The Monsoon and its Variability
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Lecture – 12
Tropical Convergence Zones and the Indian monsoon - Part 2

We are now discussing tropical convergence zones and the monsoon.

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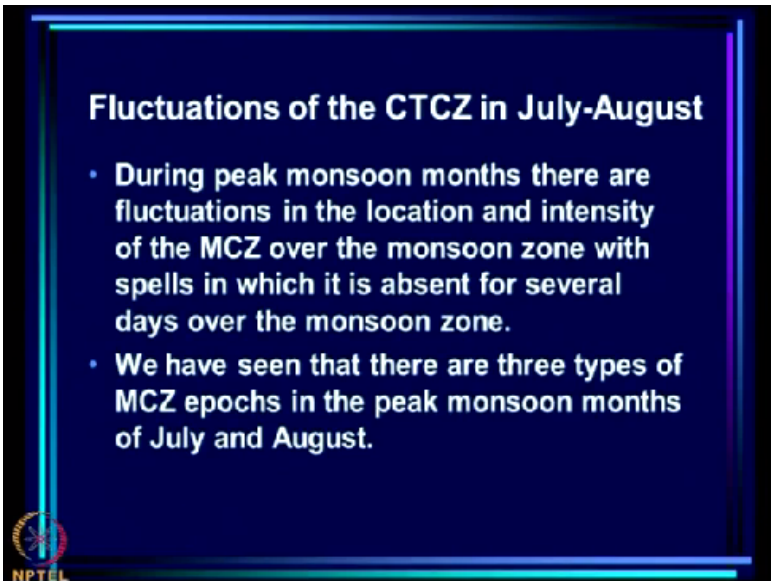

And we have already seen that the monsoon is a manifestation of the visit of a tropical convergence zone over the continent which we call the continental tropical convergence zone and we have been looking at how it fluctuates. So let us now consider fluctuations of the CTCZ in July-August which are the peak monsoon months.

So during peak monsoon months, there are fluctuations in both the location and the intensity of the maximum cloud zone over the monsoon zone with spells in which it is absent for several days over the monsoon zone. These are the cloud-free spells and we have seen that during the peak monsoon months of July and August, there are 3 types of MCZ epochs which occur and those are:

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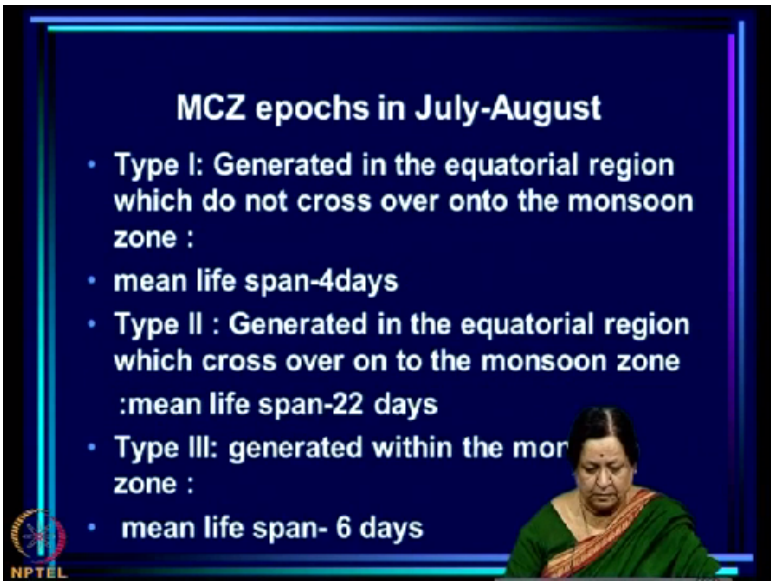

Type I is the one in which the MCZ or the maximum cloud zone is generated over the equatorial region but which do not crossover onto the monsoon zone, that is to say they get generated there over the equatorial zone, fluctuate perhaps in intensity and then die. Now the main life-span of such episodes or such epochs, MCZ epochs which are born over the equatorial Indian Ocean and die over the same region, the mean life-span is only 4 days. Type II are the most interesting of the epochs.

These are the ones which are generated over the equatorial region which crossover onto the monsoon zone. These are the northward propagating episodes or epochs. Now type III are those which are generated within the monsoon zone belt, that is to say often over the head Bay of Bengal and their mean life-span is again 6 days only. So those that are generated over the equatorial region as well as those that are generated perhaps over the head Bay or the monsoon zone have relatively small life-span.

The ones that are northward propagating modes have the largest life-span.

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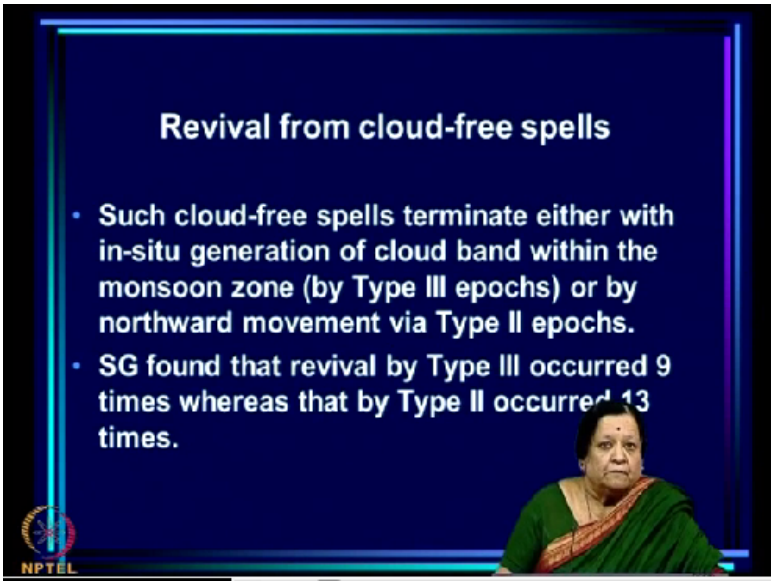

Now we talked about how the CTCZ revives from cloud-free spells. Now when we look at the observation, there are 2 kinds, 2 ways in which this cloud-free spell can get terminated. Either with what Sikka and Gadgil called in situ generation of cloud band within the monsoon zone, that is to say within the belt of the monsoon zone, that eternal belt of the monsoon zone generally over the head bay.

Alternately one can also get revival from cloud-free spells by northward movement via Type II epochs. So this is revival by genesis over the equatorial Indian Ocean subsequent northward movement. Now SG found that revival by Type III occurred in 9 cases whereas Type II occurred in 13 cases. So the 2 numbers are comparable given the small size.

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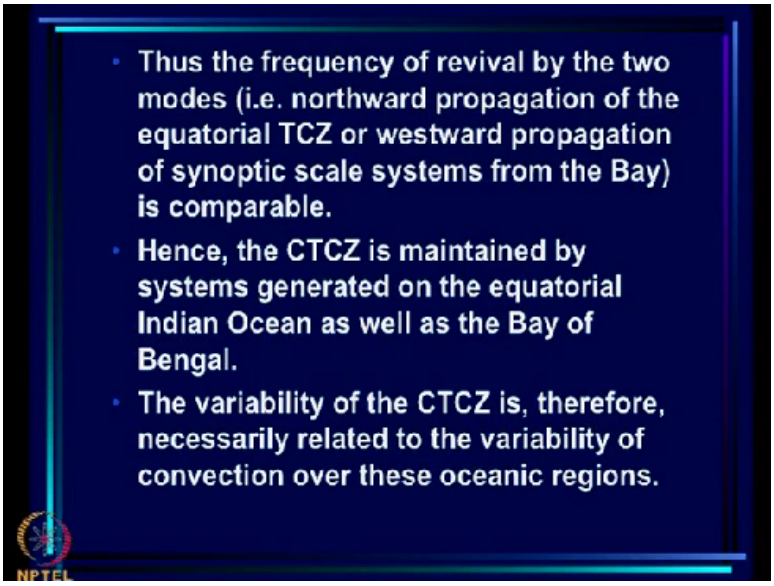

So frequency of revival by the 2 modes, that is northward propagation of the equatorial TCZ or westward propagation of synoptic scale systems from the Bay is comparable. Hence the CTZ is maintained by systems generated on the equatorial Indian Ocean as well as over the Bay of Bengal. Hence the availability of the CTCZ is naturally linked to the variability of convection over these oceanic regions.

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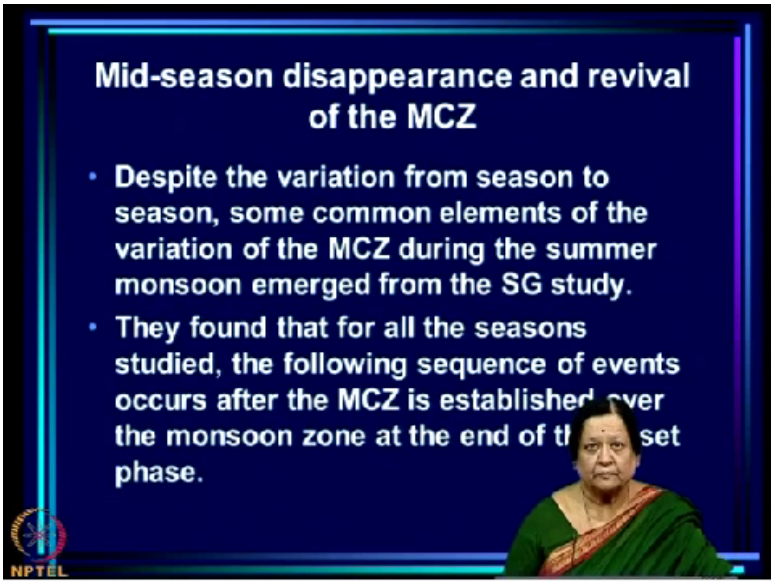

This is something that we have seen last time. Now there is a very special feature, a very special sequence of events which one sees year after year in the evolution of the season, okay and this is the mid-season disappearance and revival of the maximum cloud zone or MCZ. Now this was noted by Sikka and Gadgil and what we see is that despite the variation from season to season,

some common elements of the variation of the MCZ during the summer monsoon emerge from the study.

And what are these common elements that the Sikka-Gadgil found that for all the seasons studied, the following sequence of events occurs after the MCZ is established over the monsoon zone at the end of the onset phase. So at the end of the onset phase after the MCZ is established over the monsoon zone, then every year the following sequence of events occurred, okay.

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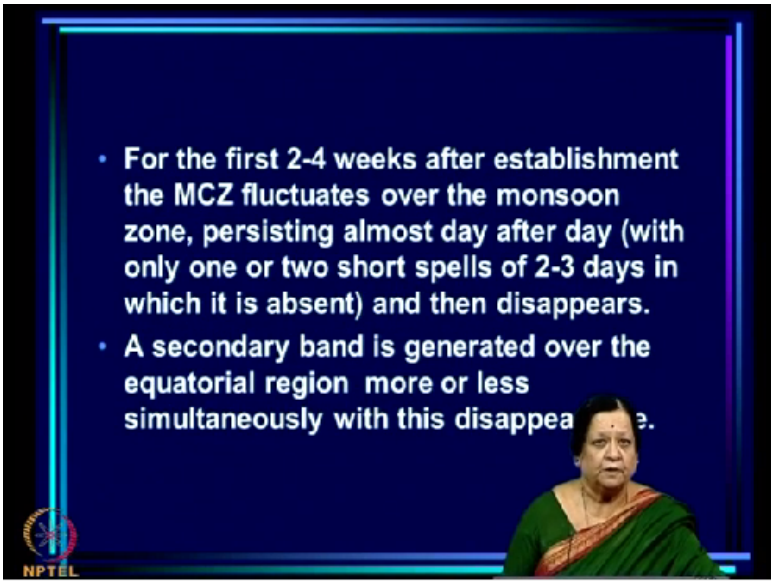

What happens? Now for the first 2 or 4 weeks, 2 to 4 weeks after establishment, the MCZ fluctuates over the monsoon zone persisting almost day after day with only 1 or 2 short spells of 2 to 3 days in which it is absent and then disappears. So for the first 2 to 4 weeks, the MCZ is fluctuating over the monsoon zone and then disappears, okay. Now a secondary band is generated over the equatorial region more or less simultaneously with this disappearance.

