The Monsoon and Its Variability
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Lecture – 20
Active-Weak Spells and Breaks in the Monsoon - Part 1

Today, we are going to talk about a very, very important facet of the variation of the monsoon within the season. What we call the sub-seasonal or inter-seasonal variation of the monsoon, namely active and weak spells and breaks in the monsoon. The fluctuations between the active-spells and weak-spells or what are known as breaks in the monsoon. That is what we will talk about today.

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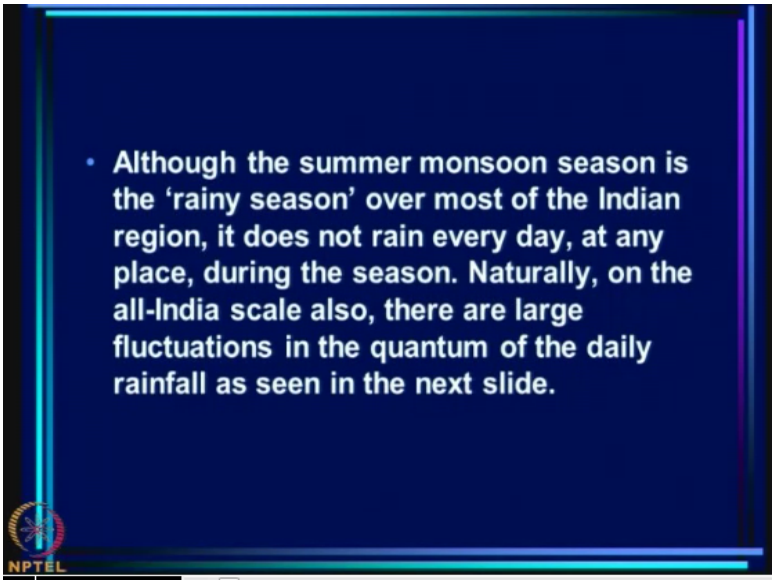

You know all though the summer monsoon season is the 'rainy season' over most of the Indian region we all know that it does not rain every day at any place during the season naturally on the all-India scale also there are fluctuations in the quantum of the daily rainfall as we see in the next slide.

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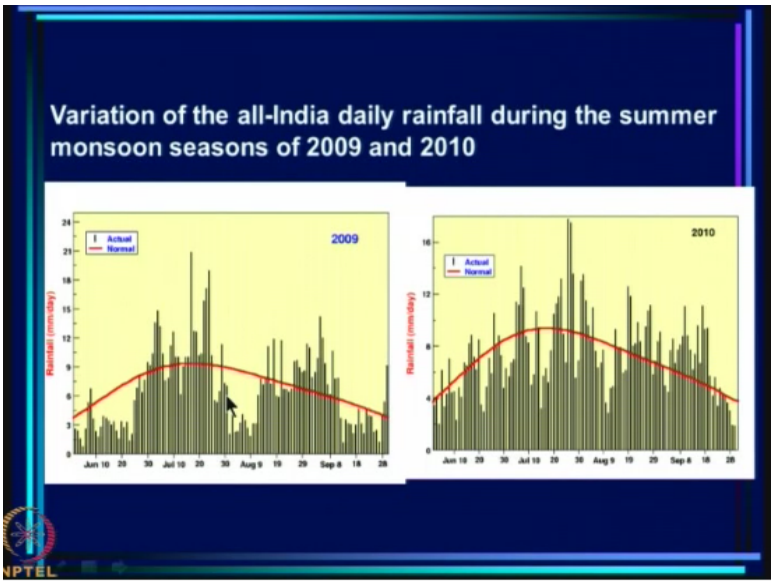

So, this is the all-India average rainfall that you see for 2 years. One is 2009 which turn-out to be drought and another is 2010. And these sticks represent the daily rainfall and this is the climatological average, average over all period. So, you can see that year-after-year there are fluctuations between what we call active spells where you see a spell which sustain high rainfall like this one or this one and so on.

And weak spells such as these and you see them all the time so even in a normal monsoon year like 2010 you see fluctuations between the active spells and the weak spells here. Now, in a drought sometimes these weak spells become very intense they can also become intense. They can also become intense without being there being a drought. So, these intense long weak spells have been called breaks.

Now you can see that in 2009 there was a weak spell here and even the onset was delayed to a large extent that is why this weak-spell occur. Even in the peak monsoon months there was a very intense weak-spell here. Such intense weak-spells in the peak monsoon months have been traditionally known as breaks. And that is what we are going to talk about today.

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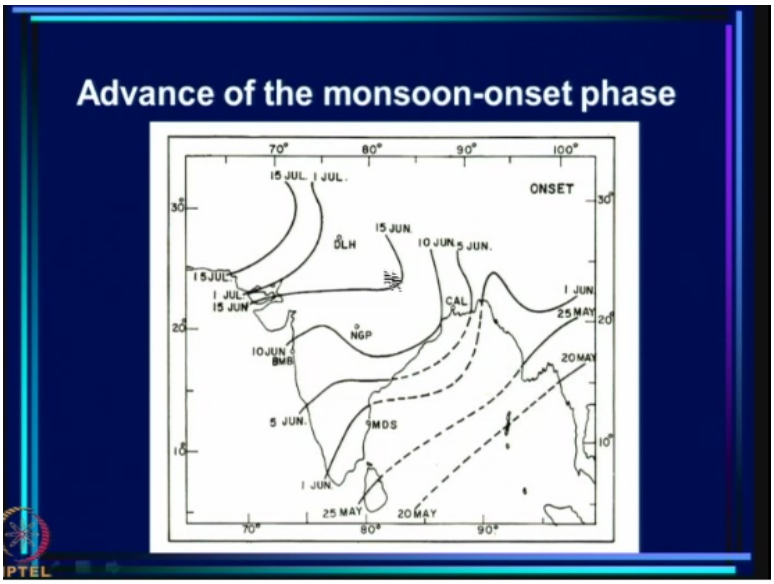

So, let us recall how the advance of the monsoon in the onset phase takes place. We know that the onset occurs over Kerala around 1st June or so. Meanwhile onset is also already occurred over the Andaman around 20th May. Now, this branch moves northward so you have the onset here around 5th June this is 10th June this branch is also moving. So around 10th June the onset has occurred all over here then continued northward progression.

And westward progression here leads to the almost the entire country being under the sway of the monsoon by 1st of July, by 15th July it has reached here. So, this is the advance of the monsoon by 1st of July the CTCG gets established in the monsoon zone here.

