The Monsoon and Its Variability
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Lecture – 11
Tropical Convergence Zones and the Indian monsoon - Part 1

Last lecture, we have seen that the system, basic system responsible for the summer, Indian summer monsoon, is a tropical convergence zone. And today, we will talk about tropical convergence zone and the Indian monsoon.

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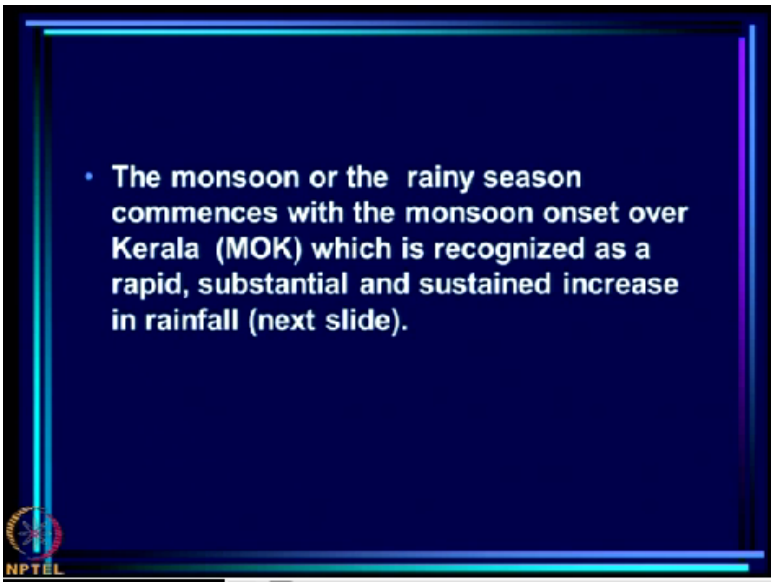

Now summer monsoon, the monsoon or the rainy season commences with the monsoon onset over Kerala, MOK, which is recognised as a rapid substantial and sustained increase in rainfall.

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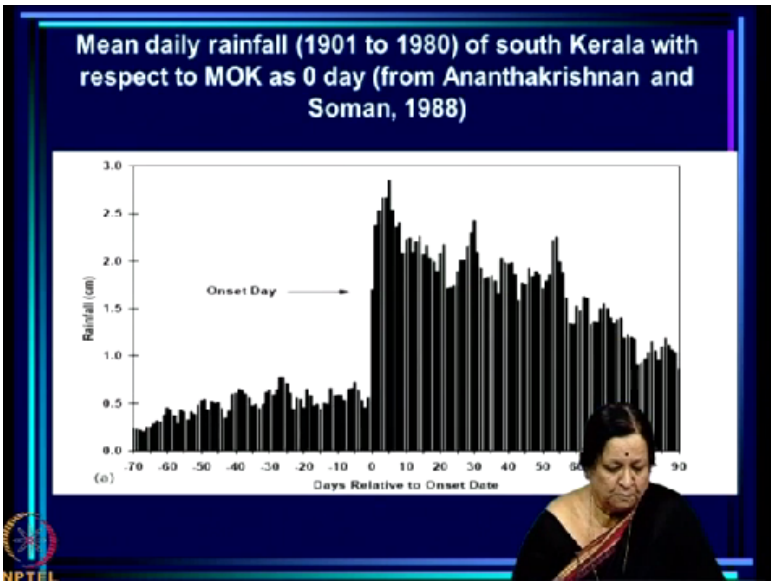

So we have already seen this. This is the monsoon onset over Kerala composite for several years, 80 years and 0 is the onset date and what you see is a very sudden increase in rainfall which is afterwards sustained. This is a very important facet of the onset.

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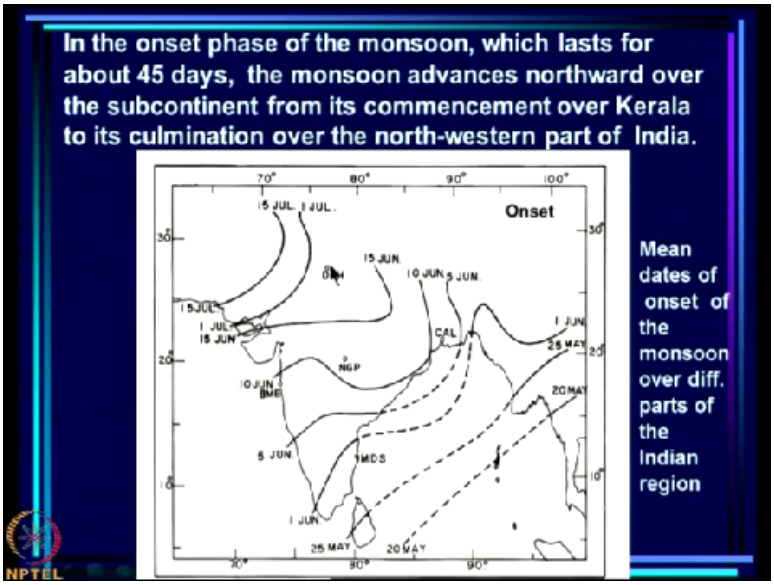

Now, after the onset over Kerala what happens in the onset phase is that the monsoon actually, the onset occurs more and more northern parts. So it goes across the peninsula and then the onset over this part also is thereby 10th of June. So after this then there is an advance of the monsoon in this direction. So there is an advance reaches northward and advance that is westward and by first of July, you can see most of India is under the sway of the monsoon. So these are the mean dates of course of onset from India Met Department.

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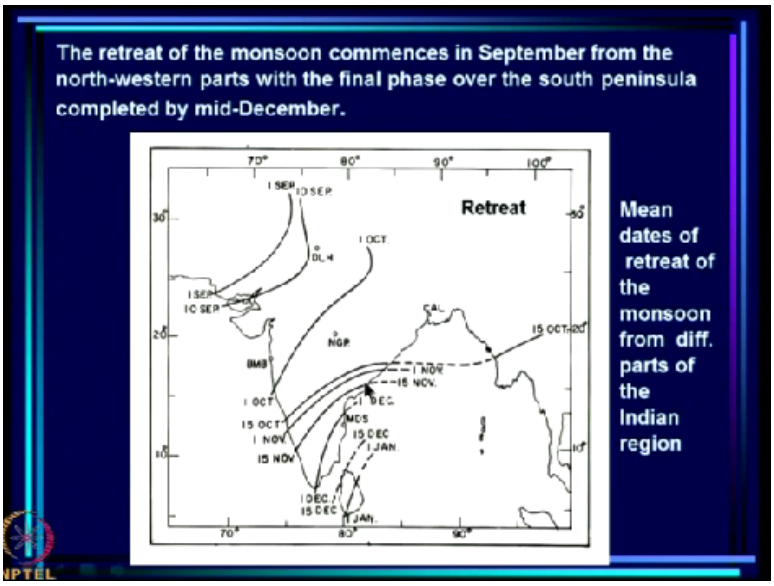

Now the retreat begins in September and slowly the monsoon retreats. By October 15th, it has retreated from most of India except for the southern peninsula and south-eastern peninsula and to retreat from these regions, it takes till December. So October to December is the post-monsoon season.

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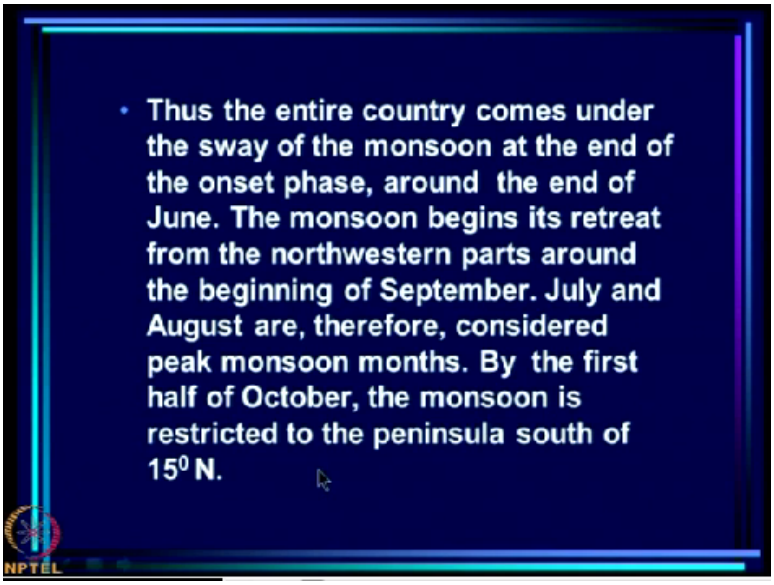

But we will first see the summer monsoon season. So the entire country comes under the sway of the monsoon at the end of the onset phase around the end of June. The monsoon begins its retreat from the north-western parts around the beginning of September and so July and August are considered to be the peak monsoon months. By first half of October, the monsoon is restricted to

the peninsula south of 15 degrees north.

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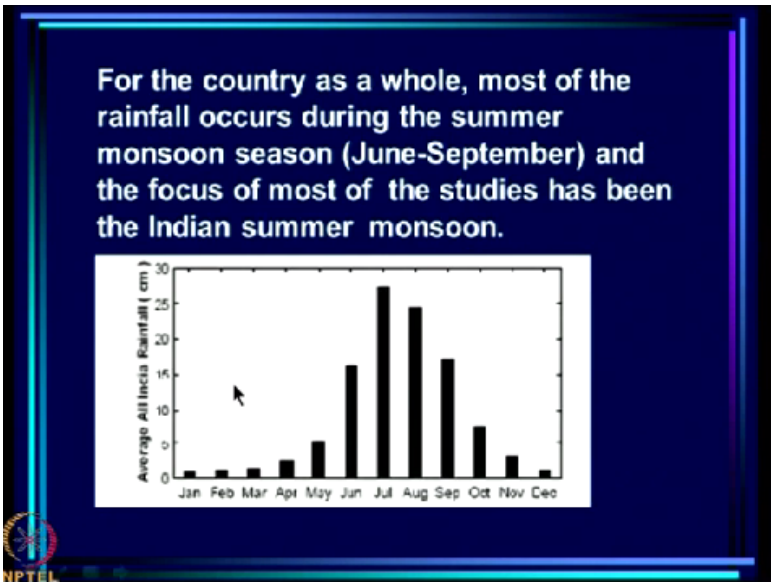

Now for the country as a whole, most of the rainfall occurs during the summer monsoon season, June to September, which we have seen already, June, July, August, September. So these are the 4 major rainy months.

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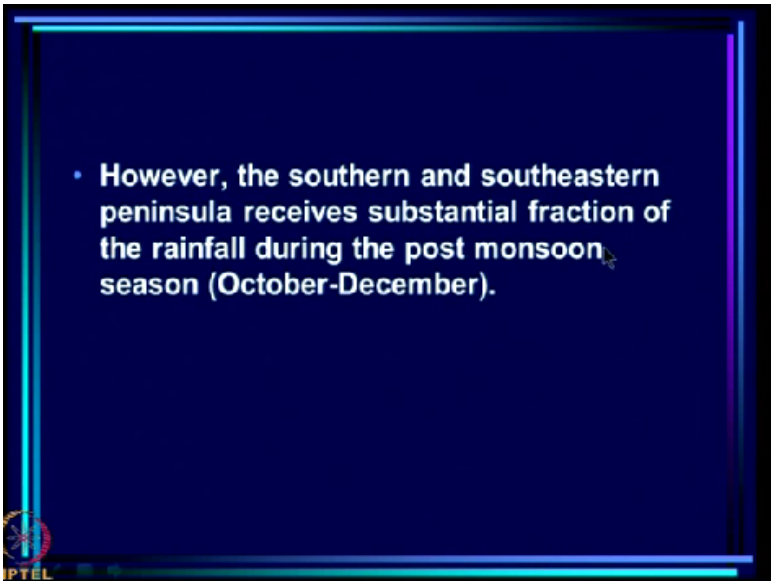

And the focus of most of the studies has been the summer monsoon. However, we should remember that southern and south-eastern peninsula receives substantial fraction of the rainfall during what we call the post-monsoon season.

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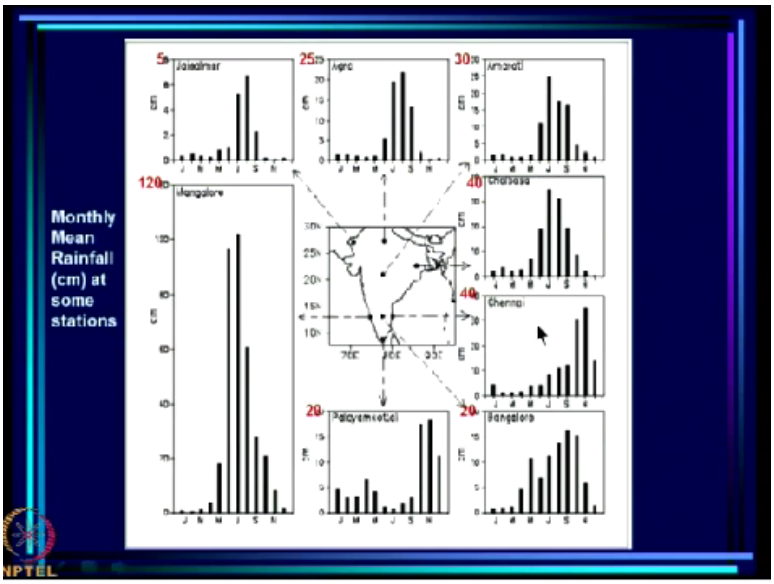

So in fact, the mean monthly rainfall if you look at different places in this northern part which is the monsoon zone, most of the rain in fact does occur from June to September as you can see here but in the south-eastern part, you see, Chennai for example, more rain in October-November than in any other months and then Bangalore we have rain from the summer monsoon as well as rain in post-monsoon.

Palayamkottai at the tip of the peninsula here, we have rain primarily in October-November-December but on the west coast, we get rain most of the rain in the summer monsoon but the rain continues in October-November as well. So this part whatever is theory, we have for the basic system responsible for the monsoon must not only explain the fact that over this part, the monsoon zone, the monsoon, most of the rain occurs from June to September.

But we should also understand from that basic system that a large amount of rain occurs here in October-November and so on.

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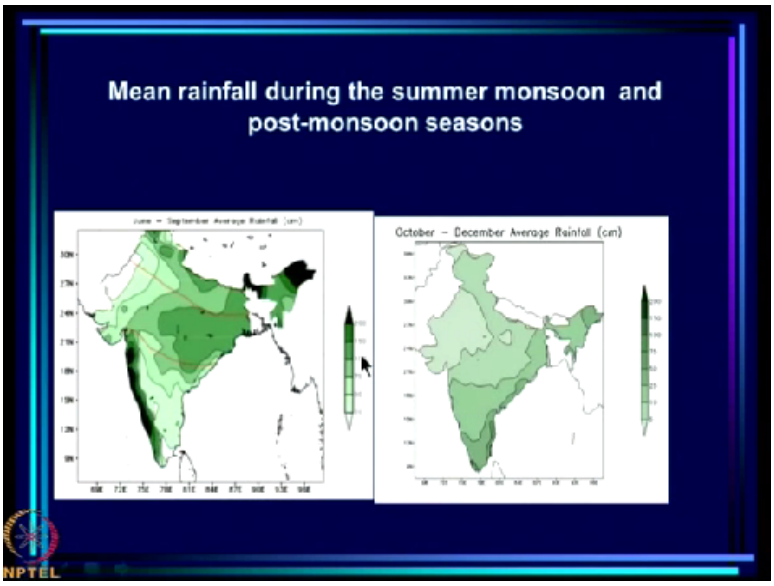

So now what is the mean rainfall during the summer monsoon and post-monsoon seasons? So this is the mean rainfall during the summer monsoon and this is the monsoon zone over which most of the rain occurs and this is really the seed of the tropical convergence zone that we talked about last time. In addition to that there is heavy rain on west coast which is partly accounted for by orography and heavy rain in the north-east as well.

The post-monsoon on the other hand, we get most of the rain south of 15 north over the southern part of peninsula to some extent over the east coast as well, okay.

