon took to advance from Kerala to the north western corner here.

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So, this is the question we ask and when we look at the data, so the normal duration of the advance phase is about 1 month, if you look at this part, but if you look at the final destination of the monsoon, it is about 45 days. However, there is considerable variation in the duration of the advance phase from year to year. The relationship between ISMR and the duration of the onset phase ok, onset phase begins with the onset over Kerala and ends with the onset over north western parts of India.

So, the duration of the onset phase is the time it takes for the advance of the monsoon and now we want to ask the question, does the total rainfall over the Indian region during the Indian summer monsoon depend on how fast this advance took place or the days between onset over Kerala and onset over the north western part.

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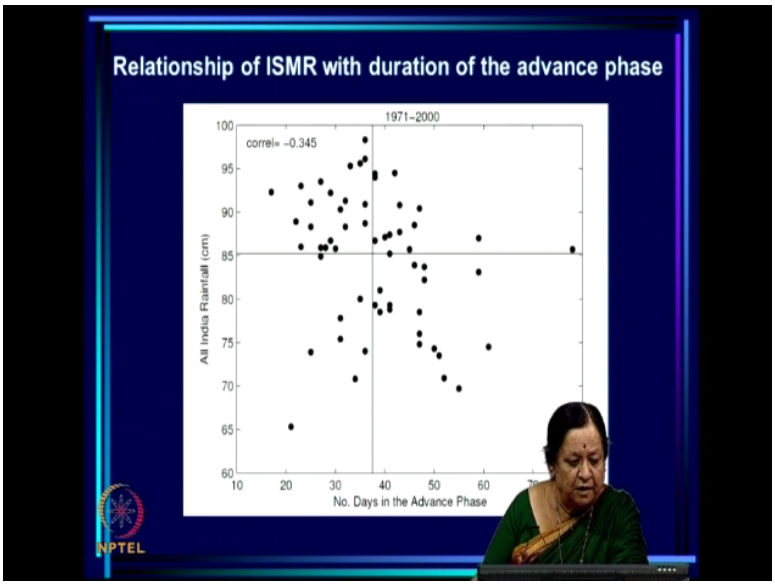


Now, actually it turns out that, there is some relationship between the number of days it took to advance and the all-India rainfall okay. By enlarge if it is a very fast propagation, you tend to get above normal rainfall, if the advance is very rapid, you get above normal rainfall, if the advance is slow, actually the situation is not very clear, you seem to get above or below. But if it is extremely slow, you are more likely to get below rainfall, then above rainfall, that is very clear and so the correlation is .345, it is a negative correlation of course.

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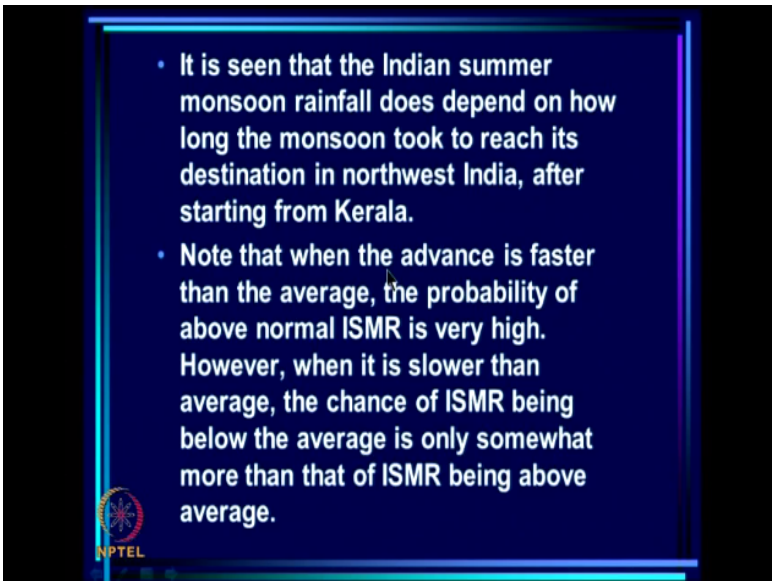


So, Indian summer monsoon does depend on how long the monsoon took to reach its destination in the northwest of India after starting from Kerala. Note that when the advance is faster than the average, the probability of above normal ISMR is very high, we saw that in fact.

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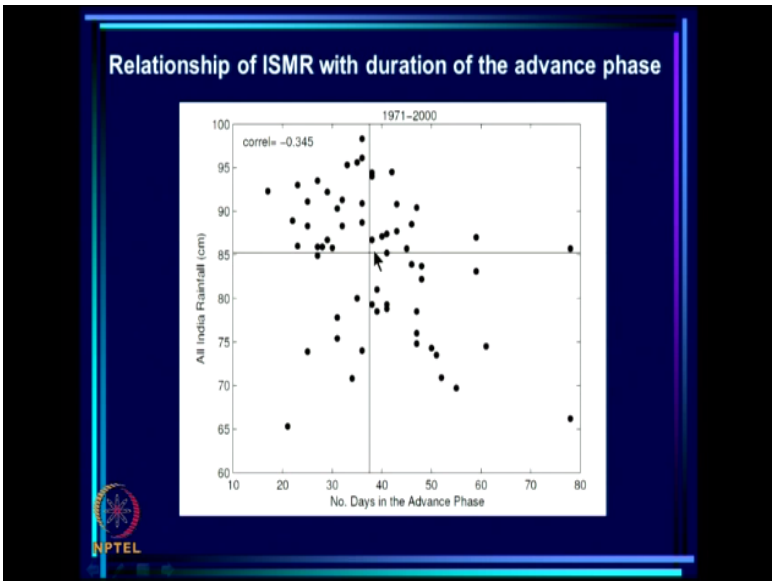


So, if the rate is faster than normal, then above normal rainfall probability is higher than below normal rainfall probability. But if it is slower than normal, then the picture is not so clear.

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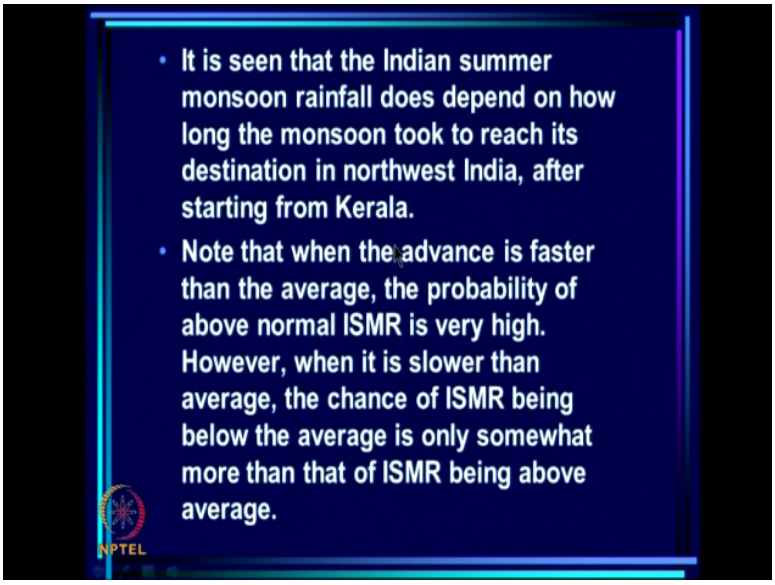


When it is slower than average then chance of ISMR being below the average is only somewhat more than that of ISMR being above the average. So, there is not much signal there, but if the advance is fast, then you can guess that ISMR is likely to be above average okay.