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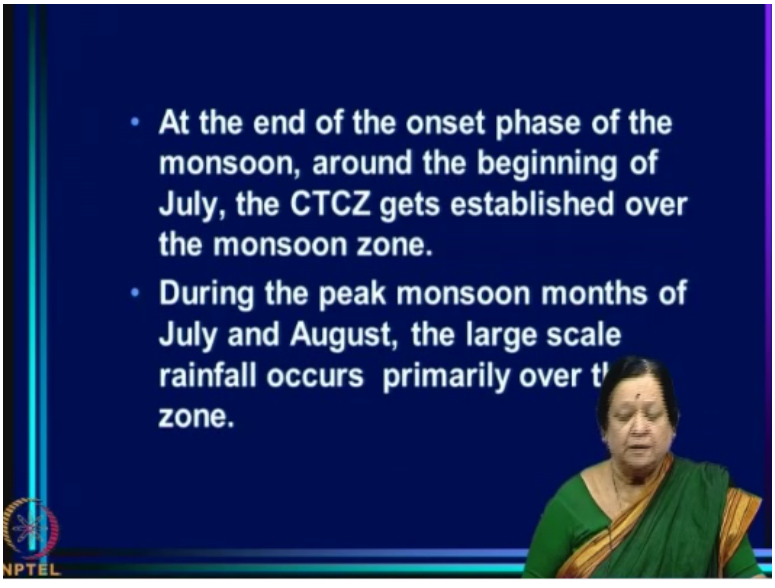

Now at the end of the onset phase of the monsoon around the beginning of July the CTCG gets established over the monsoon zone. Now, during the peak monsoon months of July and August the large scale rainfall occurs primarily over the monsoon zone.

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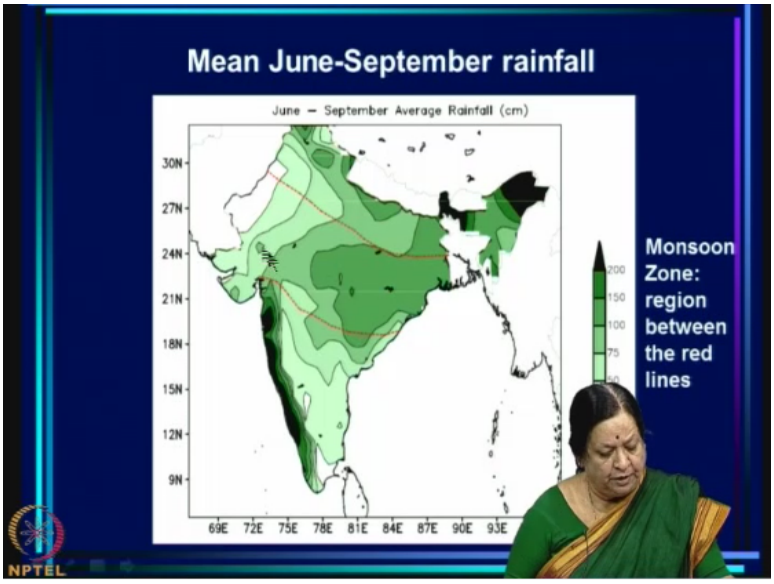

This is the monsoon zone just to remind you. So, during the peak monsoon month most of the time CTCG is located over the monsoon zone.

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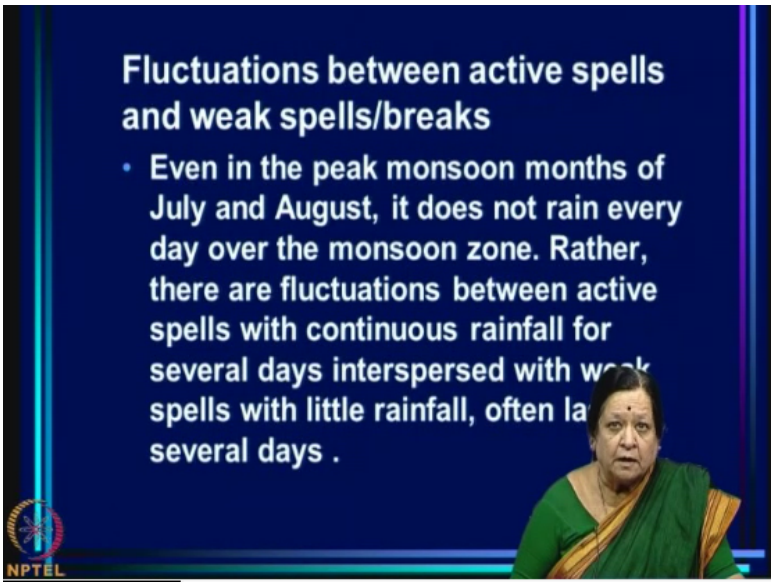

Now, we consider the fluctuations between active-spells and weak-spells of break. So, even in the peak monsoon months of July and August it does not rain everyday over the monsoon zone. Rather there are fluctuations between active spells with continuous rainfall for several days,

interspersed with weak spells with little rainfall, often lasting several days. So, this is phenomena which is observed year-after-year.

The fluctuation between active-spells and weak-spells for rainfall over the monsoon zone during the peak monsoon months. Let me just remind you that during the peak monsoon months of July and August the CTCG fluctuates primarily over the monsoon zone.

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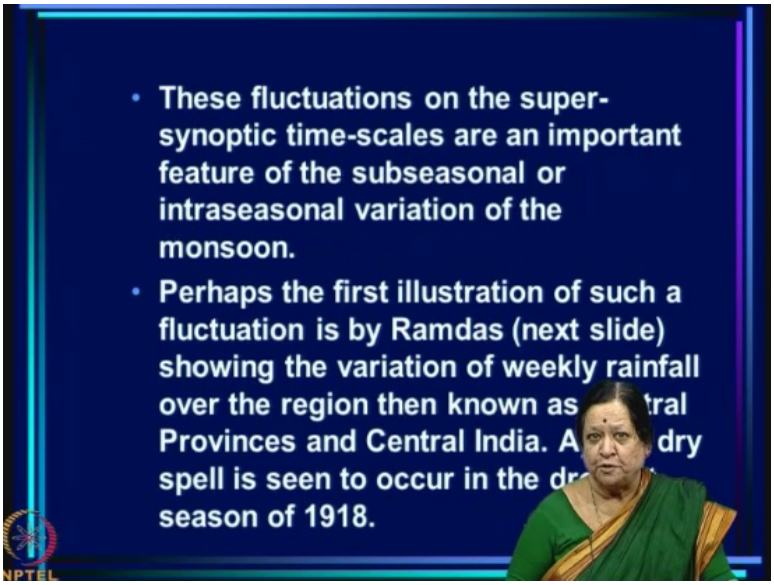

Now, these fluctuations between active-spells and weak-spells on the super-synoptic time-scales these are synoptic would be of a few days they are characteristic of the kind of genesis of lows or depressions and propagations those are the synoptic scale systems and synoptic time-scale. Super-synoptic would be few days up-to-weeks and on the super-synoptic time-scales we see these fluctuations in active and weak-spells.

