The Monsoon and Its Variability
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Lecture - 16
Seasonal Transitions – Part 1: Spring to Summer Transition

Today I am going to talk about seasonal transition, the first one being from spring to the summer that is the summer monsoon.

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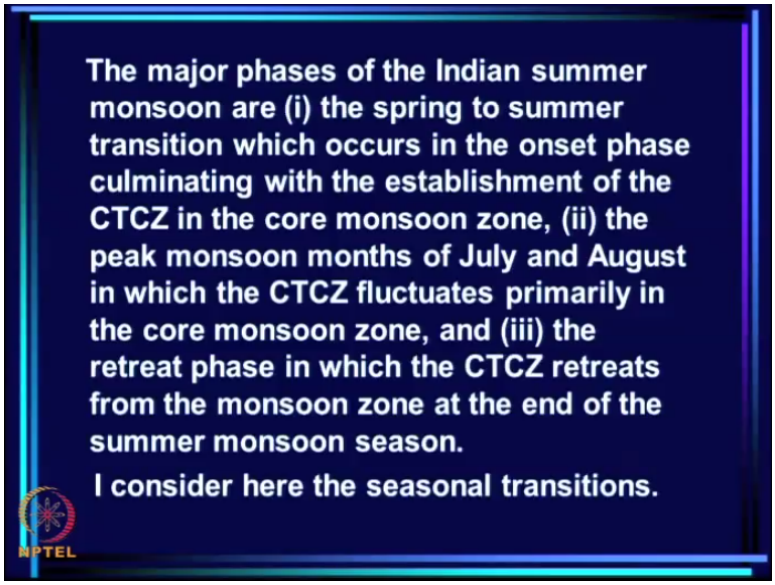

See, the major phases of the Indian monsoon are the spring to summer transition, which occurs in the onset phase, culminating with the establishment of the CTCZ in the core monsoon zone, you know what the core monsoon zone is? And in fact establishment of the rain belt in that core monsoon zone indicated by the red dash lines, within those red dash lines is actually the culmination of the onset phase.

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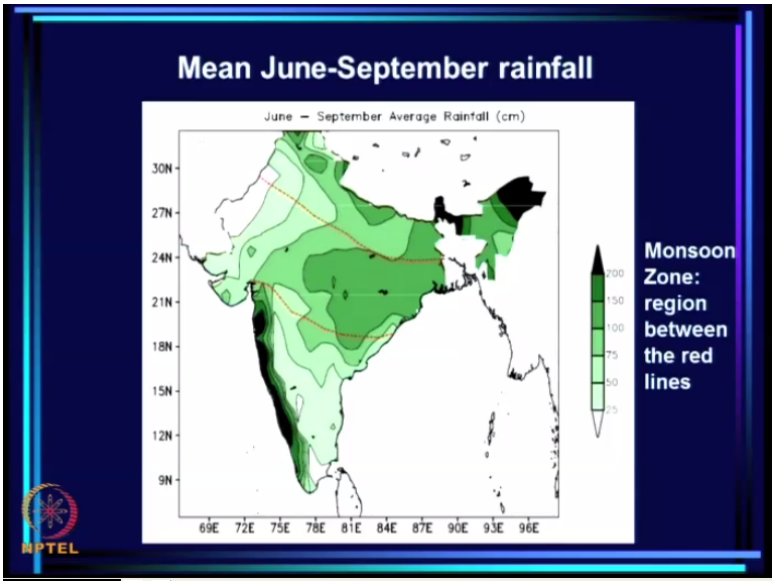

So it culminates with the establishment of the CTCZ in the core monsoon zone then in the peak monsoon months of July and August in. Which CTCZ fluctuates primarily in the core monsoon season and finally the retreat phase in which the CTCZ retreats from the monsoon zone at the end of the summer monsoon season. So here in this lecture, I will consider first the seasonal transition from spring to summer.

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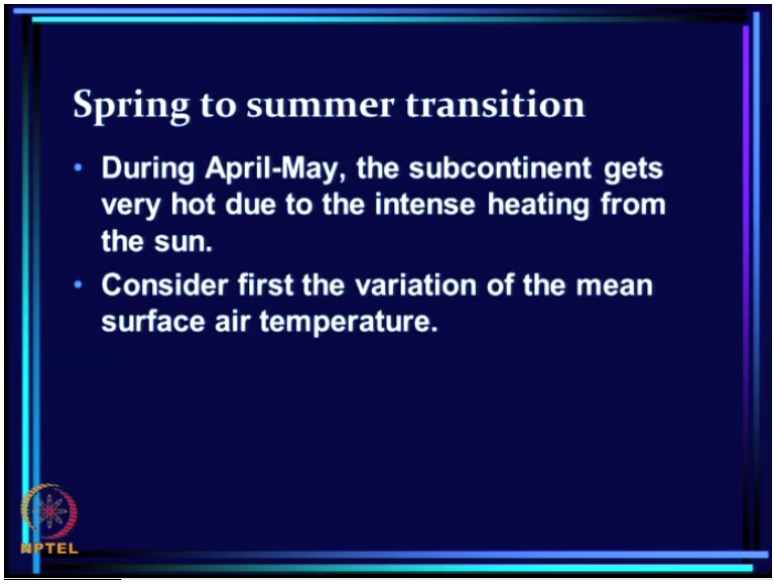

So spring to summer transition, spring is during April-May, the sub continent gets very hot due to the intense heating from the sun.

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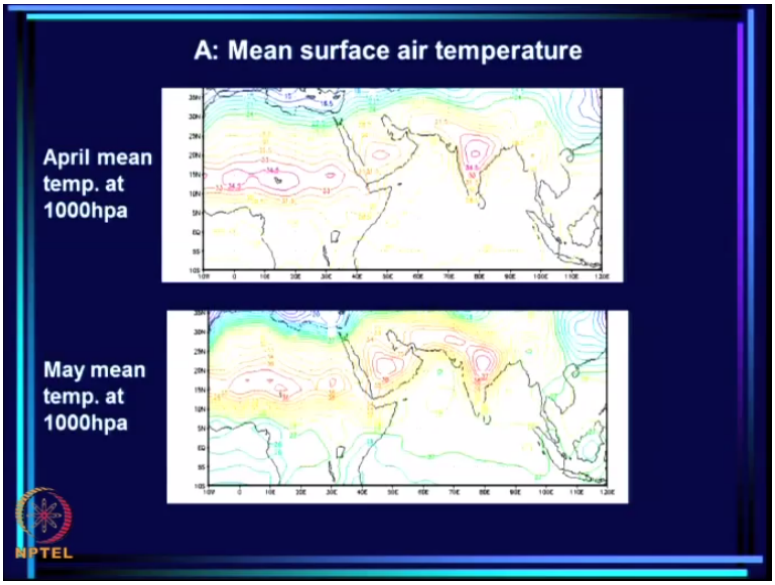

Consider first the variation in the mean surface air temperature and what you see here is actually the mean surface air temperature and you see that it is very high over the central part of India here. This is April and this is May, this is 34.5 and these are even higher temperatures here. These are mean monthly temperatures. So this is May and this is April. So already you see a hot belt here, right from Africa up to India.

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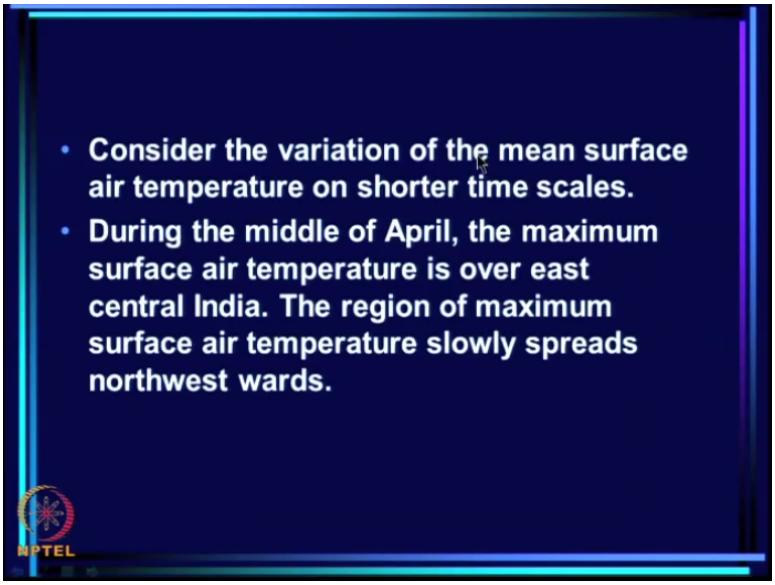

Consider the variation of means surface, air temperature at shorter time skills. What we saw first was monthly. So when we see on shorter timescales what do we see. During the middle of April, the maximum surface air temperature is over East Central India. The region of maximum surface air temperature slowly spreads northward.

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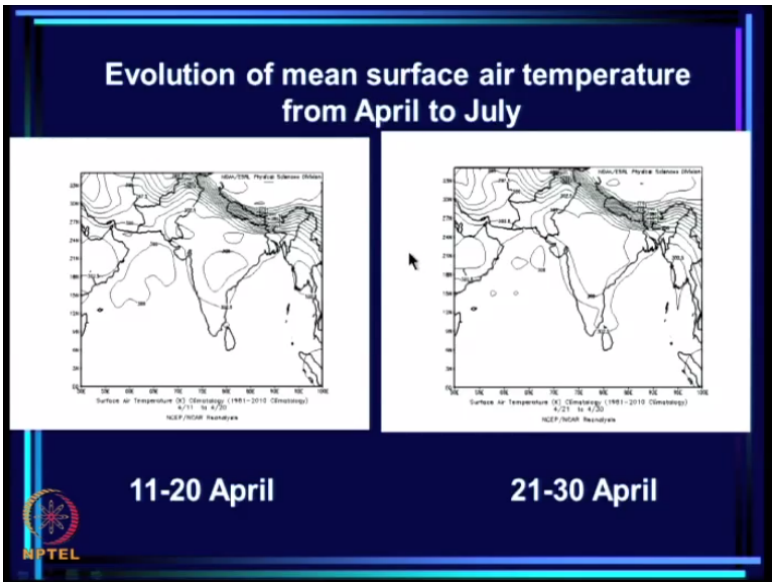

So now this is 11 to 20th April and you see this is the maximum surface air temperature and now it is spreading here, slowly spreading northward, 21 to 30.

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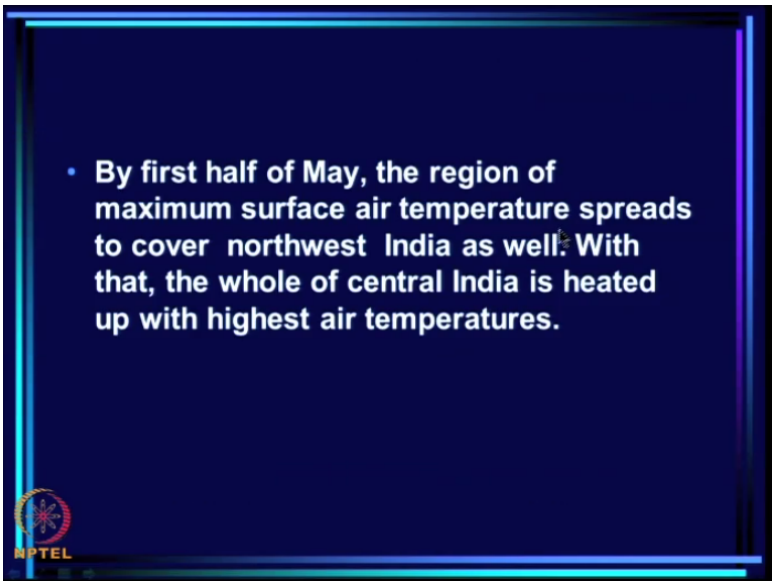

By first half of May, the region of maximum surface air temperature spreads to cover Northwest India as well. With that the whole of central India is heated up with highest air temperatures.

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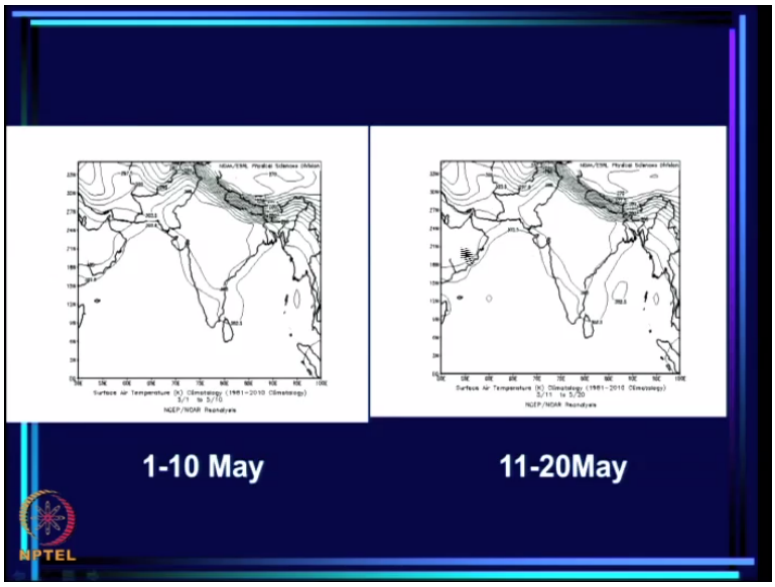

So this is you see all this region is very hot now and now by middle of May it has started spreading here to the northwest region as well.

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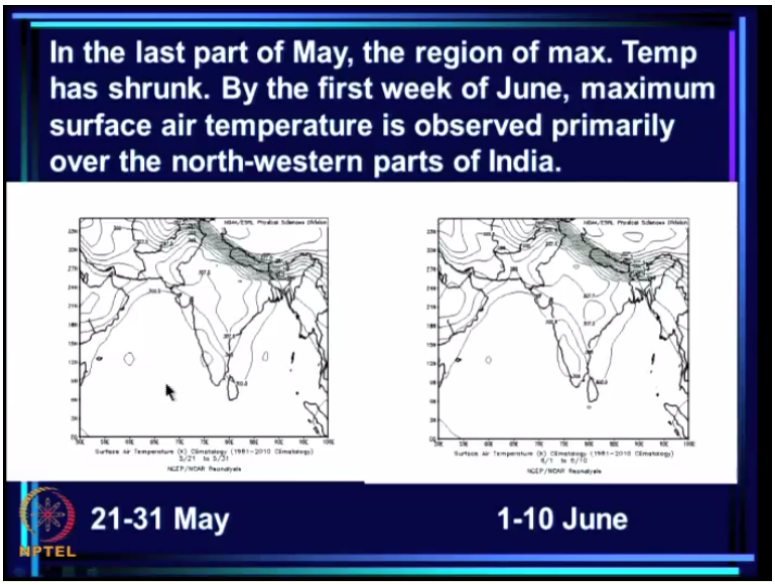

And in the last part of May, the region of maximum temperature actually shrinks. So you see it was rather big here from 11th to 20th May, but we now know we start getting thunder showers towards the second part of May and with thunder shower this part has cooled and the reason of maximum temperature is actually shrunk and the 1st to 10th June it has shrunk even further. So it has receded so to speak northward, the region of maximum temperature.

In June the maximum air temperatures over northwest India increased to even higher levels. So here it is getting even hotter. But here it gets cooler in June and so this is getting even hotter here, here we are getting cooler.

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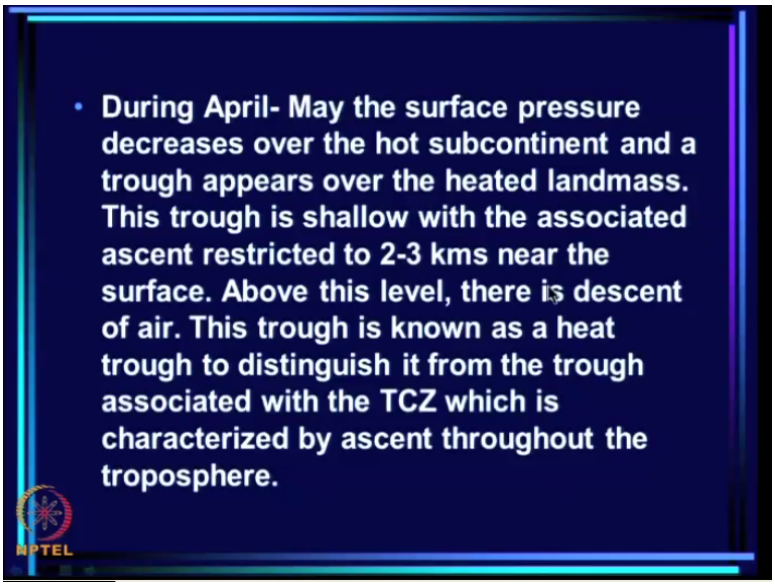

So during April-May the surface pressure decreases over the hot subcontinent and the trough appears over the heated land mass. This trough is shallow with the associated ascent restricted to 2-3 kilometers near the surface. Above this level there is descent of air. This trough is known as the heat trough to distinguish it from the trough associated with the TCZ which is characterized by ascent throughout the troposphere.