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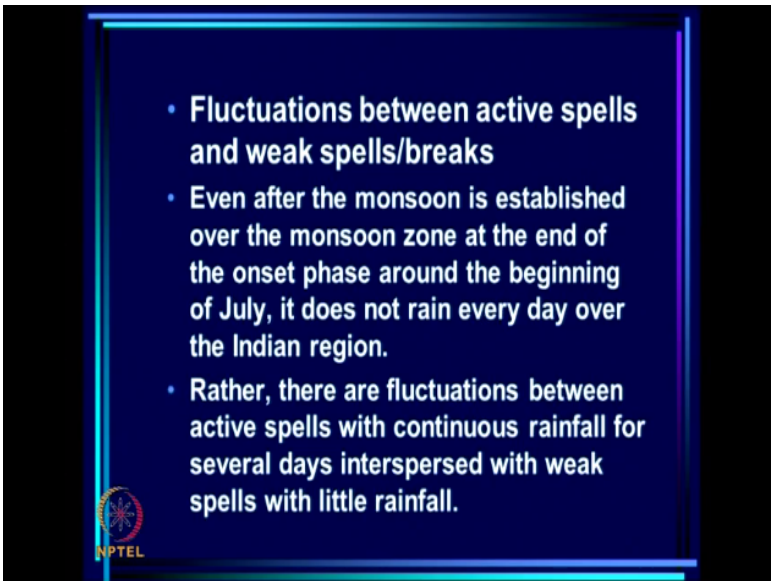


So, so far we have seen the variability of 2 important events of the monsoon, one is the date of onset over Kerala and we have also seen all-India monsoon rainfall is not related to the date of onset over Kerala. The second facet we saw of the monsoon was how long it takes the monsoon to advance from Kerala to the north western region or how long is the duration of the onset phase.

So, it turns out that the monsoon does depend on the duration of the onset phase but more so when there is a rapid advance of the monsoon, so that the duration is less than average, then you are more likely to get above normal rainfall, if it is a sluggard case. If the monsoon takes too long to advance, it is difficult to say which way the monsoon rainfall will go, ISMR anomaly can be positive, monsoon can be above normal or it could also be below normal okay.

So these are 2 important facets of part of the monsoon season that we call the transition, this is the transition to development of the full fledged monsoon and this is the onset phase. Now, at the end of the onset phase, what happens? At the end of the onset phase, the monsoon is established over what we call the monsoon zone okay and let me see if it is here, it is not here. It does not matter; we have seen it in the last lecture.

The monsoon zone, so it gets established in the monsoon zone which is the seat of the measure end but, by beginning of July, around the beginning of July, and even after it is established there,

it is not as if it rains there every day okay. If we looked at the monthly mean picture, you would think oh there is rainfall there in June, July, August and September. Remember that is what all the stations in the monsoon zone showed.

That they yet rain in June, July, August September. That is very true if you total the rainfall in the month, but if you look at daily rainfall, nowhere is it true that it rains day after day during the rainy season or during the monsoon. In fact, even in the monsoon zone, during the peak monsoon months, after the monsoon is established in the monsoon zone, it fluctuates in intensity between active spells and weak spells.

Active spells in which you have rainfall continuously for several days and weak spells in which the rainfall is subdued and dry spells in which it is absolutely absent. So, there are fluctuations between active spells with continuous rainfall for several days interspersed with weak spells or what we call breaks of the monsoon which I will come to.

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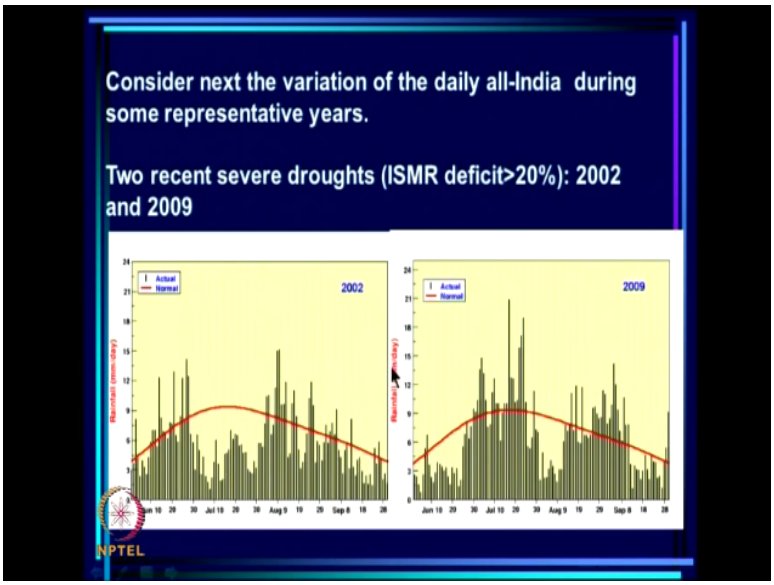


Now, as we did for the case of inter annual variation let us first look at the all-India average picture and by the way I should mention the diagrams like this for every year are available in the website of the Indian Institute of Tropical Meteorology, Pune, to which I have already given a reference to that website okay. So, now what you see here is the daily variation of rainfall and

there are these sticks, when the sticks are high, you have wet spells, when the sticks are low, it is relatively weak.

Remember this is all-India average. So, relatively weak means rainfall is occurring somewhere, but not everywhere and not sufficiently intense. So, these look very much like the Manhattan towers that people who make cricket commentary talk about. So, you have these many, many runs scored in some of these and hardly any action in some of these other spells. So this are the active spells and you can see even within the large-scale active spell here, there are 4 short scale active spells and there are weak spells here and then again active spells resume.

This red line here is the climatology. That is to say it is the mean all-India rainfall. So, when the sticks are above the red line, all-India rainfall is higher than the mean, when they are below, all-India rainfall is lower than the mean. Now, 2002 was a drought year and what you see is that for a many, many days, the rainfall was below the normal okay. 2009 was another drought year and both with actually 2 recent severe droughts with ISMR deficit > 20%, so these are really severe droughts, 2002 and 2009.

But you can see that even they are similar in terms of how much the deficit was in an all-India average, you still see that there are differences in how the monsoon evolved. See, in this case when the dry spells or weak spells occurred. In the case of 2002, June was quiet ok, this is month of June. But in July, you got many, many weak spells. Whereas in 2009, June itself was a huge deficit and then it recovers somewhat in July and then we got another major deficit slot in August. So there are differences on the daily scale also between droughts.

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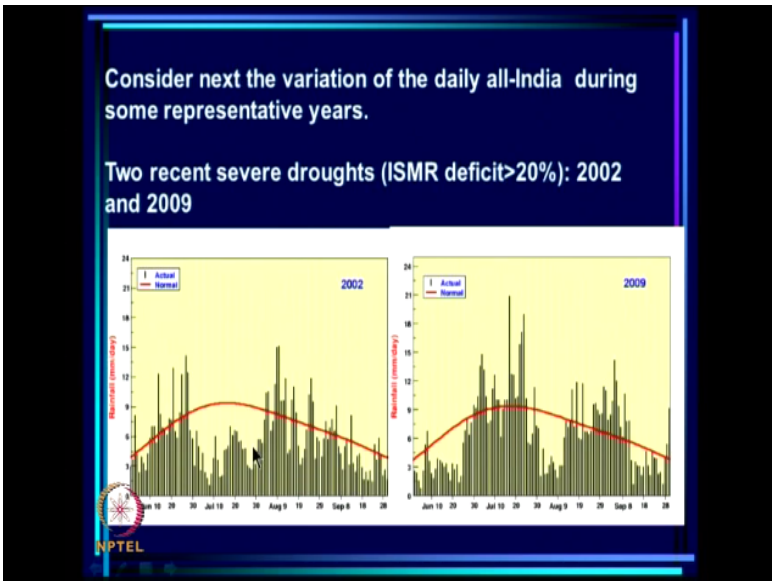


Now you look at normal monsoon years, so called normal monsoon years, which means, at the end of the season, the all-India summer monsoon rainfall was very close to the average. In this case, ISMR was 2% above normal for these 2 years okay. And these are 2010 and 2011. By the way the 2 years that followed the severe drought of 2009. And what you see is that even in normal years, the rainfall fluctuates, it is unlike climatology, which is so dull and flat.