And it is a very, very important feature of the sub-seasonal or the intra-seasonal variation of the monsoon. It is interesting how reach our literature is vis-a-vis the various important facets of the monsoon. Now, perhaps the first illustration of a fluctuation between active and weak spells over monsoon zone came from Ramdas which we see here.

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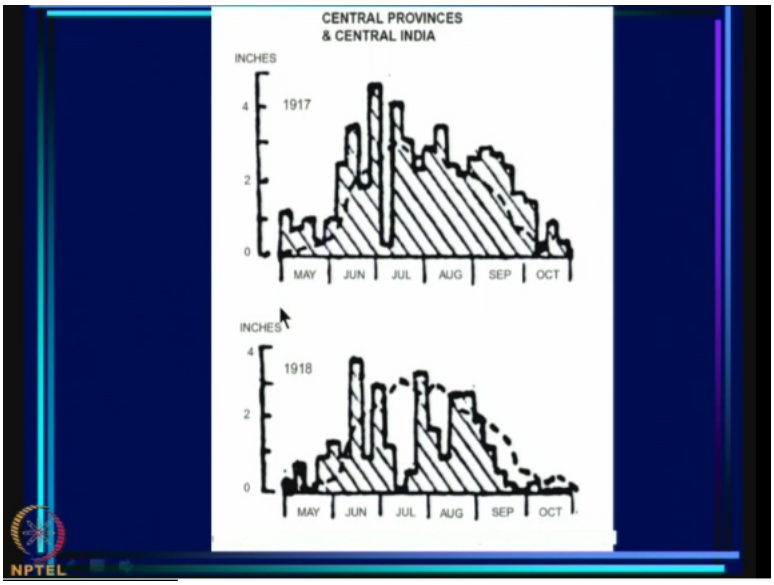

And this is the 1917 remember now rainfall is in inches and Ramdas has depicted variation of the weekly rainfall from May to October over what was then called central provinces and central India. So, this is over the central part of India and what you see is that there are active-spells and weak-spells and you can see this is on the weekly time scale and still they are clear. This is what one means by super-synoptic time scale.

So, even in 1917 which was a good monsoon year you do get active-spells and weak-spells fluctuations. And in 1918 which turn out to be a very severe drought you get a very, very long intense weak-spell here. This is a break in fact. So, this is one of the first illustrations that I could find of the active, weak fluctuations over the central region of India. So, this is the first illustration perhaps of such a fluctuation.

Which shows how the weakly rainfall over the region known as Central Provinces and Central India varies and we saw a long dry spell is seen to occur during the drought season of 1918. This is the long dry-spell here.

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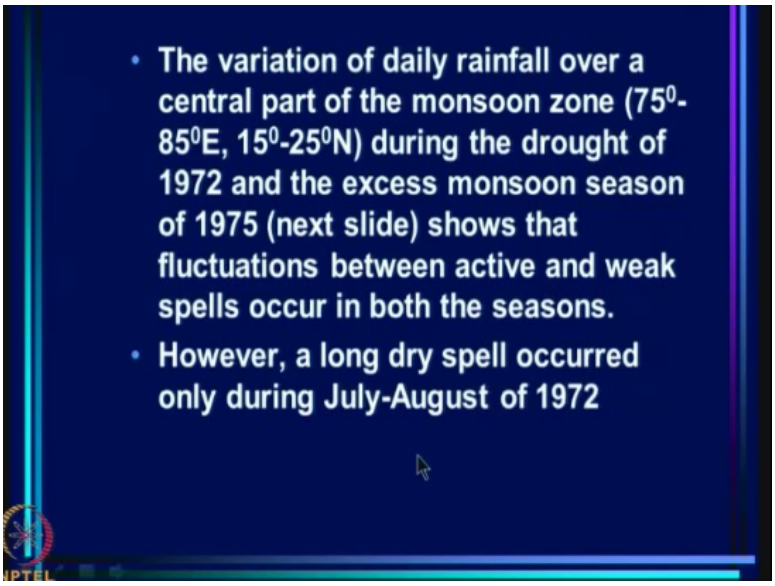

Now, the variation of daily rainfall over a central part of monsoon zone which is 75 to 85 degree east and 15 to 25 north during the drought o 1972 and excess monsoon season of 1975 is what we see here.

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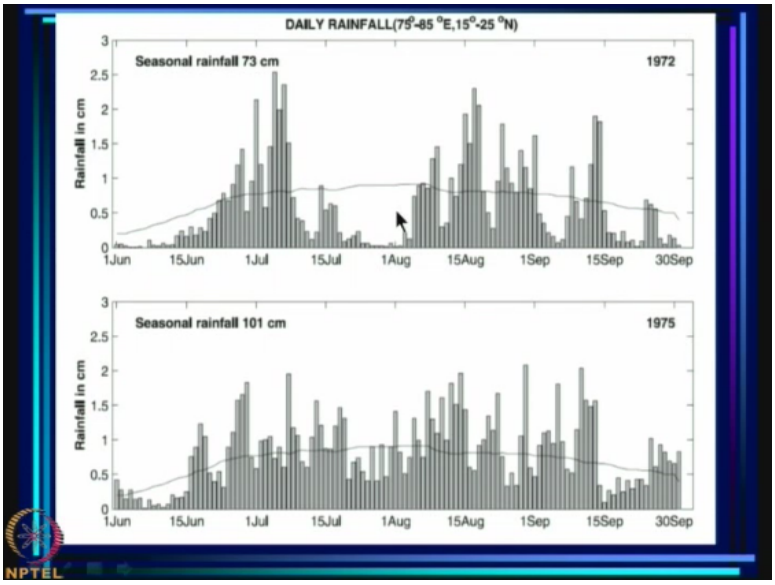

This is a picture that Krishnamurty and Balmay first had and what you see again here is a daily rainfall between 75 to 85 and 15 to 25. So, this is the central portion of the monsoon zone and you can again see active-spells and weak-spells. In 75 there are just active-spells and weak-spells, no long intense weak-spells. But in 72 we have active-spells and in addition to that an intense dry-spell here and this is a break.