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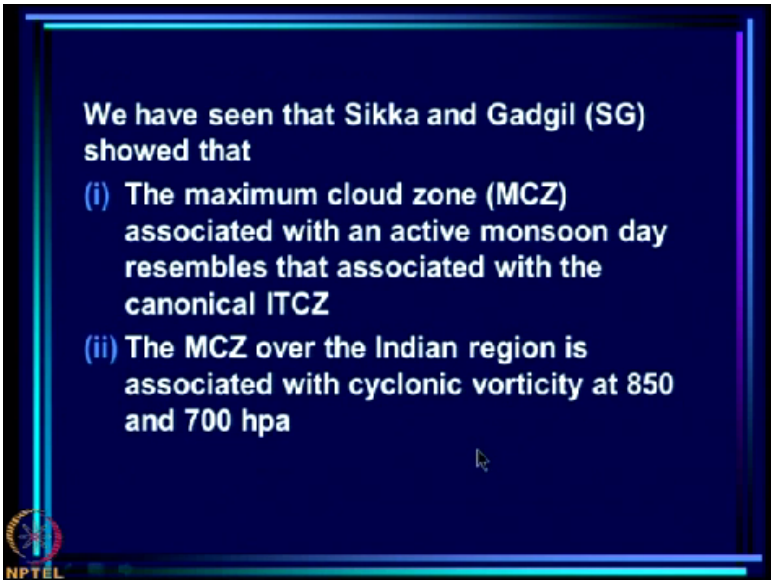

Now we have seen from the first study of satellite imagery that Sikka-Gadgil showed that the

maximum clouds on MCZ associated with an active monsoon day resembles that associated with the canonical ITCZ, the intertropical convergence zone which was known to tropical meteorologist as the system that gives rain over tropical Pacific for example. Now the MCZ over the Indian region is associated with cyclonic vorticity at 850 and 700 millibar. We have already seen that.

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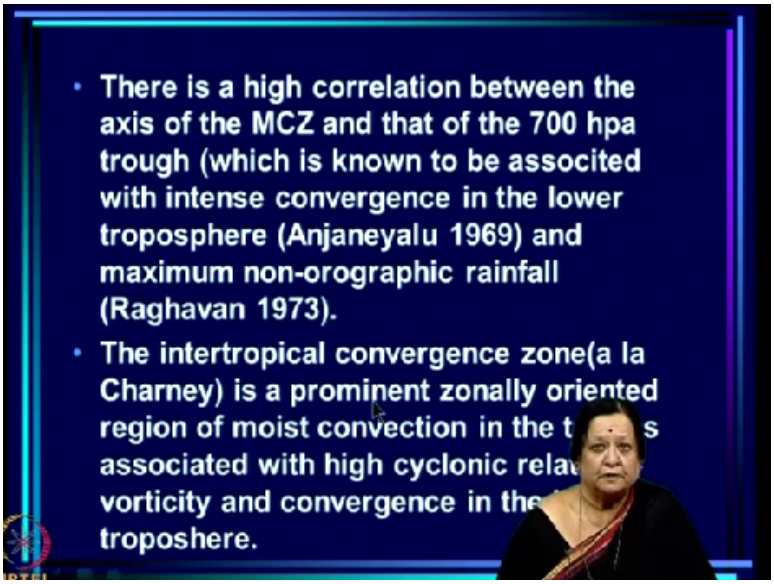

Furthermore, Sikka-Gadgil showed that there is a high correlation between the axis of the MCZ, maximum clouds zone and that of the 700 millibar trough which is known to be associated with intense convergence in the lower troposphere and maximum non-orographic rainfall. So it was known to Indian meteorologist that the key element in the dynamics to look for is where the 700 millibar trough is because that is the axis of the non-orographic rainfall.

But Sikka and Gadgil showed that what you saw from the satellite as maximum cloud zone, axis of that zone and axis of the 700 millibar trough which is the axis of the non-orographic precipitation, which is to say axis of the large-scale rainfall in the monsoon, are in fact highly correlated. This was shown by Sikka and Gadgil. So the intertropical convergence zone, as conceived by Charney, is a prominent zonally oriented region of moist convection in the tropics associated with high cyclonic relative vorticity and convergence in the lower troposphere.

These were the major dynamical attributes of the ITCZ.

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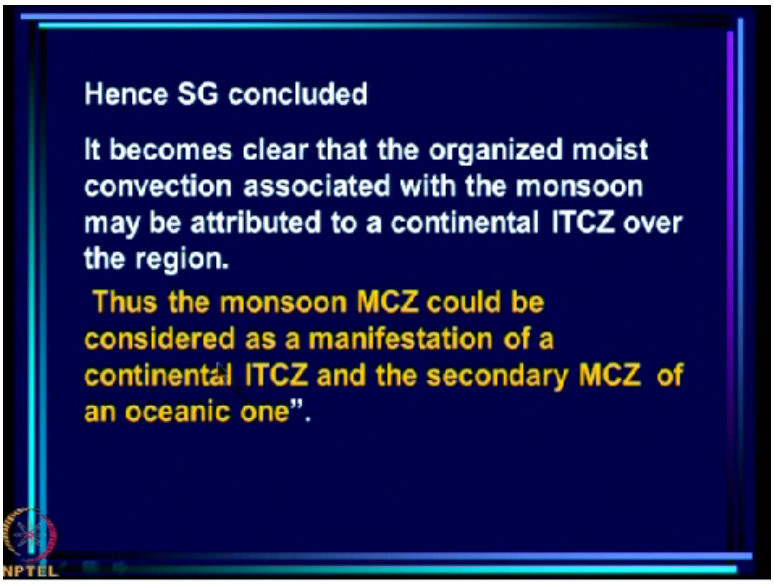

So putting these 2 together, putting the fact that the axis of the maximum cloud zone was highly correlated with the 700 millibar trough and had all the dynamical characteristics of the canonical ITCZ, Sikka and Gadgil concluded that it becomes clear that the organised moist convection associated with the monsoon may be attributed to a continental ITCZ over the region. So they said that the monsoon MCZ could be considered as a manifestation of a continental ITCZ and the secondary MCZ and oceanic one.

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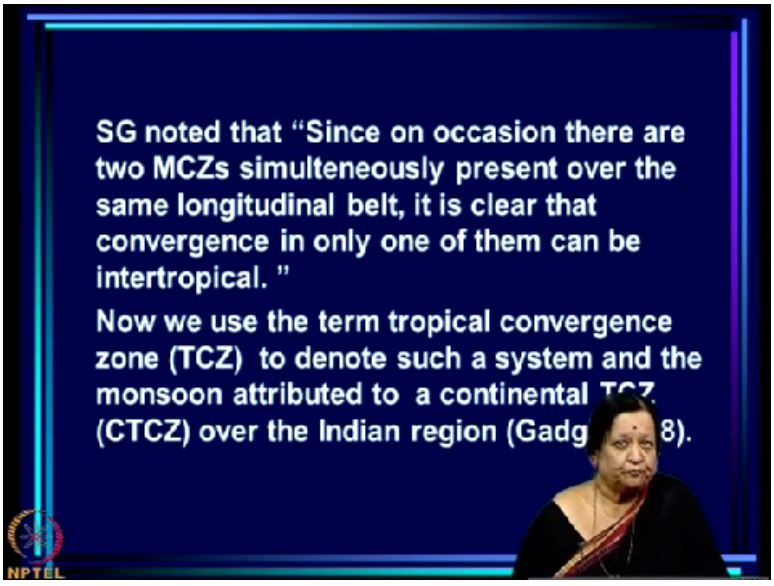

Now the term intertropical convergence zone comes from the fact that convergence in the zone is between air from the 2 hemispheres; however, we have seen already that on Indian longitudes,

very there are 2 cloud-bands, one over the equatorial Indian Ocean and one over the monsoon zone. So it is to be noted that since on occasion there are 2 MCZ simultaneously present over the same longitudinal belt, it is clear that convergence in only one of them can be intertropical from the 2 hemispheres.

And so we have dropped the eye from ITCZ and we only use the term topical convergence zone to denote such a system and the monsoon is attributed to continental TCZ or CTCZ over the Indian region. So this was the conclusion.

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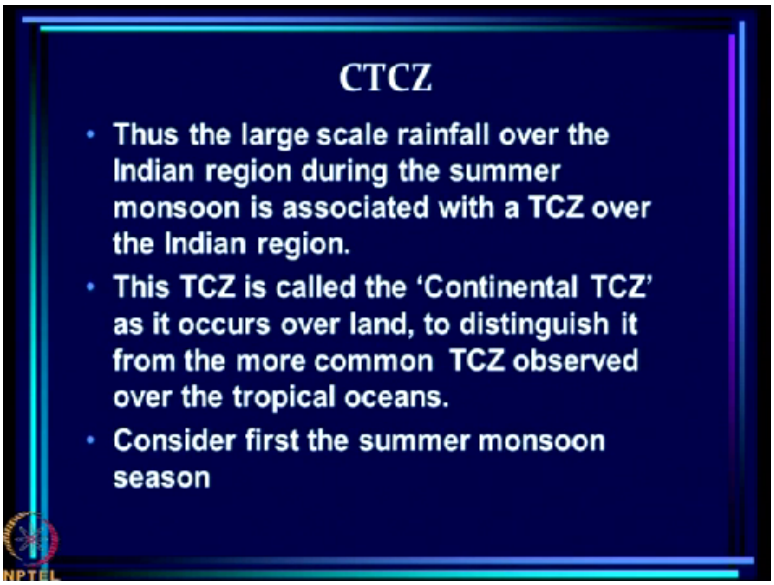

So now today we are going to talk about the variability of CTCZ. CTCZ is the basic system responsible for the large-scale monsoon rainfall. So large-scale rainfall over the Indian region during the summer monsoon is associated with the TCZ and this TCZ is called the continental TCZ as it occurs over land to distinguish it from the more common TCZ observed over tropical ocean.

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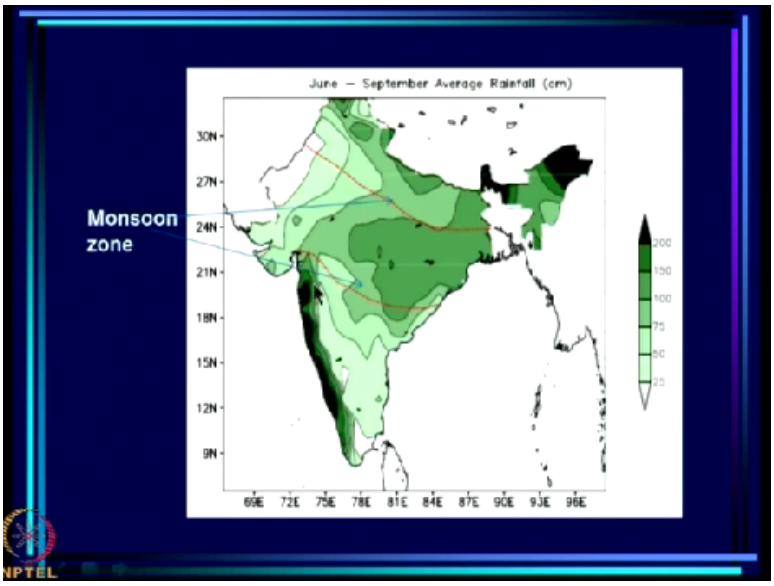

So first let us consider the summer monsoon season and this is the monsoon zone that we have seen before over which the large-scale rainfall occurs.

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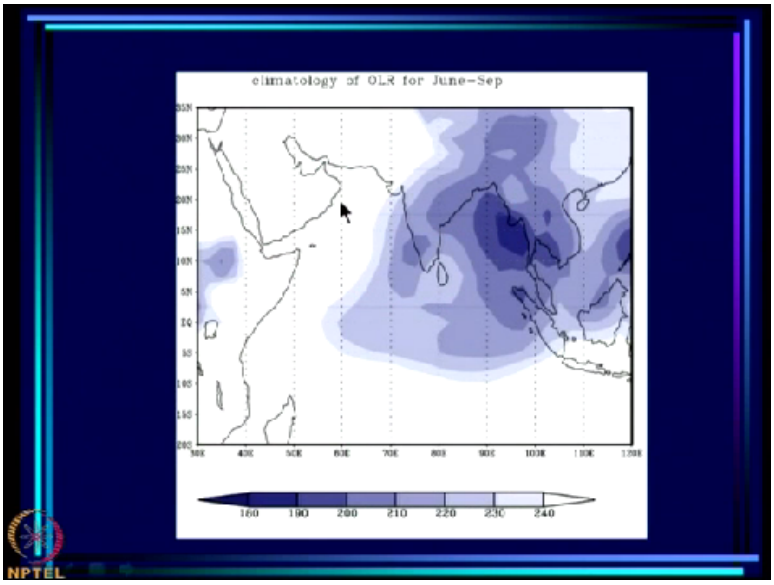

Now since we are going to look at the CTCZ in this lecture, we will look at first and foremost what the satellite shows us. So what we now look at is the climatology or mean or the average outgoing longwave radiation map for June to September averaged over 4 months and what you see here is the darker shade means higher the clouds, the lower the OLR, okay. So these are clouds with very very high tops here, the dark ones and the entire region is marked so that only OLR below 240 Watts per second is shaded.

So there are deep clouds almost everywhere here but highest frequency of deep clouds occurs in this region here, this dark region here. So from June to September, you can see this is what gives the rain over the monsoon zone here, you have this kind of a gradient that you saw also in rainfall but you will see a lot of rain occurs over the head bay during June to September. You notice that there is another tongue here over the equatorial Indian Ocean, these comes from the oceanic TCZ that we have seen that occurs simultaneously sometimes with the continental TCZ.

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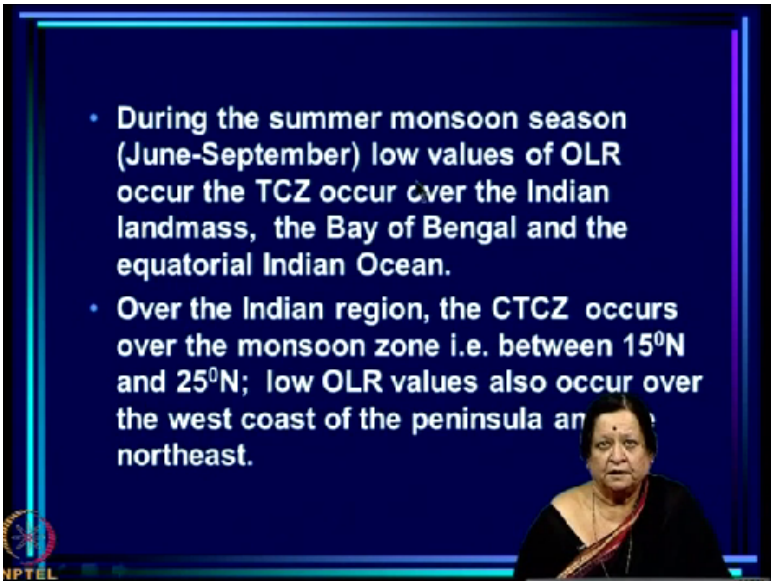

So during the summer monsoon, low values of OLR occur over the Indian land mass, the Bay of Bengal and the equatorial Indian Ocean. Over the Indian region, the CTCZ occurs over the monsoon zone that is between 15 and 25 north, low values of OLR also occur along the west coast of peninsula and the north-east that we have seen before, okay.

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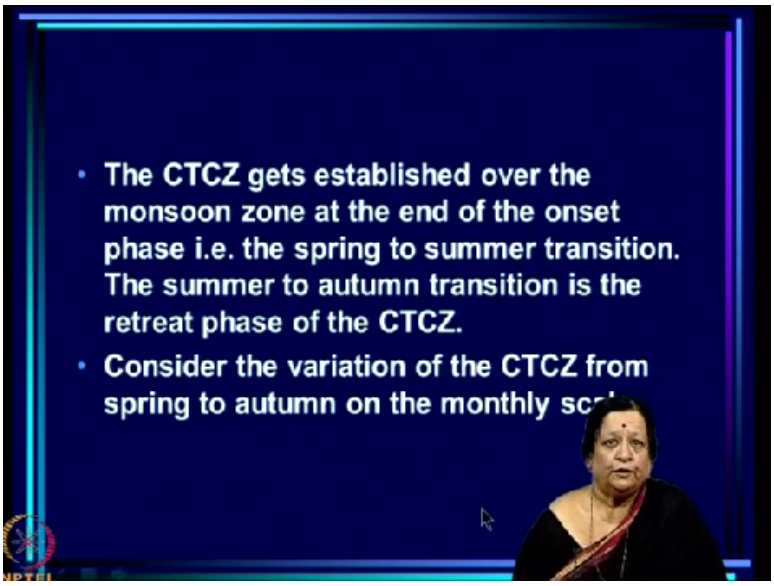

Now the CTCZ gets established over the monsoon zone at the end of the onset phase that is the spring to summer transition. The summer to autumn transition is the retreat phase of the CTCZ.