Now we have seen the difference between heat low and dynamic low in earlier lectures.

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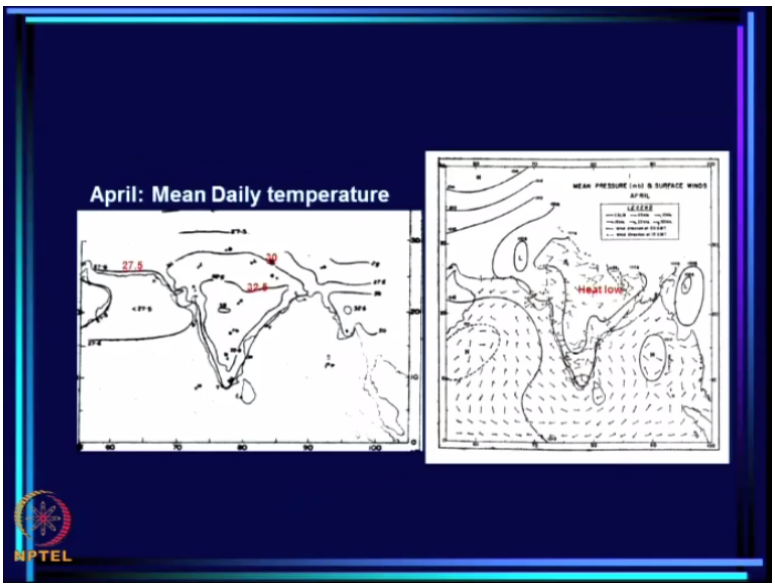

So what you see here, this is the April mean daily temperature and you see there is huge blob of high temperature here sitting over India and over that blob in fact the pressure is rather low at the surface. But this is a heat low here.

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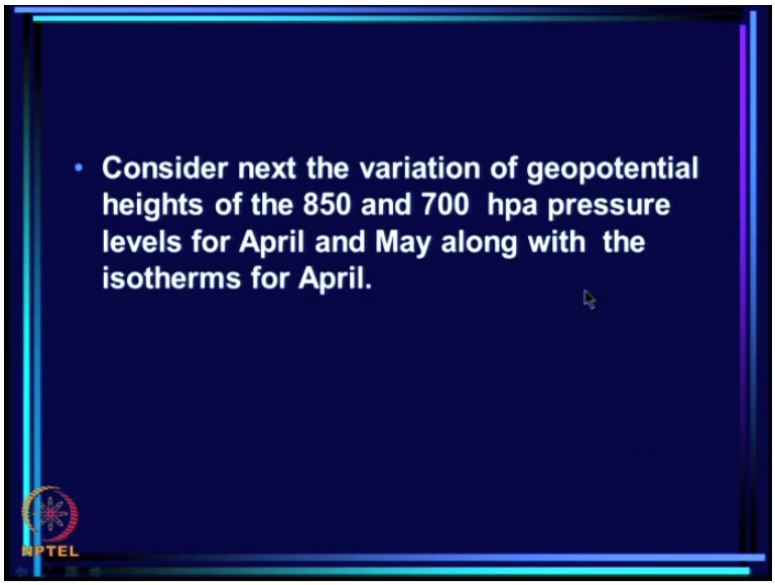

And now we can just see what happens to geo potential heights.

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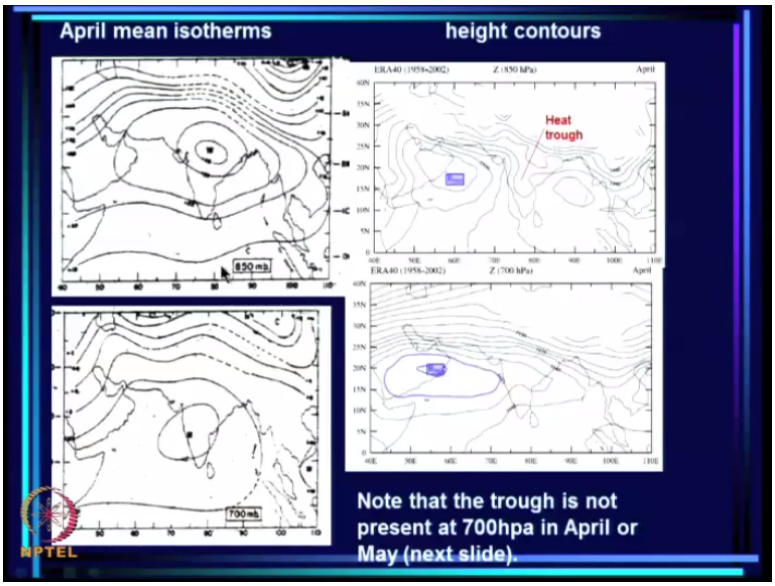

So these are the April mean isotherms at different geopotential heights. This is 850 millibar, you see it is still warm here where the surface was very warm and what you see at 850 millibar is a trough here. This is the heat trough associated with these warm temperatures. But you see at 700 millibar there is no trough at all. This in fact is the signature of the heat trough.

Heat trough does not extend beyond 2 to 3 kilometers, 700 hpa is about 3 kilometers and by that level there is no trough at all. And at 700 this is the temperature distribution.

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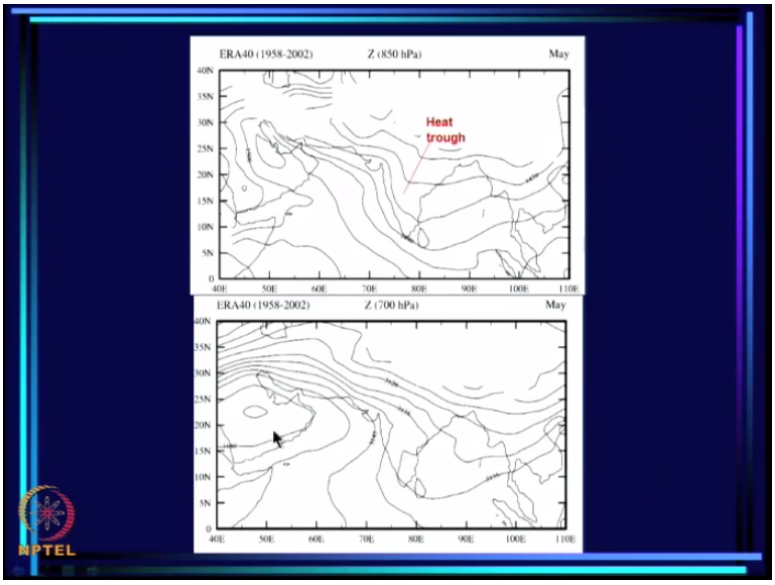

So this is for May and for May also you see now there is a heat trough here over land and at 700 there is no trough in that region at all. So a heat trough is a very well developed in April and May.

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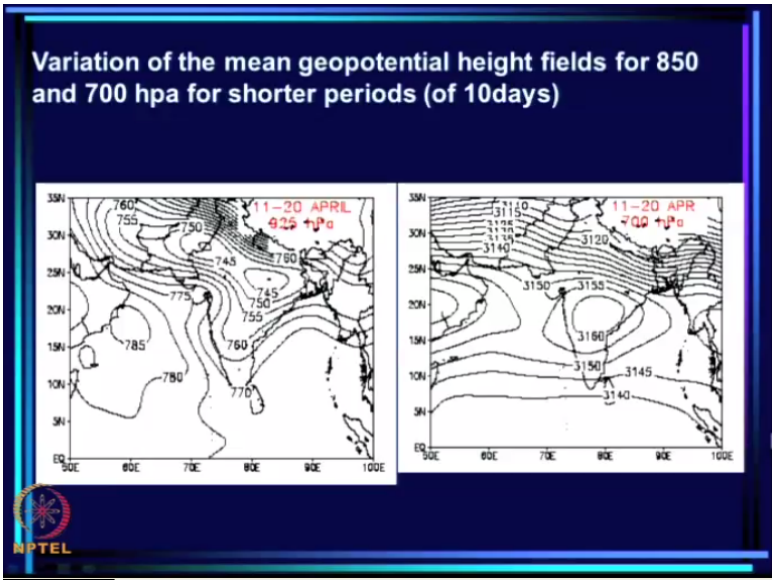

Now if we see on a shorter time scale, how does the geopotential heights field vary. Then we have this is the situation from 11th to 20th April, you see here a low pressure here, extending all the way here and at 700 there is no low pressure at all, in fact this part is a high pressure here. So this is a very clear signature of the heat trough again.

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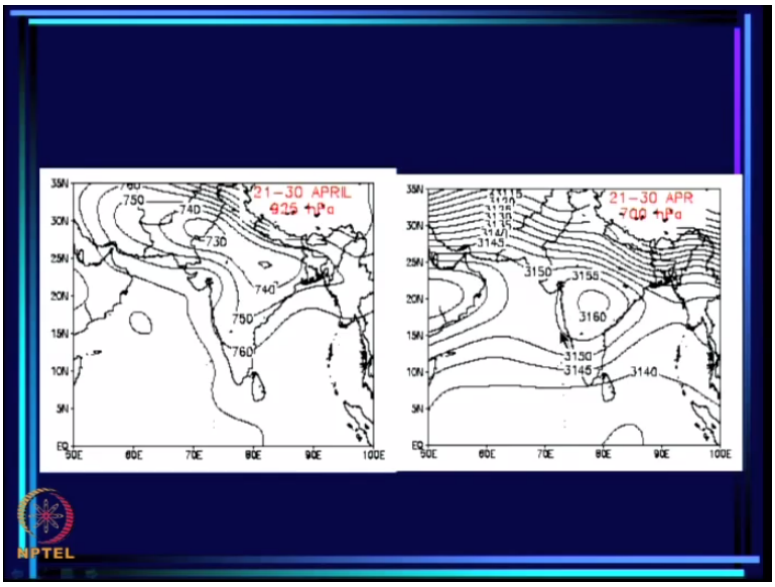

21st to 30th April you see the low here, this is the heat low and at 700 there is a ridge or high pressure belt here.

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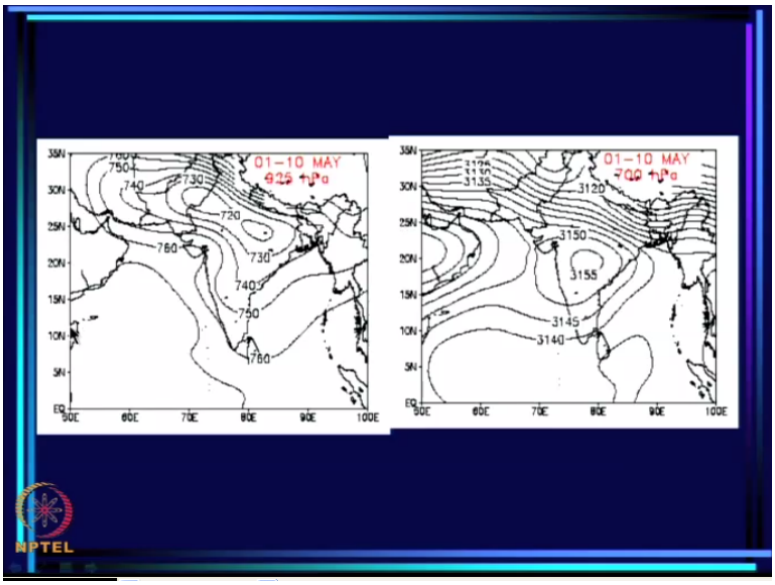

Now this is 1st to 10th May you see again a low pressure very well developed here, but only at low levels, nothing seen at 700 except the high pressure here.

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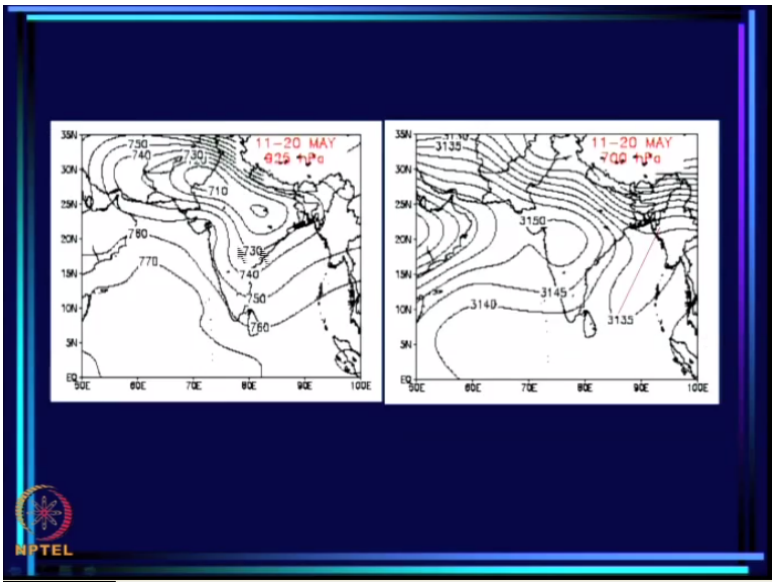

Now 11th to 20th May again the surface low persists and the ridge here is still present. So there is a high pressure here and now the same story till the end of May, 21st to 30th you see a trough here in the surface or 925 hpa and a ridge here.

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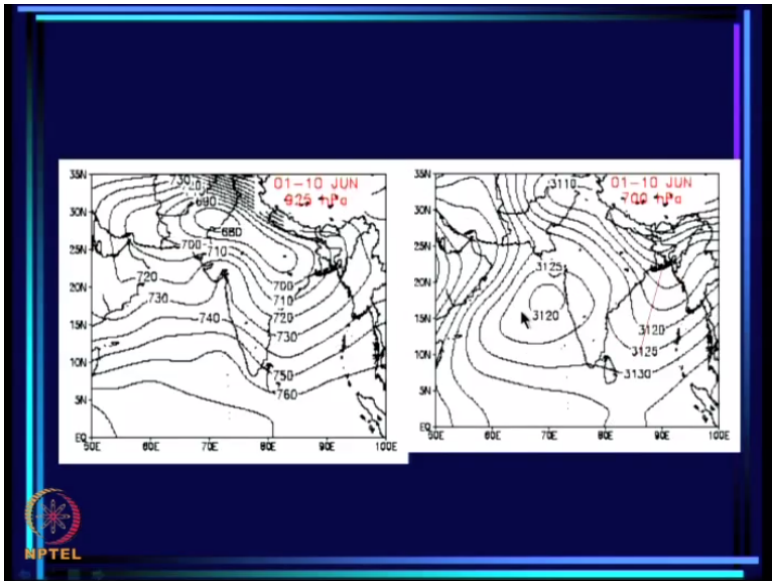

1st to 10th June now you see this is still persisting, this is the heat low, low pressure here but what you say here is very interesting. Over the Bay of Bengal now, a pressure trough has appeared here. You see this is a trough here which has appeared with the Bay and as we will see later this is because the monsoon has already onset over this part of the Bay. This is why we see a development of a dynamic low or a trough here at 700 hpa.

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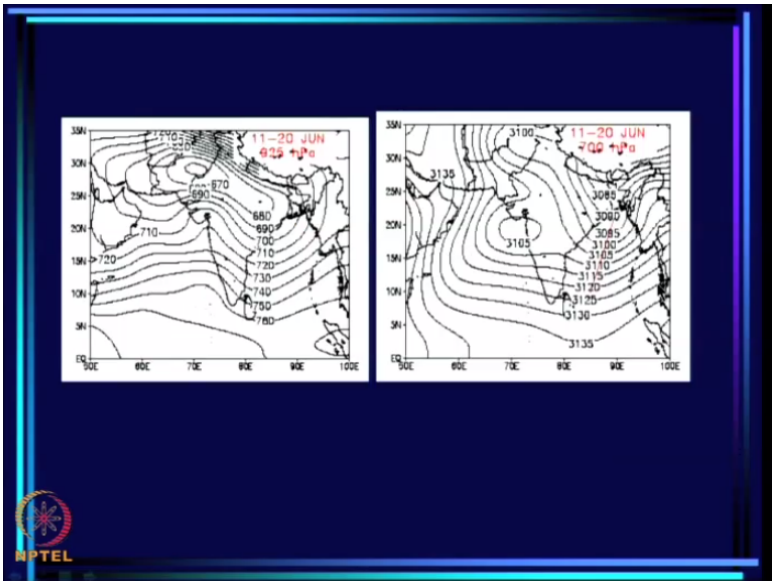

Then from 11th to 20th June, again this persists and you see the trough continues at 700.