So first of all at the end of the onset phase, the MCZ is established over the monsoon zone. Now in the first few weeks, it fluctuates within the zone with few cloud-free spells which are not very long and after which it revives and then disappears. Now when it disappears, a secondary band is generated over the equatorial region more or less simultaneously with this disappearance, okay.

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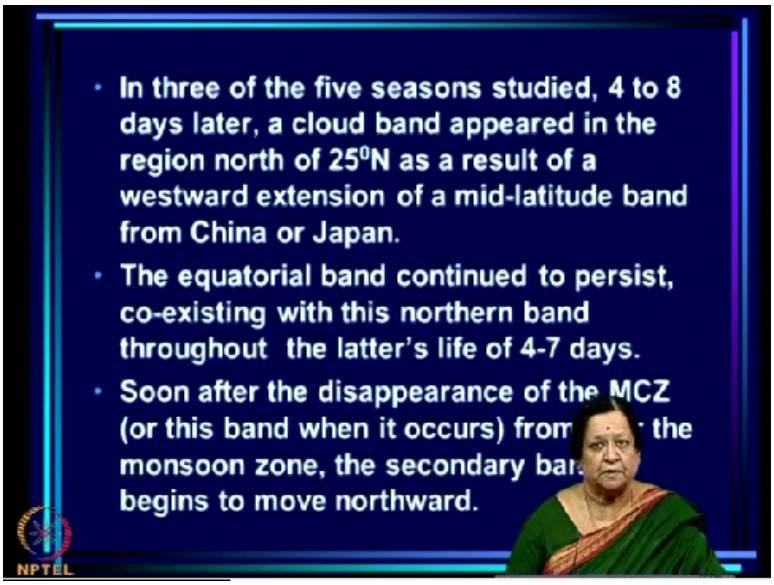

Now in 3 of the 5 seasons studied, 4-8 days later, a cloud band appeared in the region north of 25 north as a result of westward extension of a mid-latitude band from China or Japan. Now all this is going to become very clear to you when I will illustrate all this with an example from 1975 but let us just try and list the events that happened. So first you have the establishment of the CTCZ over the monsoon zone, then for a few days, 2 to 4 weeks, it fluctuates within the monsoon zone more or less and at the end of that, it disappears.

Now after it disappears, a few days after it disappears, a band comes over the region again at 90 east but it does not necessarily penetrate to over the Indian region, west of 90. So it is often not seen at 80. So another band appears and this is what we used to call the Chinese connection. This is a cloud band which goes from about, it is generally north of 25 north and it goes from their right up to China or Japan.

Now the equatorial band continues to persist coexisting with this northern band throughout the latter's life of 4 to 7 days with some fluctuations often. Now soon after the disappearance of the MCZ or the band when it occurs. See this band does not occur every year. So once the MCZ disappears and this band disappears, soon after that, the secondary band begins to move northward. Secondary band is the band over the ocean which we also called the oceanic TCZ.

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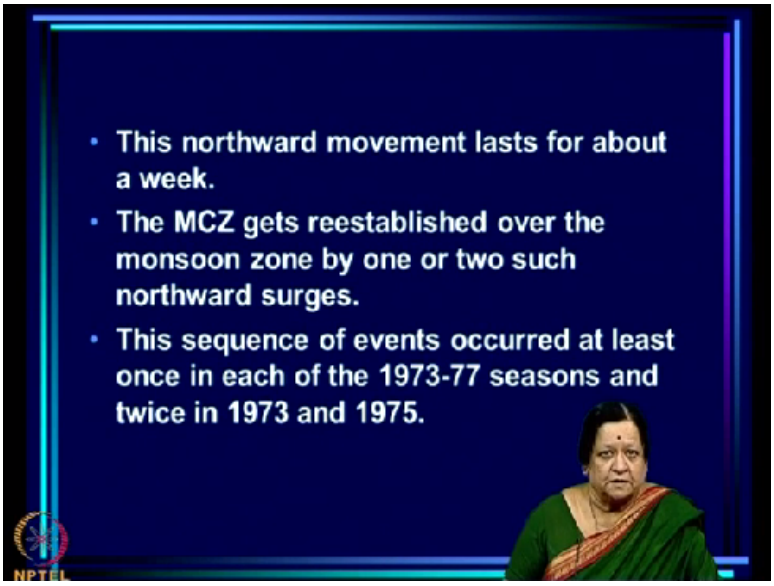

Now this northward movement last for about a week. The MCZ gets re-established over the monsoon zone by 1 or 2 such northward surges. Now this sequence of events, Sikka-Gadgil noted occurred at least once in each of the 1973 to 1977 seasons and twice in 1973 and 1975. So you have a sequence of events in which the continental TCZ disappears, a secondary band appears and the continental TCZ revised by northward movement of the secondary band.

This is the sequence of events which we see year after year during the summer monsoon season and sometimes even twice.

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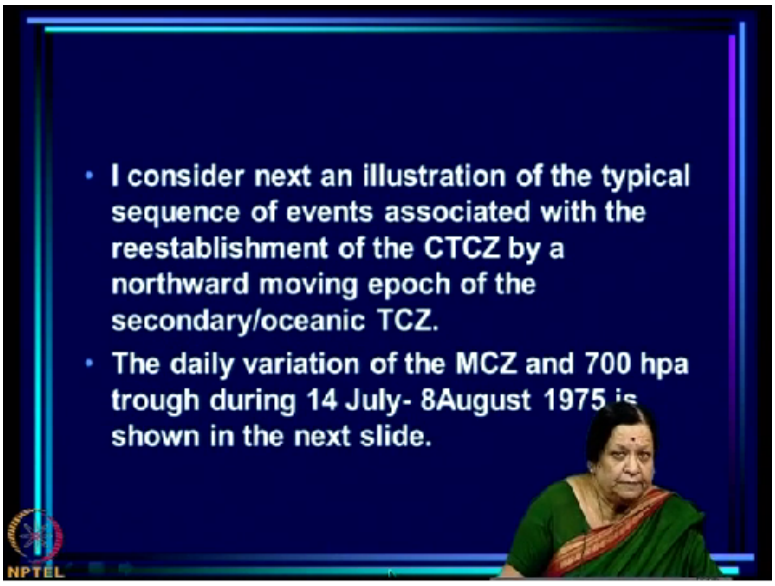

Now in fact what I will do is, show all these events by an illustration of the typical sequence of

events associated with the reestablishment of the CTCZ by a northward moving epoch of the secondary or oceanic TCZ by looking at one example and this is 14th of July 1975 to 8th August 1975.

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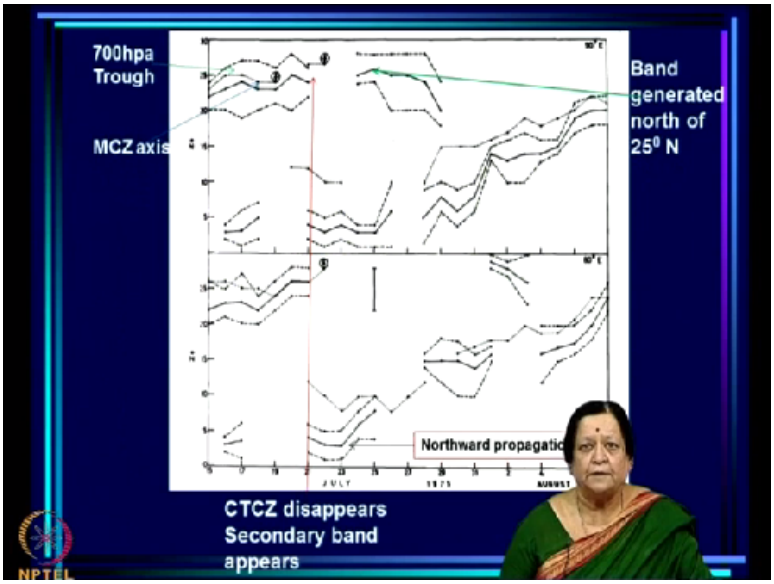

So let us look at this case and you will see all the features that I mention. So what you see here is a daily variation of the MCZ axis which you see here is the solid line, the southern and northern limit of MCZ also which you see here and in addition to that, the 700 millibar trough which we have been talking about which is the axis of the 700 millibar trough which is the axis of the non-orographic large-scale rainfall.

So this is what you get from the weather chart, this is what you get from the satellite imagery and both are shown here. So you see the daily variation of these things when they do not occur in the image, in the image when there is no maximum cloud zone, you will get a gap like this. For example, over this latitudinal belt, there is a gap. So now let us follow the thing. See the CTCZ is already been established over the monsoon zone. Remember this is 14th of July.

Typically, it gets established towards the beginning of July. This is 90 degrees east and this is 80 degrees east, okay. So this is the central longitude of India and this is 90 degrees east which is the one that passes through Kolkata, okay. So this band was there, this is the CTCZ. Notice that while it was going strong, another band appeared but soon disappeared within 3-4 days. You see

that secondary band appeared but disappeared.

Now at the end of this phase here, around 21st of July, this CTCZ or the MCZ has disappeared, okay and almost simultaneously you see that a secondary band has formed at 80 and 90, okay. So the northern band has disappeared and a secondary band has formed. Now after a few days, this Chinese connection has come up. A band which connects goes all the way to China or Japan starting at 90 degrees only here, not seen at 80 degrees but you seen this mid-latitude connecting band, cloud band here.

But throughout its existence more or less, the secondary TCZ is around, it has not died. For several days, it continues to coexist. It weakens a little bit but is there at the same place when the band dies, okay. So this is when that band disappears finally. Now as soon as the band disappears, this secondary TCZ which is here when it disappeared, starts moving northward you see that and at 90 degrees, the movement is continuous and at 80 degrees, it occurs in 3 spells that you can see.

You can also see that during this movement, the 700 millibar trough is more or less consistently moving with this. In fact, let us note that when we began the clouds free spell here, when the CTCZ disappeared from the monsoon zone here, we had a 700 millibar trough line around 10 north that was seen both at 80 and 90. You have to remember that this trough line is drawn from the weather charts.

So one can primarily write on land and you know south of 8 degrees north is ocean. So this is why the southernmost location is generally just 8 degrees or so. Anyway this was a zone of cyclonic vorticity has appeared here even before the thing has started moving and then it starts moving and when it moves, the 700 millibar trough also moves with it, okay. So this is the northward propagation.

So this is the sequence of events. First the band being established, then it is hanging around, then it dies. Once it dies, it is all quiet on the western front for a few days. During that time, the secondary band has appeared. Then this mid-latitude band from China has come and when that

dies, then you get clean northward propagation at 90 and reasonable northward propagation at 80.