If you plot the daily rainfall of any season, it fluctuates a great deal, whether it is a normal monsoon season or whether it is a drought. It fluctuates a great deal and typically you have wet spells of few day's durations interspersed with weaker spells and this is what you see here as well.

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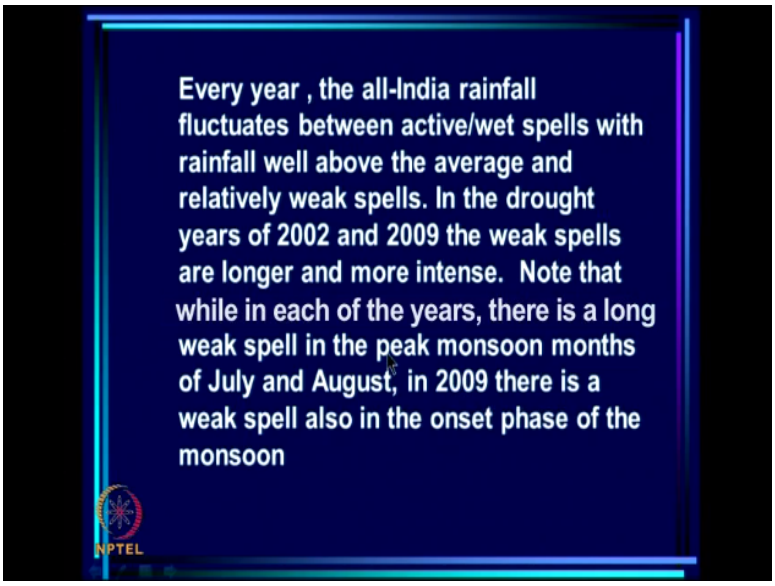


So, every year the all-India rainfall fluctuates between active and weak spells, active or wet spells with rainfall well below the average and relatively weak spells. Now as I pointed out in the years of 2002 and 2009 the weak spells are longer and more intense and we can see that, if you look at this, you have a fairly long and a sufficiently intense weak spell. Here also one long weak spell, another long weak spell and if you were to compare it with the normal years, normal years also have weak spells but they are much shorter.

So droughts do seem to have longer weak spells and while in both the years, this is something I pointed out while seeing that you know where the weak spell occurs seems to differ from one drought to another okay.

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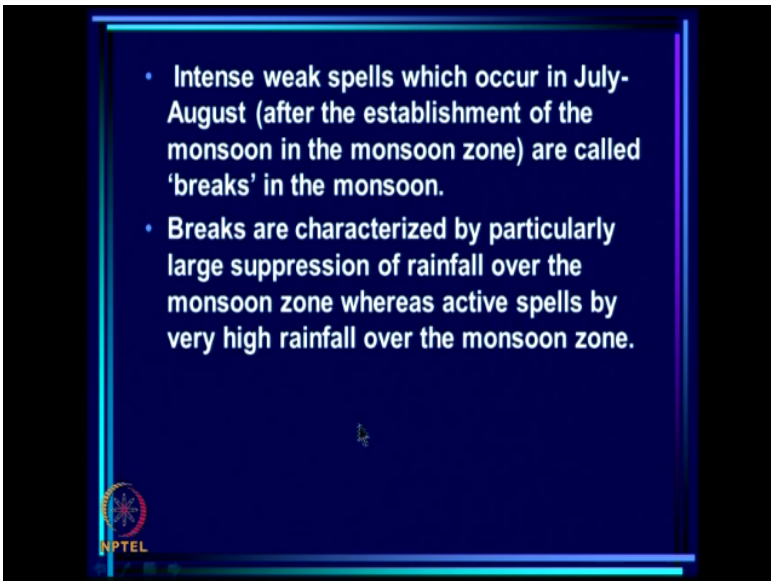


Now, there is an interesting facet of these sub seasonal variations, we call these sub seasonal variations because we are looking at variation within the monsoon season, we have derived them from high frequency data, that is daily data. So these are variations within the monsoon season and what we find is one of the major characteristics of this is what is called break in the monsoon. Now this is a word that has become extremely popular in fact to the extent that people have started defining breaks the way they like them, which has created considerable confusion.

And we will come to that when we discuss inter seasonal variation in great detail. But, let us now see what are the distinguishing attributes of breaks. See breaks are intense dry spells in the monsoon zone. After the monsoon is established in the zone, that is to say during the peak monsoon months of July and August, if we have intense dry spells in the monsoon zone, these events are called breaks. So, breaks are special cases of weak spells in the monsoon zone.

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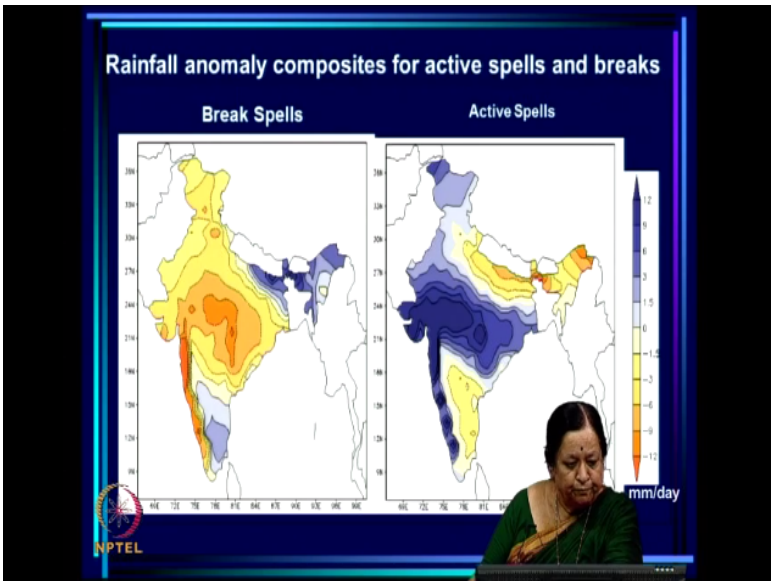


Now, again we will get in to the detail of this when we look at rainfall for active and weak spells and the data for several years and so on. But let me show you just the average or the composite picture. So, if you just take the average rainfall anomaly over all the breaks, that have been identified in the 100-year time span then what do you find? You find that there is a very severe rainfall anomaly over the monsoon zone here which is to be expected.

Because breaks are dry spells of the monsoon zone. So you have a very huge rainfall anomaly large deficit over the monsoon zone. Interestingly, although in the definition of breaks and derivation of these data, what we used was only the rainfall over monsoon zone, it turns out that rainfall over west coast also shows very large deficit during the breaks. So, rainfall has very large deficit over the monsoon zone which is the critical region for the monsoon.