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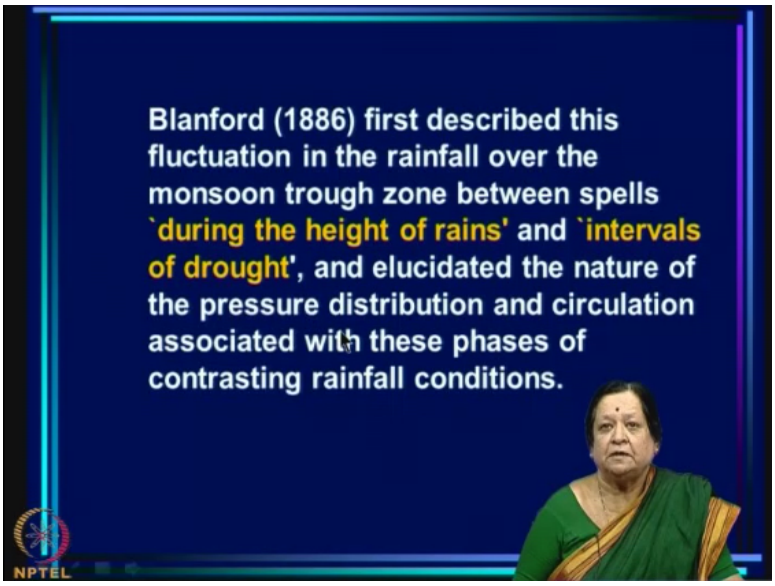

So Blanford first described this fluctuation in the rainfall over the monsoon trough zone as he called it between spells during the height of rains and intervals of drought. So, he talked of active spells as spells during the height of rain and weak-spells or breaks as intervals of drought. And he in fact illustrated the nature of the circulation and pressure distribution associated with these phases of contrasting rainfall condition.

So, Blanford talks of what happens during height of rains in active-spells and what happens in intervals of drought which are weak-spells or breaks.

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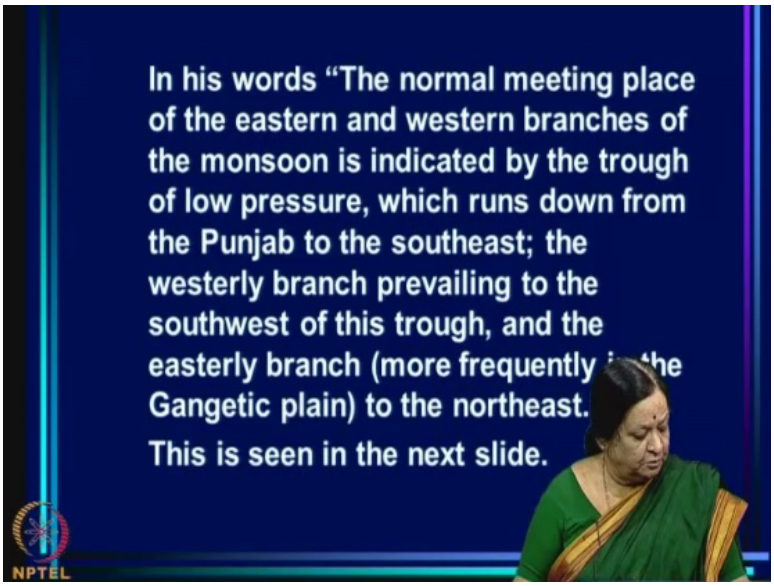

Now how did Blanford put it? He said the normal meeting place of the eastern and western branches of the monsoon is indicated by the trough of low pressure, which runs down from the Punjab to the southeast; the westerly branch prevailing to the southwest to this trough, and the easterly branch more frequently in the Gangetic plain to the northeast. So, we see that in the slide here.

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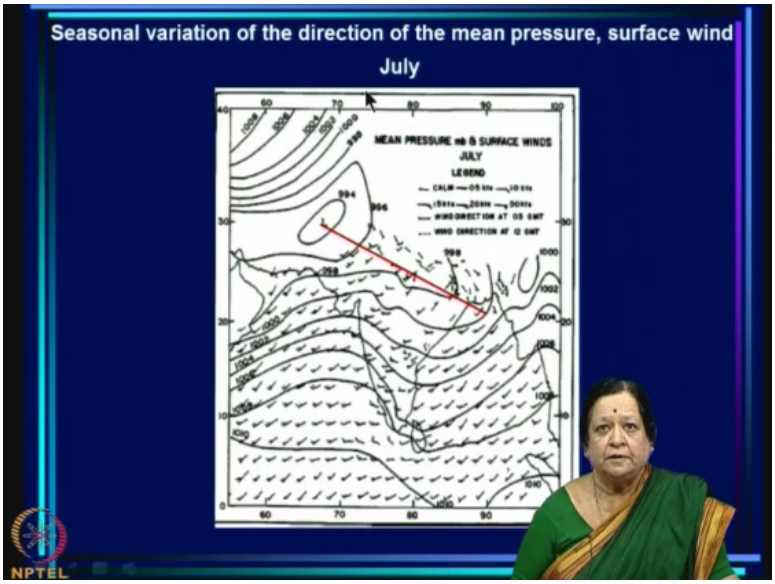

This is the trough at the surface and you have westerly winds to the south and easterly winds to the north. So, this is the trough that he describes here that this is the normal meeting place or the convergent zone if you wish of the winds of the westerly and easterly type here. So, this is the normal meeting place is the way he put it.