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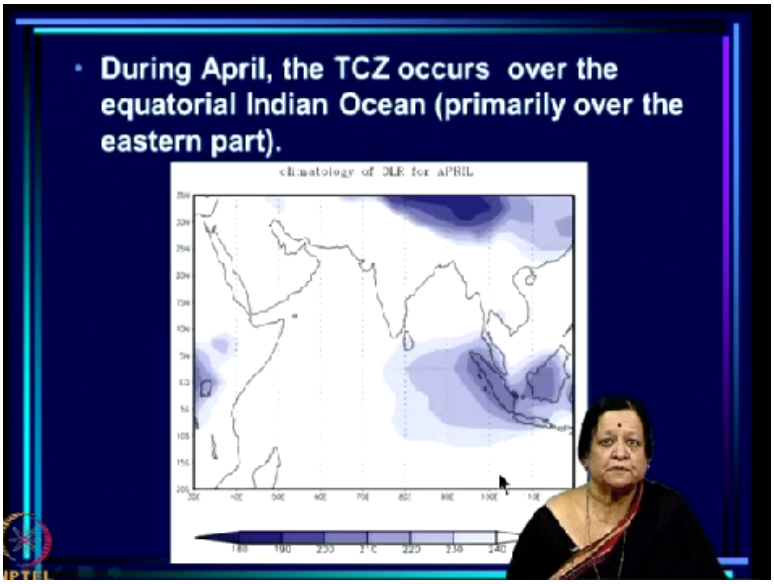

So consider first the variation of the CTCZ from spring to autumn on a monthly scale, okay. So April-May are supposedly the spring months and first we see the picture in April and what you see is, this of course is the mid-latitude rain that you see here, this has nothing to do with the tropical systems. What you see is a tropical convergence zone if you wish over the eastern equatorial Indian Ocean.

So there is rain over eastern equatorial Indian Ocean. On the average, no rain at all over the

western equatorial Indian Ocean and so the rain is restricted to this region.

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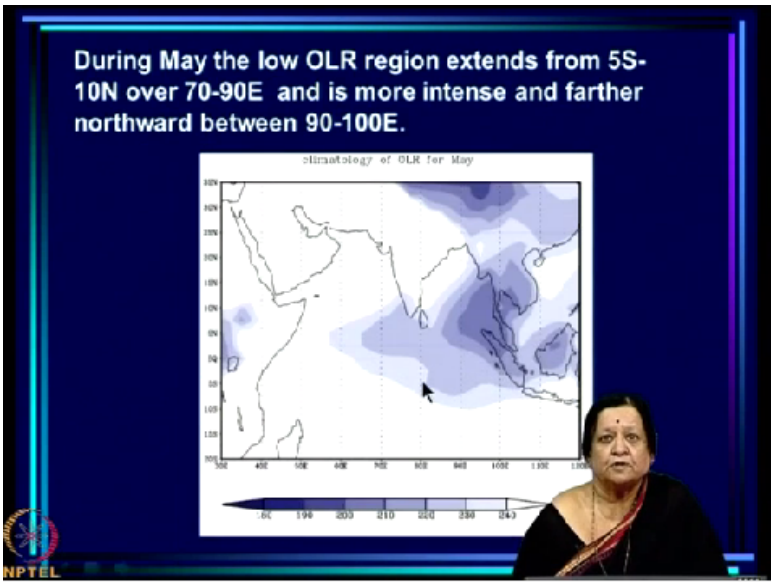

The deep clouds are restricted to this region in April. Now in May you see that it has expanded northward and a little bit westward, right. So the region extends from 5 south to 10 north. See it extends a lot over this region over 70 to 90, from 5 south to about 10 North, see tip of India has also come under the low OLR region and it is much farther northward over Myanmar and this part of the bay, okay.

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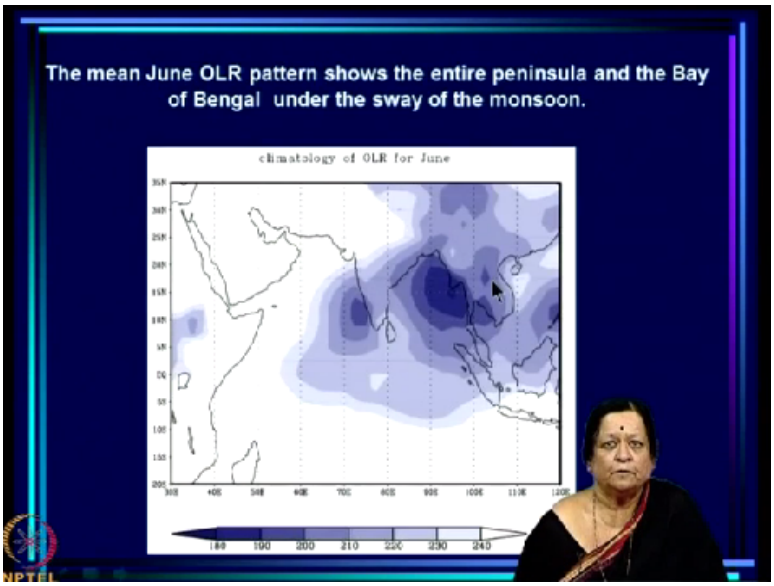

Now this is the June, mean June rainfall, remember the MOK or monsoon onset over Kerala typical date is 1st of June. So entire June, the monsoon should have been here and furthermore

you know that by 10th of June, it covers this much of the continental TCZ and then later on progresses. So almost the entire peninsula is now under the sway of the monsoon when we consider the mean monthly OLR picture but notice the high rainfall or low OLR region of the west coast and also head bay near Myanmar coast.

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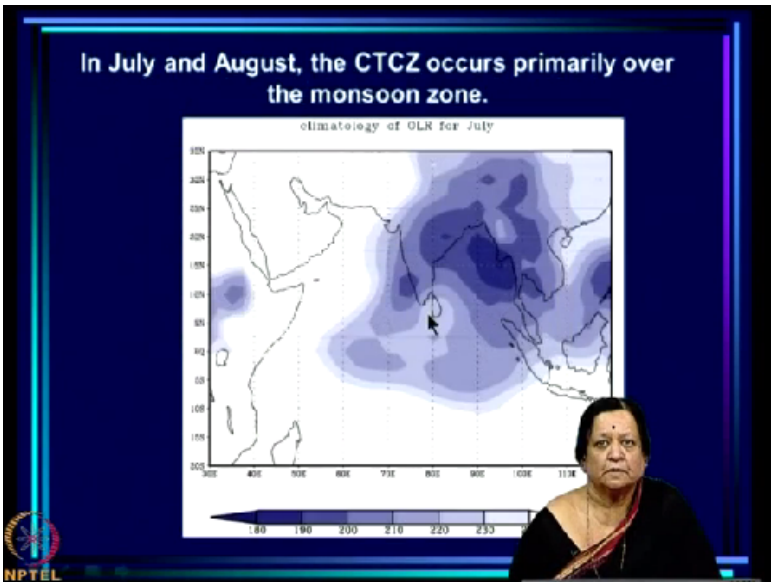

So now June is over. Now we come to the peak monsoon months of July and August and here you see are very typical pattern. This is the continental TCZ here now. This is the continental TCZ but remember that you it does not end with the Indian region. In fact, as you go eastward, it dips into the bay where it is even more intense, okay. So if you like you can say the CTZ here changes to an oceanic TCZ here.

So we have an oceanic TCZ and a CTCZ here and notice we have a full-fledged oceanic TCZ here, okay. This is the equatorial Indian Ocean. This is for the months of July and August.

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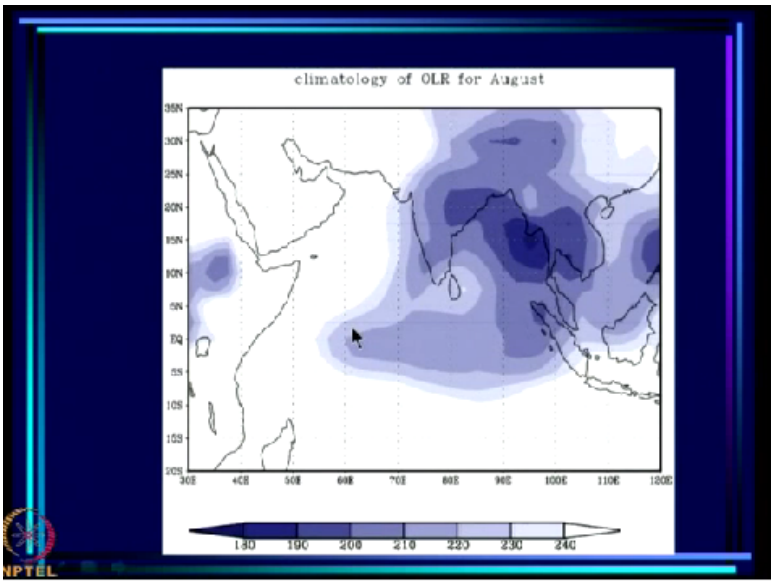

And if you look at August, sorry, the last one was for the month of July. This was for the month of July and you see already the CTZ is well established and this is the month of August and again you see the equatorial Indian Ocean ITCZ here, the TCZ here and this is the CTCZ with convection over the bay.

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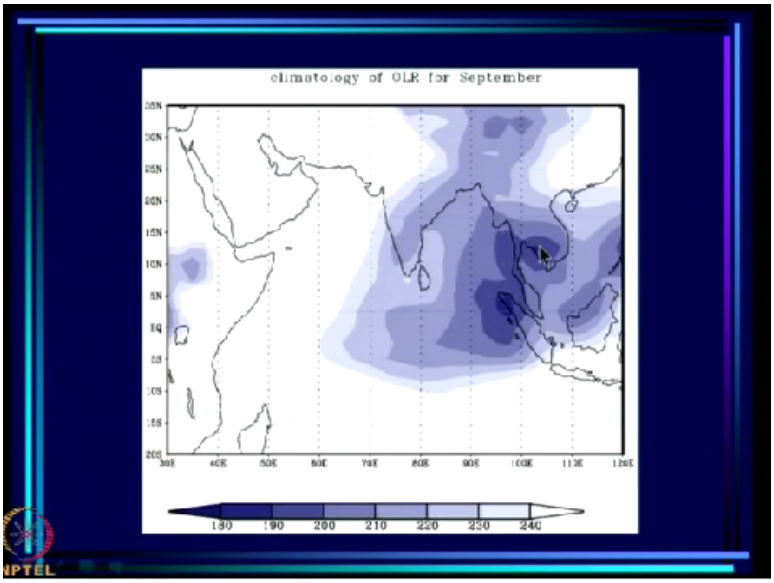

This is the month of September, remember 1st of September, the monsoon already starts retreating from here. So September, the rain is restricted more or less to the eastern part here or the monsoon zone and of course the peninsula gets a lot of rain in September. Now the excess or to speak or where the deepest clouds are, the lowest OLR is, has already shifted towards the equator but it has spread a little bit across the bay as well. This is the September story.

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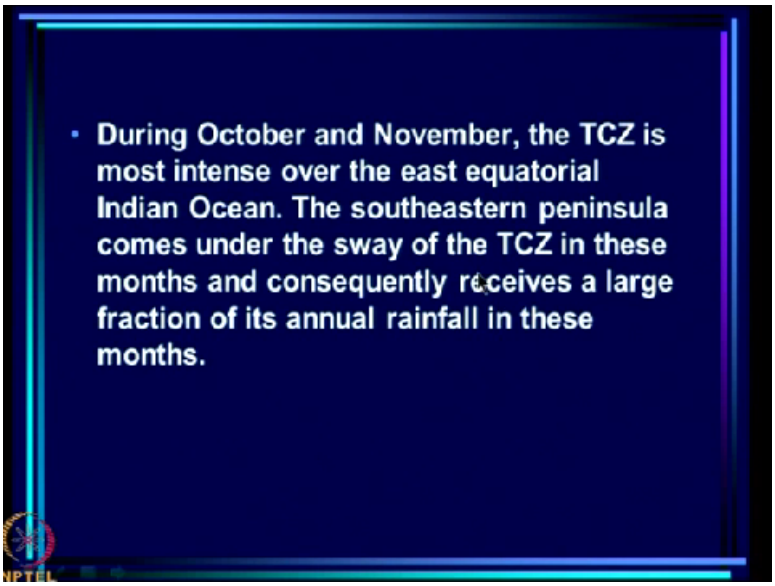

Now during October and November, the TCZ is most intense over the eastern equatorial Indian Ocean. Remember that the south-eastern peninsula comes under the sway of the TCZ in these months and consequently receives a large fraction of its annual rainfall.

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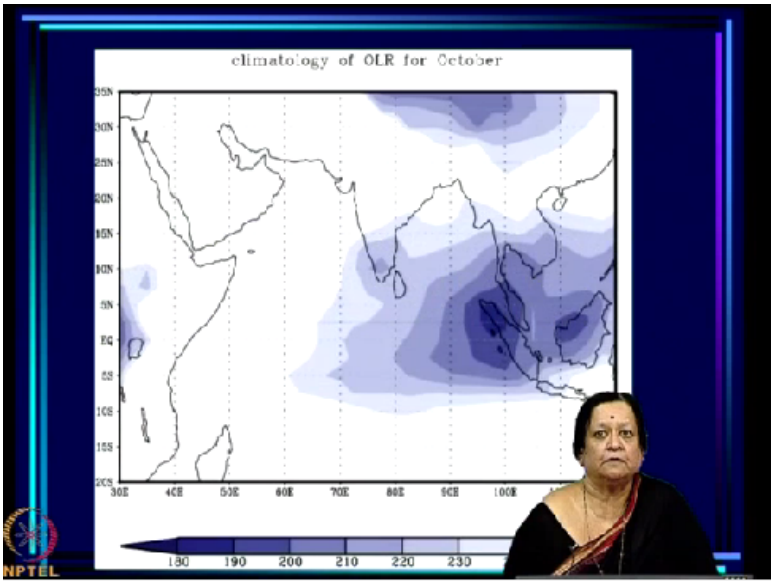

This is the picture we saw earlier that you know places like Chennai and Palayamkottai and so on gets a very large fraction of the annual rainfall in October and November and what you see is that in October-November, the centre of the CTCZ is over the equatorial region, okay and it is spread way up to about 15 North here you see. So the centre is here and we are looking at mean monthly picture and it is spread right up to here.

So associated with it, we get rainfall over India as well. But you have to remember that the centre is here, this is different from the summer monsoon case that you saw earlier where, see for example July, where there was a prominent band of cloud right over the land here, okay which was connected to the band over ocean no doubt but it was prominently here and this was where the deepest clouds were, if you looked at the entire 80 degrees east, the deepest clouds, largest rainfall would be here.

So it is not that is the system has spread to that, the system axis is here. On the other hand, when you look at the post-monsoon, it is a different story. The axis is around here and this is the periphery of the system which is giving us rainfall in October-November.