It also has very large negative anomaly's or deficit rainfall over the west coast okay. However, you see opposite sign of ISMR anomaly's, you notice here blues means rainfall is more, yellow and red means negative anomaly of rainfall. So, you have large negative anomaly's of rainfall here but positive anomaly's of rainfall over south eastern peninsula and over this north eastern region and Himalayan foot hills okay.

So this is the very interesting pattern that the rainfall anomaly's are not coherent all across the region, rather they are very coherent over the monsoon zone and the rainfall anomaly over west

coast tend to go with monsoon zone. That is to say, if monsoon zone has negative anomaly's as here, it will have negative anomaly's too.

If it is positive anomaly as far active spells, west coast also tends to have positive anomaly, then compared to in relation to what is happening over the monsoon zone, in fact the south eastern part of the peninsula always has opposite sign anomaly's. So, in breaks, it gets more rainfall than normal and in active spells it gets less rainfall than normal. And Himalayan foot hills again have the opposite sign, so that in active spells, you have negative anomaly's here of rainfall.

And in weak spells, you have lot more rain over the Himalayan foot hills and the north eastern region. So these are the typical patterns of breaks and active spells.

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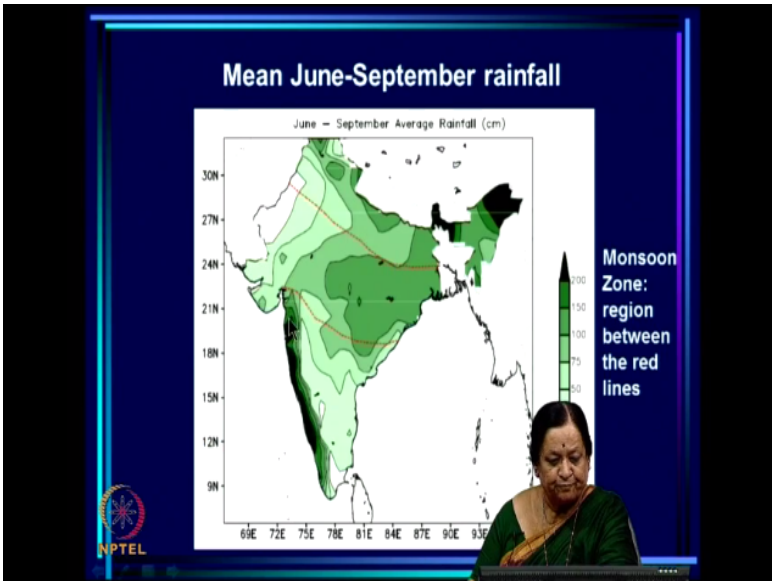


Now this, I just wanted to remind you is the mean rainfall and it is the rainfall over this monsoon zone that was used for defining breaks and active spells and you can see that the monsoon zone is around here and that is where the anomaly's are maximum okay.

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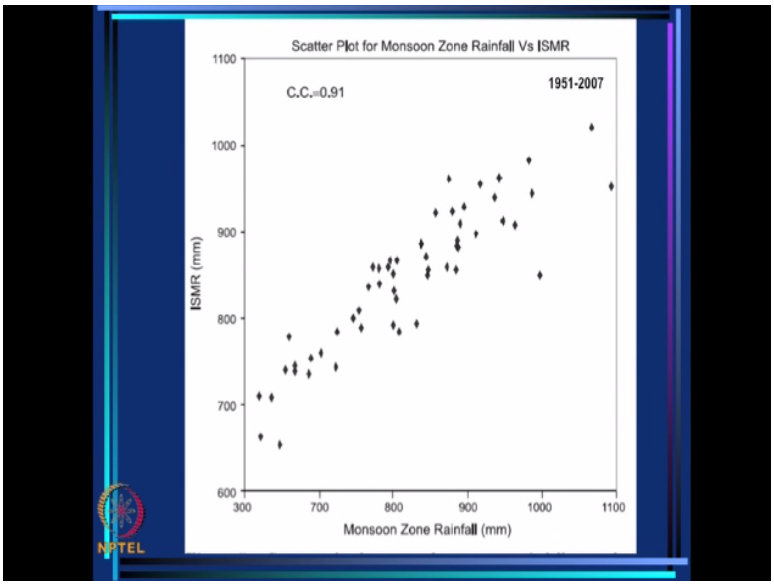


Now, suppose we consider, we have already seen that if we look at the daily picture and you look at the mean rainfall over monsoon zone, we saw the mean rainfall over the entire Indian region, then the 2 curves tend to go together. This is what we saw in the first lecture, that the variation is very, very similar particularly during July, August. Now, I ask the question, how important is monsoon zone rainfall in determining all-India monsoon rainfall, that is ISMR?

Now, to answer that what we plot here is ISMR which is the all-India monsoon rainfall for each year versus how much it rained in the monsoon zone okay. This is all based on. I am sorry the period can't be read, I think it is 54 to 2005. So, in fact this is based on the grid data. Grid rainfall data which was compiled first by (()) (36:05) and which are now available on the website of India met department.

So, from that grid data, we can actually calculate how much it rained in the monsoon zone. And what you see here is the all-India monsoon rainfall for the summer monsoon versus monsoons in zone rainfall for the summer monsoon. And what you see is that they are highly correlated. In other words, if we wanted to predict all-India summer monsoon rainfall, if we could predict rainfall of the major rain belt, which is the monsoon zone, then you have a prediction for all-India monsoon rainfall as well.

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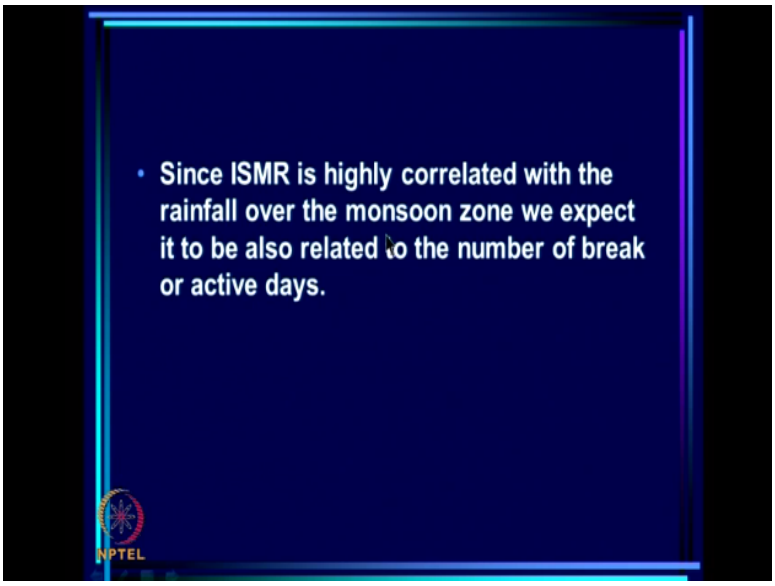


So, since ISMR is highly correlated with the rainfall over the monsoon zone, we expect it to be also related to the number of break or active days. Now you have to remember that we have defined breaks are active days depending on the rainfall over the monsoon zone, active days being those in which rainfall is in excess of normal over monsoon zone and breaks days being those in which it is highly deficit over the monsoon zone.

So, if that is the case, if the rainfall is very much depressed over the monsoon zone for many days, then we expect that all-India monsoon rainfall for the season as a whole will be deficit and so we expect some relationship between the number of break days and ISMR.