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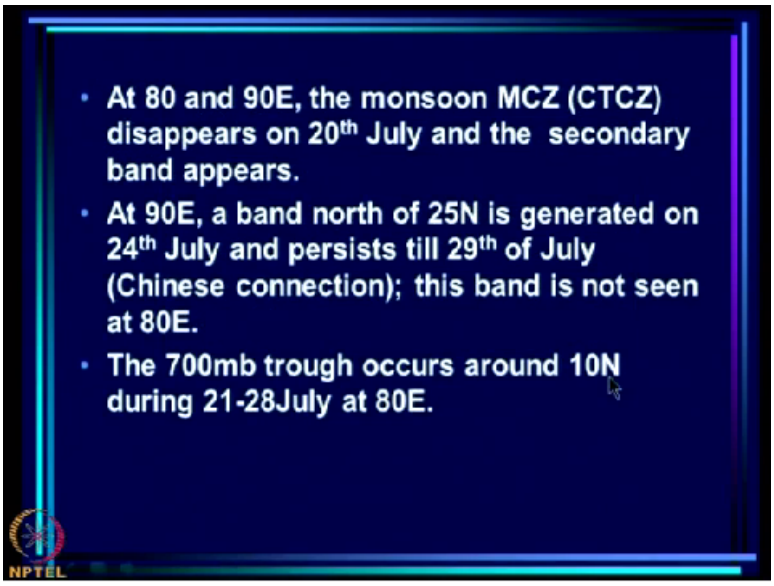

So this is the sequence of events that we talked about and so at 80 and 90, the monsoon MCZ or CTCZ disappears on 20th July, secondary band appears. At 90 east, the band north of 25 north is generated on the 24th July and you have seen that already. This is the generation of this band on 24th of July and persist till 29th of July, this is the Chinese connection. This band is not seen at 80 east. The 700 millibar trough occurs around 10 north during 21st to 28th July.

This is soon after the disappearance of the MCZ or the CTCZ from the monsoon zone, okay.

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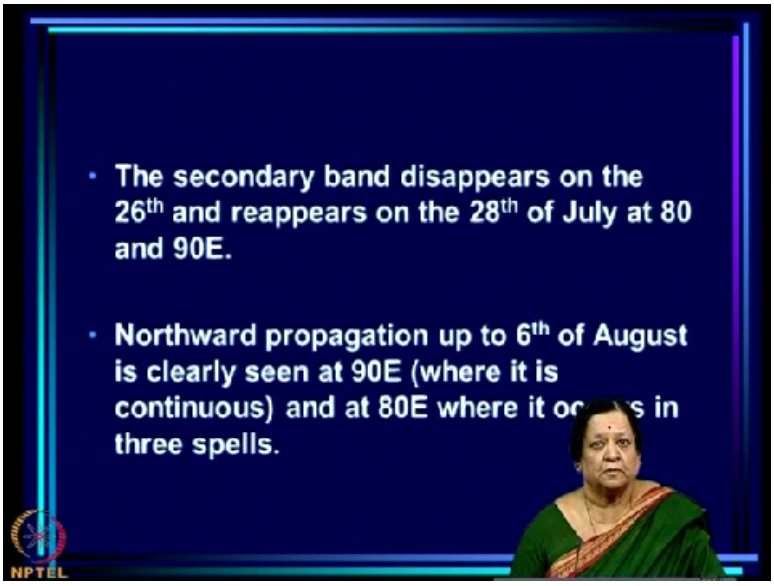

Now the secondary band disappears on the 26th but reappears on 28th. So by and large, it is present during the time the mid-latitude band is also present, okay and northward propagation than occurs up to 6th August which is clearly seen at 90 where it is continuous and at 80, where it occurs in 3 spells, we have seen this.

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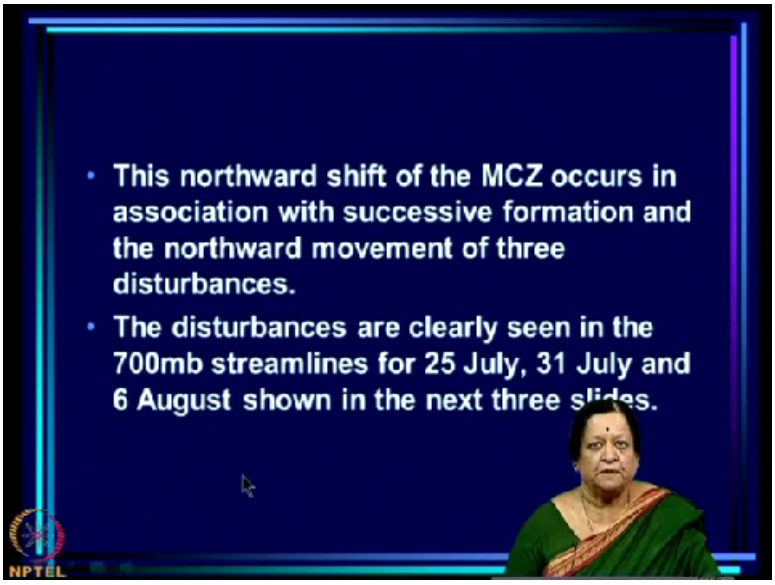

Now this northward shift of the MCZ occurs in association with successive formation and the northward movement of 3 disturbances. Now we have been emphasising time and again that although we think of tropical convergence zone as a planetary scale cloud band which is east-west, actually generally embedded in this planetary scale band are synoptic scale disturbances and often in a northward propagation, you see them as propagation of synoptic scale

disturbances.

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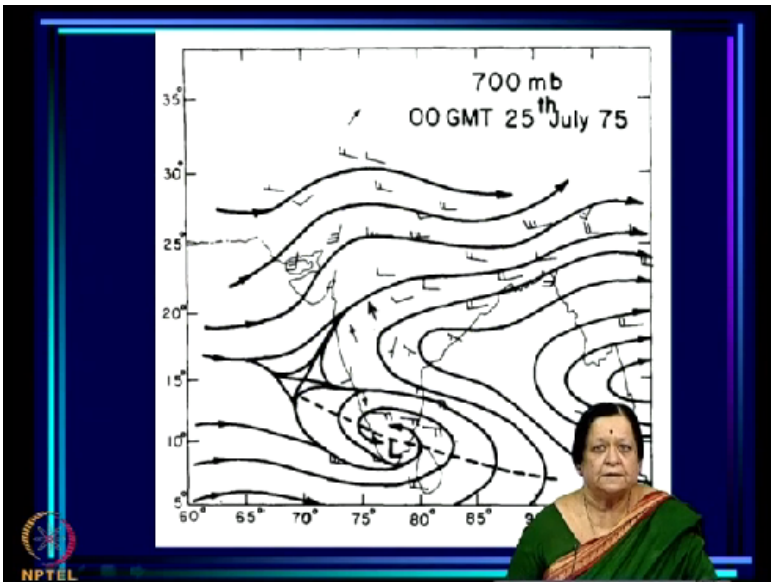

Now that you see in the next few things. This is 25th July. Remember this is a few days after the CTCZ has disappeared from the monsoon zone and what you see here is a low-pressure system. This is at 700 millibar and these are streamlines and you can see a cyclonic circulation at 700 millibar, just around 10 north or so and this is the 700 millibar trough that you can see here. So a trough has formed here on 25th July and you can see it is associated with this vortex.

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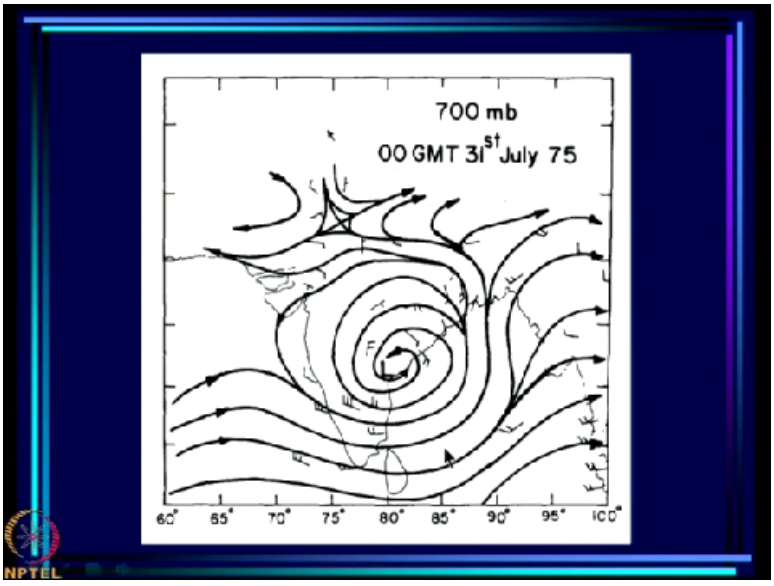

Now what happens on 31st July. On 31st July, there is a movement. It has gone northward where it was around here on 25th and it has moved northward now and you see a very clear cyclonic

vorticity pattern at 700 millibar on 31st July. Now it is centred closer to I believe 15 north or so and the next one is, I am sorry this is again 31st July, this is a repeat. So this is 31st July.

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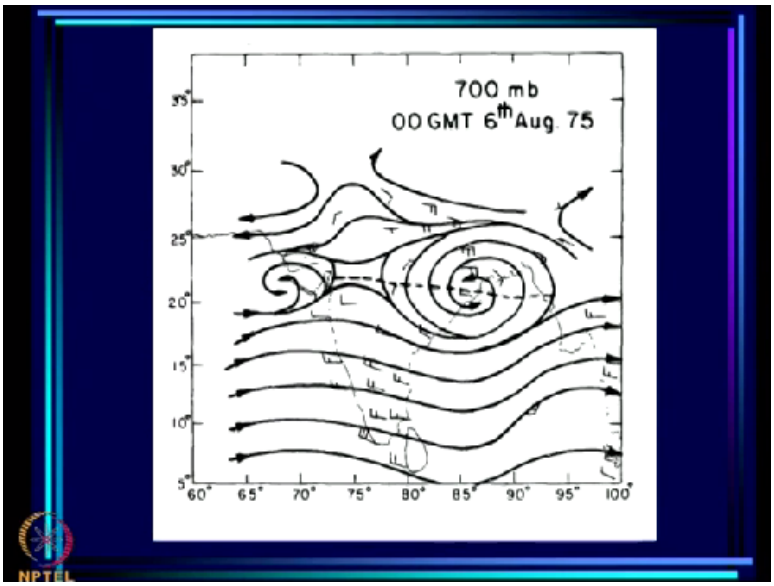

And then you see 6th August, it has now gone north of 20. So we have seen a northward propagation very beautifully in terms of the 700 millibar trough and the vorticity and it has gone all the way in 1 week from about 8 or 10 to about 22. So this is an example of the propagation and you can see that there are clearly 2 synoptic scale disturbances embedded in this trough here, okay.

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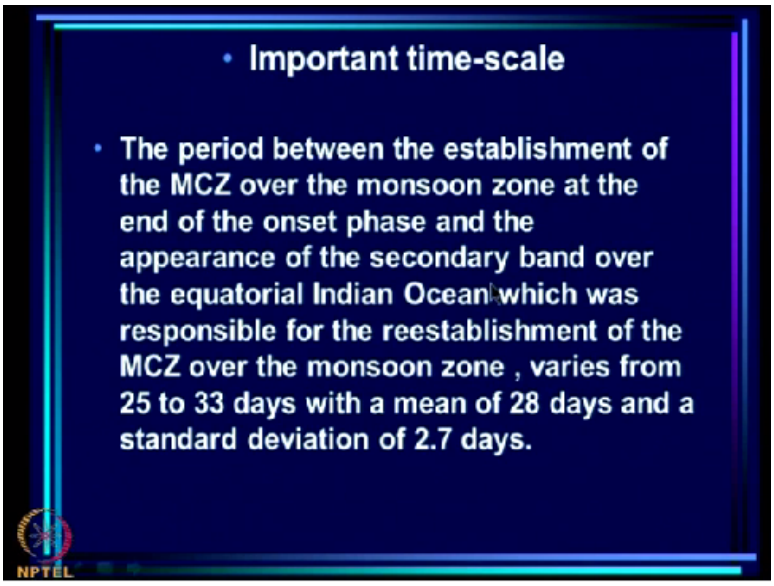

So this is the story that occurs year after year. Now the period between the establishment of the

MCZ over the monsoon zone at the end of the onset phase and the appearance of the secondary band over the equatorial Indian Ocean which was responsible for the re-establishment of the MCZ over the monsoon zone varies from 25 to 33 days with a mean of 28 days and a standard deviation of 2.7 days.