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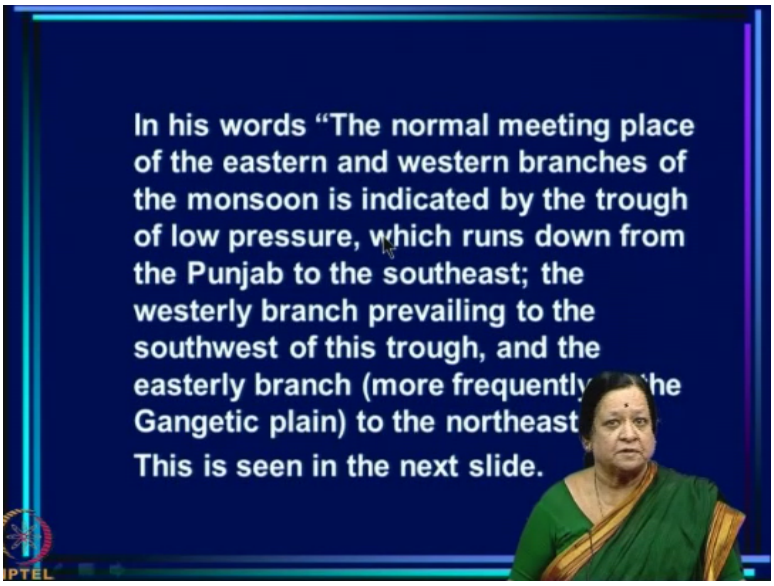

This is the normal meeting place of the eastern and western branches. It is low pressure zone which you see stretching across. This low pressure region stretching across which is also known as the monsoon trough but it is actually a surface trough.

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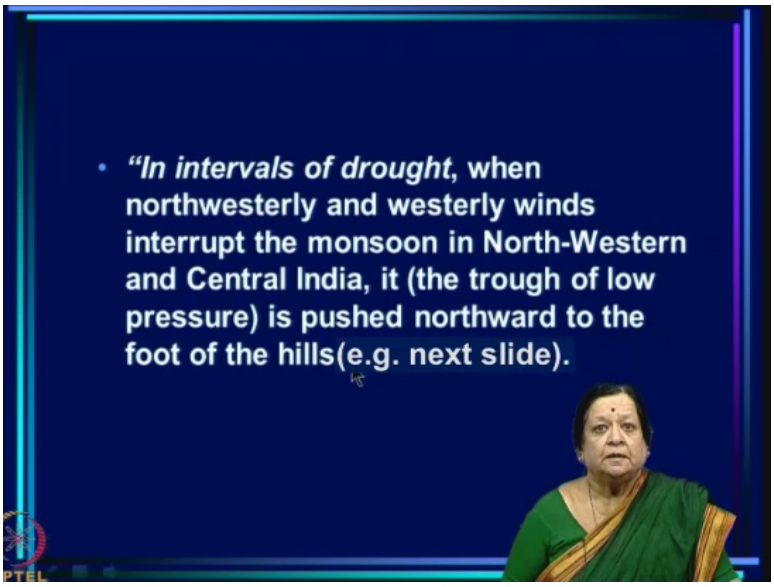

Now, then he says this is what normally. So, what you show earlier was actually the main surface wind and pressure pattern for July. So, this is the mean July situation. Now, in intervals of drought or read it as weak-spells or intense weak-spells and breaks when north-westerly and westerly winds interrupt the monsoon in North-West and in Central India, it meaning the trough of low pressure is pushed northward to the foot of the hills.

To this day this remains the definition of break monsoon as we shall see in the literature.

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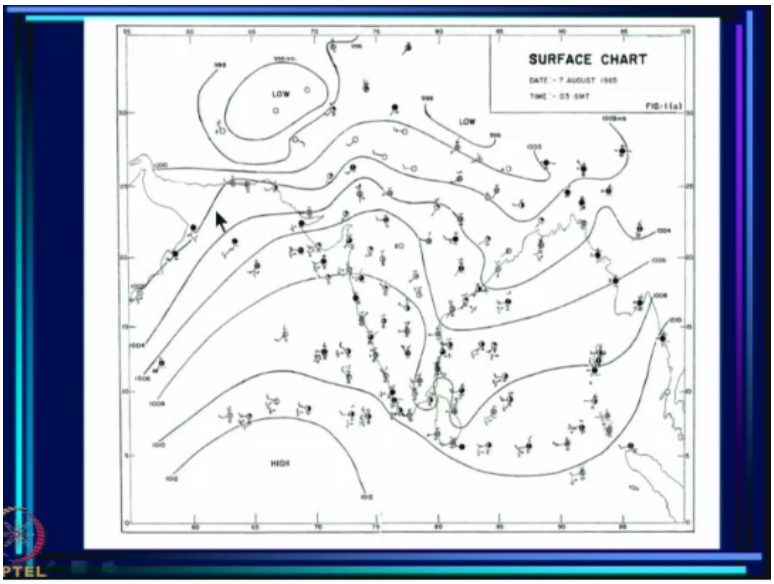

And this is a typical break monsoon day. This is the surface chart of a typical break monsoon day and what has happened is that the low pressure region has now just been pushed northward to the foot of the Himalayas remember it was here before. The eastern end was in the head way this was the mean location. Now that end has been pushed here so the surface low pressure is here and what you see is all westerly winds are penetrating here.

There are no easterly at all. So, this is the surface chart of a typical break day which Blanford himself described earlier.

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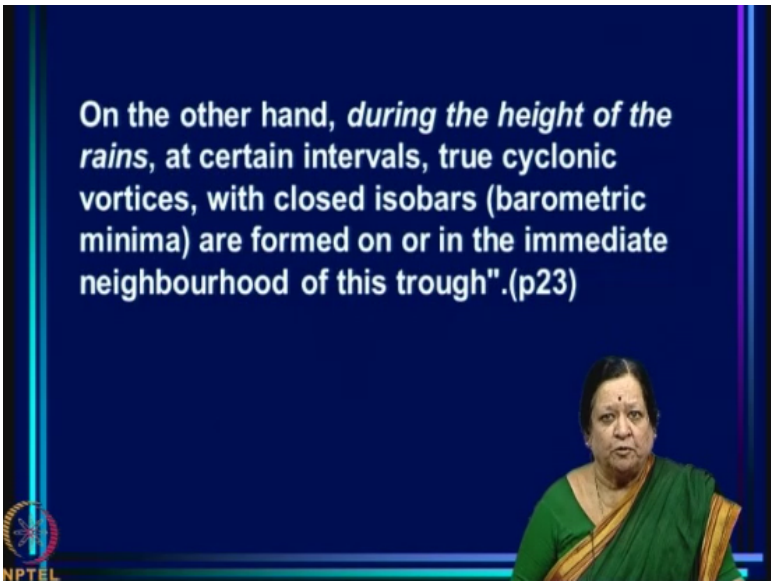

Now let us contrast it to what happens during what Blanford called the height of rains. He says during height of rains at certain intervals true cyclonic cortices, with closed isobars that is barometric minima are formed on or in the immediate neighbourhood of this trough. This is the way he describes it.