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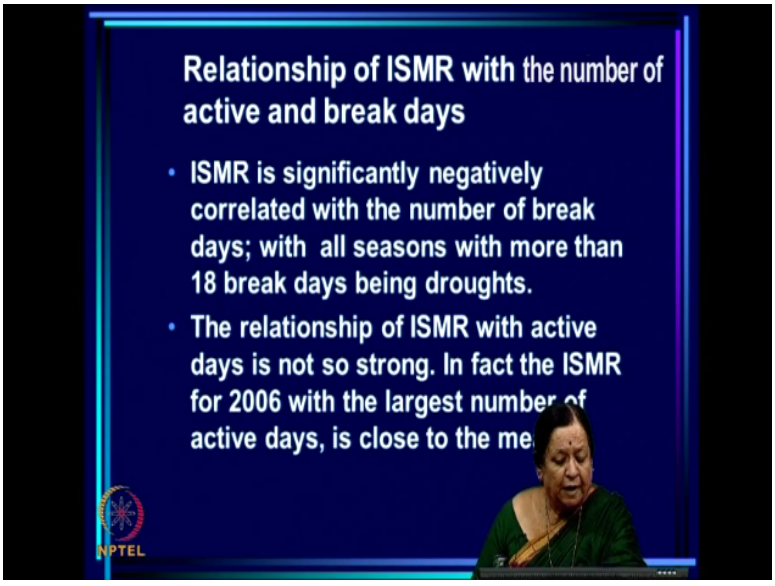

We have to also ask the question, Is the all-India monsoon rainfall related to how many active days were there in the monsoon zone and we look at both those.

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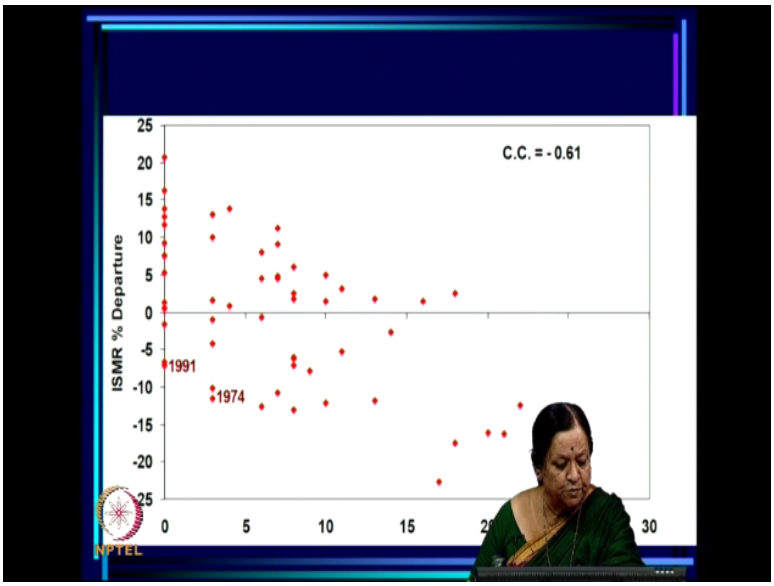


So, this is the ISMR% departure, so this is the ISMR anomaly which we had seen earlier expressed as a% of the mean and this is the number of break days okay. So, first and foremost, if we looked at the years in which actually there was no ISMR anomaly that is to say, the all-India monsoon rainfall was actually normal mean, then we would get a large variation, I am sorry I go back. If we look at this 0 line, this 0 line represents, years in which there were 0 days of breaks, never did the rainfall over monsoon zone become very large deficit.

Not on a single day, that is what 0 counts for. And even then, there is a large variation in ISMR, it can be as large as 21% this much time in 1961, but it can be also as small as -7 %. So, there is a huge spread given the number of break days that occur, there is a huge spread. Then we start with typically we have counted breaks only if they are more than 3 days in duration. So, this is what matters, this is the relationship that is relevant for us.

And in this relationship then, we see that there is definitely a relationship, the chance of getting below normal rainfall increases as number of breaks days' increase. And in fact in the number of breaks days are beyond 17 or so, you are not only guaranteed to have below normal ISMR but

you are guaranteed to have a drought okay. So droughts, intense droughts are all, which is seen here, more than 15% are all associated with actually large number of break days.

So, there is this relationship between the fluctuations within the season, how many break days there are and how the monsoon performs for the season as a whole, the all-India summer monsoon or what we call ISMR. So this is in fact negatively co related. However, please notice that while for large number of break days we are getting some signal in the relationship.

For breaks days within about 10 days, actually you cannot say very much about what will happen to ISMR, that is to say the all-India monsoon rainfall really varies a great deal if the break days are < 10, it varies between a drought to an excess season, anywhere between the 2. And so, it is very difficult to say anything about it. In other words, the relationship is not very strong when the number of break days is < 10, when it is more than 15 or 17, it becomes very, very strong.

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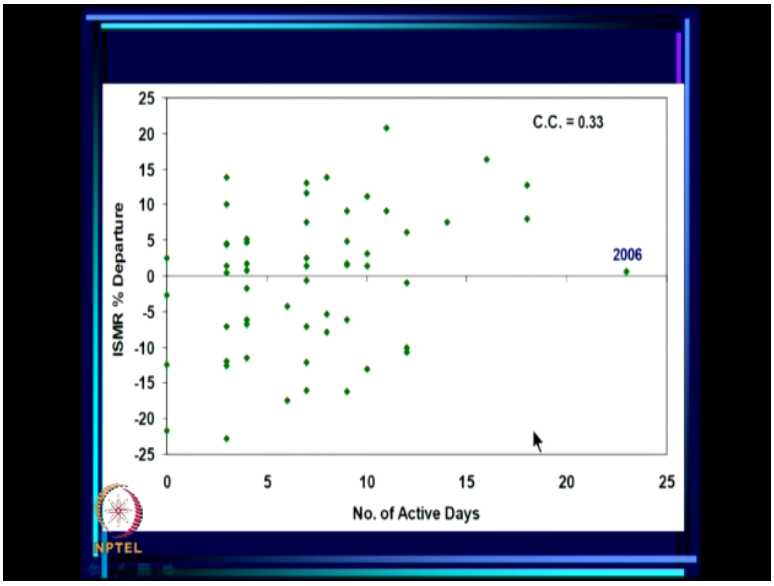


Now, this is the correlation with number of active days. Let me just point out that, here the correlation is highly significant. It is .61, which means that the number of break days explain about 36% of the variance of ISMR. So, this is the very significant correlation and this is the first glimpse we have of a relation between sub seasonal variation or intra-seasonal variation, variation within the season and year to year variation or inter annual variation.

Now, when we look at number of active days, actually the story is not that great. If we look at number of active days, the correlation has dropped substantively. So that, now the number of active days explain only < 10% of the variance. So, correlation has dropped substantively and you can see for each number say here you have 7 active days, and the ISMR varies all the way from -15 %, which is a drought to +15 %, which is excess.

So, there is very little relationship between number of active days and ISMR except when the number of active days is reasonably large. But even there, when you have number of active days say exceeding 13 or so, then you always get above average ISMR. In 4 out of 5 cases, in fact you are getting significant anomaly. It is more than 5% excess of ISMR over the mean is more than 5 %.

But then you have a year like 2006, in which you had so many active days and yet the rainfall was very close to 0. So, you can say a lot more about what the ISMR corresponding to a situation with a given number of break days is provided of course you have had a large number of break days. Relative to what you can say about ISMR from the information you have about number of active days okay.