Now, what are we talking about? At the end of the onset phase, the band gets or the MCG gets established over the CTCZ that would be sometime in early July, right. Then secondary bands may appear after that. In fact, it may be worthwhile to go back to this slide. Now this is 14th of July. So for several days almost 2 weeks already, the CTCZ has been established over the monsoon zone, okay.

Now during this period, a secondary band did appear here but this band did not lead to any propagations or re-establishment, okay. This band appeared when the CTCZ was active here and it just died, nothing great happened with this band but then this band appeared, okay and this is about 14 days or so, about a few days, I think 7 days, it has appeared in this case. So it may be about 3 weeks or whatever since the establishment of the band and this is the band that actually led to the revival through northward propagation.

So this is what we are talking about here and so there is the timescale emerging from here and that timescale is the period between the establishment of MCZ over the monsoon zone at the end of the onset phase and the appearance of that secondary band over the equatorial Indian Ocean which is responsible for the re-establishment of MCZ over monsoon zone varies from 25 to 33 days, this is what they are say with a mean of 28 days and standard deviation of 2.7 days.

So a timescale is emerging here, a timescale of about a month and this is very interesting because this has to be pursued further.

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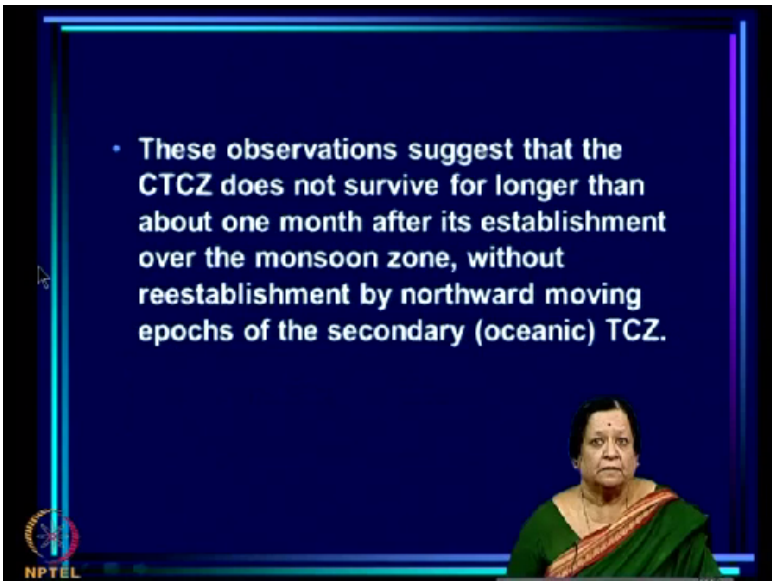

So what is this saying. This is saying that the continental TCZ or the CTCZ cannot survive for longer than about a month after its establishment over the monsoon zone without re-establishment by northward moving epochs box of the secondary or the oceanic TCZ. So it needs refurbishment of the moisture from this oceanic TCZ one month after its first establishment. If it is not, without that it cannot be maintained.

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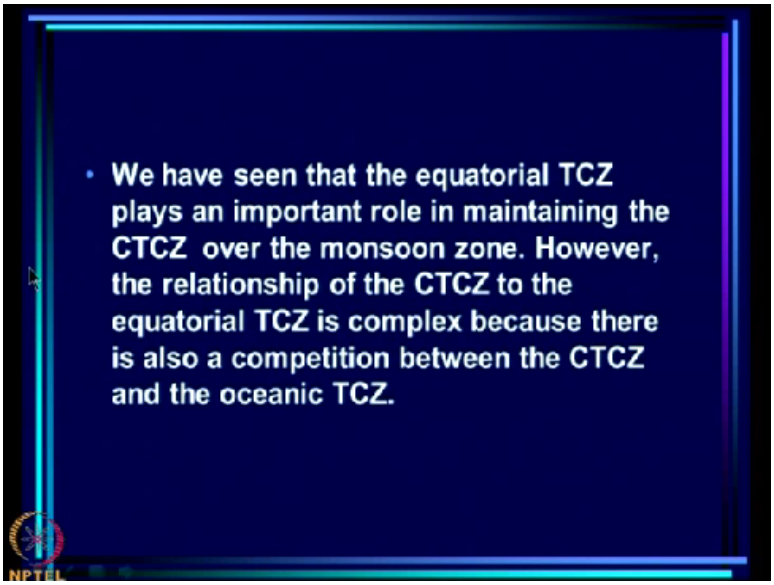

This is very clear because this is seen year after year. We have seen that the equatorial TCZ plays a very important role in maintaining the CTCZ over the monsoon zone and so we expect that, you know, in fact equatorial oceanic TCZ is a friend of the monsoon. It is helping, it is helpful in maintaining the CTCZ over the continent and therefore helpful in the large-scale monsoon

rainfall which is associated with the CTCZ but you know the relationship is not all positive. The relationship between the CTCZ and the oceanic or the secondary TCZ over the equatorial Indian Ocean is complex and why is that?

Because there can also be competition between the CTCZ and the oceanic TCZ. You may remember that in a TCZ, the air is ascending and TCZ is a zonal belt extending over some latitudinal range. Now north of the TCZ as well as south of the TCZ, air that is pumped up by the TCZ actually descends. So this means that if there are 2 such animals which are at 2 latitudes over the same latitudinal belt, then each will try and suppress the other through the descending limb. So this we expect will lead to a competition between the 2 TCZ's.

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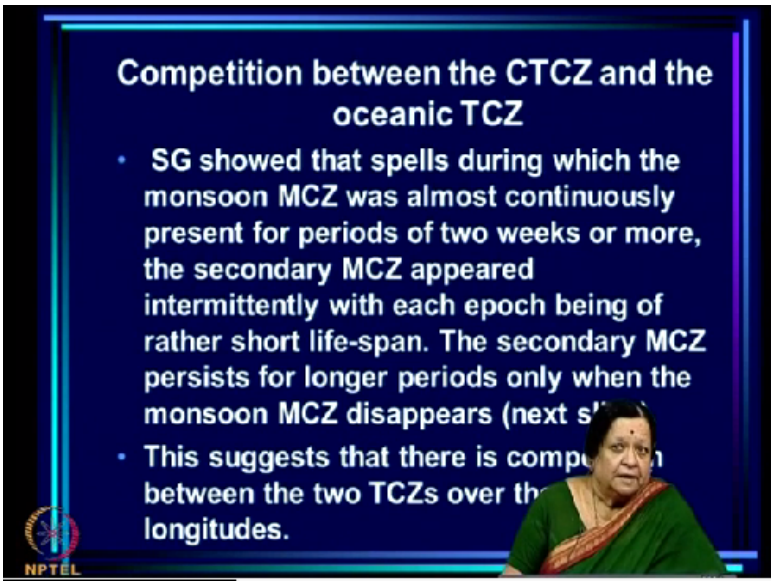

And in fact what Sikka-Gadgil found in that study was that spells during which the monsoon MCZ was almost continuously present for periods of 2 weeks or more and we have seen an example of this in the beginning from 14 July onwards when a secondary band appeared, so when it is continuously present for periods of 2 weeks or more, the secondary MCZ appeared intermittently with each epoch being of rather short life-span.

So it just appears and within a few days, it is gone. This is because the monsoon MCZ or the CTCZ is going strong, okay. Now the secondary MCZ persists for longer periods only when the monsoon MCZ disappears. So there is a seesaw in the activity of the monsoon MCZ and the

secondary MCZ or the CTCZ in the oceanic TCZ. There is a competition between the 2 and active spells of monsoon TCZ will be associated with weak spells of the equatorial TCZ and vice versa. This is what we expect due to competition.

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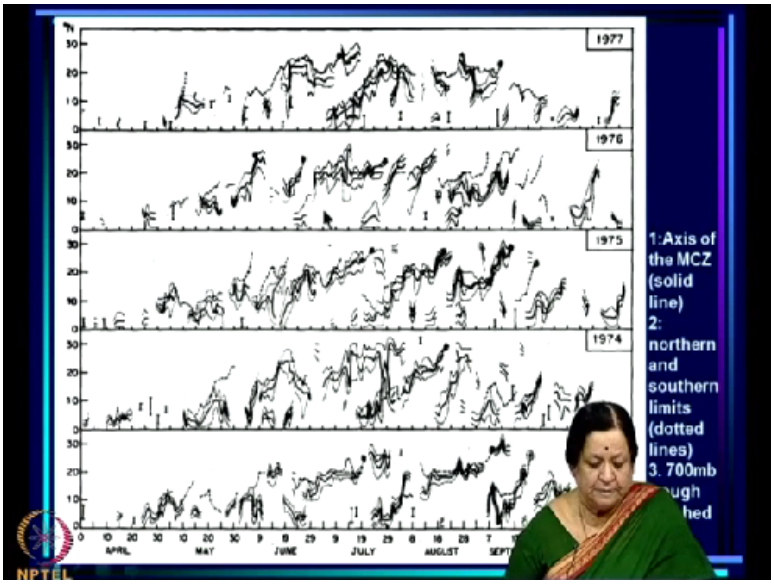

And this was deduced from the kind of picture you have seen earlier that in several cases for example here in 1975, you see that when the thing is going strong, several times the secondary band has appeared but of no consequence. Only when it disappears finally, then the secondary band goes strong and moves northward.

Similarly, here now when the band is going strong, see the oceanic TCZ has appeared only for 2-3 days but when it disappears, then it starts moving northward again. So just from these kind of observations, they deduce and later on, we will see correlations and so on which prove the point that in fact active spells of the CTCZ or monsoon MCZ are associated with weak spells or short spells of the oceanic TCZ, okay and only when the CTCZ disappears, the oceanic TCZ has a longer life and furthermore moves northward, okay.

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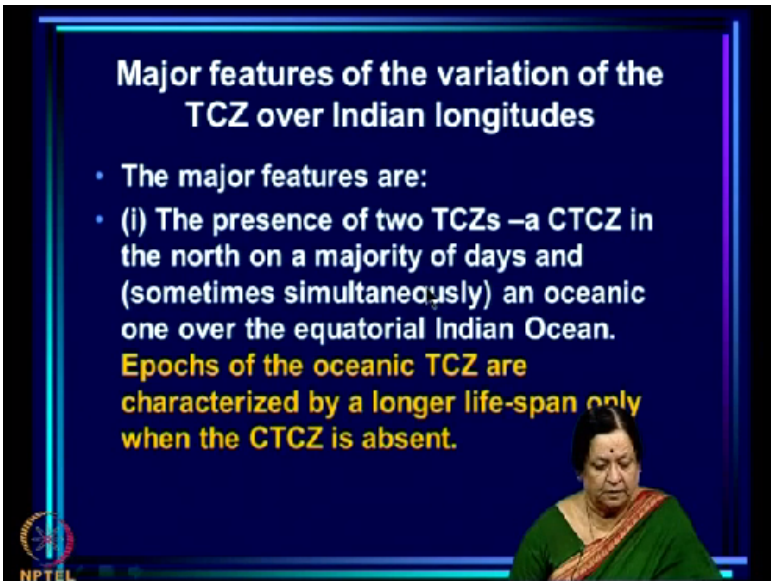

So this is what we have learnt now as the typical sequence of events that occurs and also the complexity of the interaction if you wish between the CTCZ and the oceanic TCZ. Since a lot of things were discovered in this very first study, let us just recapitulate what are the major features that have emerged and many of them have been discovered for the first time in this study. The major features are the presence of 2 TCZs right.

You remember we showed that if we look at frequency of occurrence of MCZ's at different latitudinal belts, then there is mode over the continent if you look at July-August for example. There is a primary mode over the continent and a secondary mode over the equatorial ocean with kind of minimum frequency of occurrence around 7 degrees or so. So one can talk of 2 TCZs occurring and we have also seen that sometimes they occur simultaneously, sometimes only one of them occurs, okay.