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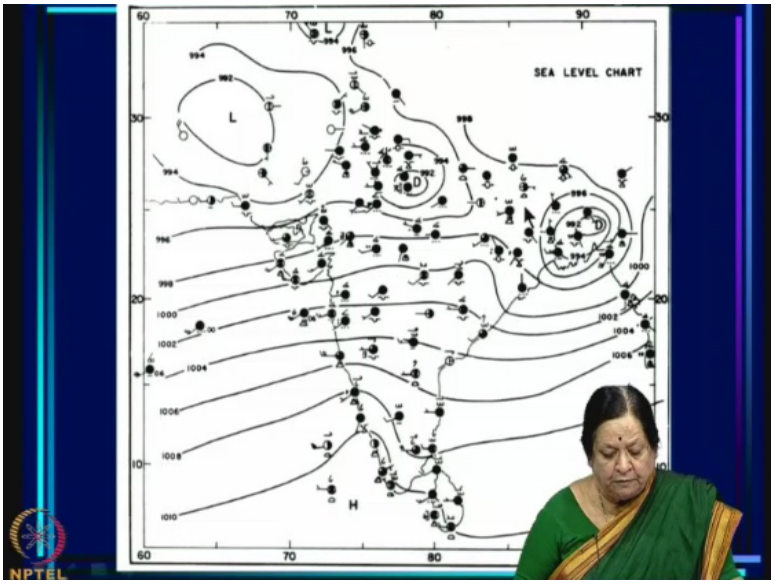

And this is the situation, this is the sea level chart for a typical active day and what you see here these are the vortices and in fact they happen to be depressions these are the cyclonic vortex you see which are embedded in the trough actually which are along the trough and these of course cause a lot of rain. So, on a typical active day then at certain intervals true cyclonic vortices with

closed isobars which is what you show are formed or on or in the immediate neighbourhood of this trough.

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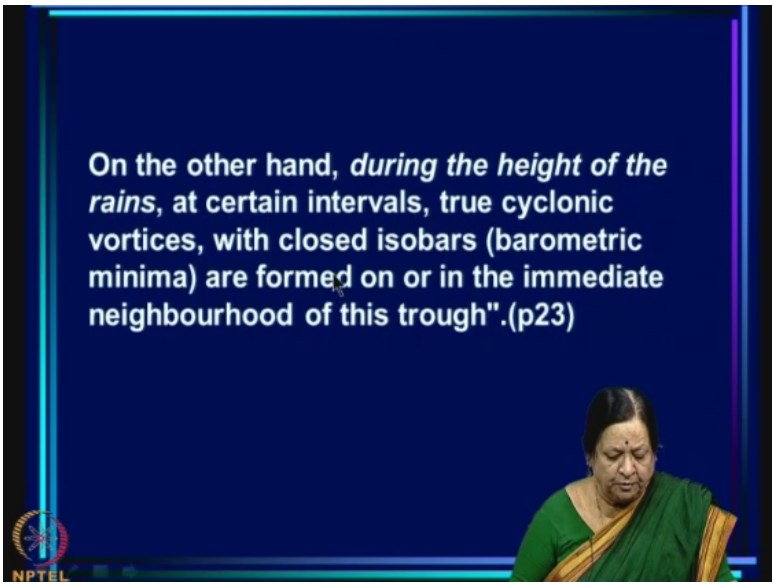

So, this is a typical active day here and you have seen these vortices formed here.

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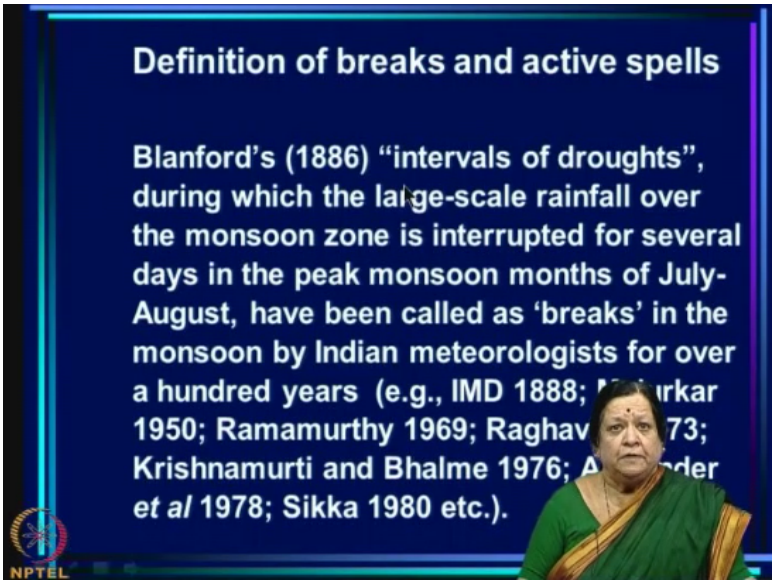

Now, we have to define what we mean by breaks and active spells and that is what we will now look at. How do we define them? So, Blanford's intervals have drought during which the large scale rainfall over the monsoon zone is interrupted for several days in the peak monsoon month of July, August have been called as breaks in the monsoon by Indian meteorologist for over a 100-years.

So, it is as if a break has occurred after the monsoon has been established over the monsoon zone when suddenly it stops raining and that condition persists for several days. They call it a break as if the monsoon has broken in the middle. So, this is the origin of the term breaks as been used by monsoon meteorologist for a long time.