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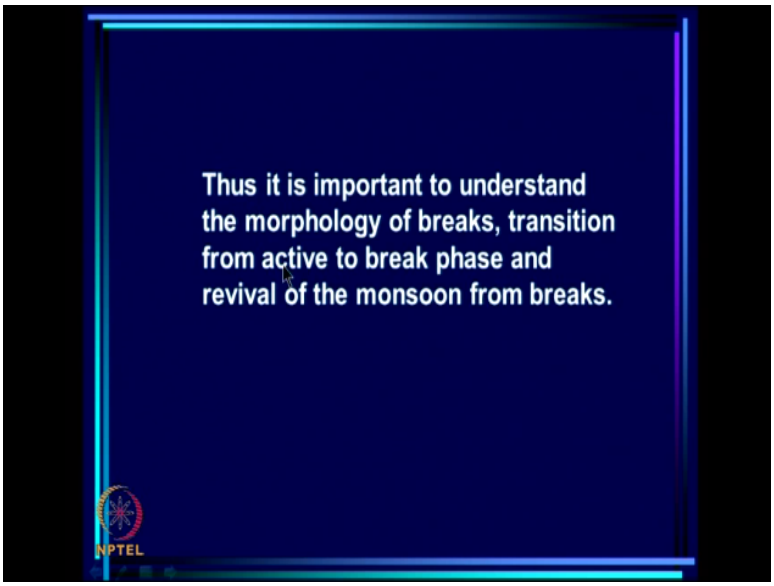


Now, so this says that even if your final aim was to understand only the inter annual variation of the all-India summer monsoon okay. Even then, it is important to understand breaks. Because it

is very clear that you have a 1 to 1 correspondence between very long breaks and droughts and so it is very important to understand the morphology of breaks. You know what is the structure of the breaks, what are the rainfall patterns elsewhere in the world and so on and so far.

Now, how does the transition from active to break phase occur? We saw several of these transitions earlier in this all-India case.

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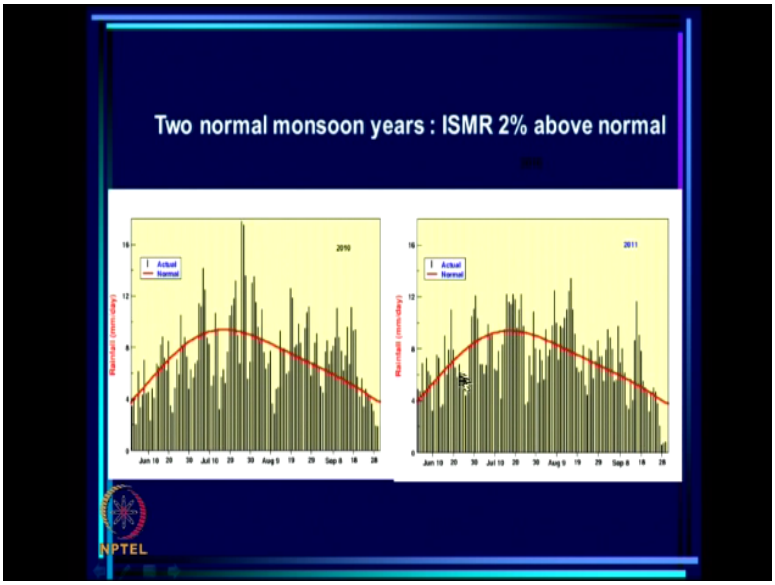


You saw several transition, this is an active spell and there is a transition to a weak spell okay. This is the weak spell and there is a transition to an active spell, again active spell and transition to a weak spell. So there are these transitions, but we ought to be able to understand how these occur and do we understand the mechanisms that lead to these transitions?

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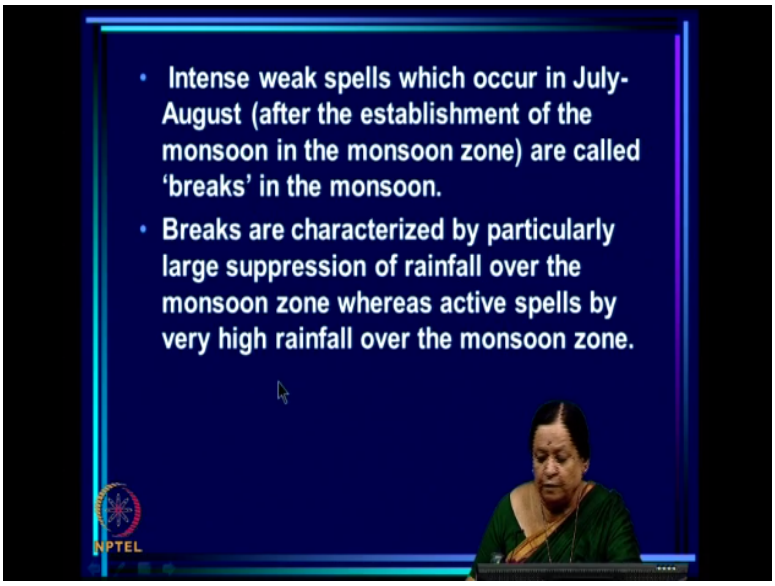


It is only if we can understand the mechanisms we will be able to model them and we will be able to predict them okay. We have seen all these okay.

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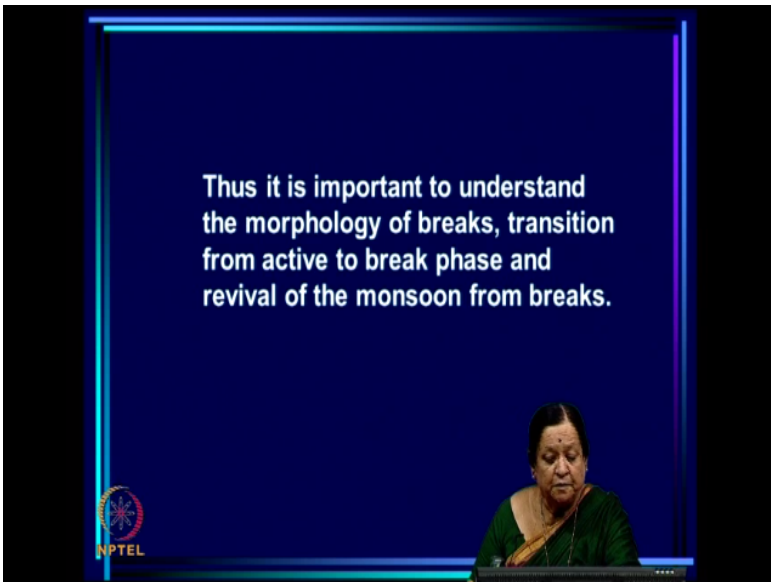


Thus it is important to understand the morphology of breaks, the transition from active to break phases and revival of the monsoon from breaks. So these are all facets of the monsoon, which we will look at in great detail when we look at intra-seasonal variation. In this lecture, I am only identifying the important facets okay.