So this is a major new feature that there are 2 TCZs here. A CTCZ in the north on majority of the days and sometimes simultaneously an oceanic one over the equatorial Indian Ocean and epochs of the oceanic TCZ are characterised by longer life-span only when the CTZ is absent. So this is an important point to note.

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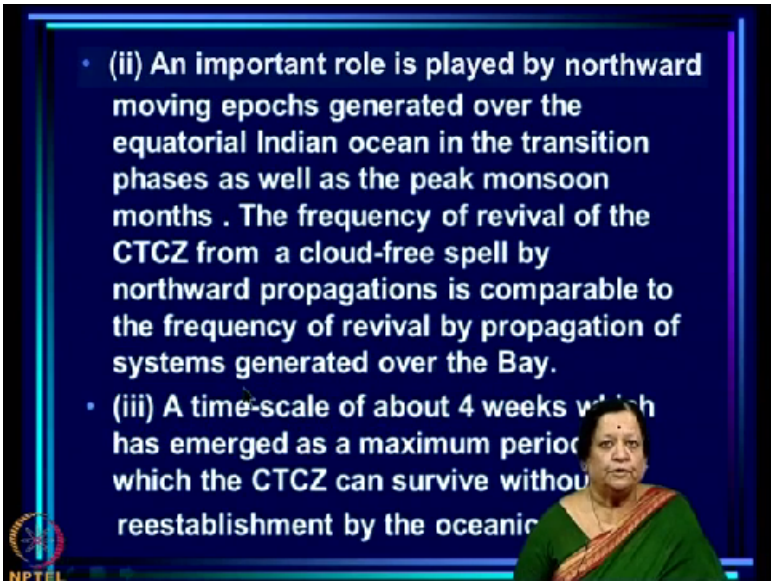

So the first feature is the fact that there are 2 TCZs over the same longitudinal belt. The second of course is something we have been talking about. The important role played by northward moving epochs generated over the equatorial Indian Ocean in the transition phases as well as in the peak monsoon months. See the fact that the things move northward in the transition phase has been known for a very very long time because we have known that rain belts move northward.

And in fact Kalidasa in his Meghadut talks about the cloud messenger is talking about northward movements. Yaksha is telling the cloud messenger that when he goes north, he should take a message for his lover and so on and so forth. So northward propagations during onset phase were very well-known simply because they are manifested also, it is rainfall propagation but what was not known before the study is the role played by northward propagations even during the season, even during the peak monsoon months.

So this is the new thing and they also showed that the frequency of revival of the CTCZ from a cloud-free spell by northward propagations is comparable to the frequency of revival by propagation of systems generated over the bay. So the so called in situ revival by propagation of system generated over the bay or northward propagating systems giving revival are comparable, okay.

And a timescale of about 4 weeks has emerged which is the maximum period for which the CTCZ can survive without re-establishment by the oceanic TCZ. So this is a very interesting result and which still I think has not been completely understood with our theoretical and modelling exercises.

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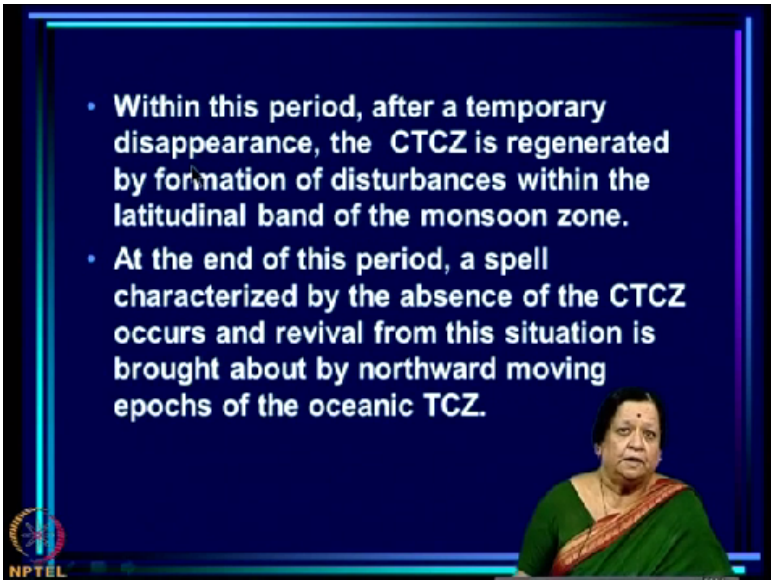

Now within this period after a temporary disappearance, the CTCZ is regenerated by formation of disturbances within the latitudinal band of the monsoon zone. At the end of this period that is to say we are now talking about 4 weeks from when it was first established in the monsoon zone. So at the end of this period, a spell characterised by the absence of the CTCZ occurs and revival from this situation is brought about by northward moving epochs of the oceanic TCZ. So this is another important result.

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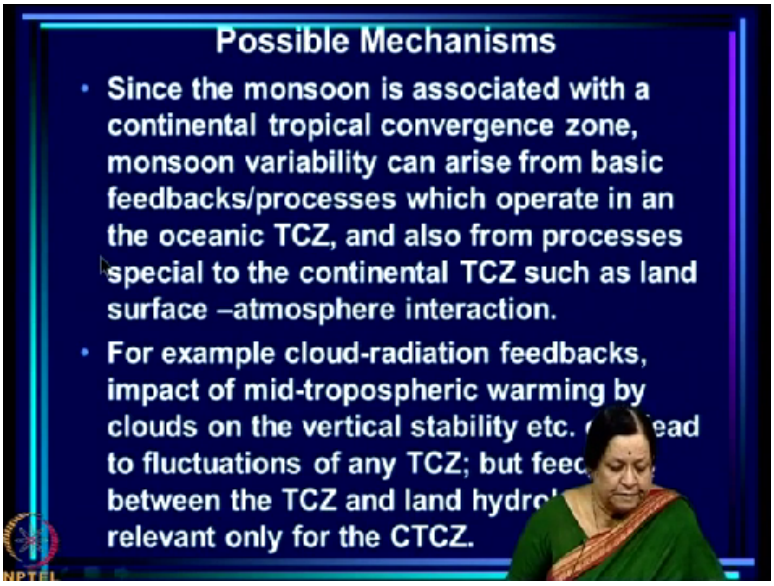

And Sikka-Gadgil actually even in that paper considered what are the possible mechanisms. Now I shall in my later lectures go into the physics of the system in greater detail and elucidate the possible mechanisms and so on in greater detail but I think it is worth mentioning right now, the kind of feedbacks and so on that could lead to these observed fluctuations of the TCZ.

Now since monsoon is associated with the continental tropical convergence zone, monsoon variability can arise from basic feedbacks and processes which operate in an oceanic ITCZ and also from processes special to the continental TCZ such as land surface atmosphere interaction. See this is the important fallout if you wish of our real recognition that the basic system responsible for the monsoon is a tropical convergence zone which in its dynamical characteristics is the same as the tropical convergence zone over the ocean which is commonly called ITCZ.

And a great deal is known and great deal has been thought about why the ITCZ fluctuates, what are the possible feedbacks that give rise to these fluctuations and so on. Now the point is that our system, the monsoon system defers mainly in the fact that now the TCZ is over land and not over ocean. So certainly the feedbacks that operate for an oceanic ITZ or oceanic tropical convergence zone, would also operate in this because it is also a tropical convergence zone.

But in addition to that because it is on the continent, there are other processes also such as land surface atmosphere interaction which will contribute to the variability of the CTZ. So this is

where the linking of the system to TCZ has made a difference in our understanding and in our proposing the mechanisms. Now what are the mechanisms which have already been thought off for the tropical convergence zone, the typical one seen over the ocean commonly called ITCZ.

There are cloud radiation feedbacks and there is another feedback which is impact of mid-tropospheric warming by clouds on the vertical stability. Now you remember we talked about how clouds were a result of an instability and that the atmosphere was conditionally unstable. So clouds are basically a result of this manifestation of this instability. Now what happens is when you have deep clouds, they warm the middle atmosphere because that is where a lot of latent heat of condensation is being released.

Now because they warm the mid-troposphere, what will happen is that the instability will decrease because now the temperature increases, right. It has become warmer in the mid-troposphere. So as I said we will get into details of this at later stage but let me just mention that the instability which is the source of these clouds that itself decreases because of the mid-tropospheric warming associated with these clouds. Now what will happen in that case that eventually the clouds will cease to be, right because what they feed on itself is becoming less and less intense.

And so the clouds will become less and less frequent and eventually there will be cloud-free region. Now when there is a cloud-free region, this instability will get re-established as it was earlier because now the mid-tropospheric warming has gone, okay and this is within a few days since the re-establishment. So the thing gets established again and again you will have intensification of a tropical convergence zone there. So these are fluctuations caused by feedbacks between the clouds and the vertical stability profile.

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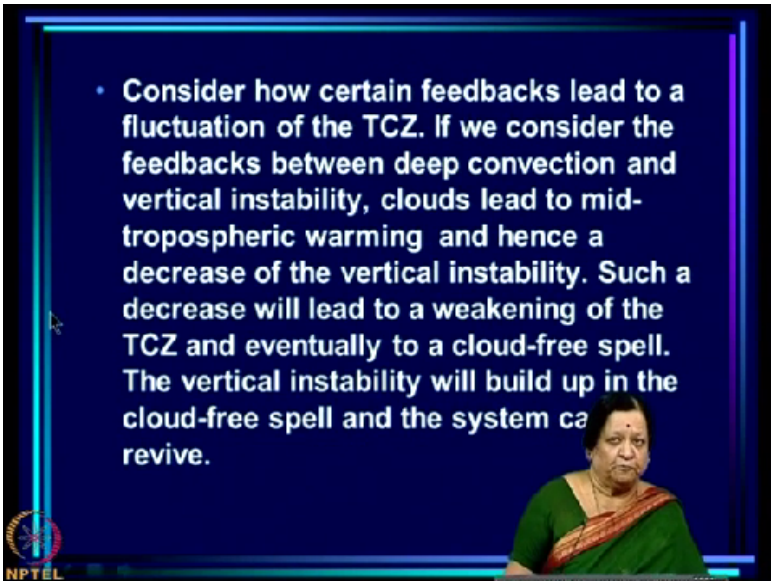

So this is how I just explained to recapitulate if we consider the feedback between deep convection and vertical instability, clouds lead to mid-tropospheric warming and hence a decrease of the vertical instability, such a decrease will lead to a weakening of the TCZ and eventually to a cloud-free spell. The vertical instability will build-up in the cloud-free spell and the system can revive. So in this way these feedbacks can lead to fluctuations of the TCZ.

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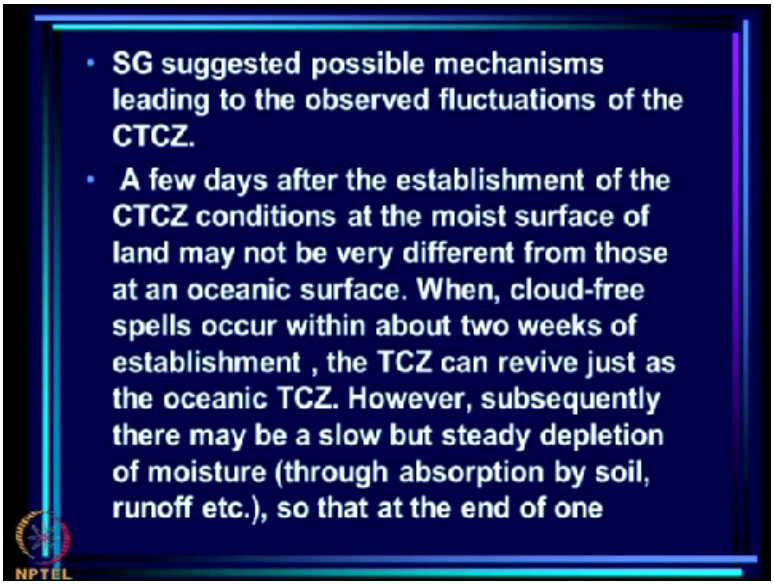

In addition, as I said, there will be impact of land also. Now what Sikka-Gadgil did was suggested possible mechanisms leading to the observed fluctuation of the CTCZ and in particular, the observed sequence of events that they noticed is a part of the evolution of the monsoon season which occurs year after year.