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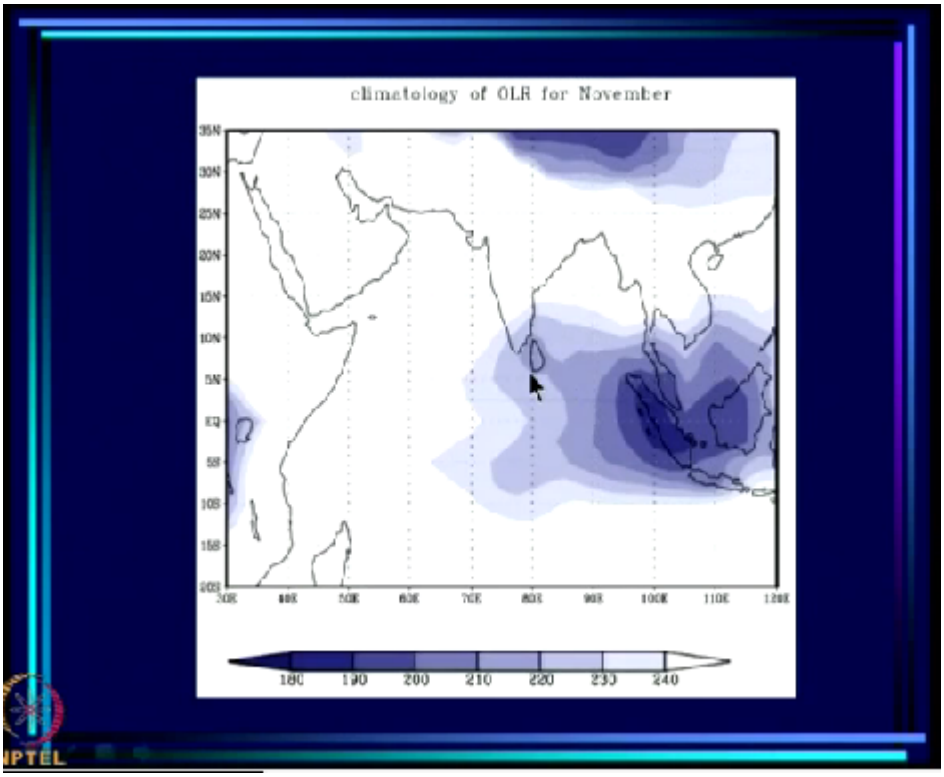

Same story, even more so in November. You see the system has become more intense and shrunk a little more and only a small part of the peninsula is getting deep clouds in November.

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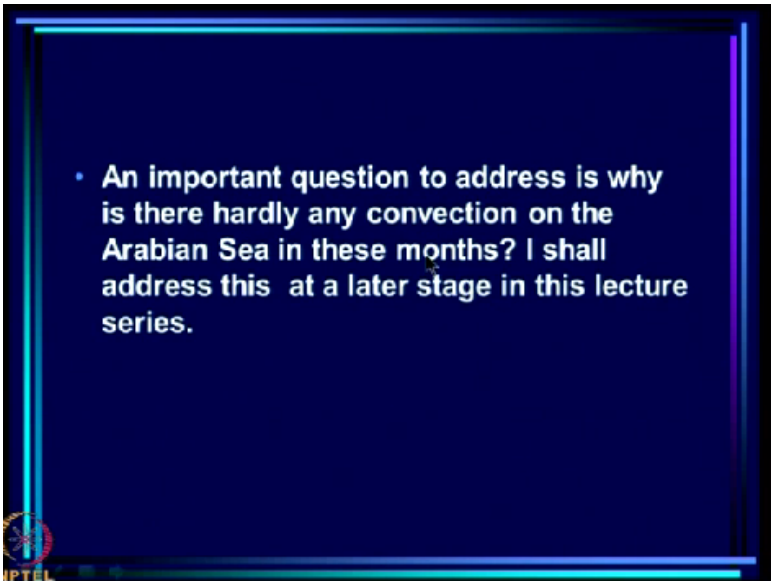

Now an important question to address is, why is there hardly any convection on the Arabian Sea in these months. We can just note this. If you look at October and let us look at the earlier seasons, say July or August, if you look at Augusta, there is quite a bit of a OLR here over the Arabian Sea, okay, that is east of 70 degrees east or so, but even then there is hardly any low OLR here but in the equatorial region, you see that this is extending right up to 60 east or so in August.

Now what happens, in September also you see it up to 60 east but October, now it has begun to shrink but the equatorial thing is fine in October but November you see it has shrunk even further and there is absolutely nothing over the Arabian Sea in November. Where as in October also, you did not have much over the Arabian Sea but there was a little bit here but in November, it has totally disappeared.

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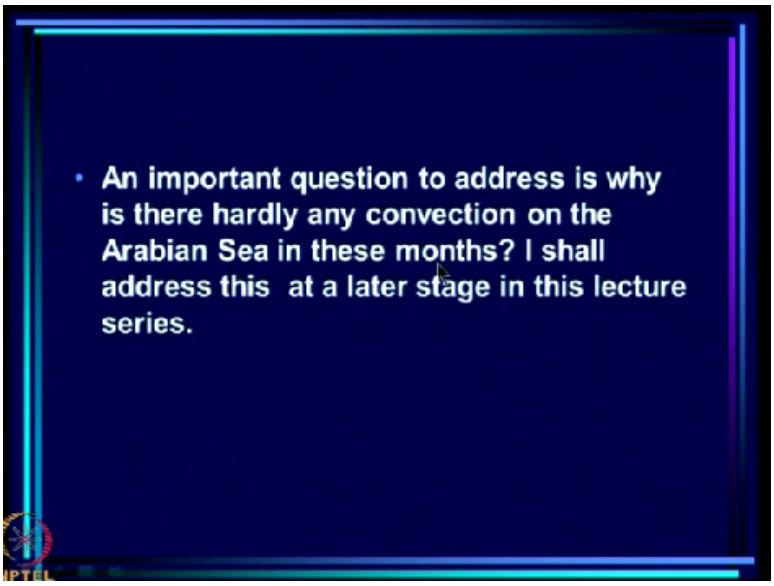

Therefore, an important question to address is, why is there hardly any convection on the Arabian Sea in these months, okay and in fact I shall address this question at a later stage in his lecture series when we understand a little more about what determines where the TCZ will occur over the oceans, okay. We are going to look at that a little later and after we understand that, we should be able to explain why there is hardly any convection over the Arabian Sea during October-November, why is it restricted to the bay, okay.

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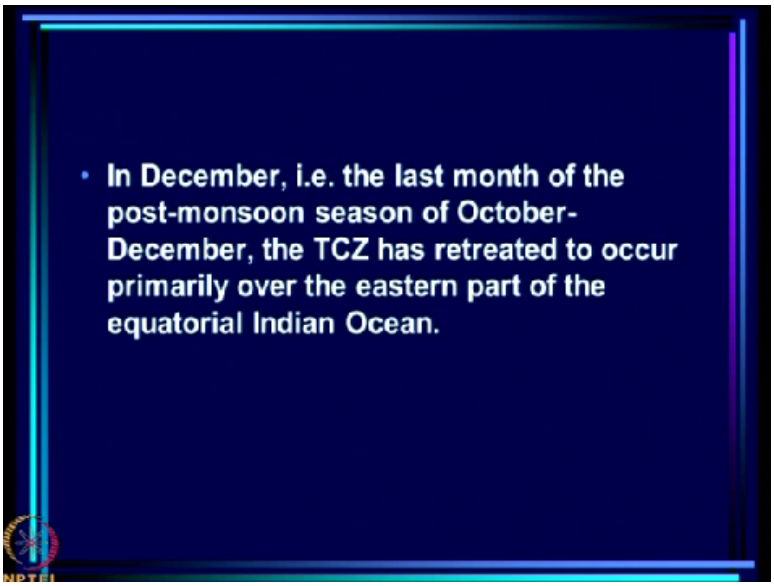

Now in December which is the last month of the October to December season, you can see that in the mean, there are no deep clouds at all over India.

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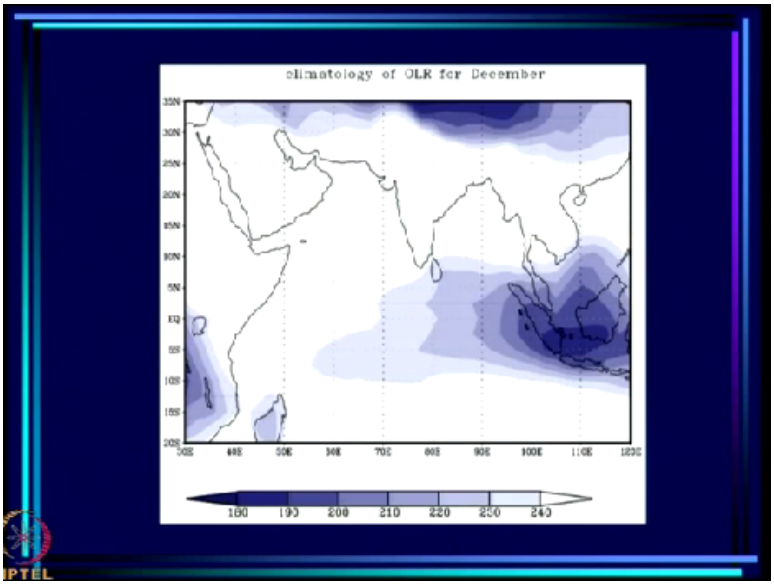

Of course, there would be events in which they occur here but other times, there are no clouds at all. So the average OLR does not reflect few days of deep clouds here. So again you see here, December is very much concentrated over eastern equatorial Indian Ocean and this part of West Pacific with no deep clouds anywhere else.

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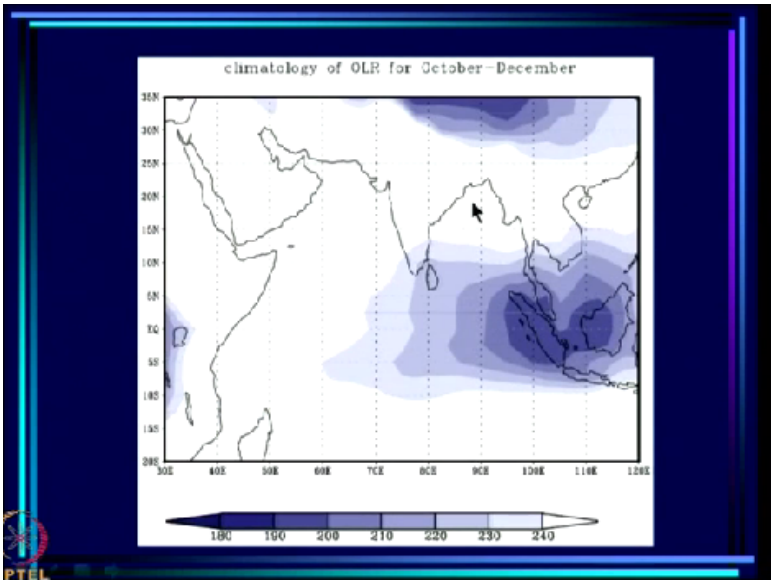

So climatology of OLR for October to December is that the TCZ if you wish, the axis of the TCZ is on the equator. It extends basically from about 90 east, which is here, to about 110 east which is here but on the periphery, you know south peninsula and so on which gets rain during the post-monsoon season, okay.

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Now question is, what is the system which gives us rain in the post-monsoon season? In the summer monsoon, we have seen that it is a tropical convergence zone and we have called it a continental tropical convergence zone because it occurs on the continent. Now we should see what is the system that gives us rain in the post-monsoon season.

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Now this is an example that we have seen before of what happens in the summer monsoon season. This is 7th of August 2007 and what you have seen is a very bright cloud-band stretching across here and you can see this is India, I hope you can see that and that is Sri Lanka right there and this cloud-band which we would call MCZ or maximum cloud zone, is over the monsoon zone here but it does not stop here, it stretches right across almost to the West Pacific, okay.

So this is the tropical convergence zone which is responsible for a rainfall in the summer monsoon.

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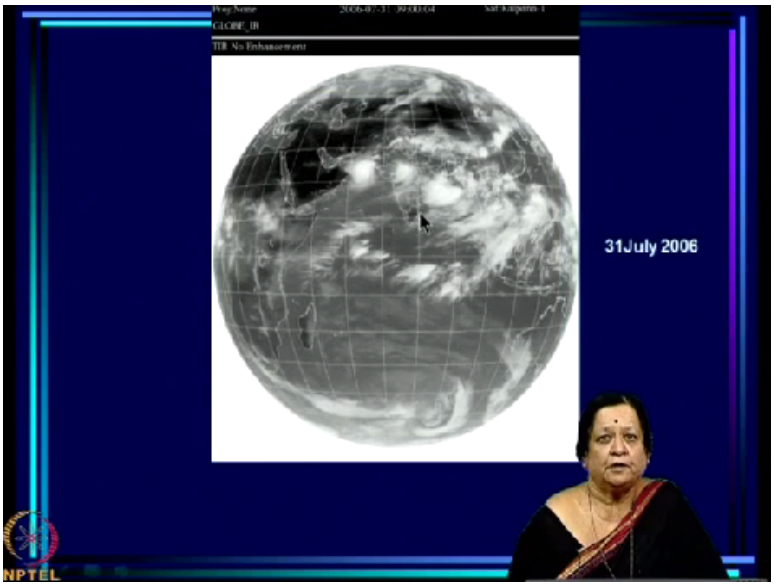

This is another picture where we have 31st July where again you see this and interestingly at the same time, we have an oceanic TCZ here as well with a link between the 2. So there are 2 tropical convergence zone and this is what we meant. You see, we cannot have intertropical convergence in both this and this. It has to be only in one or the other, that is why we call them tropical convergence zone.

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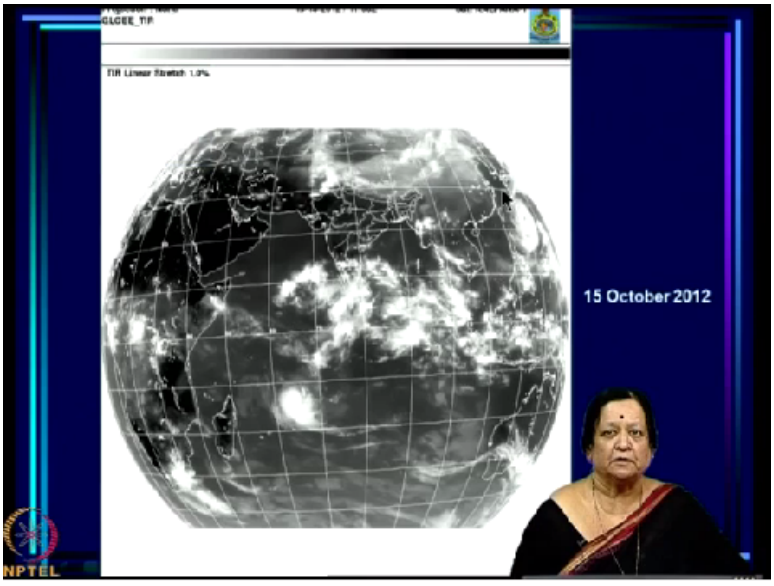

And an 15th of October, you see this is again the tropical convergence zone and beginning to look more like the classical canonical ITCZ and what you see here is again very similar to what you saw earlier but now to the south.

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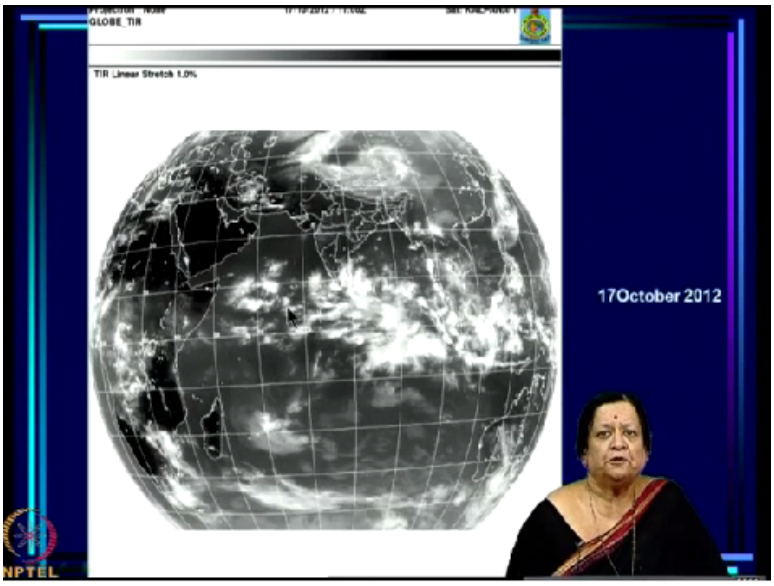

What you saw occurring here in the summer monsoon, is now occurring here at the foot of the peninsula so to speak, toe of Indian is dipping into the cloud-band here and what you see is the cloud-band very characteristic of a tropical convergence zone on 17th October. So we are now in the post-monsoon season.

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And as far as the satellite is concerned, the picture is very similar. Now this is in fact a global

picture for the next day which is 18th October and what you see is the cloud-band you saw here corresponding to our tropical convergence zone. What is interesting is across the globe you see this ITCZ here. See this is the Atlantic one and this is the Pacific one, you see.