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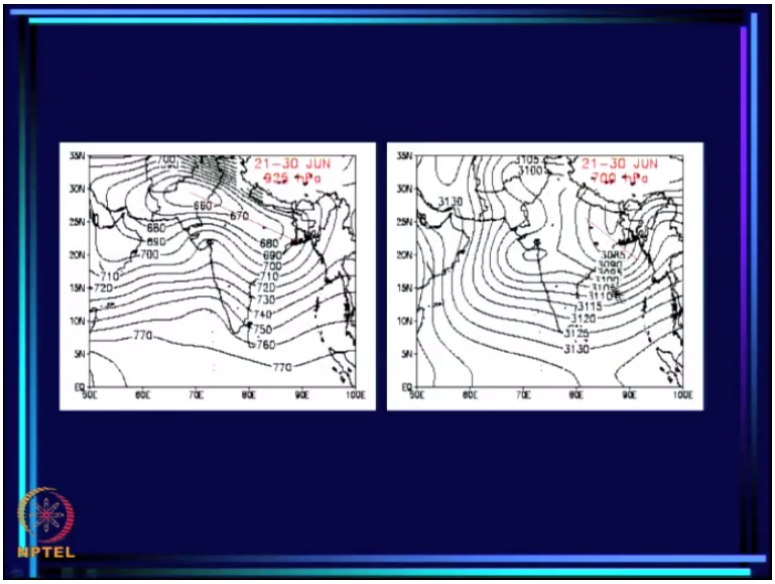

And now you see the trough from 21st to 30th June you see a trough extending from head bay to here at 700 millibar. So already the story is somewhat different by end of June, we are beginning to see the beginning of a dynamic low here and the heat low over this part of the region.

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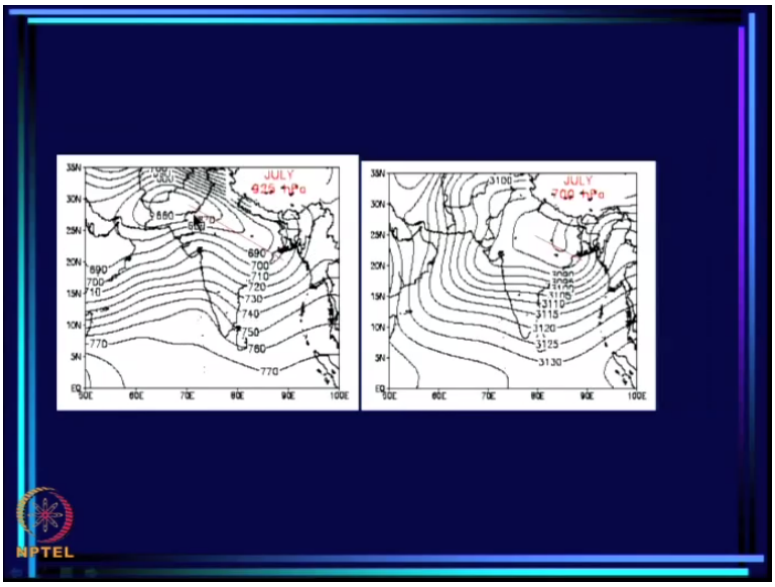

So this is the story for July, Monthly July and what you see here at 700 this is the dynamic low. And what you see at the surface this is the heat low and this is the dynamic low.

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These are the characteristics of the transition from spring to summer monsoon and what we have seen is it involves a transition from this heat trough to a dynamic trough or TCZ.

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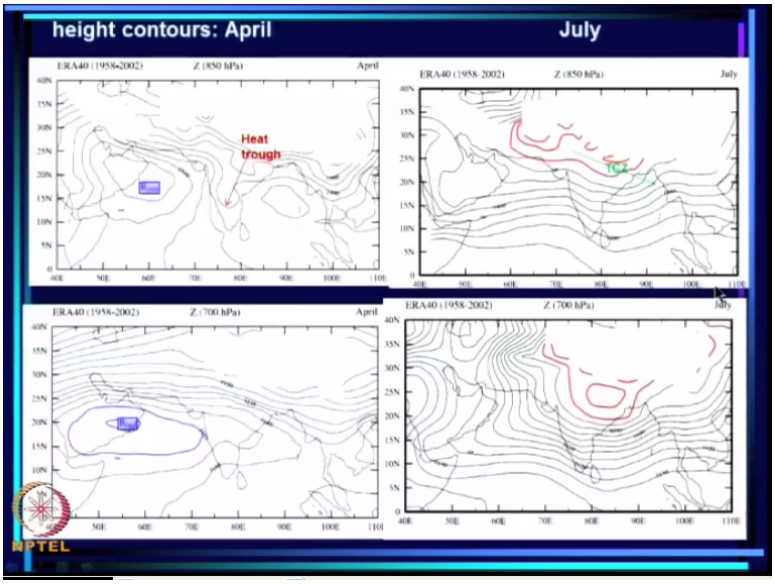

And this is very clearly brought out when we see the comparison between April where you have heat troughs sitting here. At 858 hpa you have a heat trough here and at 700 there is no trough at all because this is a heat rough. But in July you have a dynamic trough over this part and you see at 700 also very clearly the presence of a trough.

This part of it is a heat low or a heat trough and there is no trough at 700 hpa over that part of the region which is this part here. So you see what it is a transition from a heat trough which extended everywhere here to a situation where the heat low is restricted to the northwestern part and the dynamic low or TCZ appears over this part of the region. This is the characteristic of a seasonal transition.

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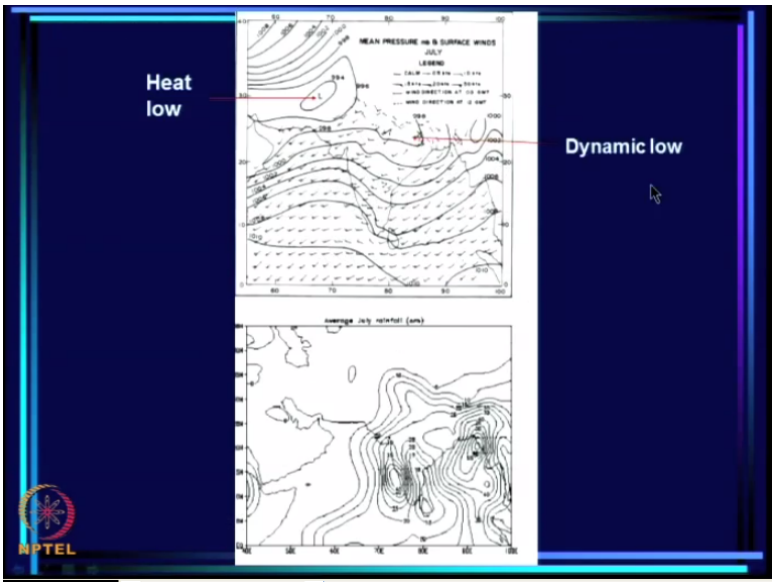

So as I mentioned before you have a heat low here, you have a dynamic low here in July and the rainfall also shows that you have most of the rains over the TCZ her and as you go here, there is no rain at all because this is the heat low here and this is of course the orographic rains because of the western Ghats.

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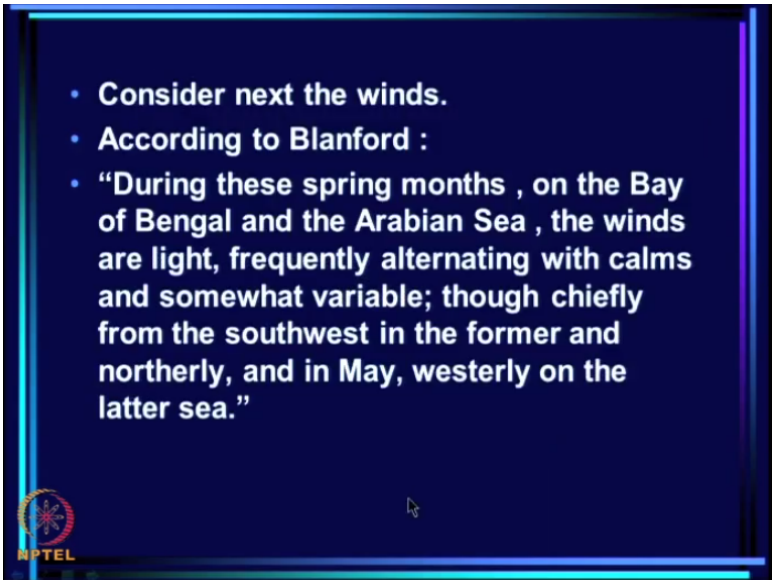

Now we consider the winds and I go back to Blanford who again has given a very deep insight into seasonal transitions as well and he puts it in very nice lucidly. During this spring months on the Bay of Bengal and Arabian sea the winds are light, frequently alternating with calms and somewhat variable, the chiefly from the southwest in the former and northerly in May, westerly on the latter sea.

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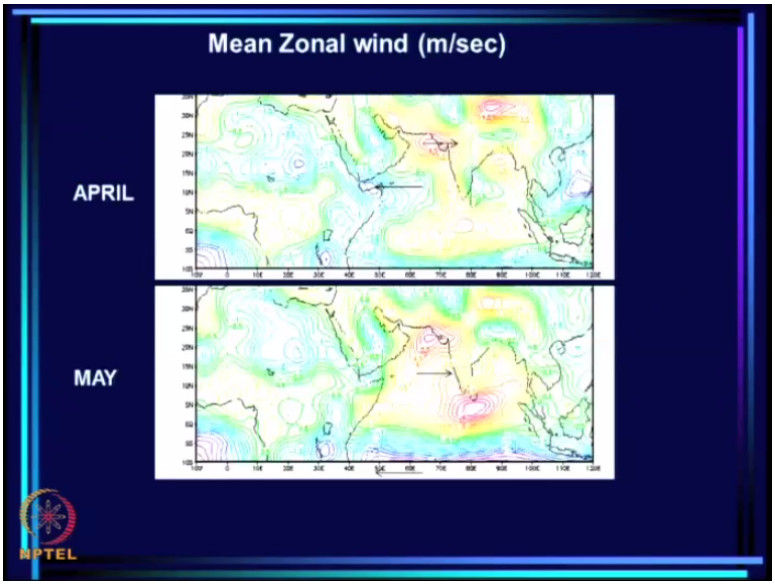

So these are the winds that you see and mean zonal winds are westerly a bit here, but they are easterly here and in April and in May you begin to see more westerly winds here. And these are the meridional wind surface one and you see actually they are northerly in April and this northerly belt is shifting a bit towards the south in May.

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So transition to summer involves strengthening and spreading of the westerlies over the Arabian Sea and strengthening of the northward velocity over the Arabian Sea and also the development of a strong cross equatorial wind along the east coast of Africa.

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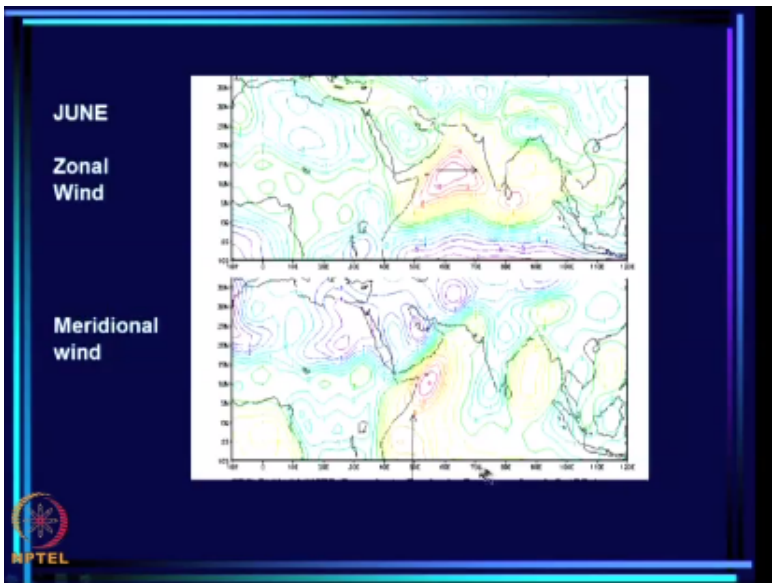

So you see here this is June and you see already you have large region with westerlies here over the Arabian sea, strong westerlies and this is the cross equatorial flow. This is the meridional wind, the north south wind and you see a strong cross equatorial flow along the

coast of East Africa here. This is a characteristic of June. So at the end of the seasonal transition already these have appeared.

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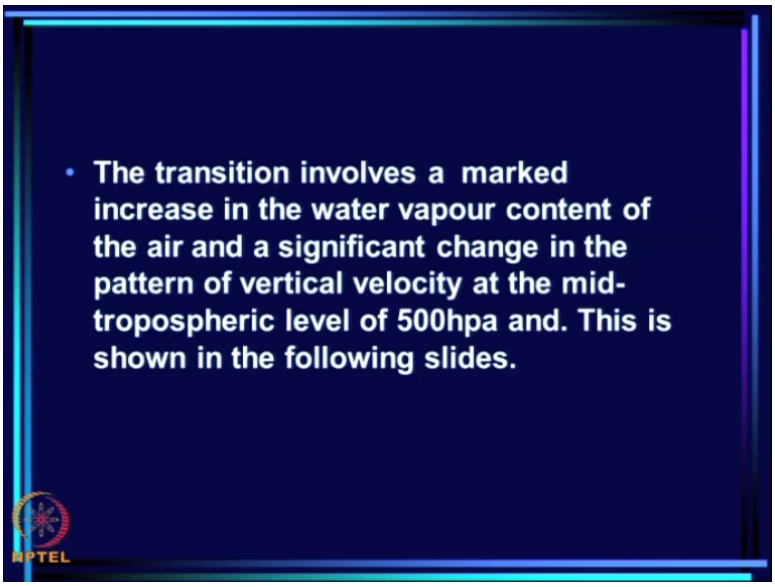

Now the transition involves a marked increase in the water vapor content of the air and a significant change in the pattern of vertical velocity at the mid-tropospheric level of 500 hpa and this is shown in the following slides.

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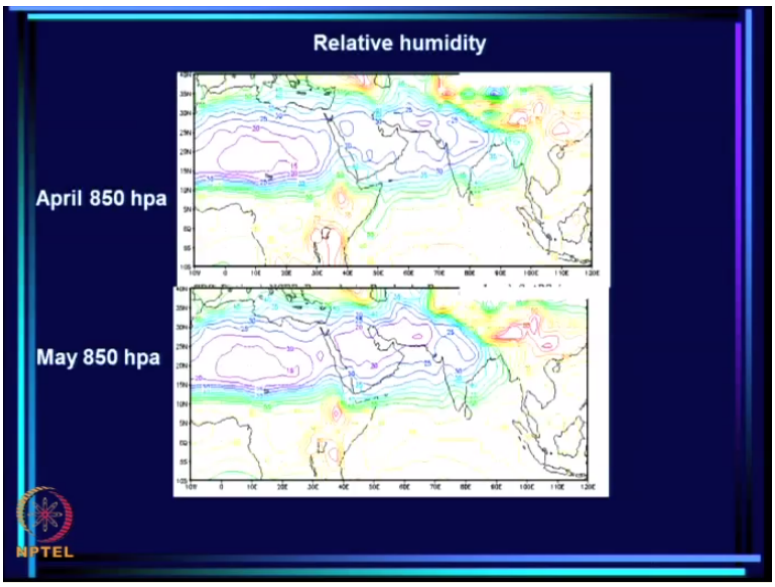

So actually this is the relative humidity and you can see that the relative humidity which was high only towards the equatorial region in April, this belt is somewhat has shifted in May. This is the relative humidity at 850 hpa and this is June, by June you can see that the humid belt has come over India and by July it is very much more humid over here except this heat low region where it continues to be dry of course.