Now what they suggested is the following: That few days after the establishment of the CTCZ, conditions at the moist surface of land may not be very different from those at an oceanic surface. When cloud-free spells occur within about 2 weeks of establishment, the TCZ can revive just as the oceanic TCZ does, right; however, subsequently there may be a slow but steady depletion of moisture through absorption by soil, run-off, etc.

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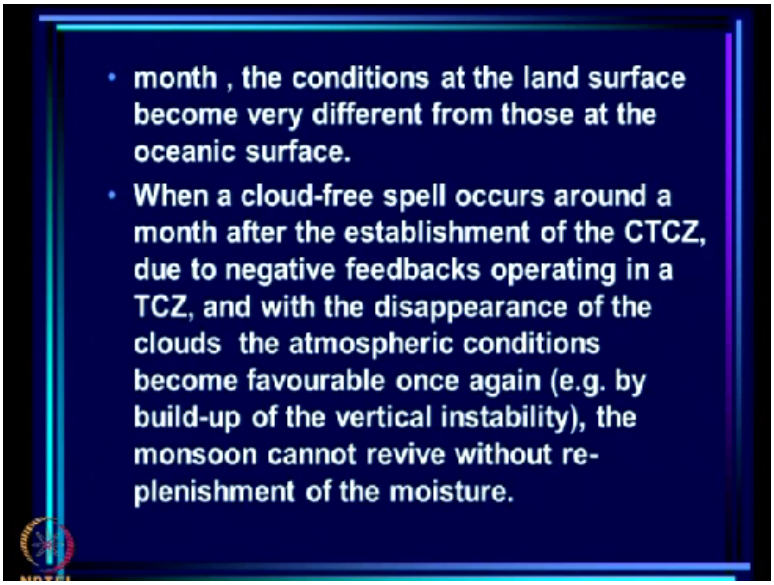

So that at the end of 1 month, the conditions at the land surface become very different from those at the oceanic surface. So what they are saying is, see soon after the establishment of CTCZ, it has rained everywhere and the land surface is extremely moist. So there is plenty of water vapour available for evaporation and the system can revive just like a TCZ does on an ocean, okay but as the season progresses, what is happening is, a lot of water that come from the rain goes to enrich the soil moisture.

There is also a large amount of run-off and so on. So eventually the soil surface is no longer as wet as it used to be. So at the end of a month, the conditions at the land surface become very different from those at the oceanic surface. When a cloud-free spell occurs around a month after the establishment of the CTCZ, due to the negative feedbacks operating in a TCZ and with the disappearance of clouds, the atmospheric conditions become favourable again, example by build-up of the vertical instability or whatever.

Even when that happens, the monsoon cannot revive without replenishment of the moisture because the conditions of land at the end of 1 month are very different from the condition at the end of 10 days after the monsoon has been established over the monsoon zone.

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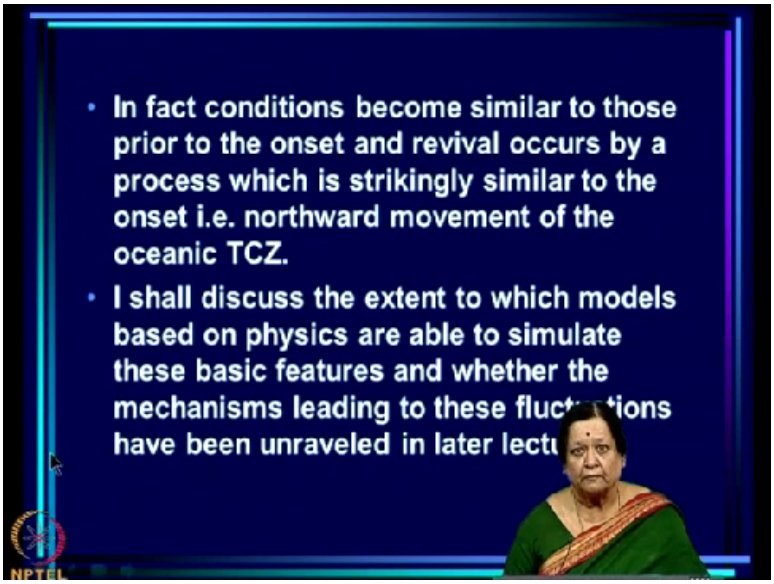

So in fact the conditions become similar to those prior to the onset and revival by a process which is strikingly similar to the onset which is the northward movement of the oceanic TCZ occurs. So this is a very interesting hypothesis that has been proposed and it has been several years since that has been proposed but as yet we have not been able to properly assess to what extent models based on physics are meaning which are governed by Newton's laws are able to simulate these basic features.

And whether the mechanisms leading to these fluctuations have been unravelled. So I will discuss all this in later lectures but I thought it is a good idea at this point just to point out that we do have some ideas about why the fluctuations occur in the TCZ and why there are fluctuations in the monsoon rainfall on the intra-seasonal scale.

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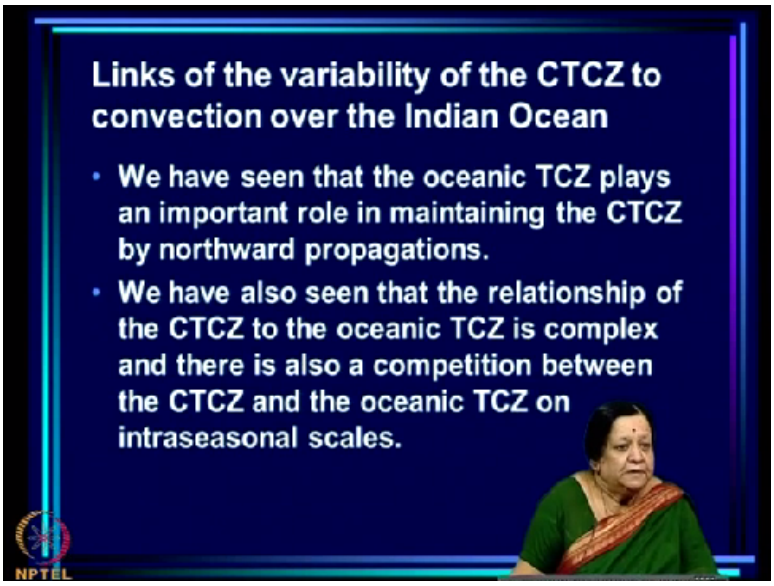

Now one thing that came out extremely clearly from this study of the satellite imagery was that the lifeline of the monsoon is the clouds over the ocean, okay. So oceanic TCZ we have seen plays a very very important role in maintaining the CTCZ by northward propagation both during the onset phase, during the retreat phase as well as during the peak monsoon months.

So northward propagation of the oceanic TCZ is very very important but we have also seen that the relationship between the CTCZ and oceanic TCZ is very complex. And there is also a competition between the CTCZ and the oceanic TCZ on the intra-seasonal scale that is the sub-seasonal scale, we know that there is a very clear competition between the 2.

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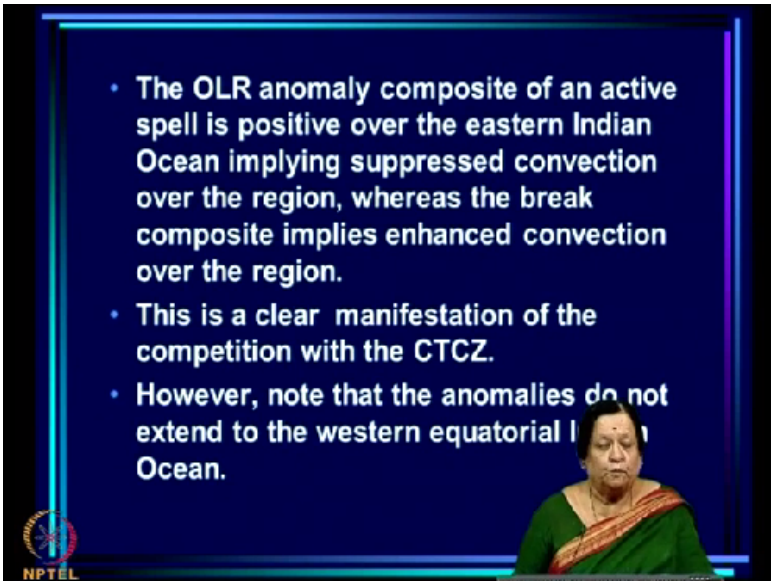

Now if we look at anomaly, OLR anomaly composites of active spells. Active spells are one in which there is sustained high rainfall over the monsoon zone and the so-called breaks of the monsoon in which you have a huge rainfall deficit over the entire monsoon zone. So when we look at, we have actually defined all these objectively

And by objective definitions based on rainfall criteria, criteria based on rainfall over the monsoon zone, we can actually define active spells and break spells. Once we define them, we know the dates on which they occurred, we can actually make a composite of these to see what is the convection pattern unlike associated with active and break spells.

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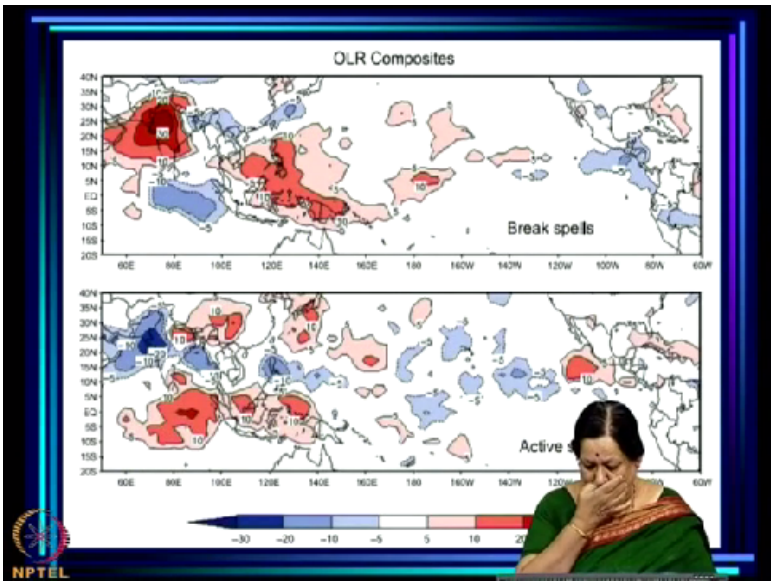

And what you see is shown here. These are OLR composites of break spells on top, these are break spells and remember here pink and red is positive OLR anomaly, right. Positive OLR anomaly means negative rainfall anomaly. So here the convection and rainfall are suppressed and this is a break monsoon condition and here is the active condition, all blues. This is when convection and rainfall is enhanced.

So these anomalies mean convection is enhanced here and notice that there is a seesaw between here and here. During our breaks, there is excessive convection over the eastern and central equatorial Indian Ocean and during our active spells, there is suppression of convection over this region. So the competition we were talking about between the oceanic TCZ and the CTCZ seems

to be manifested as this dipole of anomalies that you see are positive anomalies here, negative here, are negative here and positive here.