Ours is more intense and somewhat larger in latitudinal extent but you can see that it is the same animal which is sort of girdling the earth in the equatorial regions which is responsible for a post-monsoon rain.

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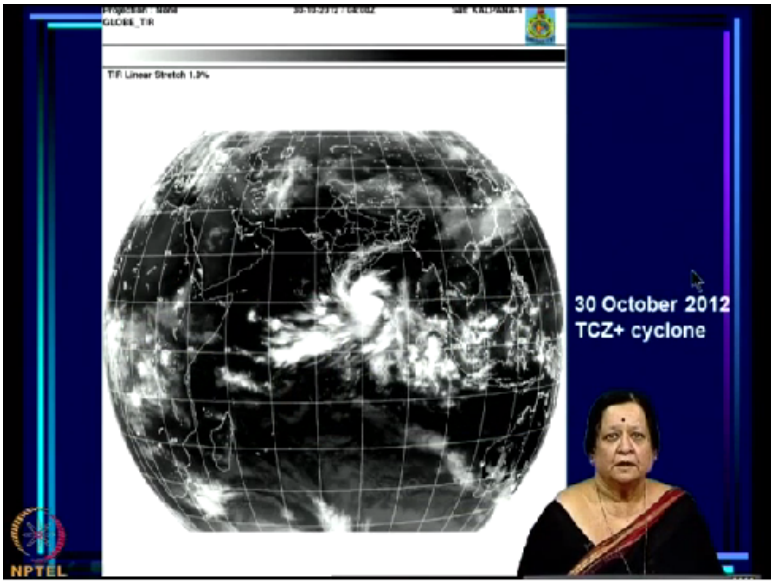

And this is a case of a tropical convergence zone from which cyclone was born and now the cyclone is taking off, you can save this very beautiful outflow region of the cyclone and the cyclone is taking off from this region.

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And the same picture here, now you see because the cyclone has become so strong, the ITCZ horizontal extent has decreased but the ITCZ persists over the Pacific.

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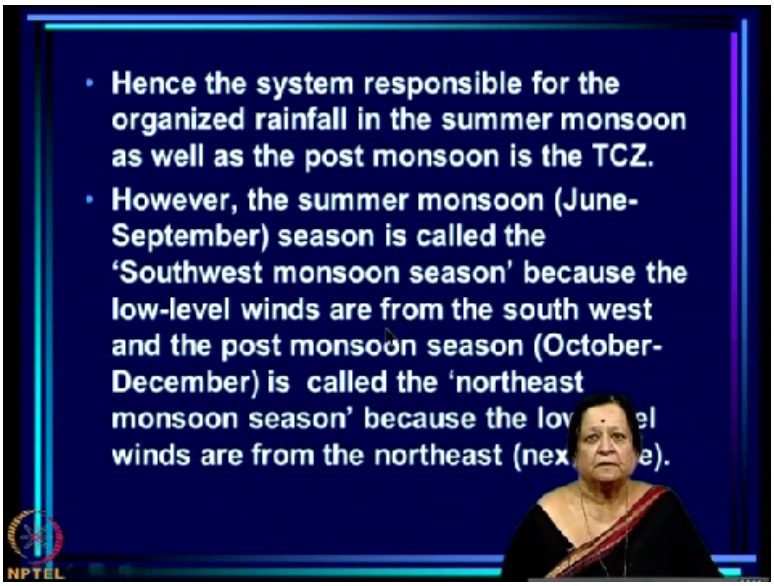

So the system responsible for organised rainfall in the summer monsoon as well as the post-monsoon is the same system. It is a tropical convergence zone; however, the summer monsoon, June to September season, it is called the south-west monsoon season because the low level winds are from the south-west and the post-monsoon season, October to December, is called the north-east monsoon season because the low-level winds are from the north-east.

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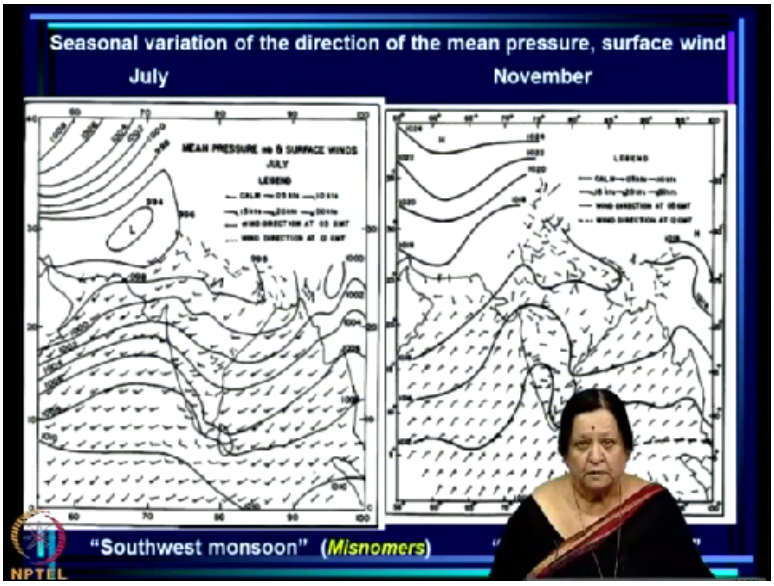

So you can see here, this is a slide you have seen before that in July, the winds are from the south-west and in November, they are from the north-east, you can see that very clearly here. This is the south-west monsoon because winds are from the south-west and this is the north-east monsoon because the winds are from the north-east, okay.

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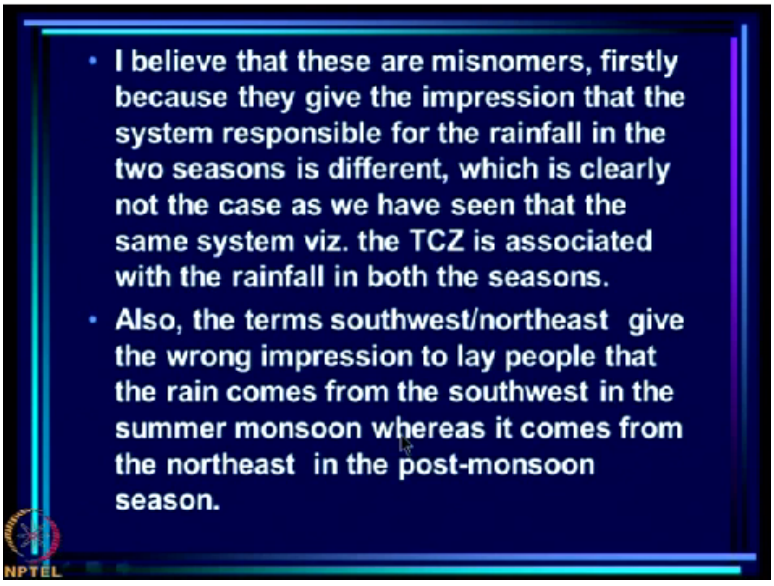

But I believe these are misnomer. Why are they misnomers, because they give the impression that the system responsible for the rainfall in the 2 seasons is different, which is clearly not the case as we have seen that the same system, namely the TCZ, is associated with the rainfall in both the seasons. Also the term south-west north-east gives the wrong impression to lay people that they will come from the south-west in the summer monsoon whereas it comes from the

north-east in the post-monsoon season.

See simply because the wind is in that direction does not at all means the rain comes from that direction but by calling a rainy season by name which conveys the direction of the wind, people who do not know the system which includes a vast majority of the people in the monsoonal region, assume that in south-west monsoon, rain must be coming from the south-west and in north-east monsoon, it must be coming from the north-east.

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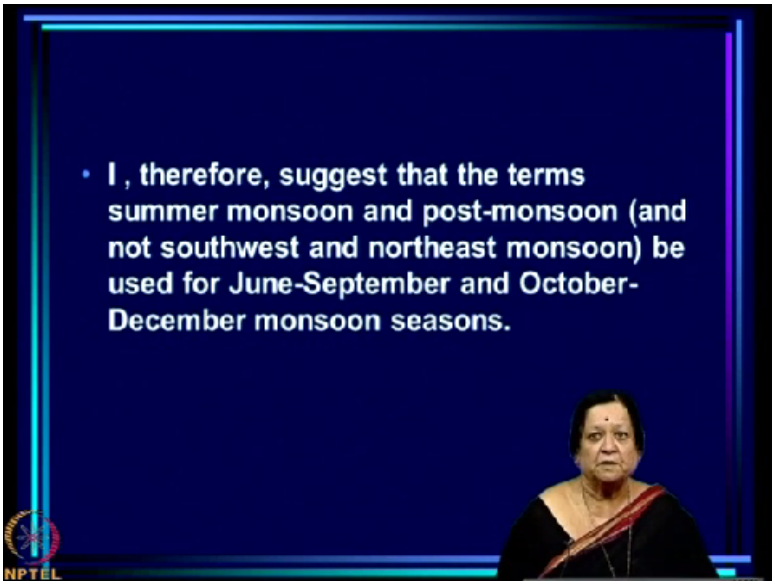

I, therefore, suggest that the term summer monsoon and post-monsoon and not south-west and north-east monsoon be used for the 2 monsoon seasons that we experience in India, okay.

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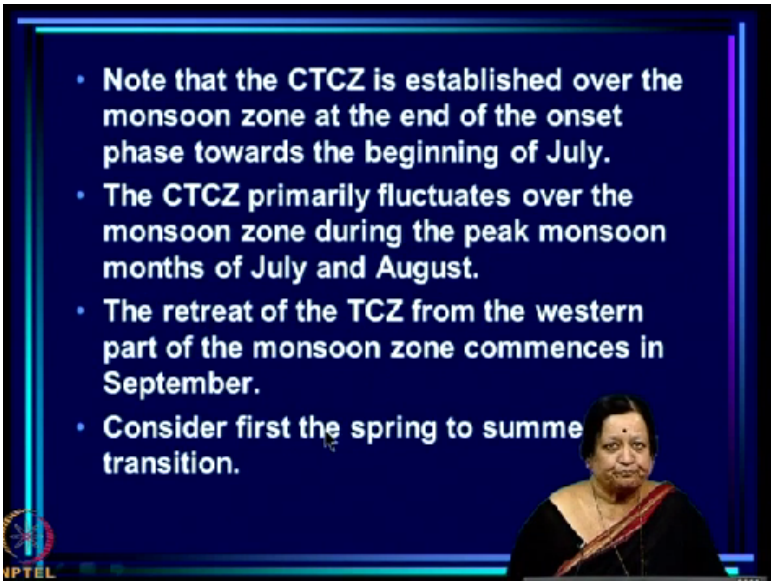

Now note that the CTZ, so the lesson so far is that right from the onset of the monsoon over Kerala on 1st June to the retreat around mid-December from the entire Indian region, the system responsible for the large-scale monsoon rainfall of our country is the tropical convergence zone, okay. Note that the CTCZ is established over the monsoon zone at the end of the onset phase towards the beginning of July.

And the CTCZ primarily fluctuates over the monsoon zone during the peak monsoon months of July and August. The retreat of TCZ from the western part of the monsoon zone commences in September, okay.

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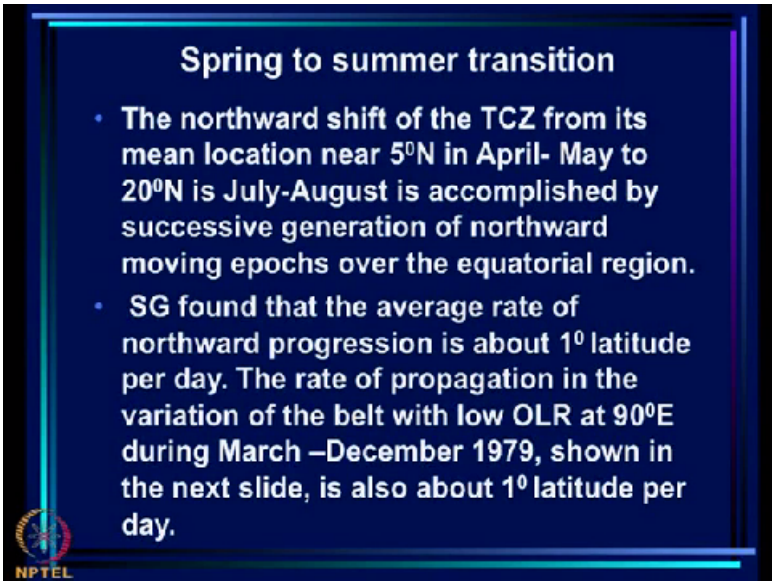

Consider first the spring to summer transition. Now let us see how the transition occurs. Northward shift is accomplished and here I would like to go to the picture first then we will come back to the description.

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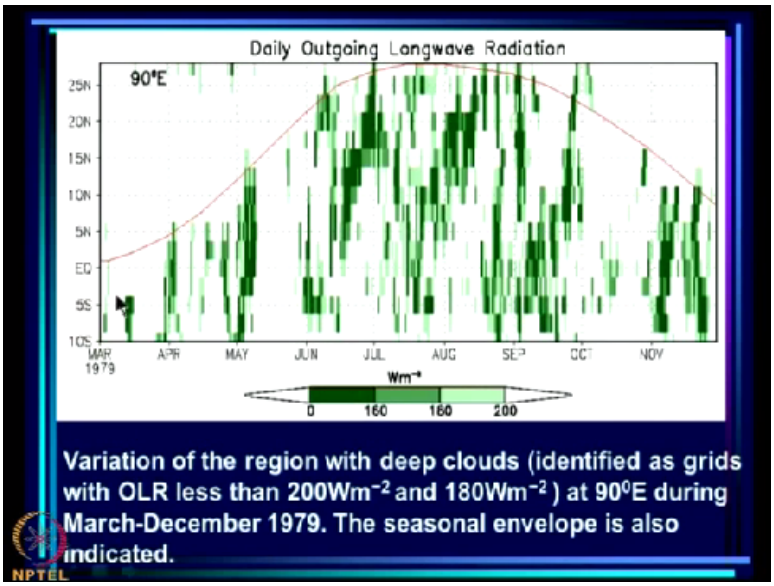

What you see here is for a particular year, these are bands. Now this is latitude going from 10 south to 25 north and we are sitting over 90 degrees east which is the latitude of around Calcutta, okay. So sitting at that longitude, we are seeing where are the deep clouds, okay. So on this specific day, this is march. On this day in March, there is a very deep cloud here and shallower clouds here. Now you see below 180 Watts per second is the darkest colour, okay.

Lighter then that is 18-160, I think below 160 is the darkest, 160-180 is the middle one, 180-200 is the lighter one. So everything coloured in green, corresponds to deep clouds because they involve on a daily scale OLR or outgoing longwave radiation of the order of 200 Watts per second. So what you see now, this is time and this is latitude. So what you are seeing here is a northward surge which went from 10 south to about 5 north.

Then it hung around for a while. Another northward surge here which went further northward, okay and then finally another surge here which took it to its final destination around 20 north, okay. So this is the spring to summer transition. It is made up of several northward surges, one after the other and that is what you saw here. Northward shift of the TCZ from its mean location

near 5 degrees north in April-May to 20 degrees north in July-August is accomplished by successive generation of northward moving epochs over the equatorial region.

As you have found that the average rate of northward progression is about 1-degree latitude per day and this is the rate of progression that we saw in the next slide, okay. So what is the average rate of this northward progression that you say, they found that it was about 1-degree latitude per day but remember this process is not linear. It is not as if it will cover 10 degrees in 10 days rather it is a very jerky process because the basis is all non-linear instabilities and so it is only an average we are talking of.

Order of magnitude of the rate, sometimes you know it will go up to some point and hang around there and then go northward as you see here. This happens very very often. So even here you see, it started then it went here very fast and then it kind of slowed down and then continued. So it is not a uniform progression but typically it is about 1 degree a day that is the progression.