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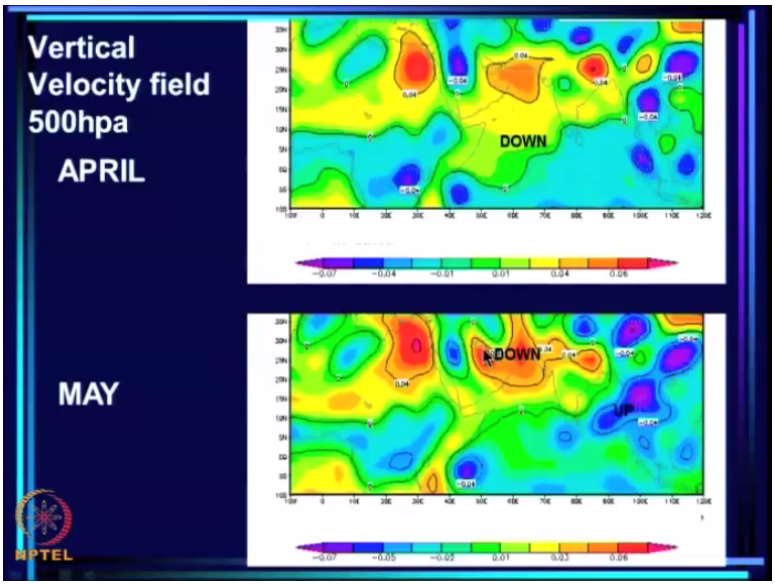

Now this is the vertical velocity field at 500 hpa let me remind you, 500 hpa is sort of the midway level of the troposphere and you know the deep convection associated with the tropical conversion zone, the TCZ in fact releases a large amount of heat at mid-tropospheric levels and in fact the deep, the TCZ is associated with ascent throughout the troposphere okay and a generation of large amount of heat and the vertical velocity associated with the TCZ is in fact maximum upward at 500 hpa.

That is why we look at 500 hpa level to see where the conversion zone is and what you see is that in April, now this is India here and in April this is primarily down. This whole region the air is going downwards. There is no ascent at all. The ascent is towards the equatorial regions here. And in May you can see the ascending region has moved a little bit to the North to touch part of the, just the tip of the peninsula and you see much more ascent over this region here, over Myanmar and Thailand and so on.

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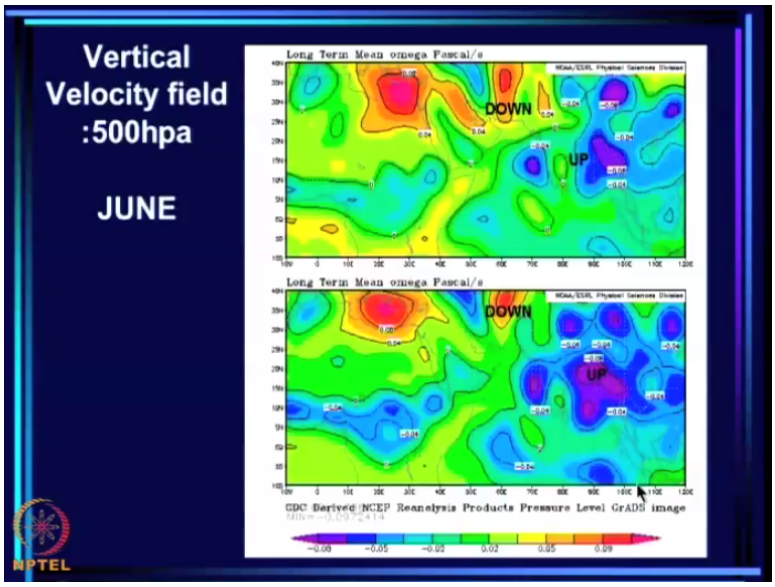

Now in June and the other hand, you will see vertical ascent, it has come almost up to 20 North here, it is much stronger over the Bay, then it is over the Indian region but you also see strong ascent on the Arabian sea of our west coast here and in fact this is moving even further. This is July and you will see it here large amount of ascent taking place over the Indian region.

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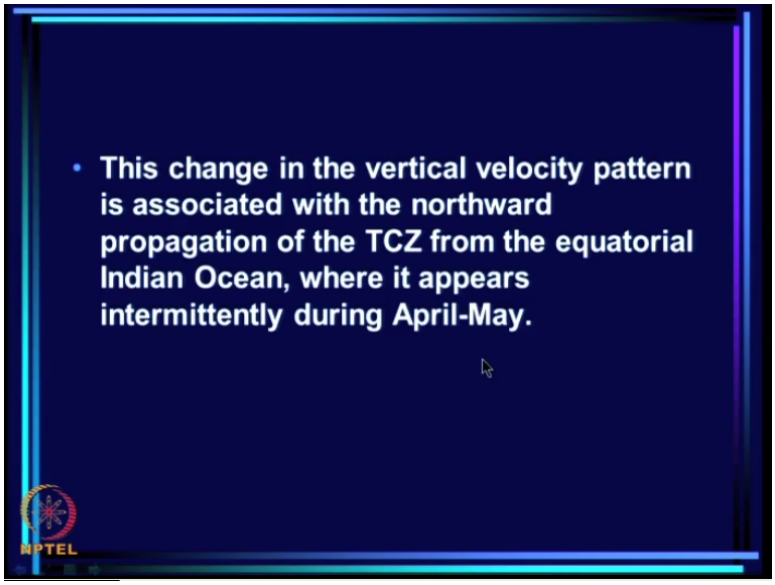

This change in the vertical velocity pattern is associated with Northward propagation of the TCZ from the equatorial Indian Ocean where it appears intermittently during April and May. So we have seen that the change in the vertical velocity pattern which we saw which vertical velocity was upward here in the equatorial region in April and May and has actually gone moved to northward here.

So the TCZ has moved northward in June and it has moved even further northward in July. And you have a huge flare up here over the Bay of Bengal. So the change in the vertical velocity pattern is associated with the northward propagation of the TCZ from the equatorial Indian Ocean.

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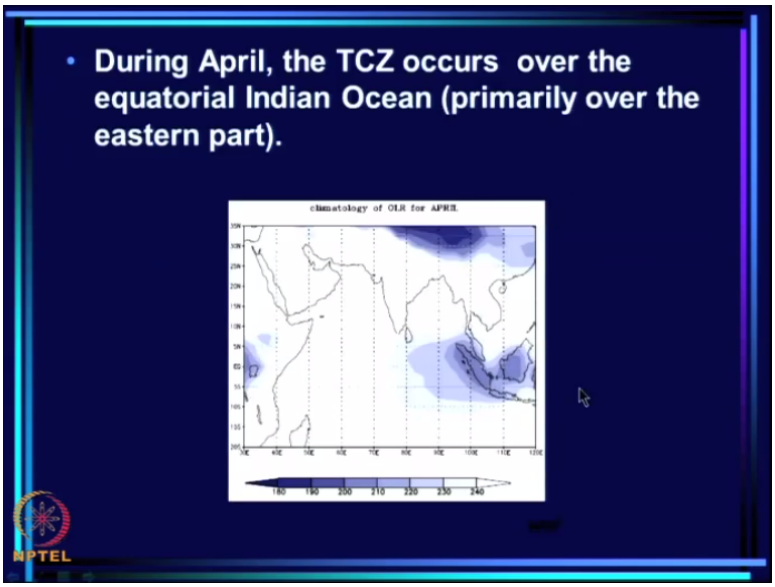

Now let us see what TCZ looks like from OLR, these are the mean OLR maps and mean climatology. So this is April you see TCZ is around here. It is over the equatorial Indian ocean but more on the east than on the west. Then during May, you see it has extended westward and moved northward. So the TCZ is around here in May.

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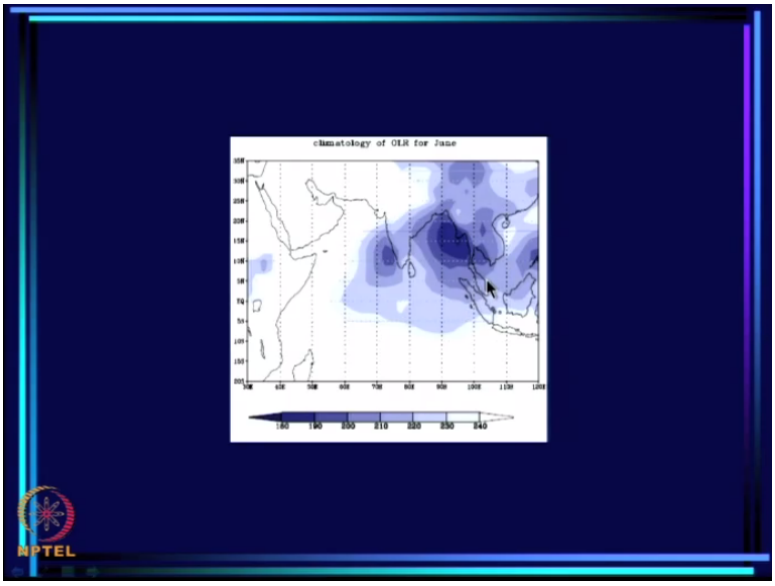

In June it has moved further up over here, in fact, the latter propagation over bay has actually culminated much more northward here but over the Arabian sea still it is slightly to the south of 20 north. So this is the situation in June as far as the OLR is concerned.

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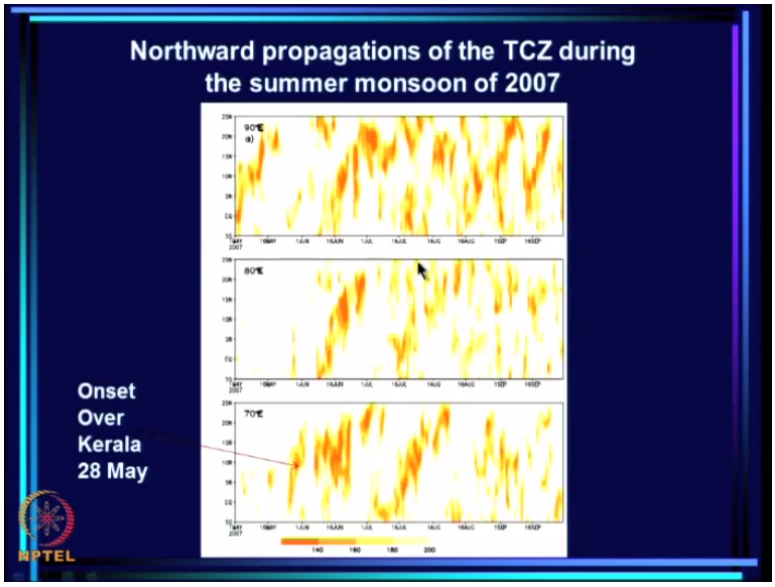

And what we just saw are propagations of this kind. So this is a typical picture of regions with very low OLR that is to say with deep clouds from 2007 and 70 degrees east is actually right here. This is 70-degree east. So 70 degrees east is of our west coast and what you see here, this northward movement is the onset over Kerala. This is the onset over Kerala and this Northward movement is the first northward movement of the onset.

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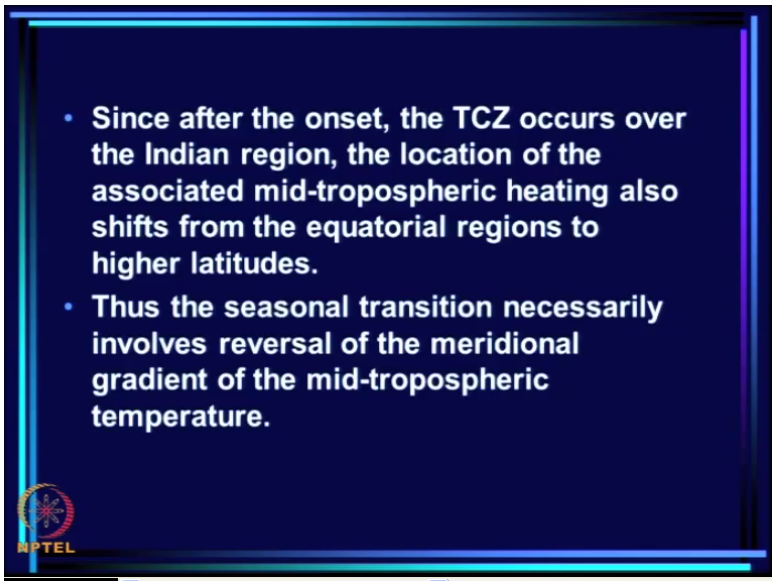

Okay, since after the onset, the TCZ occurs over the Indian region. The location of the associated mid-tropospheric heating also shifts from the equatorial regions to higher latitudes,

right? In April-May the TCZ is over the equatorial region or maximum mid-tropospheric heating will be over the equatorial region and so the mid-tropospheric temperature will decrease from equator to north.

Whereas after the TCZ is established over our longitudes, it is around 20 north or so, that is where the maximum tropospheric temperature would be. So the north south gradient will have been reversed with the warmest temperatures at 20 North and colder temperatures over the equator. So, seasonal transition necessarily inwards the reversal of the meridional gradient of the mid-tropospheric temperature.

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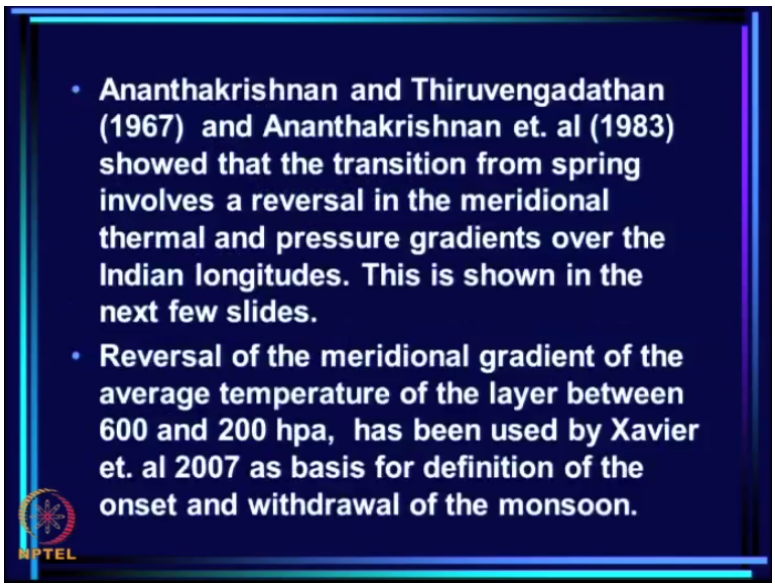

And a very nice study of seasonal transition of various parameters has been done by Ananthakrishnan and his co-workers right from 60s up to 80s. And in 2 of these important papers they showed that the transition from spring involves a reversal in the meridional thermal and pressure gradients over the internal longitude.

And this is shown in the next few slides. I would just like to mention here that we will see later on that in a paper by (()) (17:31) they have proposed that the reversal of meridional gradient of the average temperature of the layer between 6,200 hpa should be criteria for defining the onset and withdrawal of the monsoon. And the seeds of that idea really go back to Ananthakrishnan's work here which we will see.

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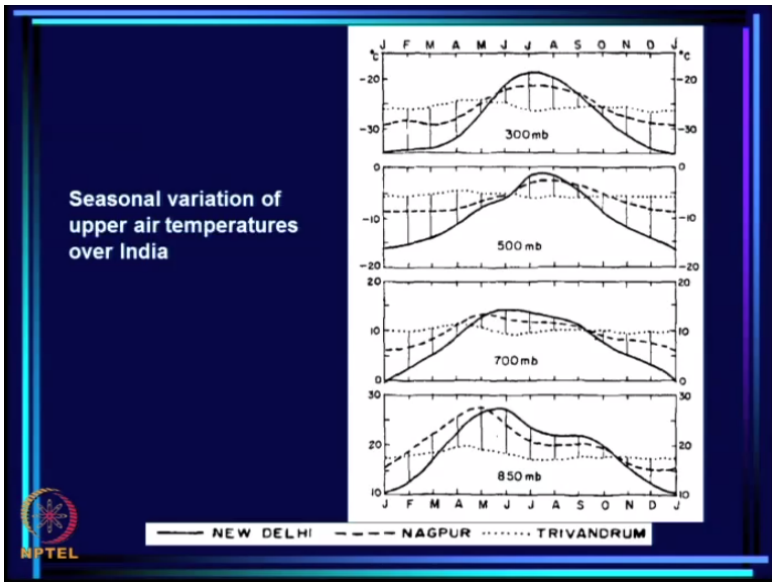

Now in those days you have to remember that there was no (()) (17:56) reanalysis data which could immediately give you the structure over the entire tropics, entire globe and so on and so forth when relied on station data. So what Ananthakrishnan has done is showing the patterns by looking at stations from north to south across the central Indian longitude.

So what you have here is New Delhi is solid line black, then Nagpur, which is to the south of New Delhi, is dash line and dotted line is Trivandrum in the south. So what you see here is in winter, in winter very clearly or even in March you can see that Nagpur is higher here, then is Delhi and when you have come to the summer here, then you see Delhi, Nagpur, and Trivandrum here.