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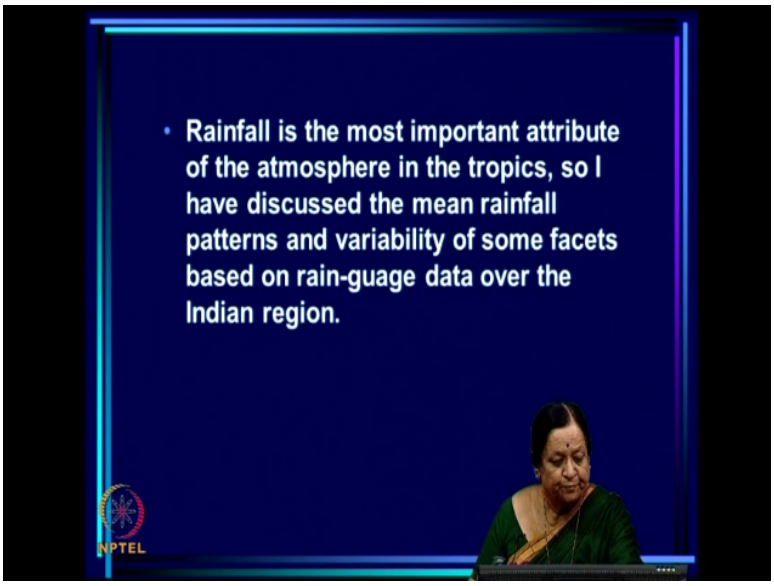


Now, rainfall is the most important attribute of the atmosphere in the tropics so I have discussed the mean rainfall patterns and variability of some of the facets based on rain-gauge data over the Indian region okay. So far, what we have talked about is something that was actually known from before the satellite itself from before we got satellite observations.

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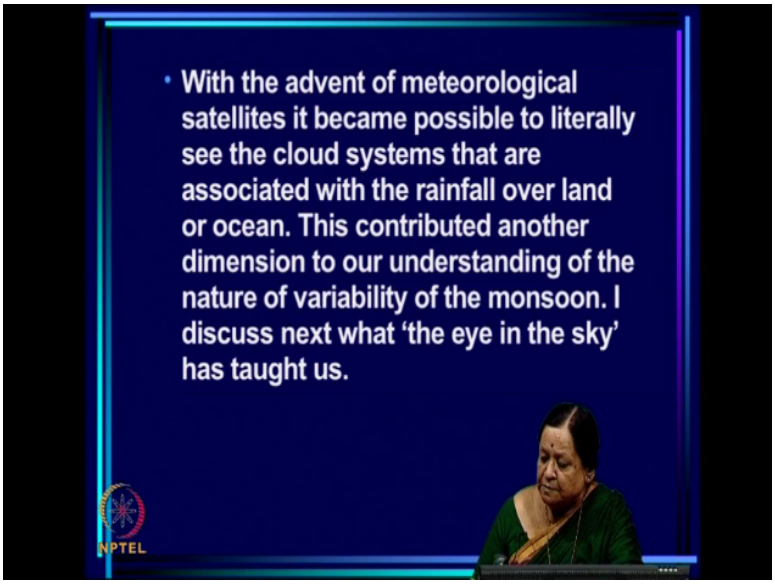


These were rainfall data that were analyzed and all these facets of fluctuations between the active weak spells, morphology of breaks and so on. People have studied and worked on with the rainfall data. But what happened is with the advent of meteorological satellites, it became possible to literally see the cloud systems that result in rainfall over land or ocean.

See after all we get rain from clouds and for the first time, we had an eye in the sky, which actually let us see every day where the cloud systems are over the entire tropical belt including the Indian region okay.

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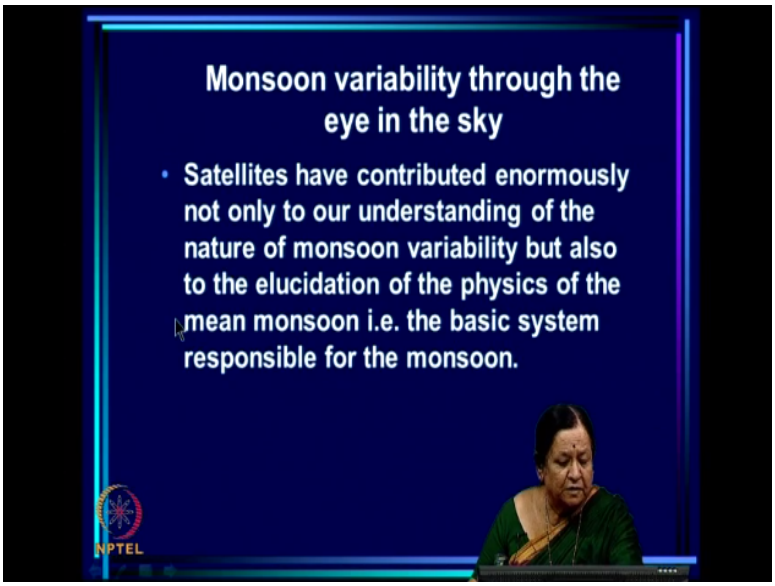


So in fact, it turns out that the eye in the sky has taught us a great deal in fact, you will see as we proceed that the kind of things we learn from the satellite, the kind of information that we could derive from satellite data has actually contributed not only to our understanding of variability of the monsoon. But also, it has helped in elucidation of physics of the system, which is responsible for the monsoon.

Physics of the mean monsoon, that is the basic system responsible for the monsoon. So, this is another case in which new observations have given new insight into the physics of the system okay.

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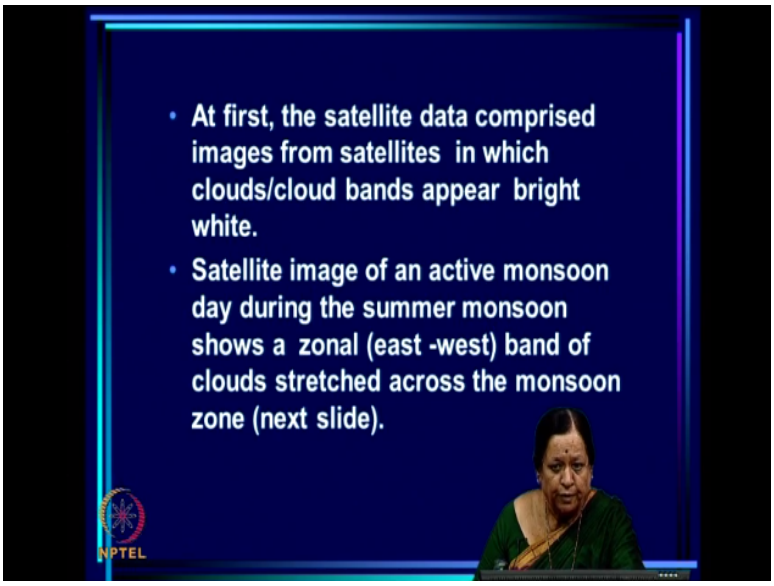


Now, so we are going to talk about what satellite data have told us. Now, initially satellite data used to comprise images, so basically there were cameras on satellites and we got pictures taken by satellites and in those pictures bright bands or bright regions represent clouds okay. Why is that? Because sunlight falls on the top of the surface and when there are clouds it gets reflected and it looks white.

So what the satellite camera notes, is a white region where there are clouds and darker regions, where there are no clouds.