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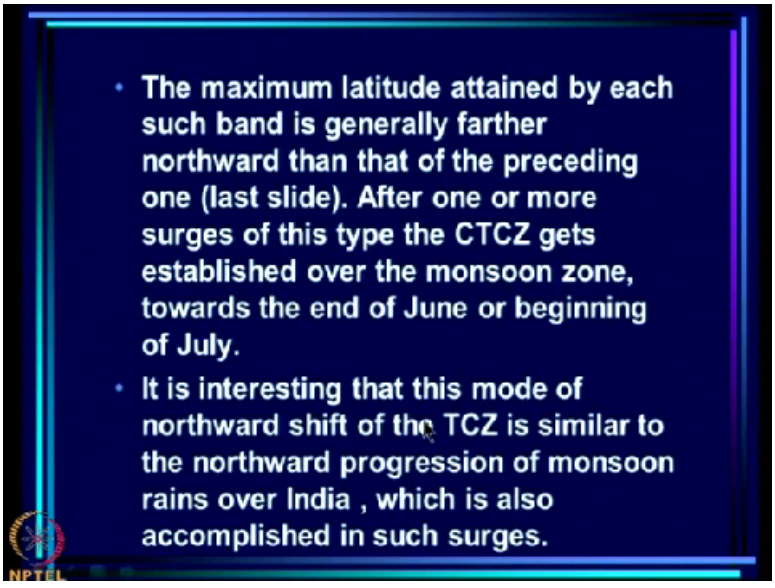

The maximum latitude attained by each such band is generally farther northward than that of the preceding one and after one or more surges of this type, the CTCZ gets established over the monsoon zone towards the end of June or beginning of July. So you saw here as you can see very clearly in the envelope we have drawn that the maximum latitude attained in each surge is further and further northward till it comes to a month of July, okay and then it is going here.

Now this is the retreat of the monsoon, okay where if you look at the envelope, it is going southward but are the bands moving southward? No not at all. In fact, what is happening is the bands are still generated over the equatorial Indian Ocean and they are moving northward but the latitude they reach is becoming more and more southward. So this thing has gone right up to beyond 20 north but the next one here, has gone only up to about 7 or 8 north, okay. So this is what happens.

So actually it is interesting that about the spring to summer transition, we had surges that went more and more northward with every succeeding surge. It is interesting that this mode of northward shift of the TCZ is similar to northward progression of monsoon rains over India which is also accomplished in such surges. So monsoon rain onset also occurs in surges and sometimes one surge will take it up to a certain point and the next surge will take it further northward and so on and so forth.

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Very similar thing we see in cloud-bands. Now when we see the summer to autumn transition, again the transition begins with the final disappearance of the TCZ from the region north of 20 degrees north in September. Note that this transition also comprises northward moving epochs just like the spring to summer transition and not southward moving ones as would be expected from the monthly location of the TCZ.

During this transition, the maximum latitude attained in each northward moving epoch decreases progressively, we have seen this already in this picture. So we have a situation in which we have northward movements throughout but the final destiny of the northward epochs actually becomes further and further northward in the spring to summer transition and further and further southward in the summer to autumn transition, that is how it occurs, okay.

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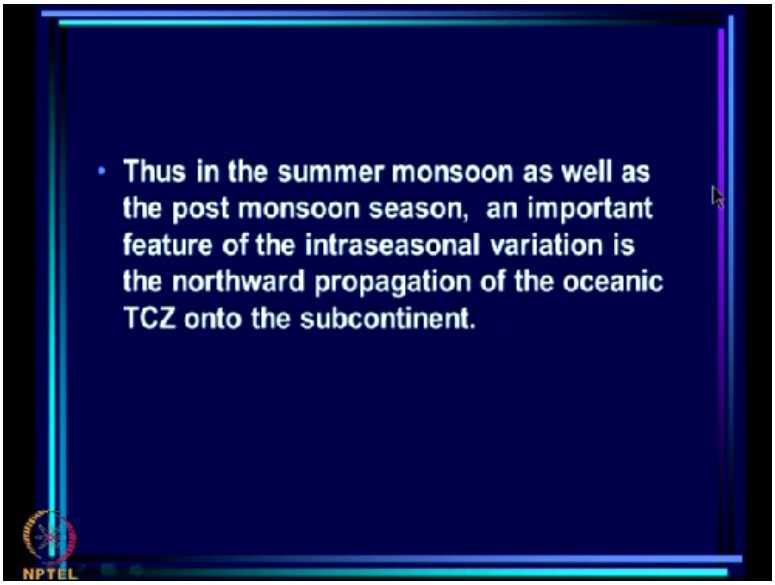

Thus in the summer monsoon as well as the post-monsoon season, an important feature of the inter-seasonal variation is a northward propagation of the oceanic TCZ onto the subcontinent. So this is a very very important feature of the variation of the cloud-bands or the intra-seasonal variation or variation within the season. Perhaps the most dominant feature if we start looking at clouds is the northward progression.

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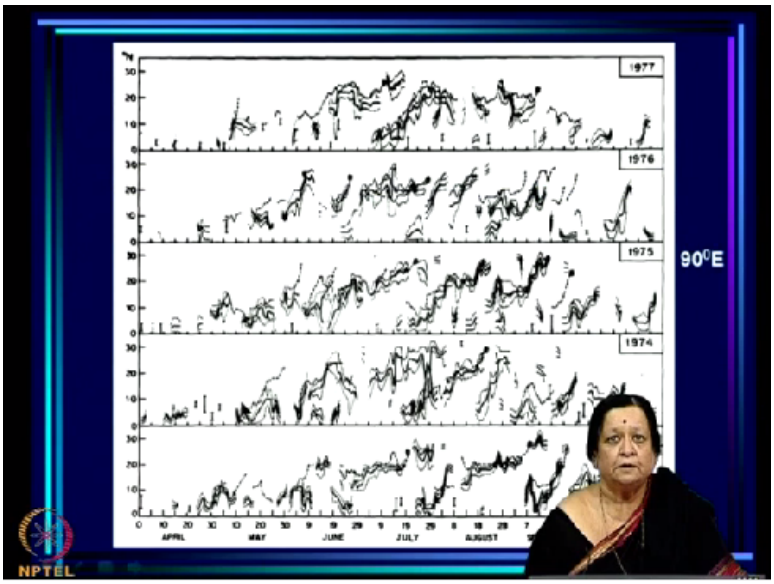

And this is a picture that you have seen earlier from Sikka and Gadgil and what you see here is that these northward progressions occur from April right up to October and they occur year after year. We have already seen that.

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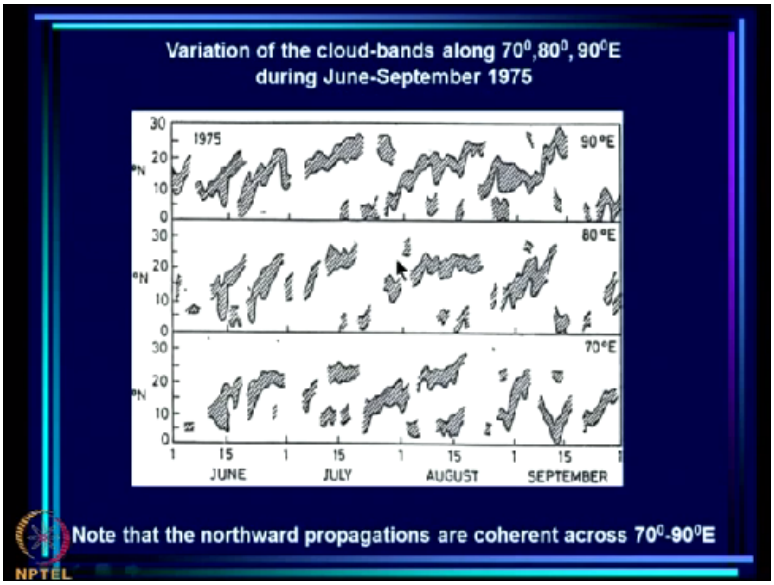

And this is from 70, 80, 90 degrees east in 1975 and you see that the northward progression is coherent across the Indian longitudes, you see, particularly here for example, 80, 70 and 90 which means that a band stretching right across from the Arabian Sea to the Bay of Bengal is going all the way from the equatorial region to 20 north or so as a band, that is why these northward movements are coherent. That is why these are movements of an MCZ. So they are coherent across.

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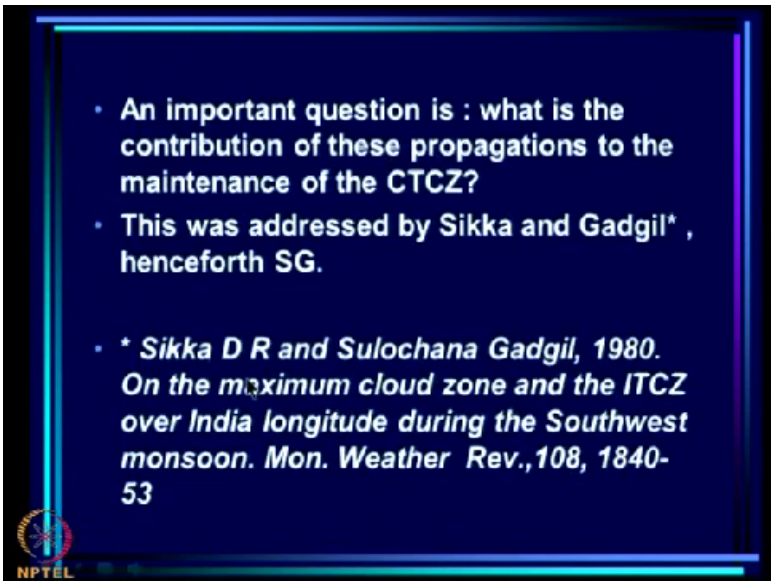

Now the question is, what is the contribution of these propagations to the maintenance of the CTCZ, okay. See we call it a continental tropical convergence zone because it is on the continent but we also notice that all the time we are getting bands from the equatorial Indian Ocean which come and end up in the CTCZ. So obviously CTCZ is maintained partly by these northward moving TCZ from oceanic side.

So question is, to what extent the CTCZ's existence depend on that? What is the contribution of this propagations to the maintenance of the CTCZ.

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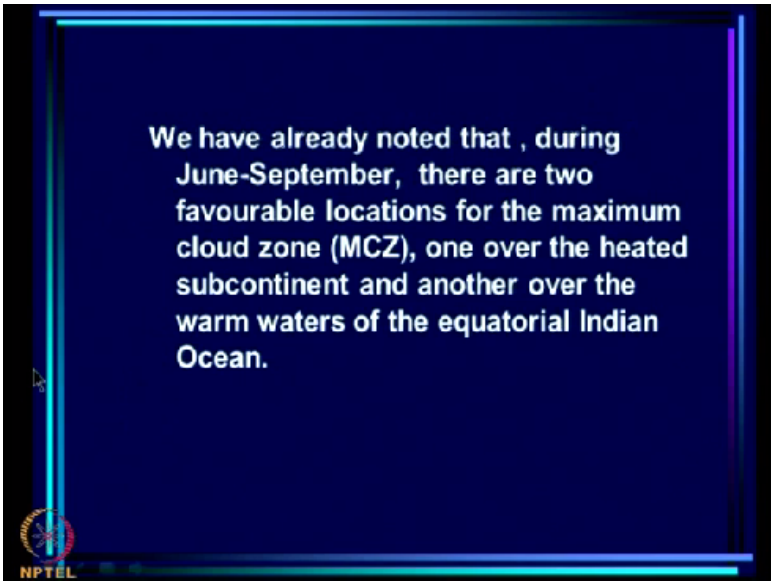

And in fact in that paper, Sikka and Gadgil also addressed this. Now how did they address it? To do that, we have to again define a few things properly. First of all, we have already noted that there are 2 favourable locations for MCZ, one over the heated subcontinent and another over the equatorial Indian Ocean.

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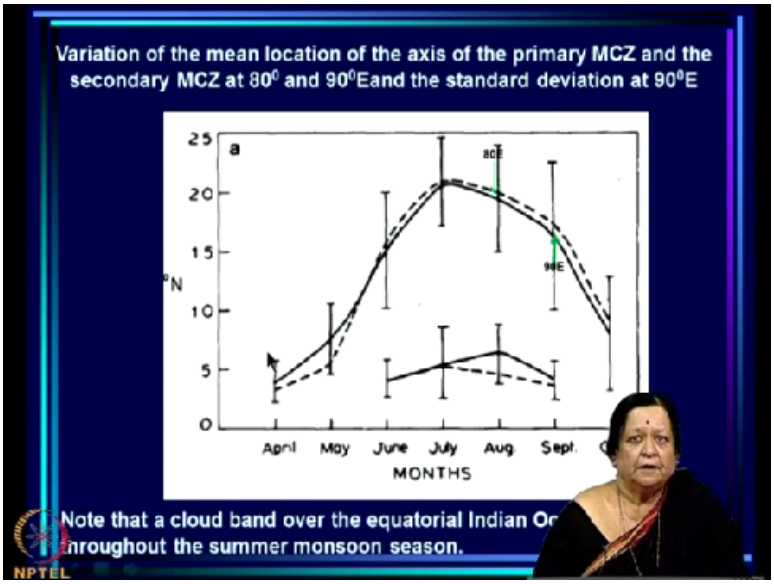

And remember, they assume that the boundary between the 2 is a kind of no man's land where the frequency of occurrence was minimum, around 7-degree north or so. To the south of that is what they call a secondary band, to the north of that is what they call a primary band or the monsoon band which we can call the CTCZ. So variation of the mean location of the axis of the primary MCZ and at this point, this is the primary MCZ.

So we should not call it the CTCZ at this juncture becomes the CTCZ only here when it is over land. So this is the primary band and this is the main location of the axis of the primary band moving northward and moving southward but throughout the season, June to September, intermittently we saw secondary band appear over the equatorial Indian Ocean and that is what you see here and that axis remains more or less fixed, standard deviation is higher here when it is to the north and the standard deviation is roughly same all around here.

So these are the 2 bands we are talking of. What is the contribution than of the oceanic TCZ to the maintenance of the CTCZ.

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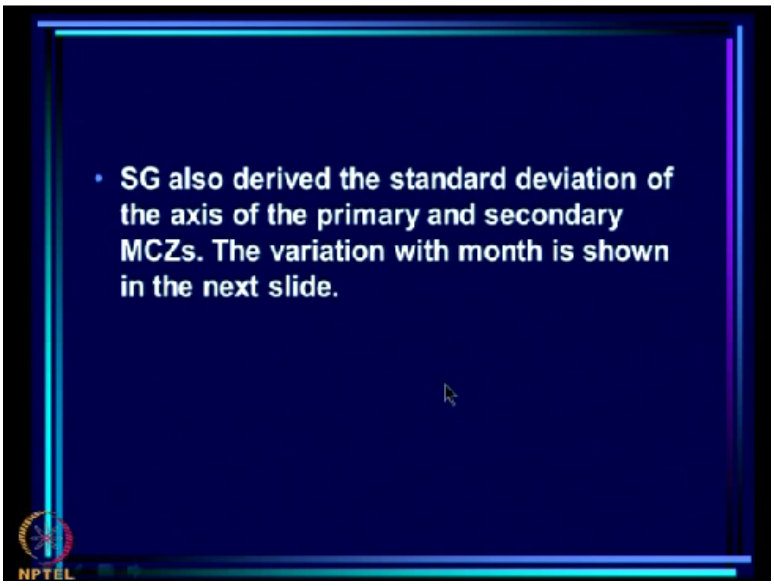

Now they also derive the standard deviation of the axis.

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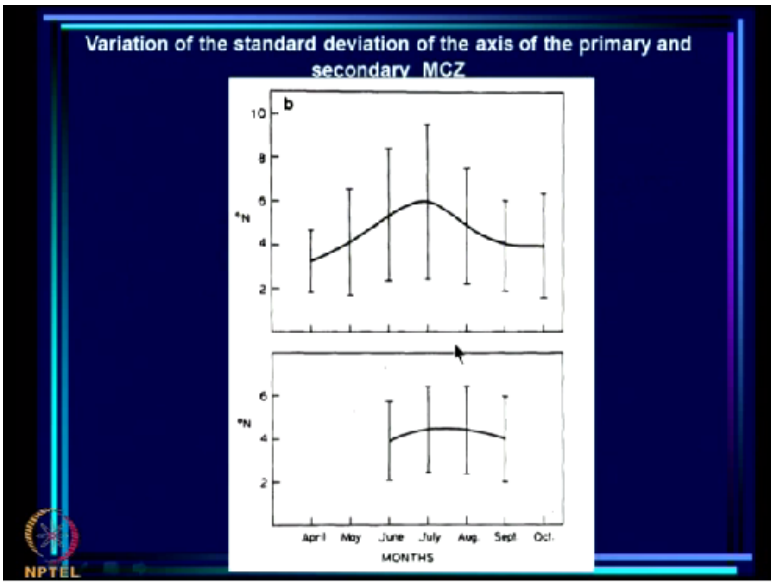

And this is the standard deviation of the axis, okay and what you see, generally it is below 7 degrees, okay. The spread is a little large in July-August but it is all < 6 degrees or so where as standard deviation here is about 4 degrees for the secondary band.