So we get a reversal of the gradient, seasonal reversal of the gradient and that is seen everywhere see, particularly if you go to higher levels, at mid-tropospheric level then you see it very, very clearly. This is Trivandrum, this is Nagpur, and this is Delhi. So here the temperature, the mid-tropospheric level is decreasing as you go the north, but here during the summer the temperature is increasing as you go to the north. This is the seasonal reversal that characterizes the region.

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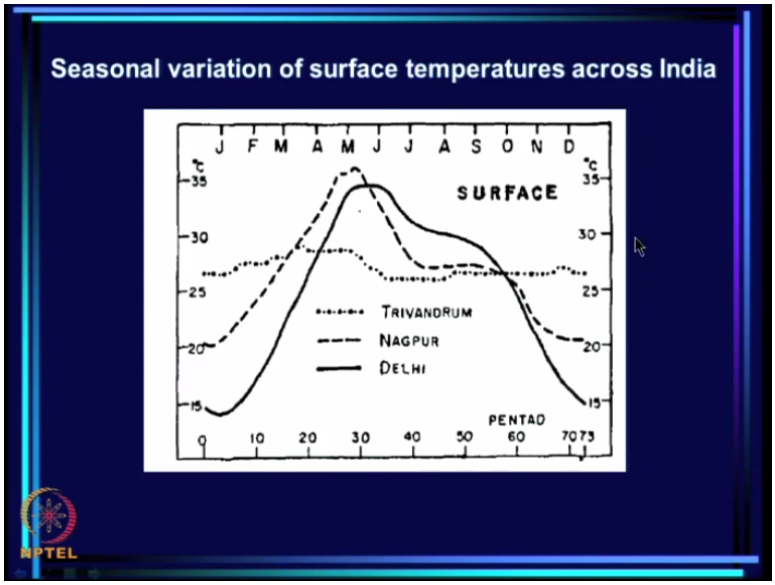

And similarly there is a seasonal variation of surface temperatures across India also, you see here that in winter the coldest is Delhi, then Nagpur, then Trivandrum. But in summer, you may have coldest sorry warmest is Delhi than Nagpur then Trivandrum.

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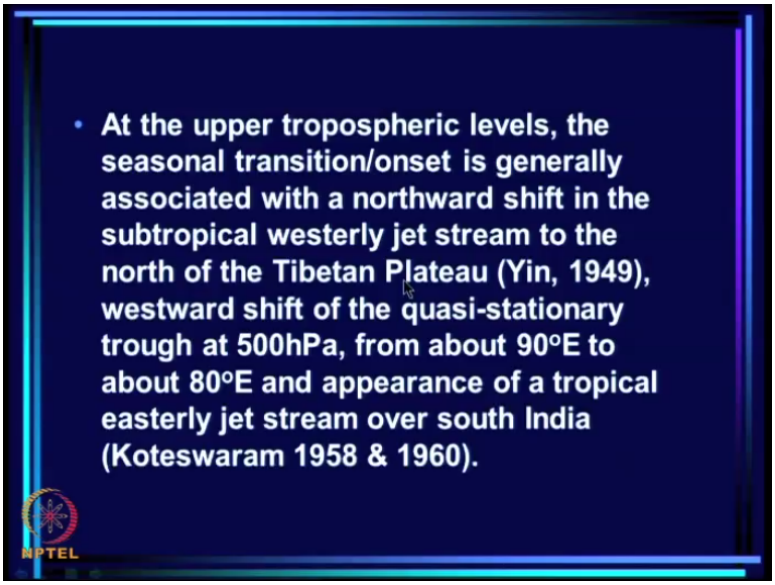

Okay, now at the upper tropospheric levels, the seasonal transition or onset is generally associated with a northward shift in the subtropical westerly jet stream to the north of the Tibetan plateau. Now this is a very important feature because the whole winter, in our winter the mid-latitude circulation with characteristic westerlies, but where is the northern Indian region.

But this shifts to the north of the Tibetan plateau with the onset of the monsoon, this is a very characteristic feature and what you see here is.

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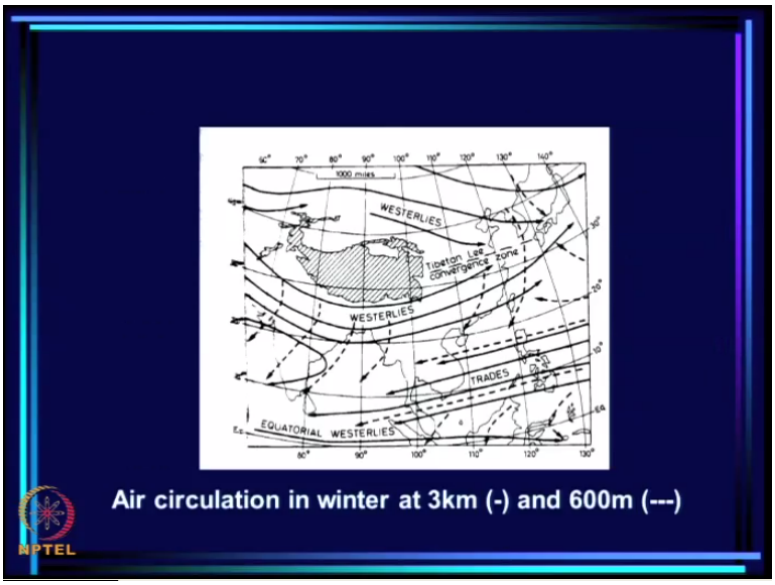

This is a winter situation where you have westerlies all over here. See, westerlies to the north of Tibetan plateau, westerlies to the south also. So well Delhi, Nagpur and so on you will get strong westerlies in winter.

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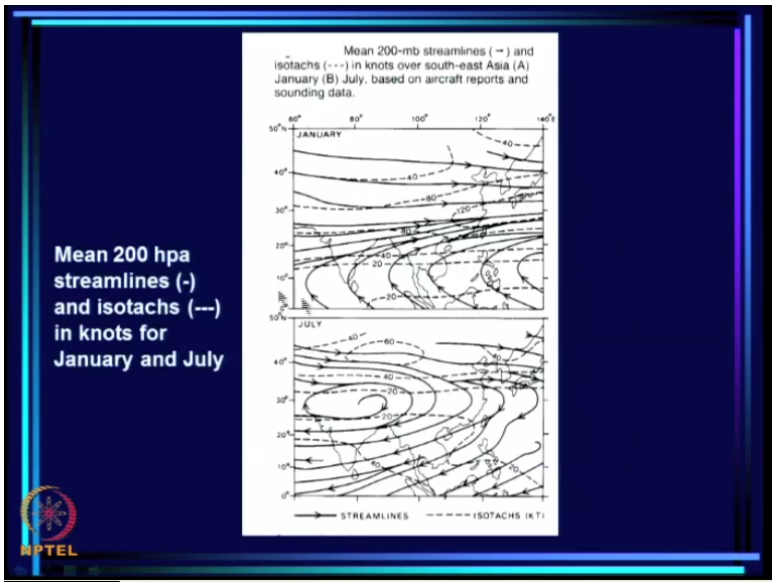

But in summer the pattern changes totally. The westerlies have been pushed to the north of the Tibetan plateau and you get easterlies here. So this is a major transition also.

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Now the seasonal variation of contour heights and winds at standard levels across level is shown in the next slide.

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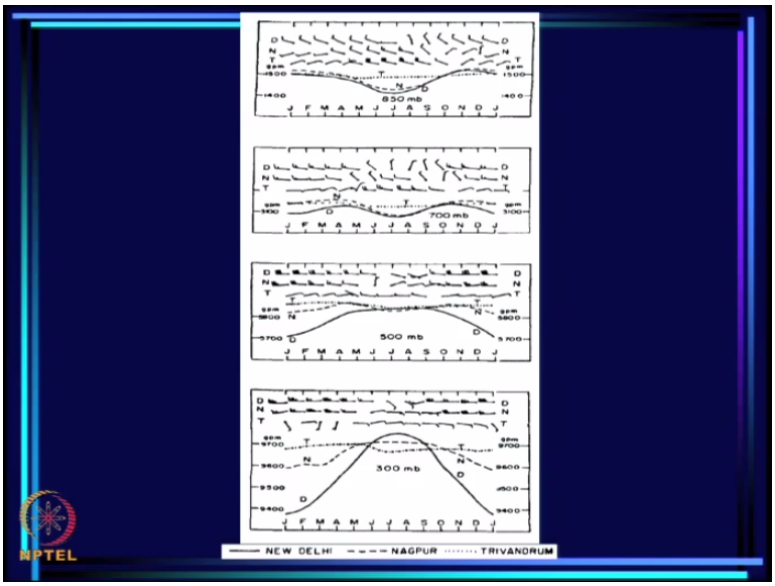

Again this is from Ananthakrishnan's work and what you see is pretty much what you saw earlier that initially you get westerlies here at say for example 300 millibar. In January, February, March it is westerlies and then it changes to easterlies.

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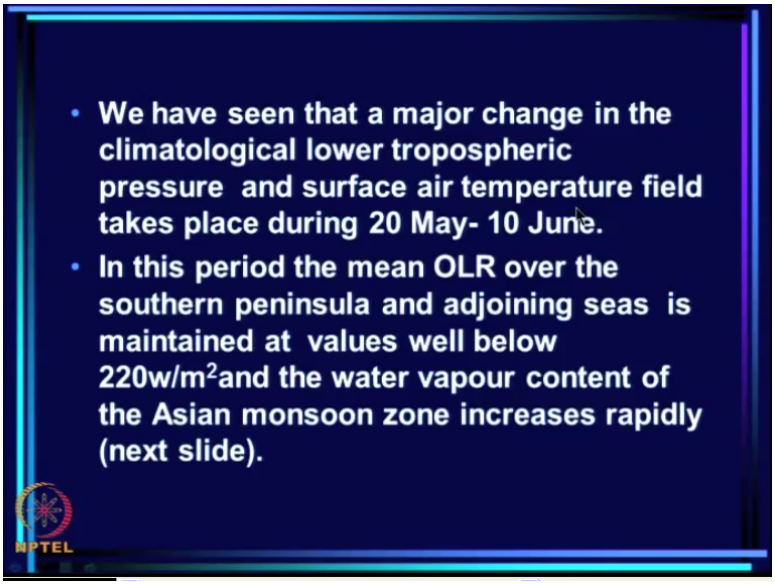

Now we have seen that a major change in the climatological low tropospheric pressure and surface air temperature field takes place during 20th May to 10th June. In this period what happens to mean OLR over the southern peninsula and adjoining seas is what we will see here.

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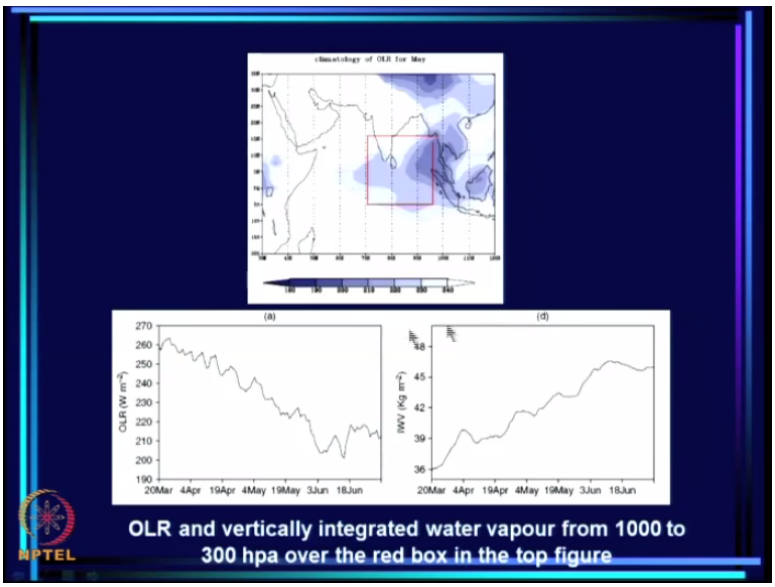

See, over this box if we look at the mean OLR, how does the OLR change? you can see that the OLR steadily decreases, as we come towards the beginning of June and the water vapor, integrated water vapor steadily increases as we come towards the beginning of June. So conditions are becoming more and more favorable for the TCZ to appear there.

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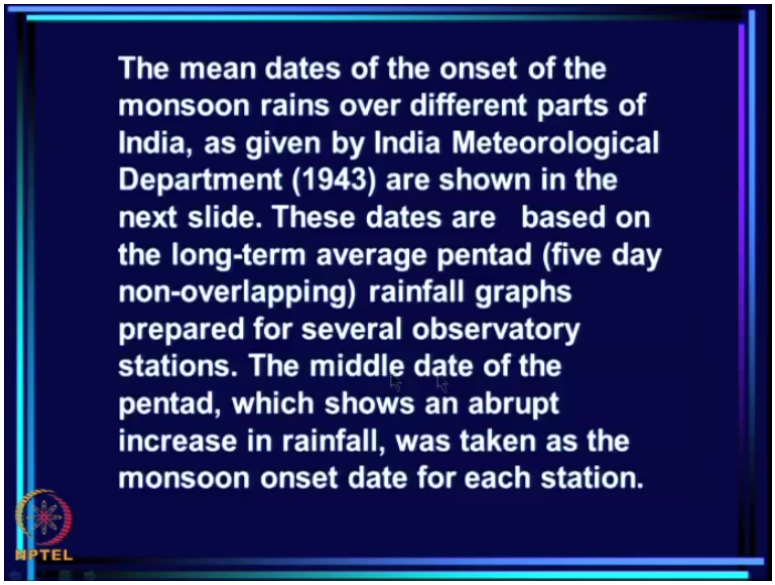

The mean dates of onset for the monsoon rains over different parts of India has given the Indian meteorological department as shown in the next slide

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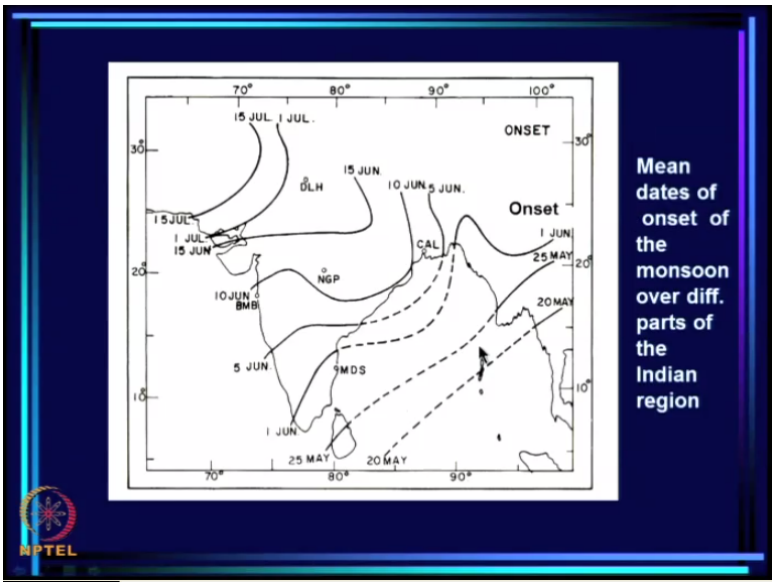

We have encountered these before. These are the mean dates of onset. Now hare are these days calculated. These dates are based on long-term average Pentad, 5 day non overlapping rainfall grasp prepared for several observatory stations. The middle date of the pentad which shows an abrupt increase in rainfall is taken in the onset and that is how these contours were drawn.

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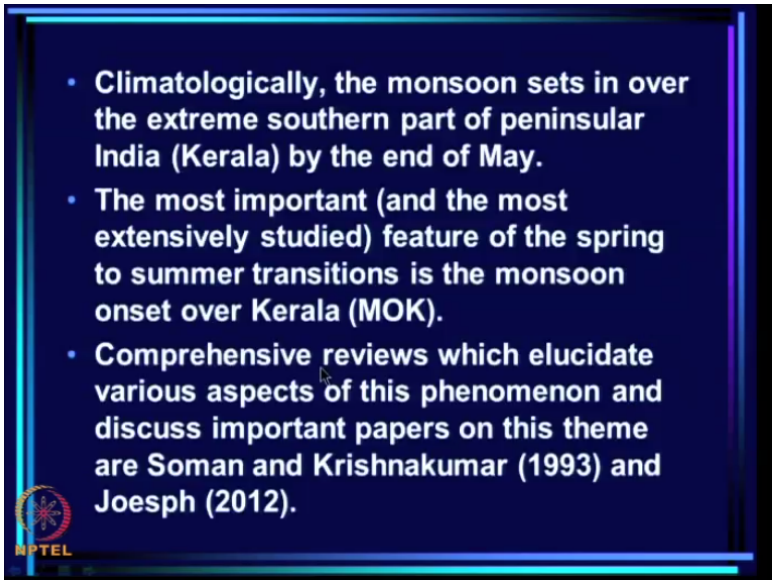

Climatologically, we have seen that the monsoon sets in over the extreme southern part of the peninsula. See this s the first or if you look at the long region of India, this is the place where the monsoon first sets in, around 1st June, climatologically speaking. The most important and the most extensive studied feature of the spring to summer transition is the monsoon onset over Kerala.