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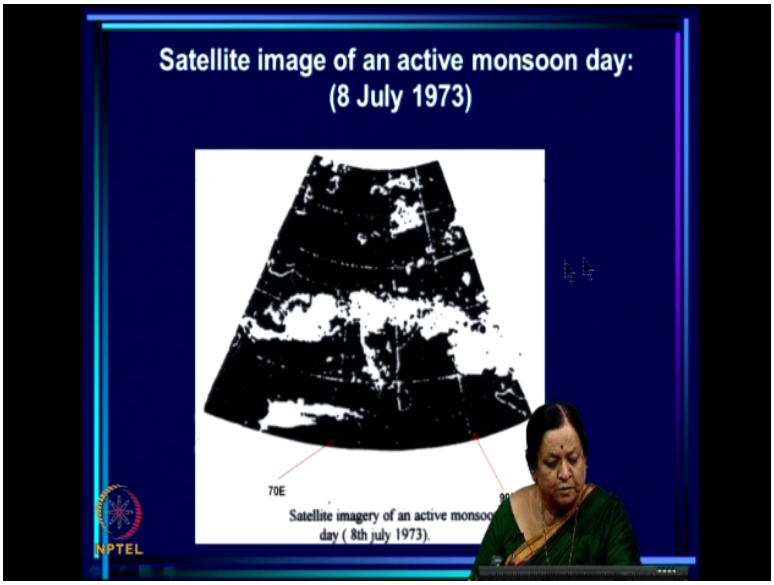

Now, satellite image of an active monsoon day is shown in this one and what you see, this is the sector okay and I hope you people can recognize what it is. This is the Indian region, you can see that and perhaps even you can even see Srilanka here okay. So this is the Indian region and what you see is, a whole band of cloud going across India. In fact, it is going across the monsoon zone as we had identified earlier. It is coming all the way from the western parts and extending here, right across eastwards.

See this is now 70 degrees east okay and this is 90 degrees east. So this is close to the longitude of Calcutta and 70 degrees east is close to the west coast okay and you can see that. This is 70 degrees east here, that is 70 degrees east and this is 90 degrees east here. It is going right through the head Bay of Bengal.

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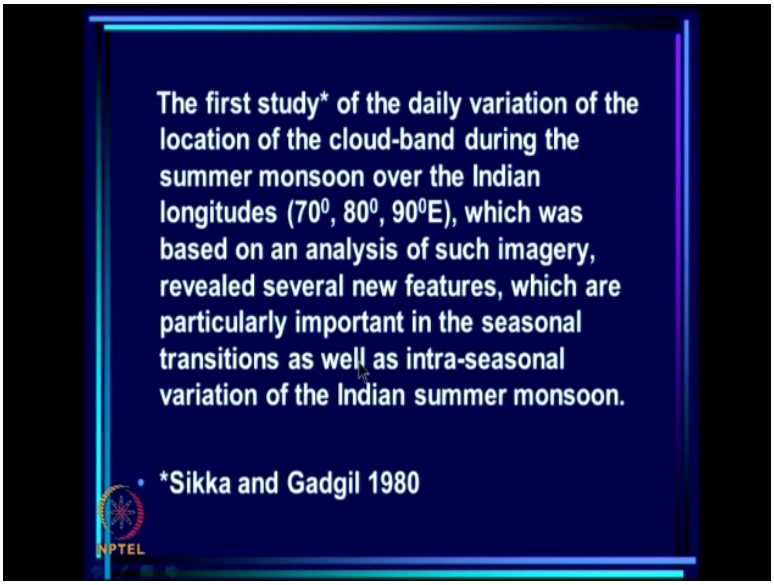


So typical pictures that we saw from satellite, the pictures like this, and in fact, the very first study of daily variation of these pictures itself revealed several new features which are particularly important in the seasonal transitions as well as intra-seasonal variation of the Indian summer monsoon. Now, this first study was carried out by us and published in 1980 and I will talk about what satellite data has taught us in the next lecture.

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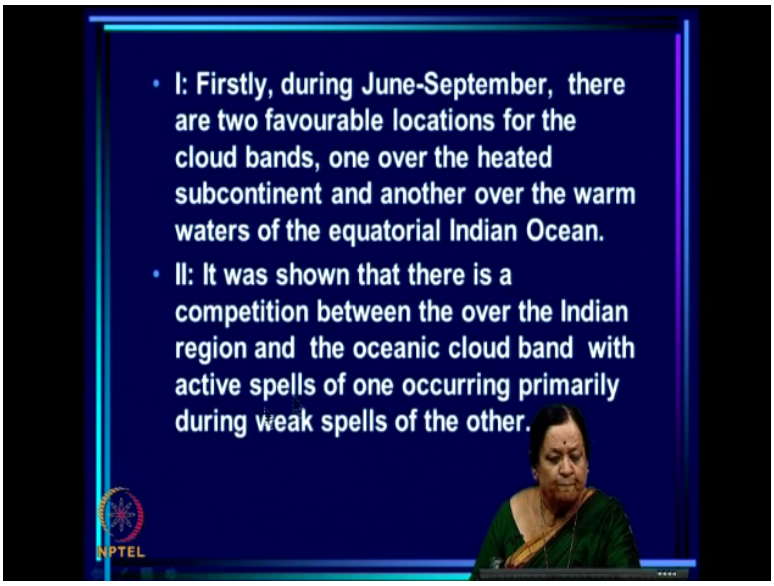


At this point, this is the good point to stop this lecture. Let me just revise what we have learnt. What we have learnt is that, there is considerable variation in most, if we look at rainfall data alone, we see that from year to year, there is considerable variation in many facets of the monsoon. We have seen that it, if you look at all-India monsoon rainfall, it varies from year to year but it is a reliable facet of the monsoon and the total range of variation that we have observed from 1876 is only 40% of the mean.

So, it is a reliable facet but, it does vary from year to year and although it is only 10% is the typical variation, 10% is the standard deviation. Even then, prediction of Indian monsoon rainfall is very important and particularly as we will see later. Prediction of extremes, whether you will have a drought or not, whether it will be an excess rainfall season or not is extremely important. So, variability of all-India monsoon rainfall is very important.

Then the facet of the monsoon we looked at was the onset of the monsoon and onset of the monsoon over Kerala is an event, which is very dramatic and which is looked forward to during the summer season. But, which does not seem to be too much related to how the monsoon will perform in the rest of the seasons. So, if we were only interested in the all-India summer monsoon rainfall.

Then we would not worry too much about onset, when the onset occurred over Kerala. Then we also looked at advance of the monsoon from Kerala to the north western region and then we see that in fact the performance of the monsoon for the season as a whole that is ISMR is indeed related to how fast it progressed across the country or how slow it was.

And in particular when it progressed faster than normal, then the chance of above normal ISMR was higher. So this is the signal we got. Then we looked at fluctuations during the peak monsoon months of July and August, in rainfall over the monsoon zone, which is the seat of the rain belt and we consider the fluctuation between active spells with continuous rain for several days and weak spell which subdued rain or intense dry spells called breaks and we showed that.

In fact, number of break days is well correlated with the performance of the monsoon in the season as a whole or ISMR and the number of break days are highly correlated. The correlation was .6 or so and in fact, if you had a season in which the number of break days exceeded about 14 or so, then you are more or less guaranteed a drought, and also all the severe droughts were associated with long breaks or large number of break days because, it need not be 1 break.

So, that pointed to us, that it is very important to study also the sub seasonal variation even if you are interested only in the all-India summer monsoon rainfall, you know the performance for the whole season as a whole. Because of this relationship of the active and weak spells, rather the breaks with the ISMR. So, we have to study the morphology of the breaks, what is the structure like? Can we predict the breaks in other words, can we predict the transition from active to break? Can we predict the transition from break to active?

Now these are all open problems and we will see how far we have gotten in terms of understanding the mechanism that lead to the transition and prediction of this intra-seasonal variation. So far, I talked about what rainfall has taught us, but as I mentioned with the advent of satellite, it opened a new dimension totally to us. And this is the dimension that I will discuss and I will discuss that in the next class, I will begin with talking about what the satellites have shown us in terms of monsoon variability in the next lecture. Thank you.