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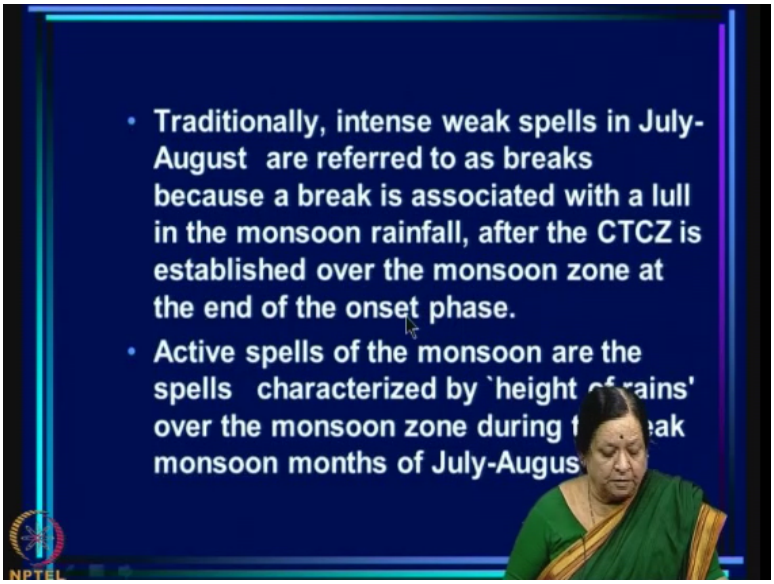

So, traditionally intense weak-spells in July, August are referred to as breaks because a break is associated with a lull in the monsoon rainfall after the CTCZ is established over the monsoon zone at the end of the onset phase. So, this is how the term break monsoon has been traditionally applied. Now active spells of the monsoon are spells characterized by what Blanford's called height of rains over the monsoon zone during the peak monsoon months or July and August.

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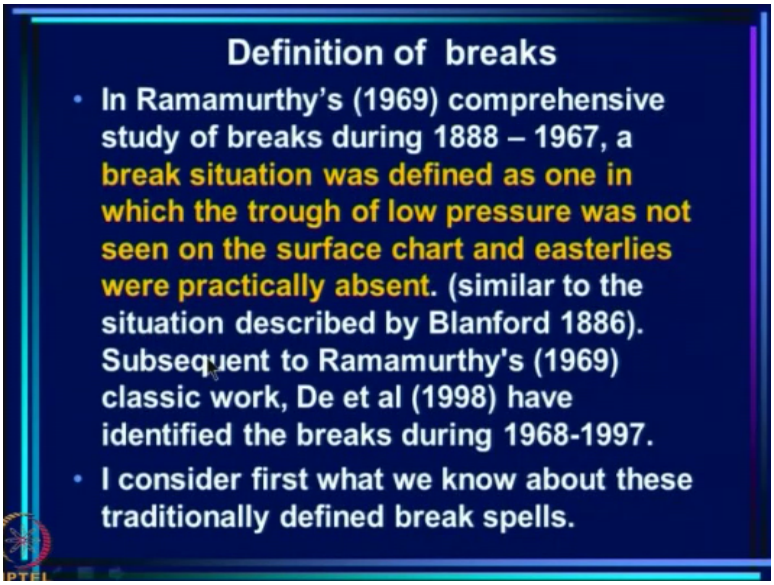

Now, how has breaks been defined actually the first comprehensive study of breaks was by Ramamurthy in 1969. And he studied breaks during 1888 to 1967 and how did he defined breaks? All though we talked of breaks as the lull in the monsoon and succession of rains in the middle of season and so on. Actually break was defined by something else that Blanford described in his classic De et al.

Namely the fact that the trough moves to the foot hills of the Himalaya's and therefore there are no Easterlies any more the Indian region. So, the break situation was defined as one in which the trough of low pressure was not seen on the surface chart and easterlies were practically absent. So, this is similar to the synoptic situation described by Blanford. Now subsequent to Ramamurthy's classic work, De et al have identified breaks during 1968 to 1997.

So, data on breaks based on this definition absent of easterlies in the chart or the surface trough moving to the foot hills of the Himalaya's are available for a very long period 1888 to 1997. So, let us now first consider what we know this, traditionally defined breaks.

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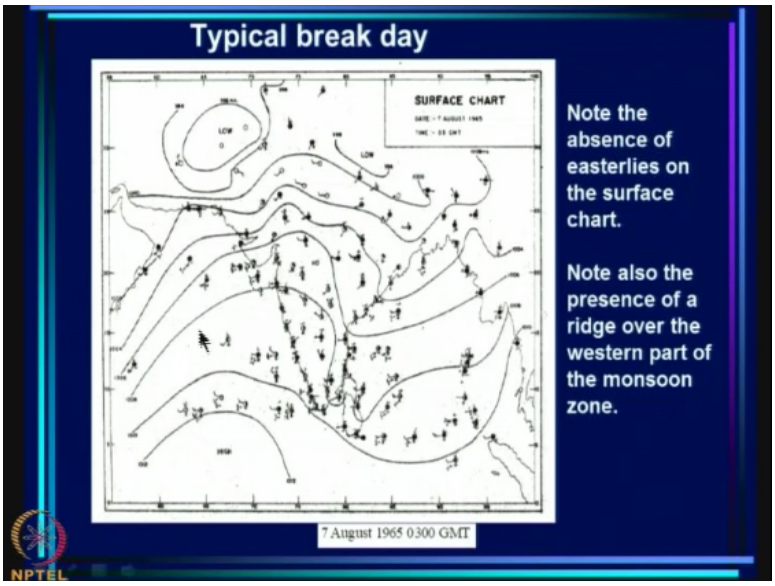

As we saw this is the monsoon trough going to the foot hills and total absence of easterlies in the surface chart this is what defines the break. Note the absence of easterlies on the surface chart. And secondly note also that there is a ridge present here over the western part which you can see at the surface. We will come back to this Simson specifically referred to it while talking of monsoon. But there is a ridge over western part here.

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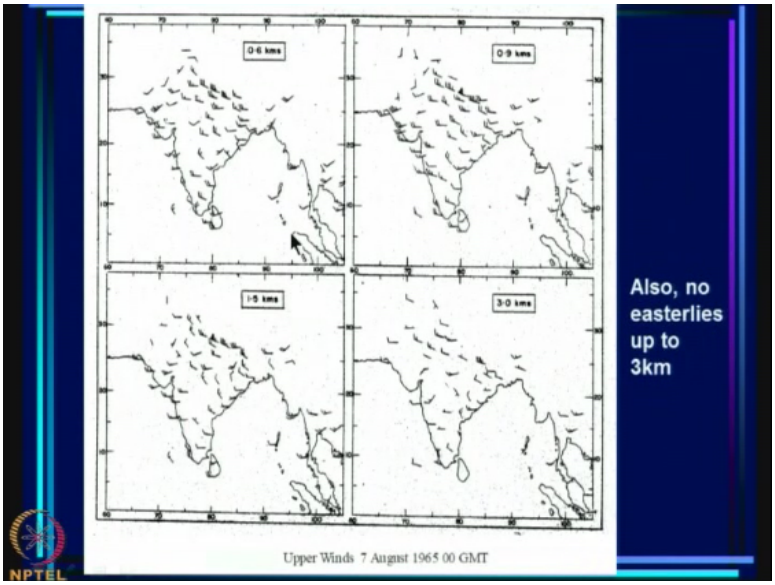

Now, let us see the circulation of this day which is 7 August 1965 at different levels in the atmosphere. So, this is at .6 kilometers, .9 kilometers, 1.5 and 3 kilometer. So, right from very near the surface you see here westerlies pervades the entire region. There are no easterlies at all

and furthermore, you can also see that the vorticity is anticyclonic because maximum the winds are occurring here same story at .9 same story about the boundary layer.