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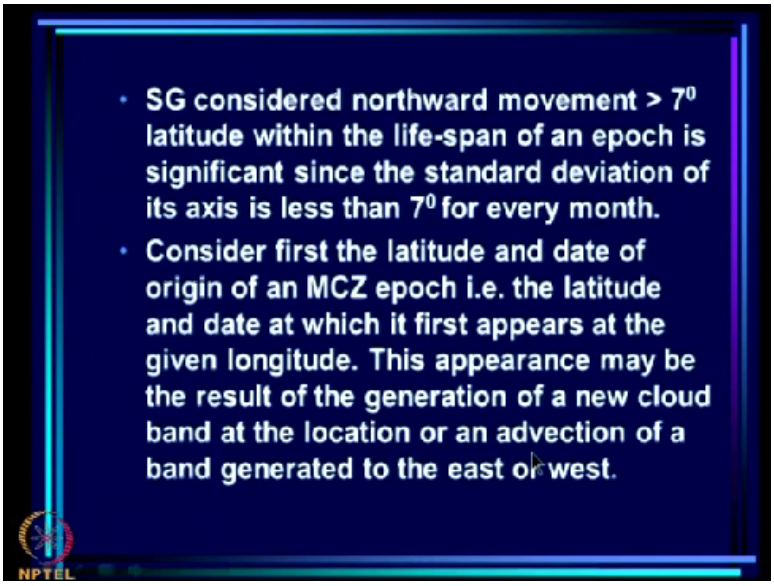

So because the standard deviation of that band that is how much the axis vary just due to fluctuations in situ is < 6 degrees, SG considered northward movement > 7 degrees latitude within the lifespan of an epoch is significant since the standard deviation of its axis is < 7 degrees for every month, okay. So remember epoch is the starting of an MCZ epoch or an event.

It started at a certain latitude on a certain date and then after a lifespan of a few days, it dies. Within its lifespan, it may propagate, it may not propagate, okay. So consider first the latitude and date of origin of an MCZ epoch that is latitude and date at which it first appears at the given longitude. Now we have to remember that we are looking at the band and as such we are not worried about what happens east-west progression and so on at this point.

We are focusing on north-south. So the appearance of a band at a given longitude may be the result of a generation of a new cloud-band at the location or an advection of a band generated from east or west. If we are sitting at say 90 degrees east and we say MCZ epoch started at 90 degrees east on a certain date, it could have started because something more there from 100 degrees east or it could have started because a cloud system got generated there at 90 degrees east. This is something that we have to bear in mind.

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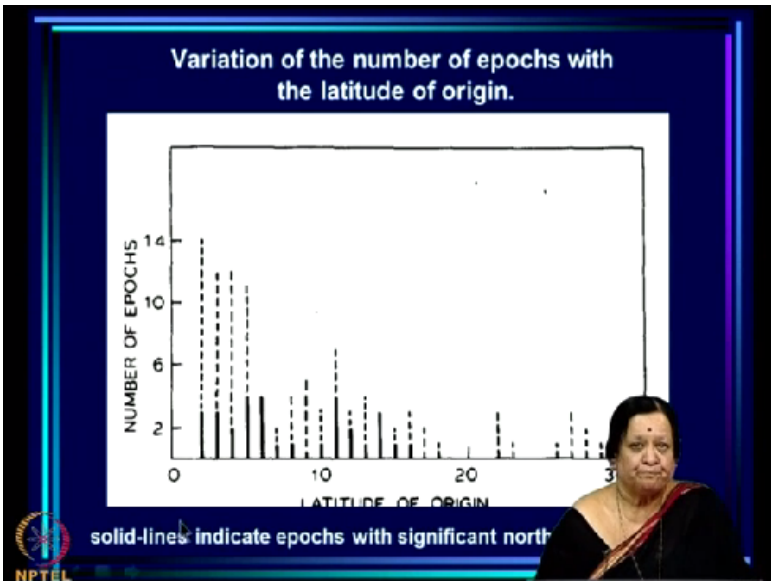

Now look at the variation of the number of MCZ epochs with latitude of origin, okay. So how many epochs are generated at different latitudes, going from 0 and all the way here till 30 north and solid lines indicate epochs with significant northward movement, okay. These are epochs with significant northward movement and these you can see up to here and what you see from this picture is, that vast majority of the epochs are generated over the equatorial ocean. Relatively few are generated over the continent.

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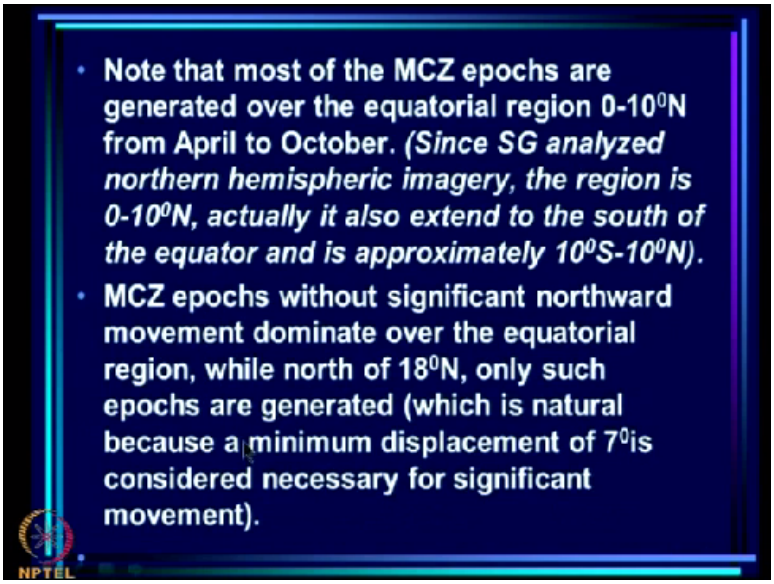

This is something very clear that most of the MCZ epochs are generated over the equatorial region, 0 to 10 north from April to October. Now we have to remember that in the Sikka-Gadgil study, the data they had available was hemispheric imagery or a hemispheric cloud mosaics. So

their data was restricted to 0 to whatever you wanted in the northern hemisphere, restricted in the northern hemisphere. So they could not go south of the equator but later studies have found that, equator is not a Laxman Rekha at all.

In fact, equatorial Indian Ocean mean stands out to 10 north or so. So actuality it is 10 south to 10 north but Sikka-Gadgil's data is only from 0 to 10 north. So they found that most of the epochs are generated 0 to 10 north. Also MCZ epochs without significant northward movement dominate over equatorial region. So what we saw was, okay, over the equatorial region that the dashed lines are much much longer than the solid lines.

So MCZ epochs which do not dominate, which do not move northward, are dominant here and there are dominant almost everywhere and north of 18, there are no northward moving epochs at all because for it to be northward moving, it has to move at least 7 degrees and there is not that kind of a span left for them to move.

So without significant northward movement dominate over equatorial region while north of 18 degrees only such epochs are generated which is natural because of minimum displacement of 7 degrees is considered necessary for significant moment, okay.

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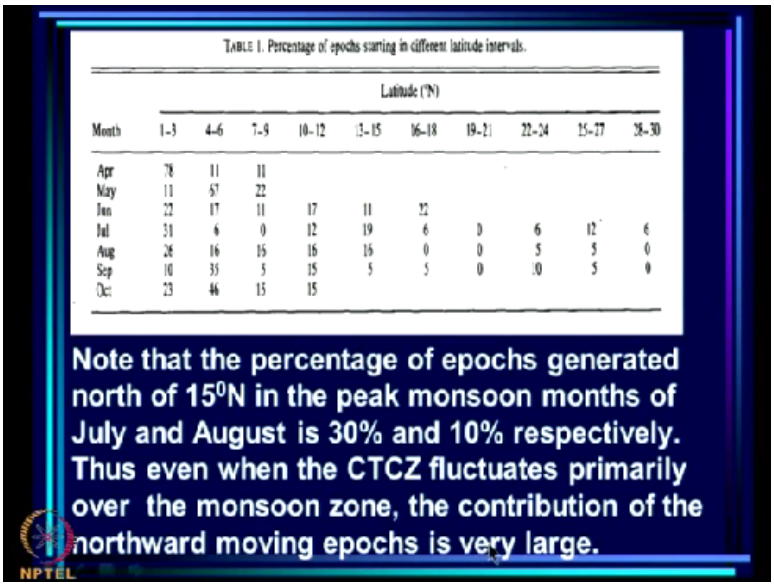

Now this is a table showing percentage of epochs starting in different latitudinal belts 1-3, 4-6

and so on in different months and what you can see here is that in April, vast majority are generated right near the equator. In May, the more shifts are little bit here but in June, it is more flat right up to here and July, it is still equatorial but you are getting some more being generated in 10 to 12 and so on.

Now you see, longer and longer tails develop here. So when you come to June to September, you do get quite a few epochs being generated even north of 20 degrees. These are generally the systems generated on the head bay and so on and so forth which we will come to later. But note that the percentage of epochs generated north of 15 degrees north in the peak monsoon months of July and August.

So if you want to look at how many epochs are generated north of 15 north that is over the monsoon zone in the peak monsoon months of July and August when CTCZ fluctuates primarily over the monsoon zone, they are only 30% in July and 10% in August. So even in the peak monsoon months when the CTCZ fluctuates primarily over the monsoon zone, most of the epochs are still generated south of the monsoon zone.

This is an important point to remember. Thus even when the CTCZ fluctuates primarily over the monsoon zone, the contribution of the northward moving epochs is very large.

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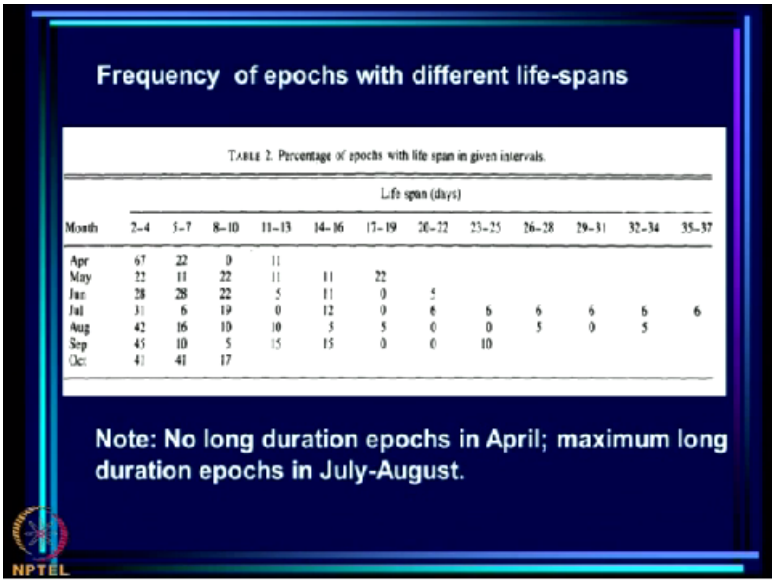

Now frequency of epochs with different life-spans. So if you look at frequency of epochs with different life-spans, then it is very interesting. In the April, they are very very short-lived epochs. Typically, 3 to 4 is the maximum number have life-spans between 3 to 4 day, several have between 5 to 7 days, none last longer than 13 days. Now long-living epochs, longer life-span epochs characterised the major peak monsoon months here, July and August.

They are the longest ones. Long duration epochs occur in July and August primarily but rest of the months, they are typically shorter with vast majority being < 5 days or so.

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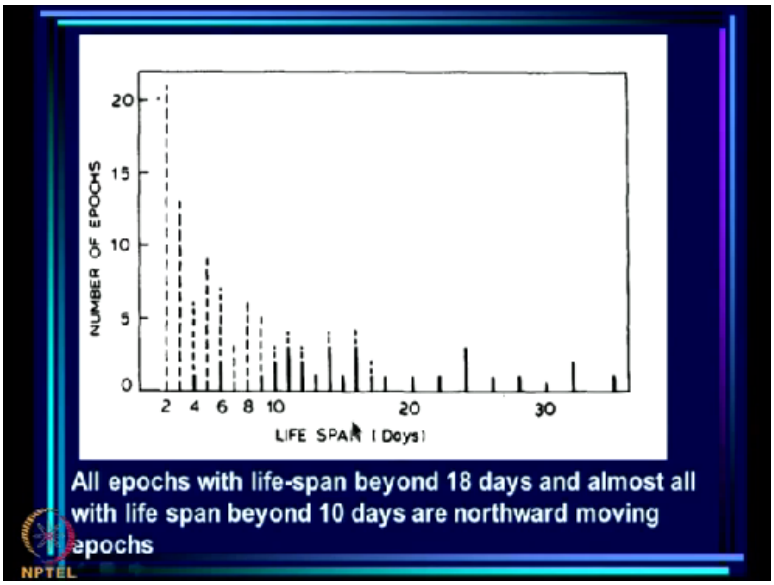

And you can see that here now this is of course combined for all the months and here you see separately the northward moving epochs from the non-northward moving epochs and you see that the longest epochs are those with northward movement. See solid bars here which indicate the epochs which move north actually dominate, in fact there only epochs that survive up to about 15 days and beyond are solid, are the northward moving ones and later on, actually here, the ones that have shortest life-span are the ones that do not move northward at all.

So you can see all epochs with life-span beyond 18 days, that is here onwards and almost all with life-span beyond 10 days, that is beyond here, almost all of them are northward moving epochs. This is an interesting thing to note.

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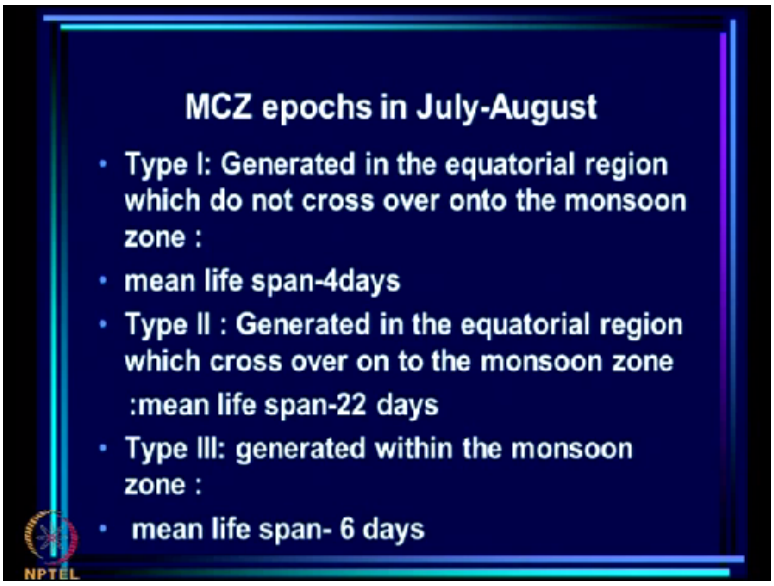

So already we see the dominance of northward moving epochs in July and August. Now what Sikka-Gadgil did was to systematically divide the epochs into 3 types, type I is generated in the equatorial region which do not cross over onto the monsoon zone and this had a mean life-span of about 4 days. See these are cloud-bands that appear over the equatorial region and disappear in about few days.

Type II were generated in the equatorial region which crossover onto the monsoon zone which had a mean life-span of 22 days and type III are generated within the monsoon zone as I said these are typically systems generated over the Bay of Bengal which then move westward on to the monsoon zone.