So this dipole is a reflection or a manifestation of the competition that you have seen between these 2 and interestingly this dipole is not extending this side of 80 degrees at all. In other words, the western equatorial Indian Ocean is not competing with the CTCZ. Only the eastern one seems to be. See our idea of saying there will be competition because suppression from one system will lead to weakening of the other.

And so on did not really specify how much the weakening would extend in the east-west direction and where its centre would be but from these data, it is clear that most of the weakening or suppression of convection occurs over the eastern equatorial Indian Ocean, Eastern and Central and almost nothing over the western equatorial Indian Ocean. Now this is interesting because we knew that the relationship is complex. The oceanic TCZ is actually very much required for maintaining the CTCZ by northward propagation.

So it appears that the positive relationship is with the western part and the negative relationship with the eastern part. So there is a division of labour if you wish that this part takes care of eastern part, takes care of the competition between the 2 and western part takes care of the positive interaction between the 2 which is again an interesting thing which we had not anticipated when the Sikka-Gadgil paper was written.

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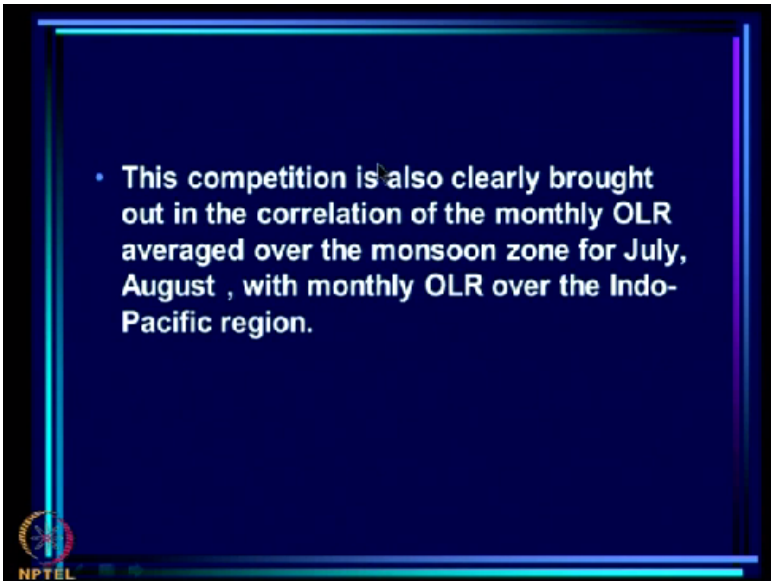

Now this competition is also clearly brought out in the correlation of the monthly OLR averaged over monsoon zone for July-August with monthly OLR over the Indo Pacific region.

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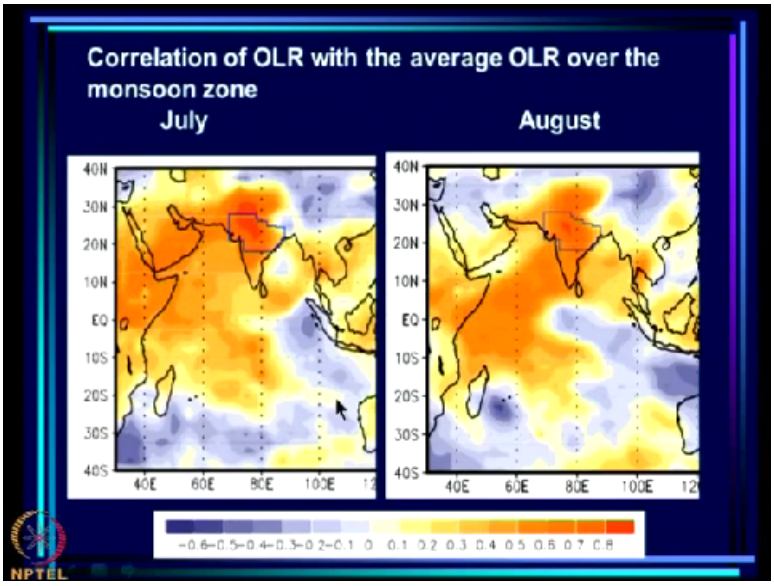

So what this is? This in the monsoon zone. So we take the average OLR over this region and correlative it with OLR at every grid point in this region and naturally the correlation is highest here over the monsoon zone because we are correlating with the average OLR of monsoon zone and it is positive here. Notice negative correlation is over the eastern equatorial Indian Ocean.

And positive correlation is over the western equatorial Indian Ocean. So this is very interesting as I said before what we saw from the active break thing, it appears that the eastern equatorial

Indian Ocean has taken charge of fighting with CTCZ whereas the friendly oceanic TCZ is on this side and the same story you see for August also.

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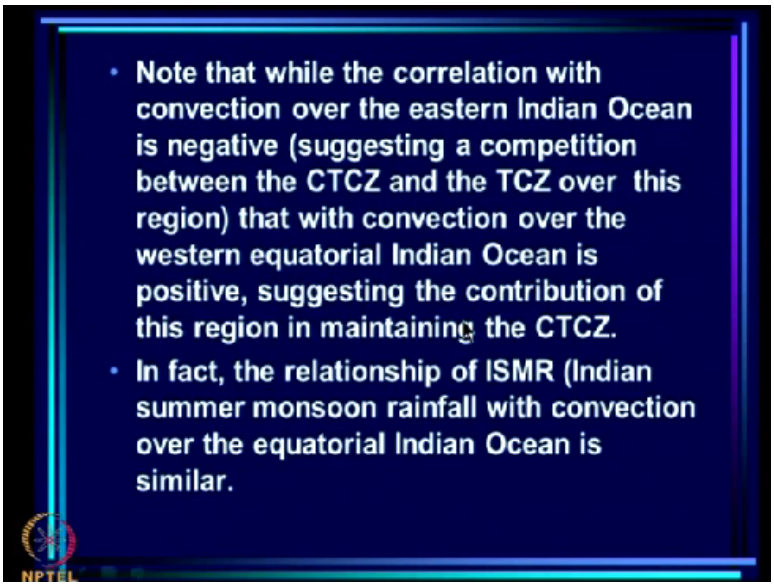

So while the correlation with convection over eastern equatorial Indian Ocean is negative suggesting competition between the CTCZ and the TCZ over this region that with convection over the western equatorial Indian Ocean is positive suggesting the contribution of this region in maintaining the CTCZ. In fact, this relationship of ISMR or the Indian summer monsoon rainfall with correlation over equatorial Indian Ocean is very similar.

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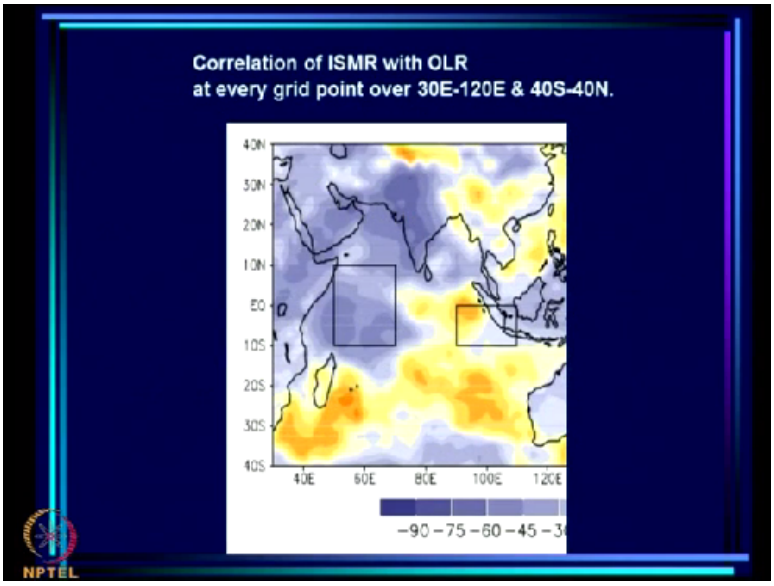

This is now the correlation of ISMR, all India summer monsoon rainfall is correlated with OLR

at every grid points and you see that the correlation of course is negative with OLR because it is tall clouds which have lower values of OLR. So lower values correspond to high values of rain. So negative correlation is what you expect between rain and OLR and you can see the same sign here whereas it is opposite here, over central and eastern equatorial Indian Ocean. So this is very interesting.

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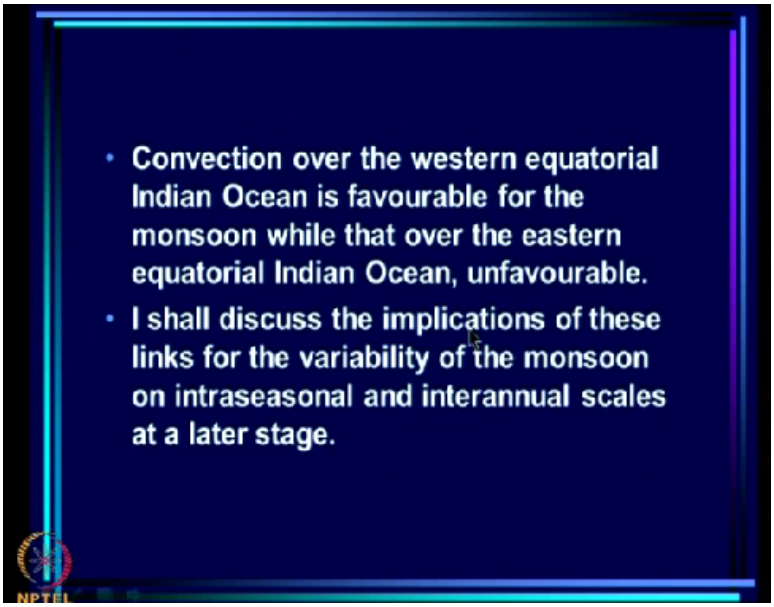

So convection over western equatorial Indian Ocean is favourable for the monsoon, while that over the eastern equatorial Indian Ocean unfavourable. I shall discuss the implications of these links for variability of the monsoon on intraseasonal and interannual scales at a later stage.

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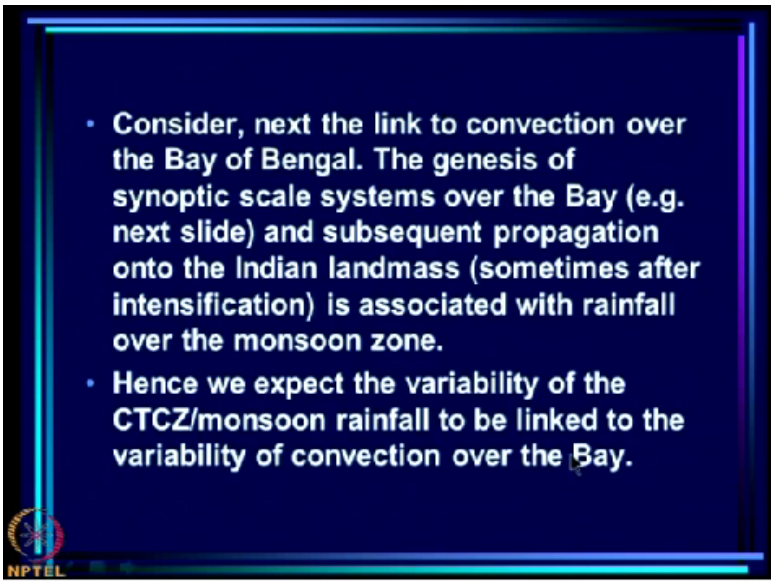

Now consider the next link to convection over the Bay of Bengal. We have said both are important, equatorial Indian Ocean as well as Bay of Bengal. Now genesis of synoptic systems over the bay which we have seen and subsequent propagation onto the Indian landmass is associated with rainfall over monsoon zone.