Comprehensive reviews which elucidate various aspects of this phenomenon and discuss the important papers on this theme are Soman and Krishnakumar and Joseph. All these references are given at the end of the second part of my lecture on seasonal transitions, which is the next lecture.

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So now let us look at monsoon onset over Kerala. In any specific year, the onset of the summer monsoon over Kerala which is at the southern tip of the peninsula occurring generally in late May or early June marks the beginning of the onset phase of the rainy season for the country. Now the spring to summer transition from a heat trough to a moist converting regime characterizing a TCZ is completed by the end of the onset phase.

So the onset phase begins with the monsoon onset over Kerala and ends with the establishment of the CTCZ over the monsoon zone.

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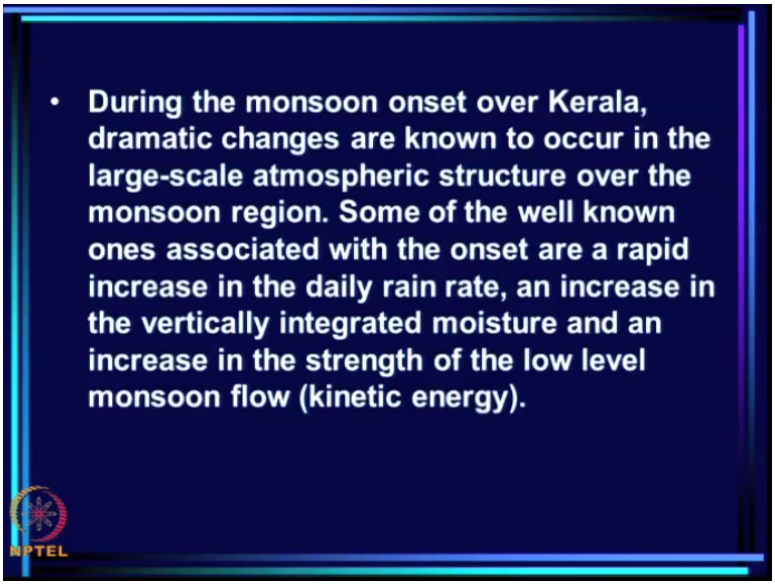

Now during the monsoon onset over Kerala dramatic changes are known to occur in the large-scale atmospheric structure over the monsoon region. And what are these dramatic changes? Some of the well known ones associated with the onset are a rapid increase in the daily rain rate and increase in the vertically integrated moisture and an increase in the strength of the low level monsoon flow.

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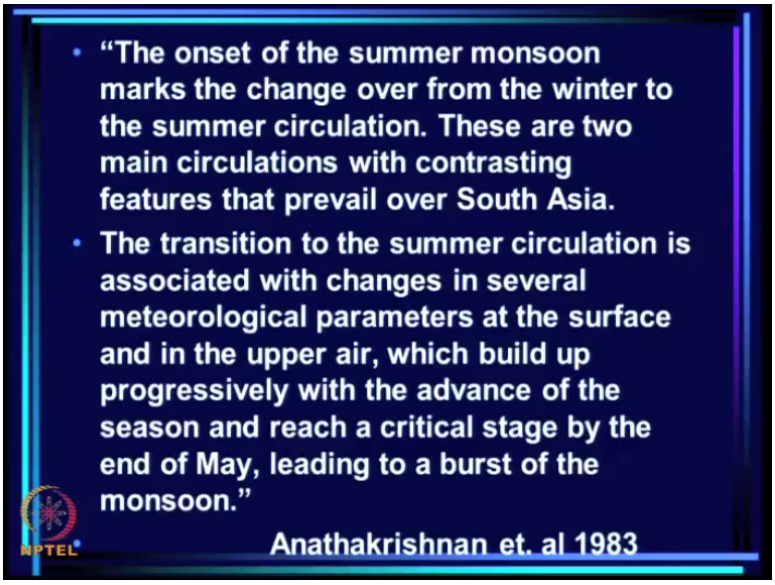

Now as Ananthakrishnan puts it, the onset of the summer monsoon marks the changeover from the winter to the summer circulation. These are 2 main circulations with contrasting features that prevail over south Asia. The transition to the summer circulation is associated with changes in several meteorological parameters at the surface and in the upper air which build up progressively with the advance of the season and reach a critical stage by end of May leading to a burst of the monsoon.

This onset over Kerala has been described as the burst of the monsoon for 100 years.

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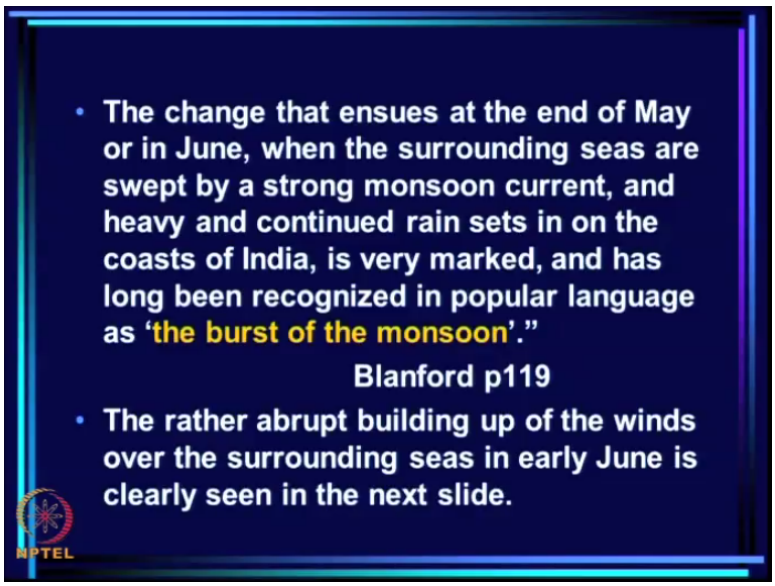

As you will see, Blanford has describes the onset in the following. He says the change that ensures at the end of May or in June, when the surrounding seas are swept by a strong monsoon current and heavy and continued rain sets in on the coast of India is very marked

and has been long been recognized in popular language as the burst of the monsoon. Now the rather building up of the winds of the surrounding regions early June, is clearly seen in the next slide.

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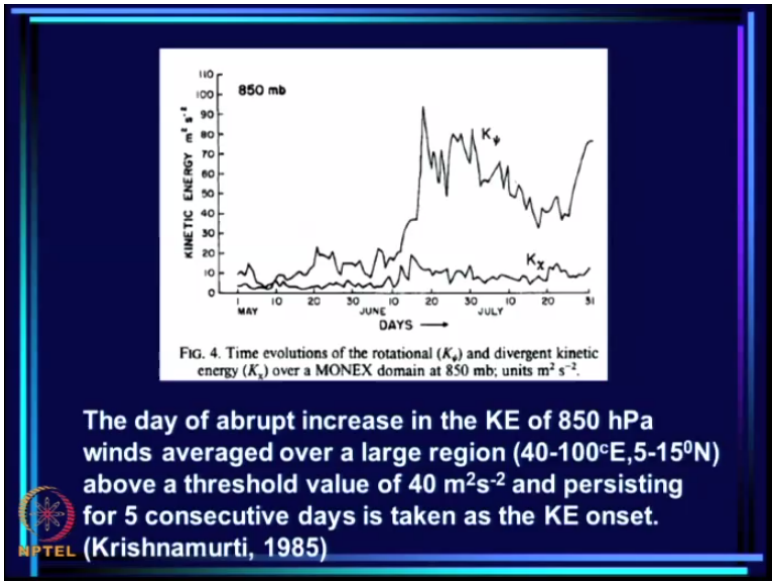

This is from Krishnamurti's work, this is for the MONEX year of 1979 and this is the average kinetic wind average over a large region, from 40 to 100 degrees east and from 5 to 15 degrees north and this is the kinetic energy here. And you can see if that, it is rather low and it suddenly builds up here. This is the strong westerly sweeping the Arabian Sea that Blanford talks about.

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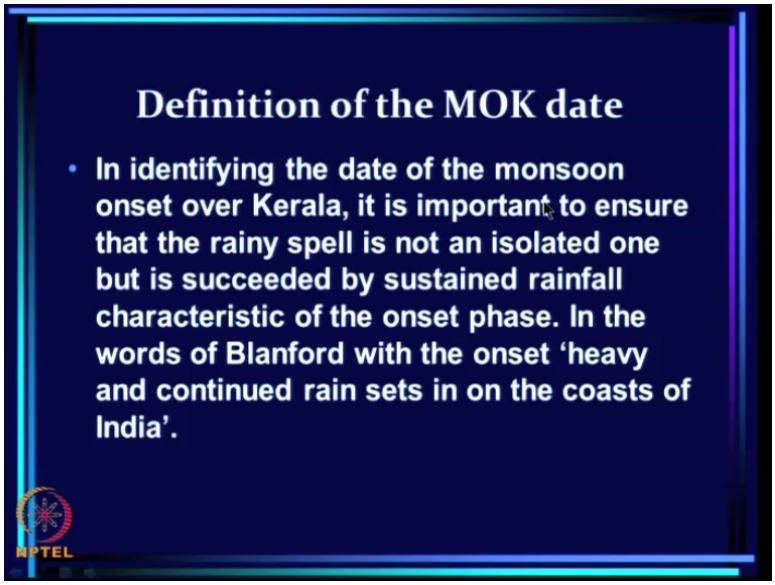

Now how does one define the date of monsoon onset over Kerala. In identifying the date of the monsoon onset over Kerala, it is important to ensure that the rainy spell is not an isolated

one and but it succeeded by sustained rainfall characteristic of the onset phase. See it should not be just a rainy spell after which there is no rain for several days.

In fact, it has to be succeeded by sustained rainfall characteristic of the onset phase or in the words of Blanford with the onset heavy and continued rain sets in on the coast of India. This is what Blanford describes it as.

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Now IMD has determined the date of MOK, monsoon onset over Kerala operationally every year for more than 100 years primarily on the basis of rainfall over Kerala. So they had criteria that is after 10th May, any 5 of these several stations receive rainfall 1 millimeter in 24 hours for 2 consecutive days, the onset of the monsoon over Kerala is declared.

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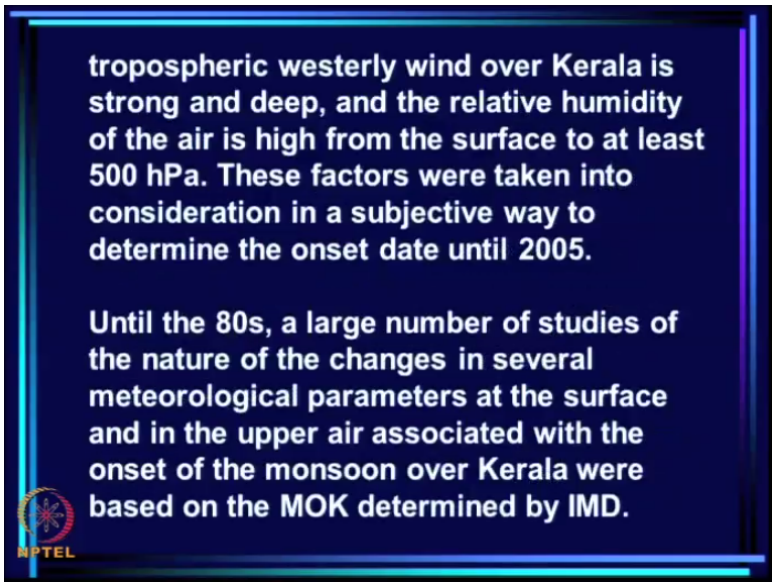

On the second day provided that the lower tropospheric westerly wind over Kerala is strong and deep and the relative humidity of the air is high from the surface to at least 500 hpa. These factors were taken into consideration in a subjective way to determine the onset date until 2005. So they had some criteria for rain and in addition subjectively they assessed whether the wind was strong enough and deep enough and the relative humidity high enough.

And until the 80s a large number of studies of the nature of changes in several meteorological parameters at the surface and upper associated with the onset of the monsoon over Kerala were based on the MOK determined by IMD.

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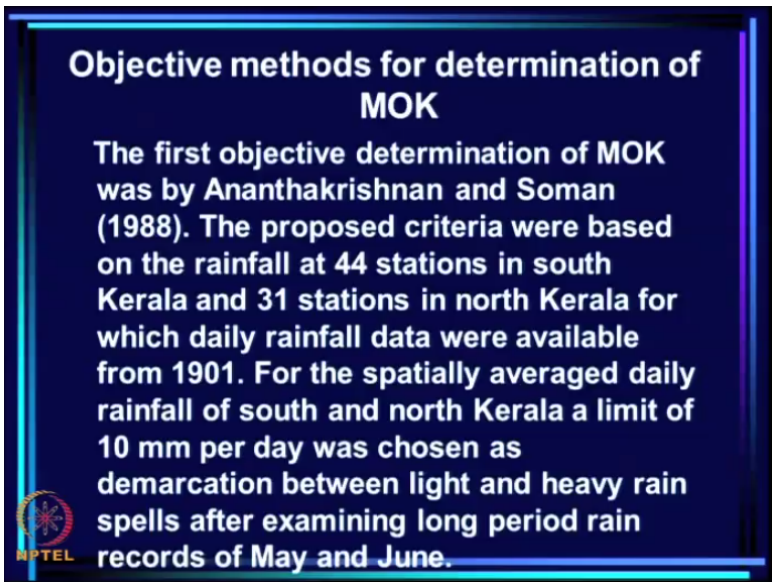

Now clearly for an event as important as the monsoon onset over Kerala it is necessary to have objective methods for determination of MOK and in fact the first objective determination of MOK was by Ananthakrishnan and Soman. What they did was there was 100 years of data daily of daily rainfall for many, many stations over Kerala available which they analyzed.

And the proposed criteria were based on the rainfall at 44 stations in South Kerala and 31 stations in North Kerala for which daily rainfall data were available from 1901. For the spatially average daily rainfall of south and north Kerala a limit of 1 cm per day were chosen as the demarcation between light and heavy rain. See one has to distinguish between light rain spells and heavy rain spells.

It is important to do so and Ananthakrishnan had looked at so much rainfall data that he could actually set a limit for what should be the limit for determining the heavy rainfall events by looking at records of May and June.

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And this is how this limit of 1 cm were set. The distinction in the nature of the 2 types of rain spells is important. Heavy rain spells imply deep convection in association with synoptic systems to the ITCZ; light spells are mostly associated with isolated pre-monsoon thunderstorm activity and not associated with weather systems. So to distinguish between the 2 they adopted criteria about rain, average rain over south and north Kerala.

The date of monsoon onset is taken as the first day of transition from light to heavy rain spell category with the proviso that the average daily rainfall during the first 5 days after transition should not be <1 cm. so it should continue to rain. Remember that most of the objective methods of MOK are retrospective post-factor assessment of the rainfall day and the first one Anathankrishnan and Soman is also retrospective.

Because you have to wait for 5 days after what you believe onset has occurred to see if the rainfall continues or not.

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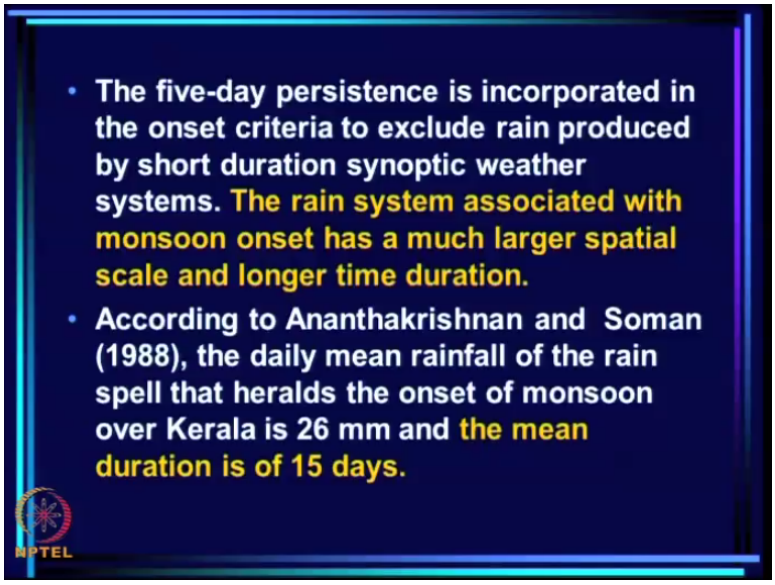

The 5-day persistence is incorporated in the onset criteria to exclude rain produced by short term duration synoptic weather systems. Now Ananthakrishnan and Soman have looked at their onset patterns and they say that the rain system associated with monsoon onset has a much larger spatial scale and longer time duration. Specifically, they say that the daily mean rainfall of the rain spells the heralds the onset of the monsoon over Kerala is 26 mm so it is well above the threshold of 1 cm and the mean duration is of 15 days.