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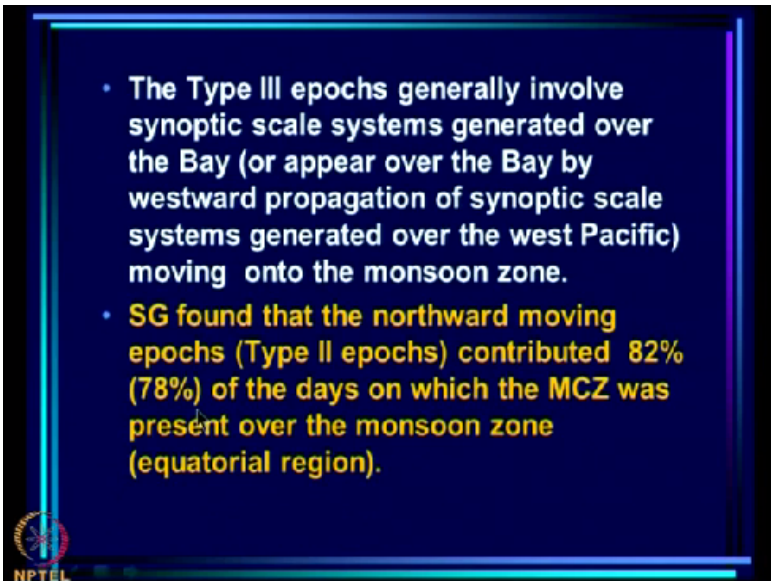

The type III epochs generally involves synoptic scale systems generated over the Bay or appear over the Bay by westward propagation of synoptic scale systems generated over west specific moving onto the monsoon zone. Now SG found that the northward moving epochs, that is type II epochs, contributed 82% of the days on which MCZ was present over the monsoon zone and 78% of the days on which MCZ was present over the equatorial region.

So whether we consider the equatorial region or over the monsoon zone, the maximum contribution seems to be coming from epochs which are northward moving epochs which are generated over the equatorial Indian Ocean and which move northward onto the monsoon zone. So it is a very very convincing proof of how important this is, these epochs are.

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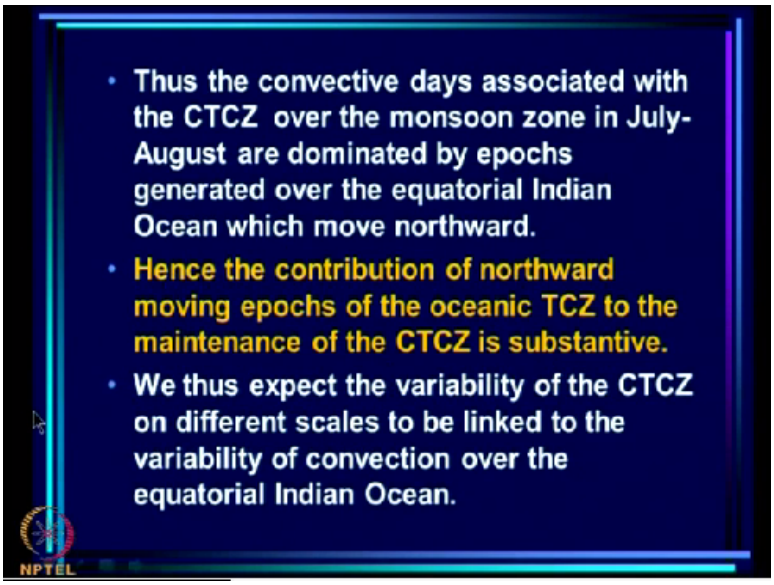

Thus the convective days associated with the CTCZ over the monsoon zone in July-August are dominated by epochs generated over the equatorial Indian Ocean which move northward. Hence the contribution of northward moving epochs of the oceanic TCZ to the maintenance of the CTCZ is substantive. So we expect the variability of the CTCZ on different scales to be linked to the variability of convection oven the equatorial Indian Ocean.

That is very clear because convection over the equatorial Indian Ocean now has turned out to be a lifeline of the monsoon, a lifeline of the continental tropical convergence zone which is the basic system responsible for the monsoon. So naturally variability over the monsoon will be linked with variability of convection over the equatorial Indian Ocean which is the source of this lifeline.

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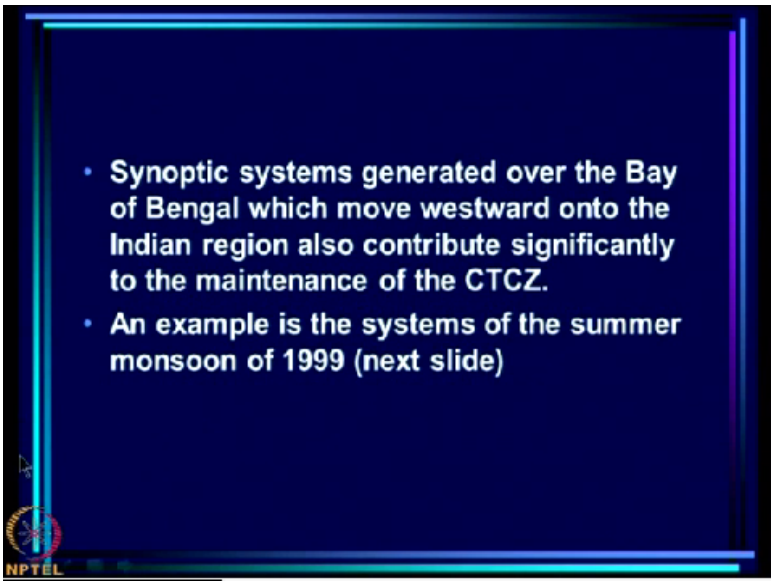

Now synoptic systems generated over the Bay of Bengal which move westward onto the Indian region also contributes significantly to the maintenance of the CTCZ. An example is the systems of the summer monsoon that we see here.

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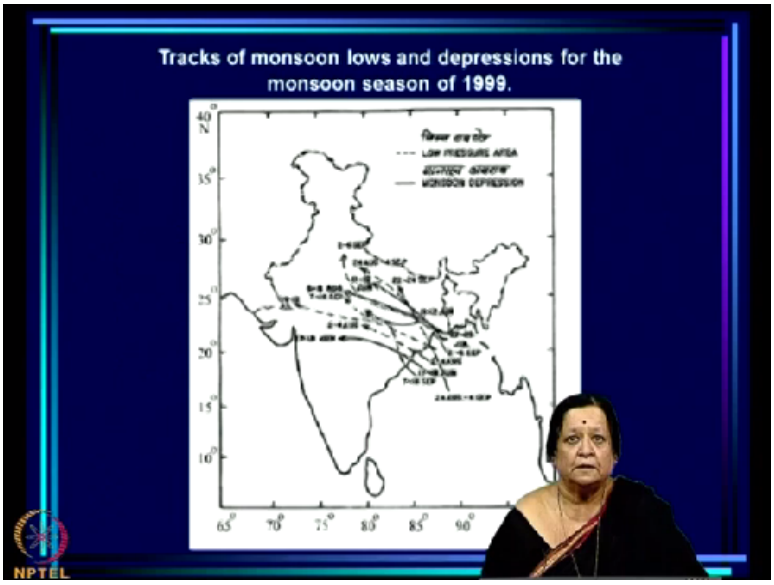

And see in 1999, summer monsoon for example, so many monsoon depressions were born here and a low-pressure system was also born and you can see they are all generated here and move along the monsoon zone, this way, okay. So these are tracks of lows and depressions. So we do get contribution from such systems also and these will not be type II because type II means, those systems come from here.

These are type III which means what we call in situ which is to say within the latitude of the monsoon zone, the system is getting generated and giving rain. So this is the other system.

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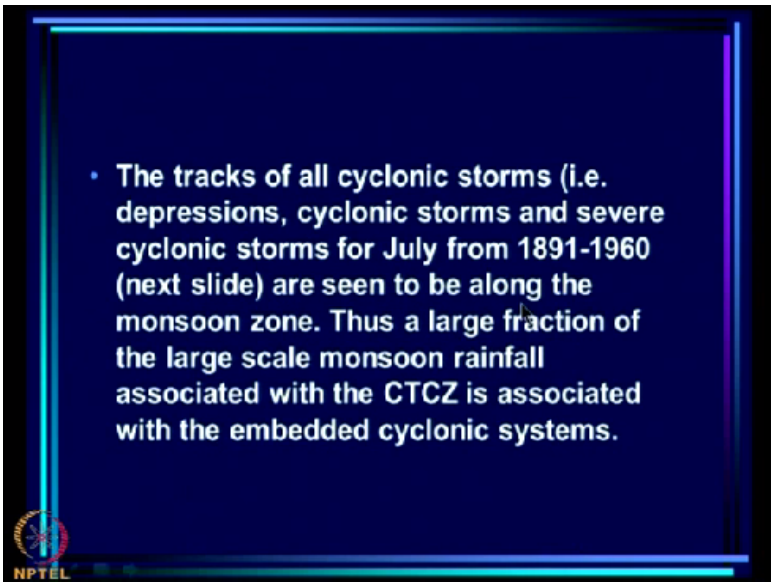

The tracks of all cyclonic storms and severe cyclonic storms from July onwards.

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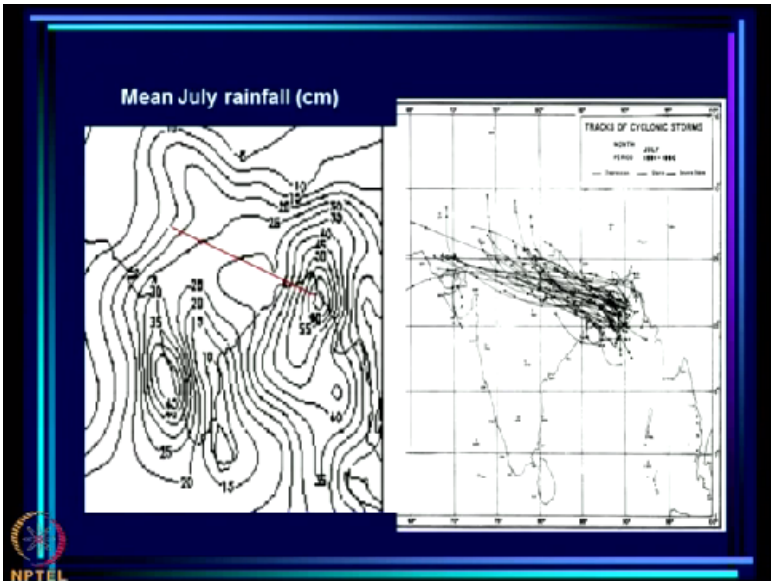

This is from IMD Atlas attack of all cyclonic storms and this is the mean July rainfall and you can see that there is an association of the July rainfall with the tracks of these storms and part of the large-scale rainfall, certainly can be attributed to genesis and propagation of synoptic scale systems.

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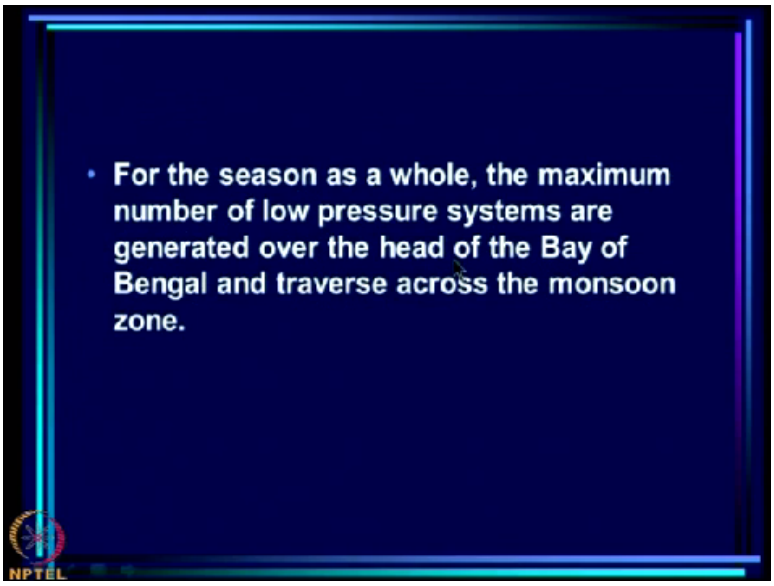

For the season as a whole, the maximum number of low-pressure systems are generated over the head Bay of Bengal.

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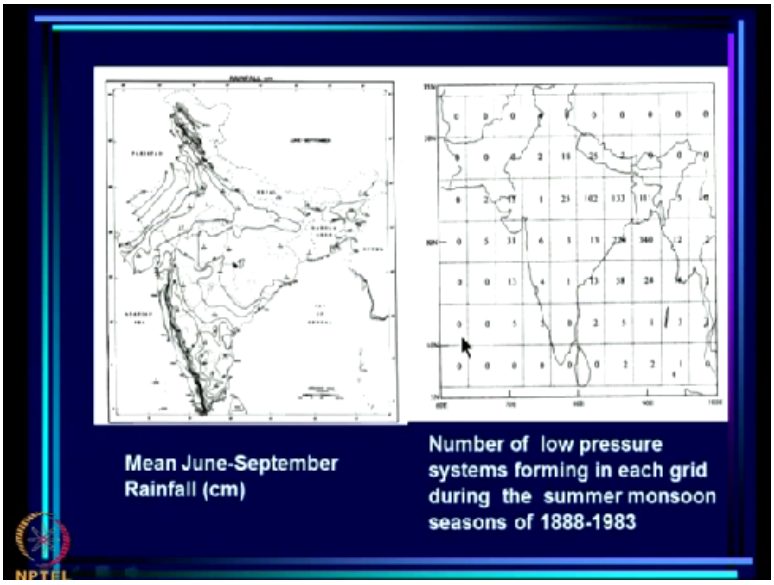

See this we have seen before. This is the frequency of genesis of low-pressure systems in different places and the maximum occurs here. This is the 40 and they all move across and give us this kind of June to September rainfall. This is the monsoon zone, okay. So these systems do contribute a great deal. These are what Sikka-Gadgil called the type III events.

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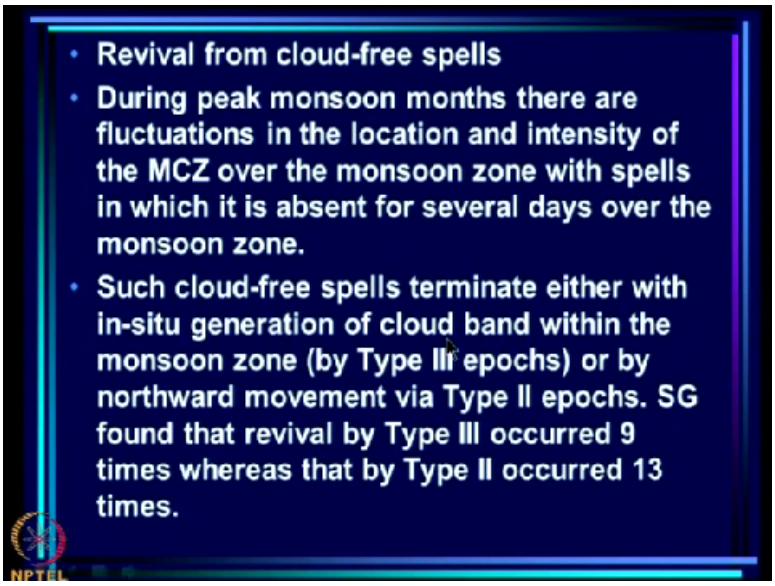

So I think now we have to also see how often does the propagation from within the system occur, type III and how often type II occur and in fact Sikka-Gadgil have also looked at how typically in a season the CTCZ gets established, how it fluctuates and when it fluctuates between active spells and weak spells, how does it revive after a weak spell and that is what we are going to look at next time.

So what we have seen this time is that in fact the tropical convergence zone is the basic system responsible for the summer monsoon rainfall as well as the post-monsoon rainfall and the rainfall that we experience, the variation of the monthly rainfall that we saw across India is consistent with this as we saw from the OLR data, how the TCZ moves from month to month. Secondly we saw that northward propagations which is the most important feature of inter-seasonal variation of the maximum cloud zone, in fact dominate the entire picture.

They are the key element of the seasonal transition with the spring to summer seasonal transition occurring with northward propagations which take the monsoon further and further northward and Summer to Autumn transition which is the retreat, again in was northward propagation, is not southward, which takes the band, the culmination of the northward propagation is that more and more southern latitude, that is how that has occurred.

And we have also seen that if we look at the contribution of these northward propagations to

CTCZ over the monsoon zone and to the oceanic TCZ. Then that maximum contribution occurs from northward propagating MCZs, more than 80% for the CTCZ and very close to 80% for the equatorial oceanic ITC. So northward propagating epochs of MCZ are a very critical element of the monsoon or the seasonal evolution of the monsoon as well as the inter-seasonal fluctuation of the monsoon.

This is what we have seen by the analysis done so far. Now we will see how the monsoon evolves and how the revival by different processes takes place and so on and so forth in the next lecture. Thank you.