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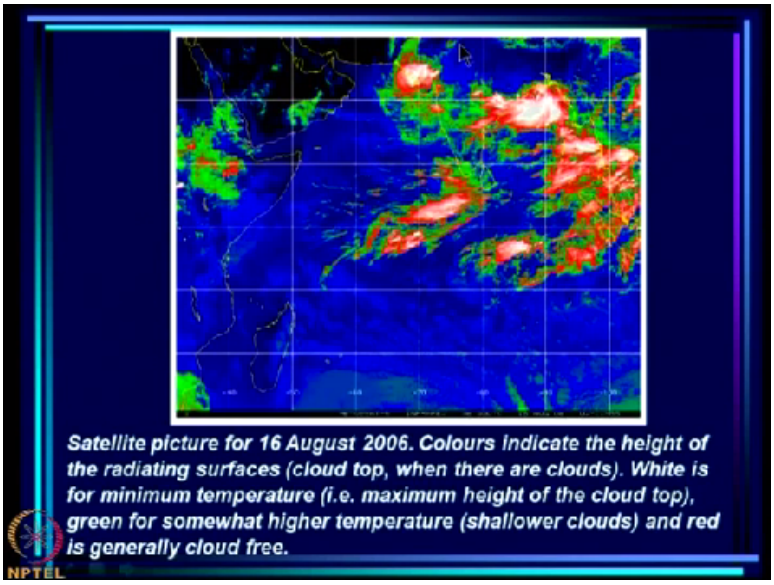

This is an example of actually synoptic scale systems, one synoptic scale system over the bay, another has already travelled to the other end of the monsoon zone.

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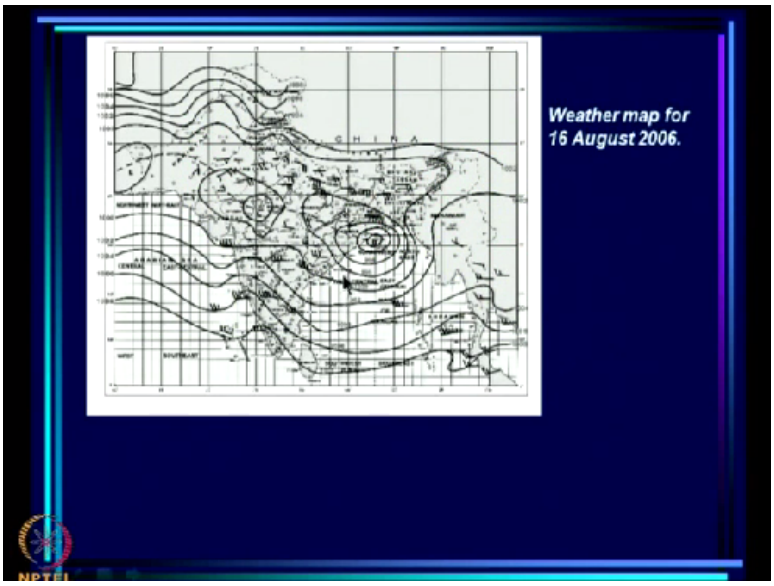

And you can see in fact that this is a strong synoptic scale system or depression, whereas this is a low here. So this is the weather map.

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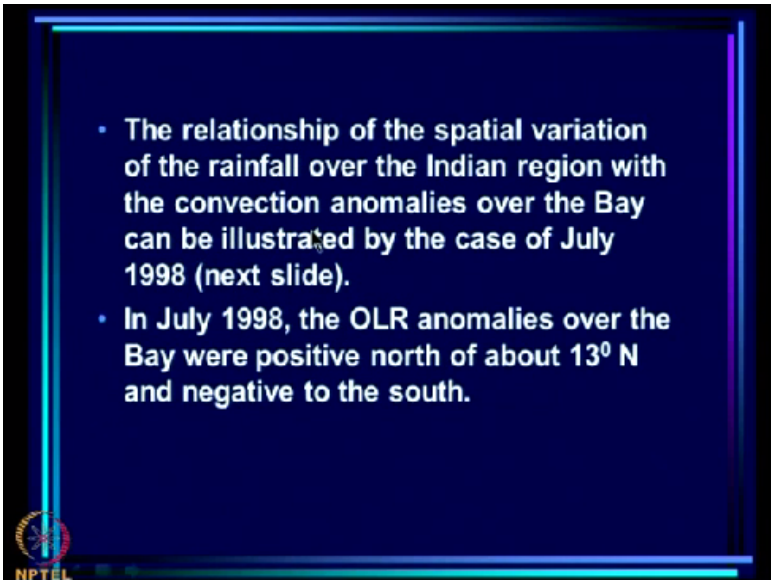

And the relationship of the spatial variation of the rainfall over the Indian region with the convection anomalies over the bay is again a little bit complicated.

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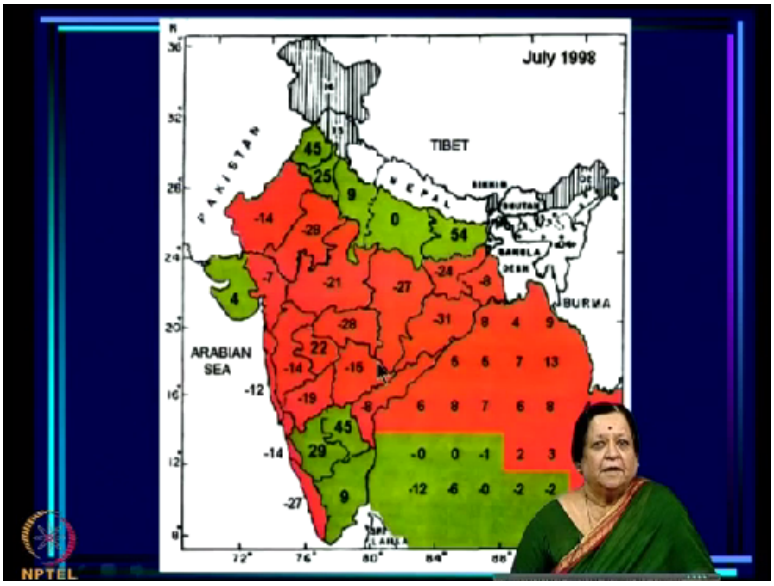

And we illustrate that with July 1998. What happened in July 1998? it was very interesting. Most of the systems were generated here in this region rather than in the central and northern bay. So there was the shift in the genesis region and because of that we got negative OLR anomalies here you see.

This is where most of the systems got generated and they moved on to land. In fact, they came here and gave us a lot of rain but since the systems were generated here and they moved to land, you see, nothing was generated here and this whole belt got deficit rain. So you can see the link is very nice between the region of genesis and where you get rain but it is a complicated kind of link.

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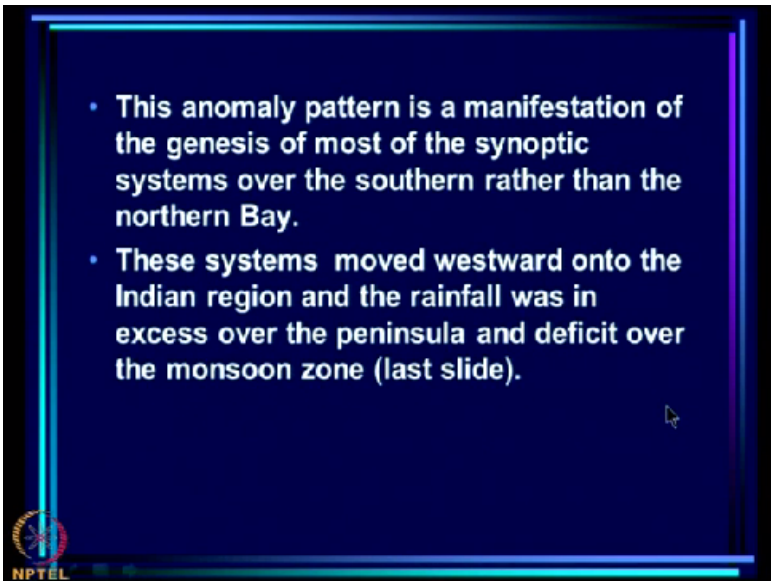

So this anomaly pattern is a manifestation of the genesis of most of the synoptic scale systems over the southern rather than the northern bay. These systems move westward onto the Indian region and the rainfall was in excess over the peninsula and deficit over the monsoon zone.

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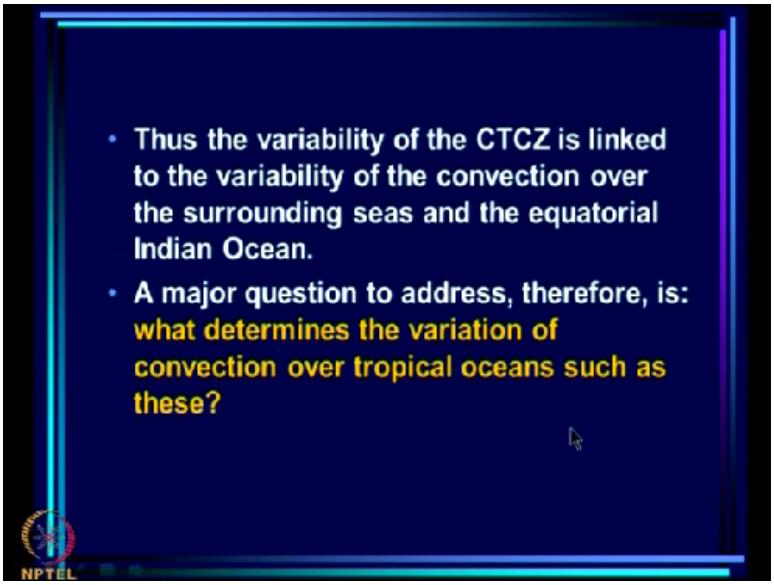

So now it is very clear that the variability of the CTCZ is linked to the variability of convection over the surrounding seas and the equatorial Indian Ocean, okay. So the million-dollar question is what determines the variability of convection over these oceans. Now it is not quite straightforward problem because we know that the convection on land also has an impact on convection over ocean and vice versa.

These are interacting systems but we still would like to know whether there are factors that determine the variation of convection over tropical oceans because those will be then critical for understanding variability of the monsoon as well, okay. So major question to address therefore is, what determines the variation of convection over tropical oceans such as these? Now when we talk of variation of convection, we are talking of organised convection, right, organise convection over several hundred kilometres, convection organised over synoptic and larger scale which is hundreds of kilometres, okay.

And we are interested in the variability of such organised convection over tropical oceans but to go back to the basics see what is the basic source material for clouds, it is water vapour, right. Clouds are condensed water vapour. Clouds contain liquid water because in clouds, water vapour actually gets transferred to liquid water, okay. So the most important input to a cloud is obviously the water vapour, okay. Now so naturally it will depend on the availability of water vapour.

Now where is the water vapour available, it is available at the surface of the ocean and we are talking of convection over the ocean. So the water vapour is available at the surface of the ocean and obviously the more water vapour in the air parcel touching the surface of the ocean, the more chance there is of getting clouds, is not it? So convection will depend on how much water vapour is in air and this is what we will discuss next time but basically we all know how much water vapour air can hold depends very much on its temperature.

This is why when we put a glass full of cold water in a room, water droplets start condensing at the outer surface of the glass. Why is that because at the outer surface of the glass, air hugging the glass becomes colder and as it becomes colder, its capacity to hold water vapour decreases. So some of the water vapour condenses on the glass to form liquid water. So the most critical element then being water vapour leads to the fact that the air temperature near the sea surface is very critical

And air temperature near the sea surface is strongly related to the sea surface temperature itself, right, the 2 go together. So in fact the first candidate if you wish for addressing the question what determines the convection, organised convection over tropical oceans and its variability is the sea

surface temperature or SST and in the next lecture, we will actually try and understand what is the relationship between organised convection and sea surface temperature, organised convection over the ocean and sea surface temperature because that will certainly give us a clue in understanding what leads to the variability of convection over the ocean. Thank you.