Now if the mean duration is 15 days the system you are looking at is certainly not localized over Kerala. It is certainly a large-scale system which you are considering.

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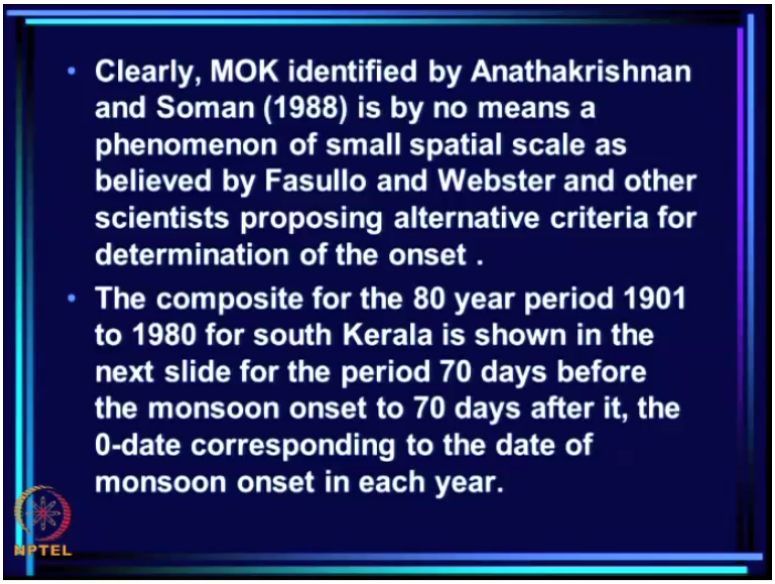

So clearly the MOK identified by Ananthakrishnan and Soman is by no means a phenomenon of small spatial scales as believed by several scientists who write about it later on including

Fasullo and Webster whose work I will discuss later proposing alternative criteria for determination of onset.

So, it should be born in mind that Ananthakrishnan and Soman criteria is in fact criteria for a large-scale onset over the region and it is not restricted to Kerala. The composite for the 80-year period 1901 to 180 for south Kerala is shown here.

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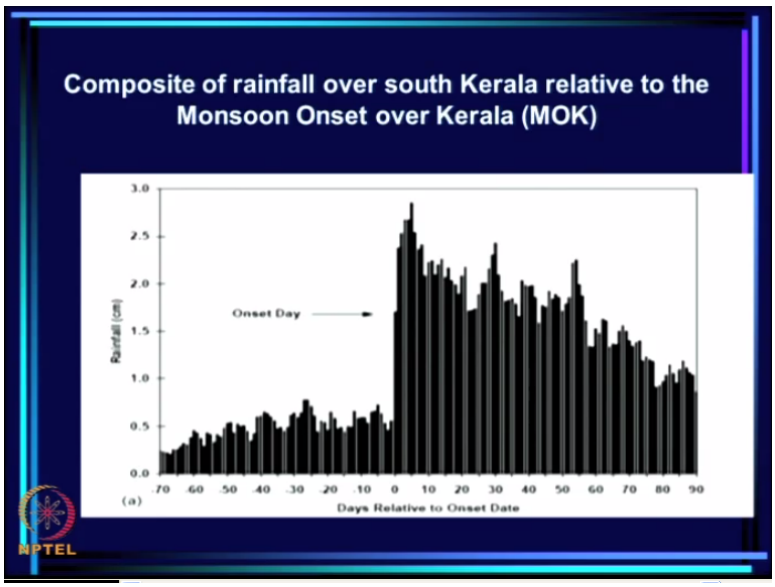

From 70 days before the onset to 70 days after the onset and this encouraging the rainfall at the composite on the onset date is spectacular and notice that once the rainfall has increased it is sustained over high level. You see it does not revert to the low level that was prevalent before the onset. These are important things to note.

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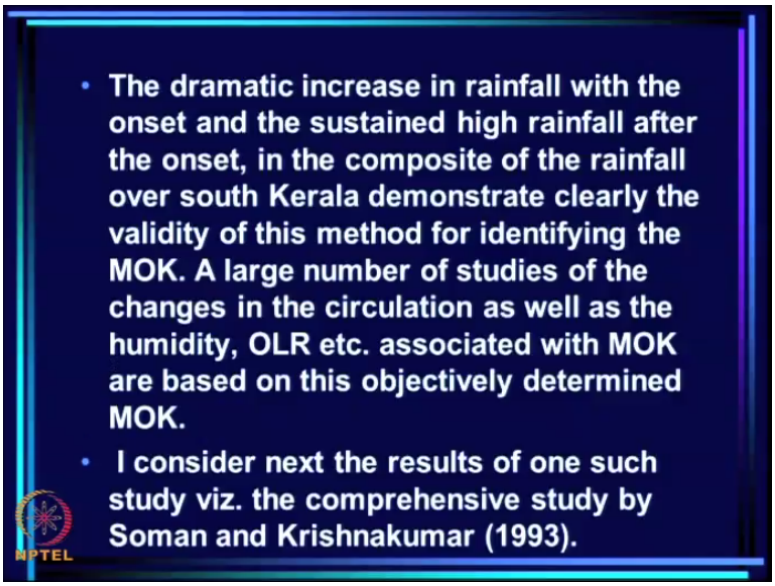

So the dramatic increase in rainfall with the onset and the sustained high rainfall after the onset in the composite of the rainfall over the south Kerala demonstrates clearly the validity of this method for identifying MOK because it satisfies. Remember this is a composite over many, many years. So it is important that all this such a sharp thigh dramatic increase has come in the average of so many years.

So a large number of studies of the changes in the circulation as well as the humidity OLR etc associated with MOK are based on this objectively determined MOK. So, next I will consider the results of another of one such study a very comprehensive study by Soman and Krishnakumar in 1993.

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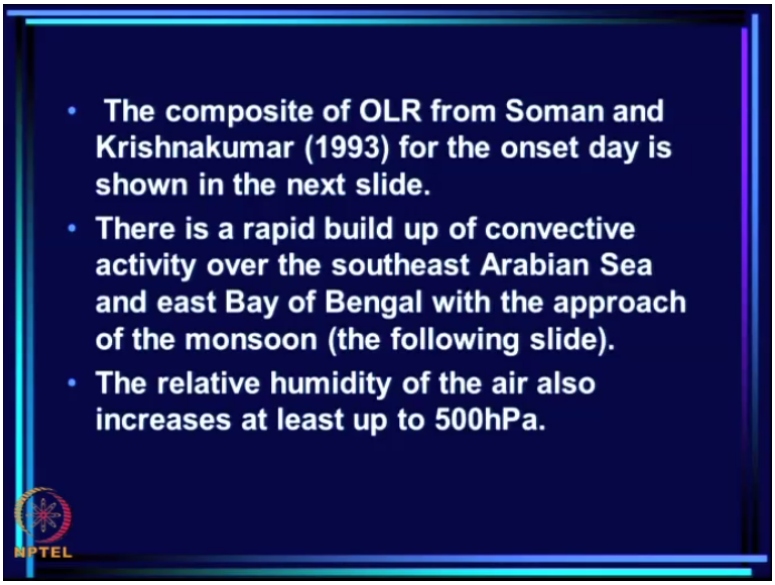

See what they did is use Ananthakrishnan and Soman's onset dates and relative to that make composites of many, many fields that for which data was available. So first thing we see is.

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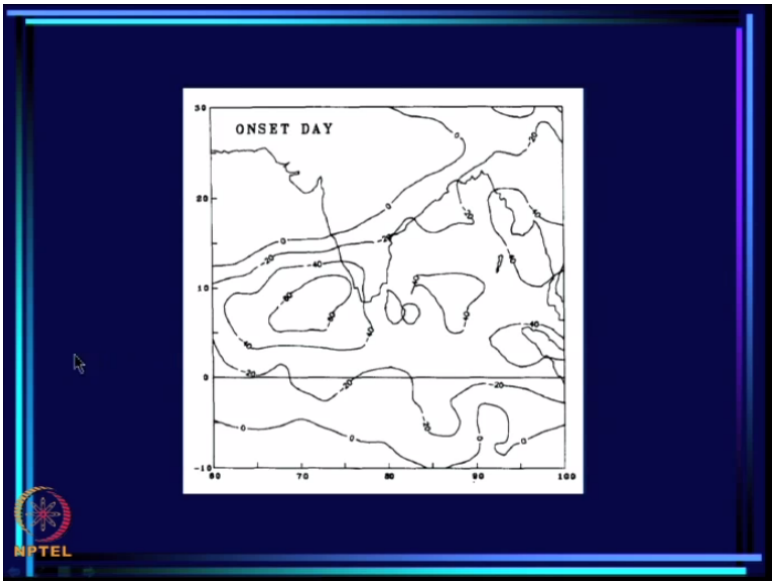

The OLR and what you see in the OLR is actually you see a low OLR region is just off the coast of Kerala here and you see another low OLR here so this is the large-scale system that is contributing to this. okay. There is a rapid buildup of convective activity over southeast Arabian sea and east Bay of Bengal with the approach of the monsoon. The relative humidity of the air also increases at least up to 500 hpa.

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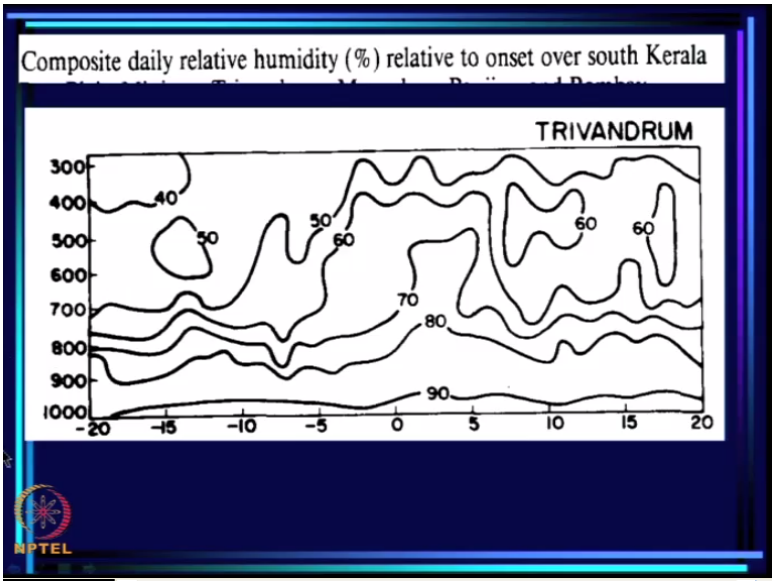

And this is the very interesting time series plot for Trivandrum. Again 0 is the onset date. So what they have done is to composite all the years for which data are available relative to the onset and what you see here is that initially this is 20 days before the onset you see that the high relative humidity is restricted to the lower part of the atmosphere and you see about 10 days before the onset it is already built up quite a bit.

And by onset, you get 50% relative humidity occurs even at 300 millibar. So you see a huge increase in the relative humidity about the week before the onset here.

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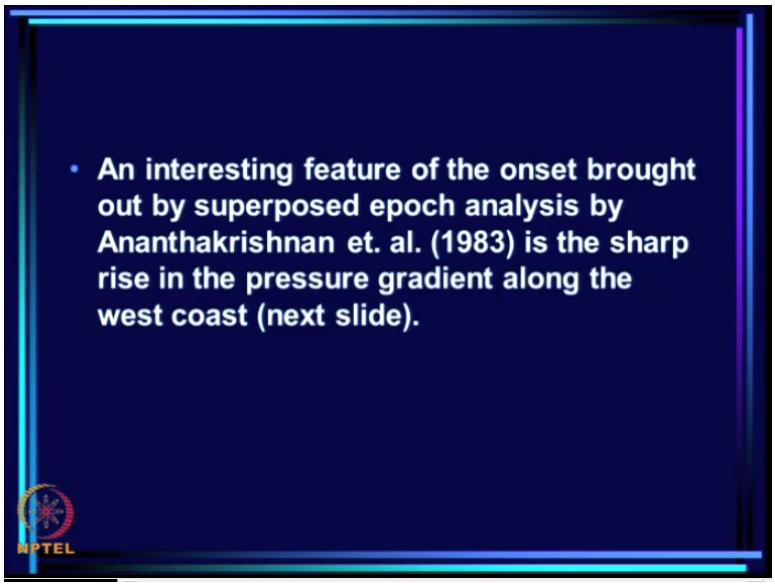

An interesting feature of the onset brought out by superposed epoch analysis by Ananthakrishnan et.al.

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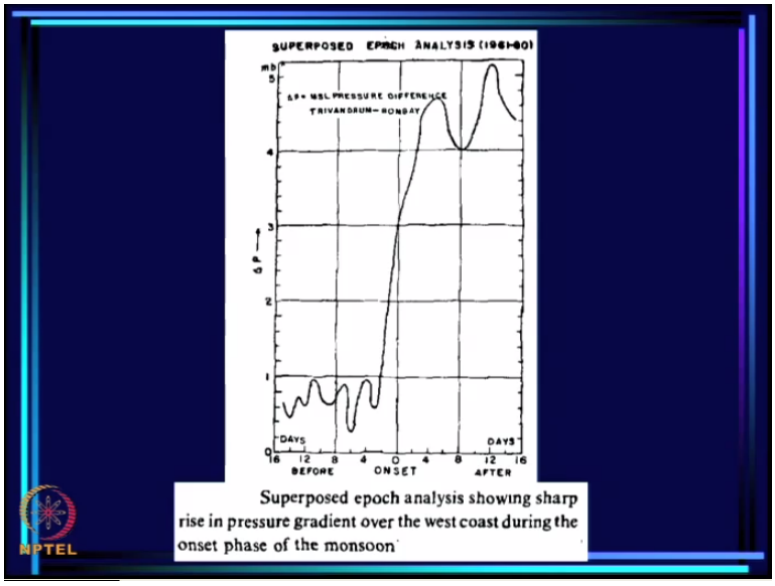

This very sharp increase in the west coast pressure gradient okay. So, this is the pressure gradient along the west coast and what you see is that before the onset this before the onset the pressure gradient is very low. This is onset date and you see just across the onset date you get an enormous increase of the pressure gradient along the west coast, huge increase.

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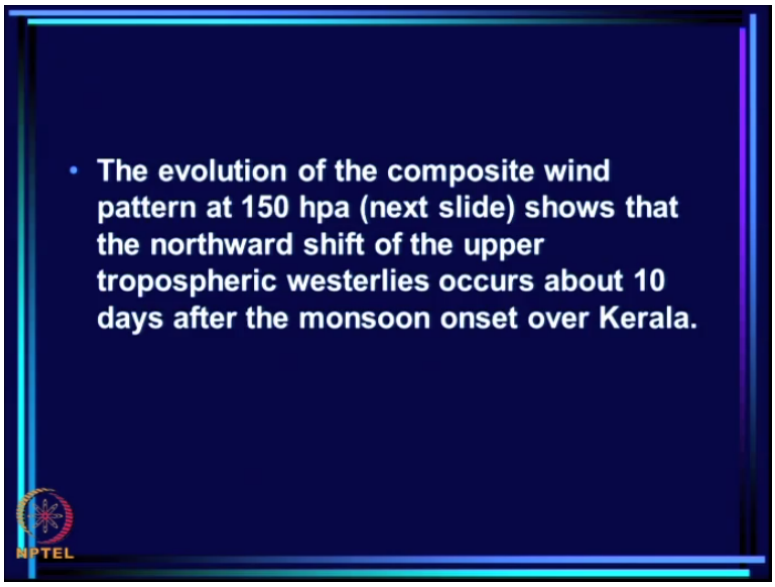

The evolution of the composite wind pattern at 150 hpa that is the upper troposphere shows that the northward shift of the upper tropospheric westerlies occurs about 10 days after the monsoon onset over Kerala.

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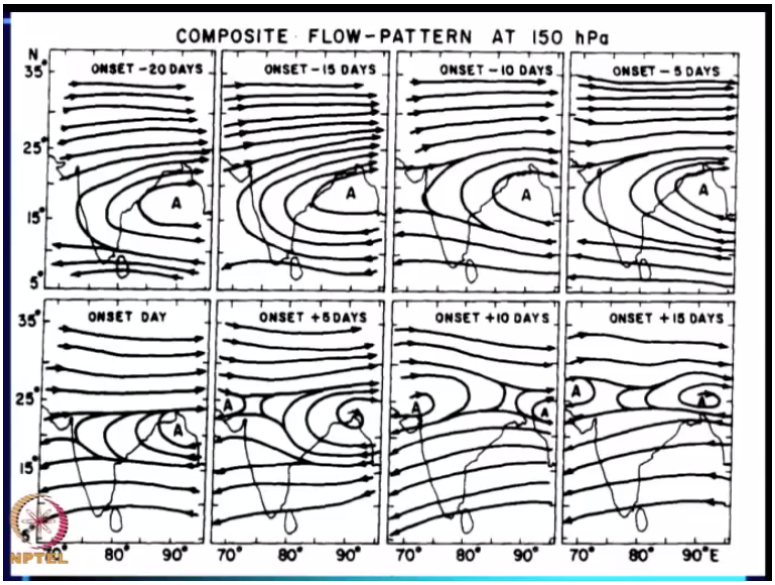

See remember this is the kind of picture we were seeing before with the Tibet and plateau and so on. Tibet and plateau is somewhere around there and what you see is 20 days before the onset you still have westerlies over India here see up to Nagpur. 15 days' westerlies are still going strong, 10 days they have started to retreat now not too, they are not as strong and they are retreating 5 days they are retreating further.

Now already they have retreated further here on the onset date +5 days they have retreated much further and finally by onset +10 days they have retreated to the north of the Tibet and

plateau and you can see at the same time easterlies which were just over the tip of the peninsula 20 days before the onset the region over which westerilies occur is spreading northward slowly.

And finally on the day of the onset you see easterlies right up to about 20 about 15 north or so and that region is spreading till after 10 or 15 days after the 10 days after the onset it has extended way beyond 20 north as well.

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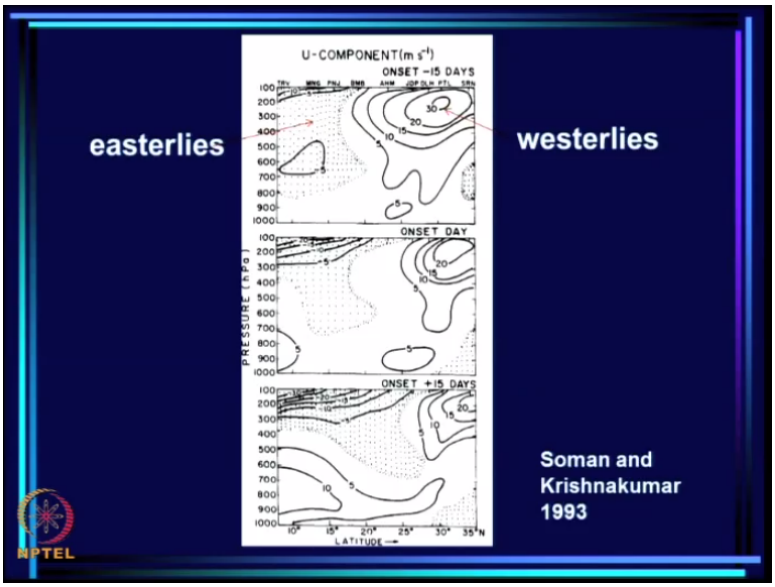

So these are the changes that occur on the smaller time scale. This is now the U component and you can see here these are the westerlies. This is 15 days. These are the westerlies here again this is Trivandrum, Mangalore, and stations like this going up to north. So easterlies which were prevailing only up to about just beyond Mangalore now have progressed to the north by onset day and have become very well established by onset by 15 days. This is the upper level changes.

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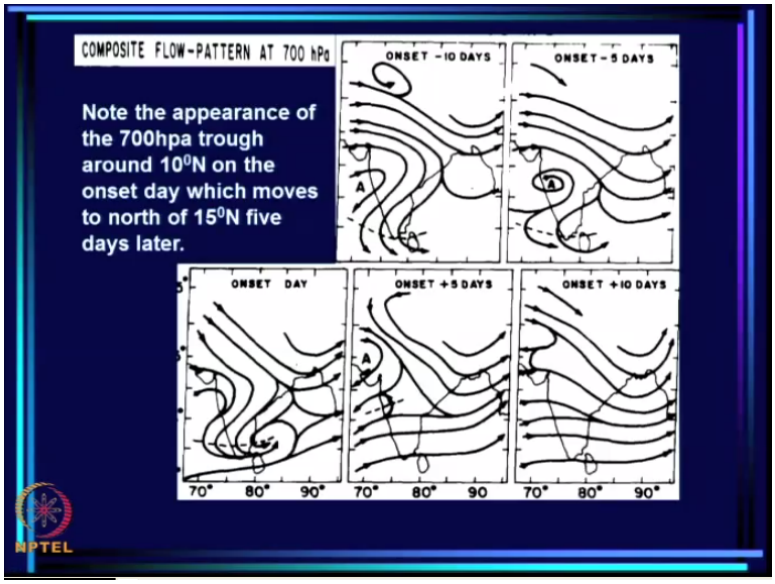

Now what happens to the 700 millibar trough 700 millibar onset -10 the trough is somewhere here. Remember 700 millibar trough is important because that delineates the TCZ or the dynamic trough and then this is the onset -5 days. This is onset day you see the onset day the trough is sitting right over Kerala here and onset +5 days it has already moved north to Mangalore or so and onset +10 days it has moved further north.

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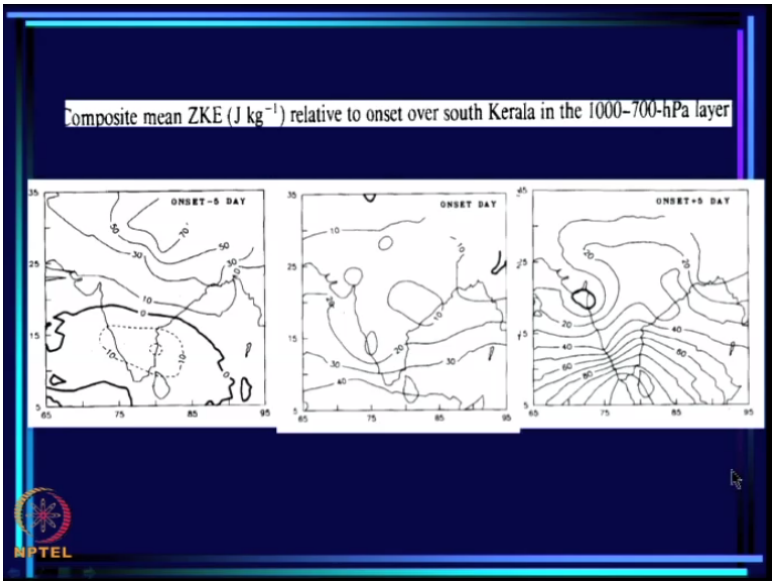

Composite, now kinetic energy that you saw earlier again you will see changes onset -5 days there is not much energy here. Now it has built up by onset day and onset +5 days you see a huge build up of the kinetic energy across the Arabian sea.

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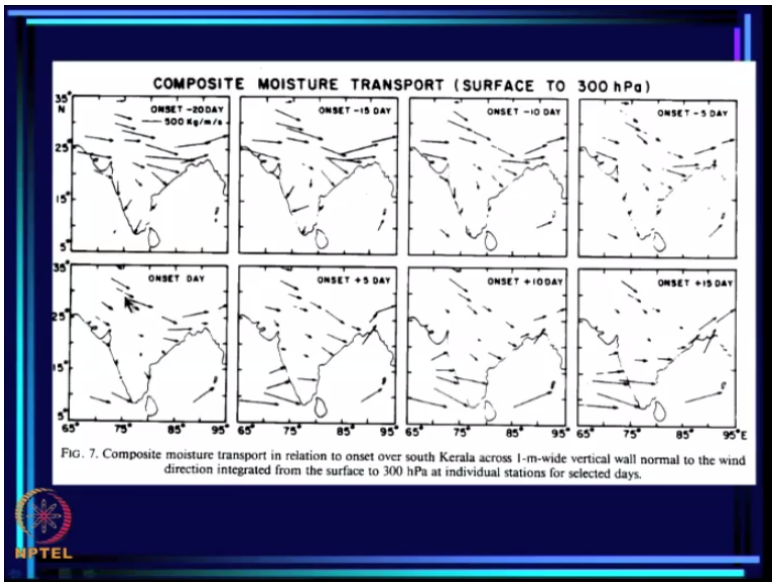

FIG. 7. Composite moisture transport in relation to onset over south Kerala across 1-m-wide vertical wall normal to the wind direction integrated from the surface to 300 hPa at individual stations for selected days.

And across India of the zonal wind. This is the composite moisture transport. See before the onset 20 days you are getting dry winds from the northwest most of the time and that continues still onset -5 days. On the onset days you see moist winds coming only to the tip of India now onset +5 days' moist transport is here up to about Bangalore, Mangalore and so on and onset +10 days.

It has gone right up to the west coast still dry winds from right prevail over the northern region and the onset +15 days this region has actually become.

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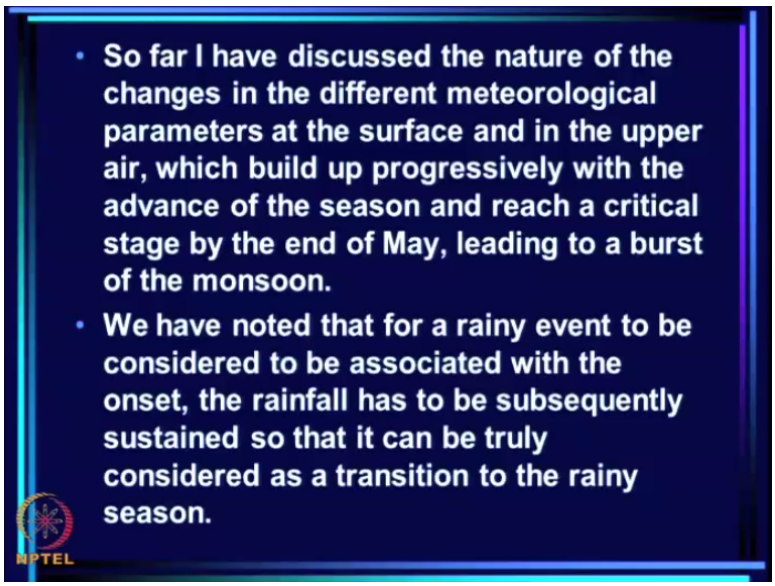

Much wider. So far, I have discussed the nature of the changes made in the different meteorological parameters at the surface and in the upper air, which build up progressively with the absence of the monsoon and reach a critical stage by the end of May leading to a

burst of the monsoon. We have noted that for a rainy event to be considered to be associated with the onset the rainfall has to be subsequently sustained so that it can be truly considered as a transition to the rainy season.

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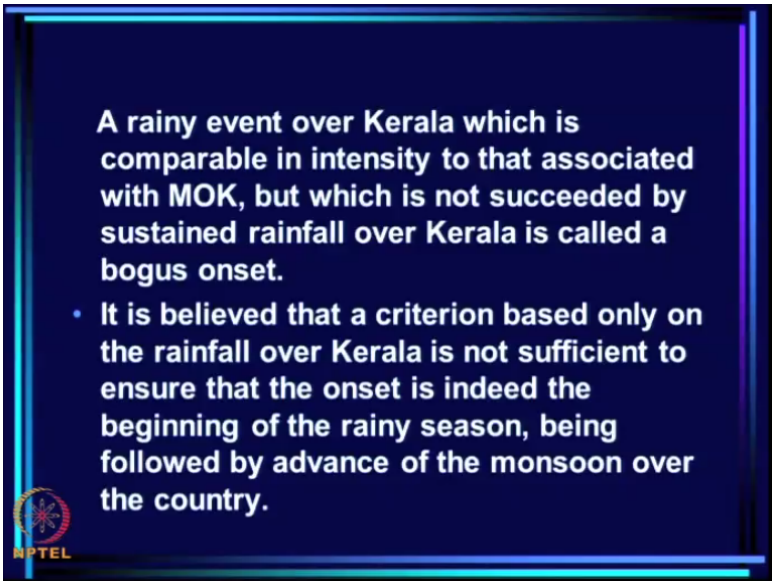

See a rainy event over Kerala which is comparable in intensity to that associated with MOK, but which is not succeeded by sustained rainfall over Kerala has been called as bogus onset.

Now, it is believed that a criterion based only on the rainfall over Kerala is not sufficient to ensure that the onset is indeed the beginning of the rainy season being followed by the advance of the monsoon over the country and I am talking about this as far as the operational definition of onset is concerned. Now let me at this point clarify that we are very much interested in studying the monsoon onset over Kerala as a research problem.

Because we want to know the nature of the seasonal transitions that take place and for that this event is a very key event. so there have been a lot of methods develop for detecting the monsoon onset over Kerala which are objective methods like Ananthakrishnan and Soman and I will talk of more such methods in the next lecture, but those are all methods to detect the monsoon onset over Kerala (()) (40:04) that is to said we could call it a retrospective assessment of monsoon onset.

However, I mentioned in the early part of this lecture that IMD has to declare every year that the monsoon onset over Kerala has occurred. So there is an operational requirement of

detection of monsoon onset over Kerala which is not a matter of retrospective assessment, but for which is the matter of assessment of the current conditions.

So far operational declaration of monsoon onset over Kerala we cannot use data obviously for days that occur after the thing and so it is necessary to have an objective definition of the assessment of monsoon over Kerala for using operationally for IMD to declare monsoon onset over Kerala. Now what has happened is the subjective way by which IMD declared monsoon onset over Kerala did not always work for example in 1972.

As we will see in detail in the next lecture IMD declared that monsoon onset had occurred in 16th May and what happened is in a few days in a couple of days the rain ceased over Kerala and actually a dry spell occurred, a heat wave occurred, and it was not the really onset at all because onset has to mean that the rainfall has to continue. Monsoon rains having set in means monsoon rains have to continue.

They cannot disappear for a week or 2 and still we cannot consider it then an onset. so this was a typical case of bogus onset in 72 and as I said I will mention bogus onsets in the next class, but it is therefore necessary to decide how to eliminate these bogus onsets when we are assessing MOK monsoon onset over Kerala for operational purposes that is to assess MOK o the basis of data of that current year.

That is a very important thing and to do so one requires in fact an objective algorithm which takes into account the major features of what is bogus onsets are and therefore can eliminate bogus onsets. So one should not IMD should not declare operationally that an onset has occurred when it is a bogus onset. It should declare it only when it is a real onset of the system.

So this before this could be done this was actually done only in 2006 but before this could be done there were a large number of studies of the bogus onset itself and also of possible objective methods of operational forecasting of MOK and they used of course the modern data that was available then from the 60s onwards and from 80s onwards because from 80 onwards we have satellite data which is also a very, very critical input.

We have seen that the onset involves northward propagation of cloud bands. Now data on such cloud bands is available only from 1979 so once more data on these became available also data on winds, more data on winds became available winds on the Arabian Sea and so on and so far as you saw the data that Ananthakrishnan and others analyzed were primarily from stations over India.

Now as more data became available it became possible to see what were the characteristics of bogus onset and therefore try and eliminate them in an operational definition of MOK in fact I will talk about all of that in my next lecture in which we will discuss what are the hints we can get from the developments evolution of the tropical atmosphere its circulation and convection patterns during from May onwards, what can we see about when the monsoon onset over Kerala is going to occur in a specific year in that year.

So I will talk about that as well as other objective definitions that people have proposed for the onset of monsoon over Kerala in the next class and then we talk finally at the end of the monsoon comes the peak monsoon months of July and August at the end of the onset phase of the monsoon in which the ITCZ oscillates primarily over the continental over the monsoon zone the CTCZ oscillates primarily over the monsoon zone.

At the end of that begins the retreats. So I will also talk about the retreat. So in the next class I will talk about the onset over Kerala, the different criteria performed by different authors, the advance from Kerala up to in the rest of the remaining phase of the onset of the monsoon and then retreat of the monsoon as well as try and see to what extent the (()) (45:25) monsoon rainfall whose variation we are interested in year to year variation is related to the timing of this onset and timing of the advance and so on and so forth, thank you