So, very clearly the entire region in the break is coming under the sway of anticyclonic vorticity here. And note that at 3 kilometers also the situation is the same there is no trough over the monsoon zone. There is a (()) (15:59) and this can be drawn near the foot hills of the Himalaya. So, there are no easterlies up to 3 kilometer in a break situation.

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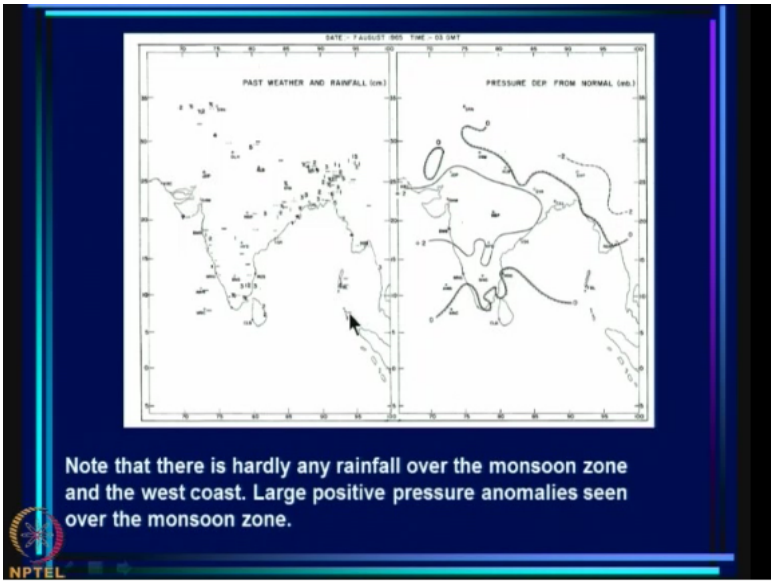

Now, for the same day there are records of how much it rained and what is the pressure departure. So, this is the rain and you can see there is hardly any rain over the monsoon zone here. There is rain over the foot hills of the Himalayas. And there is also some rain over this Tamil Nadu region southeast corner of the peninsula. This is a pattern of the rainfall for that typical day that I showed you in August 1965.

Now, what are the pressure departure from normal? This means pressure anomaly. This is the pressure away from the main pressure and what you see is that there is a very big region of high pressure departure from normal here. So, over the entire monsoon zone the pressure is higher than average and this has certain implications. So, large positive pressure anomalies are seen over the monsoon zone.

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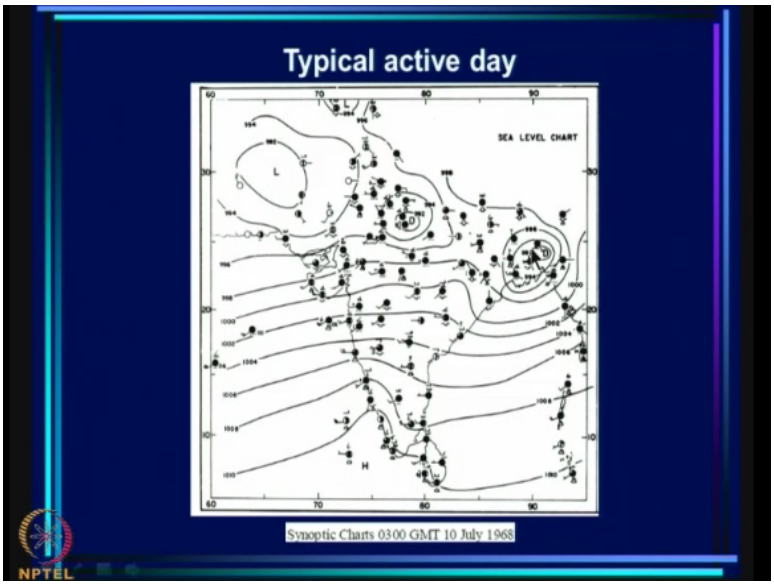

And where as for a typical active day what happens? Typical active day you have cyclonic vertices here.

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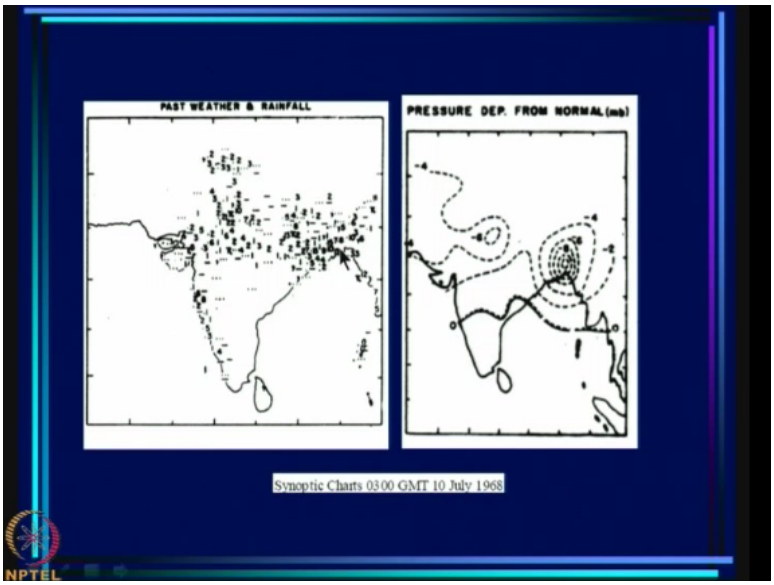

And you get rainfall which is very well-distributed across the monsoon zone. So, this is a typical active day and you see the pressure departure is negative over the entire monsoon zone. So, these are 2 opposite sides totally mirror images as you wish are opposite phases of the fluctuations of the monsoon.

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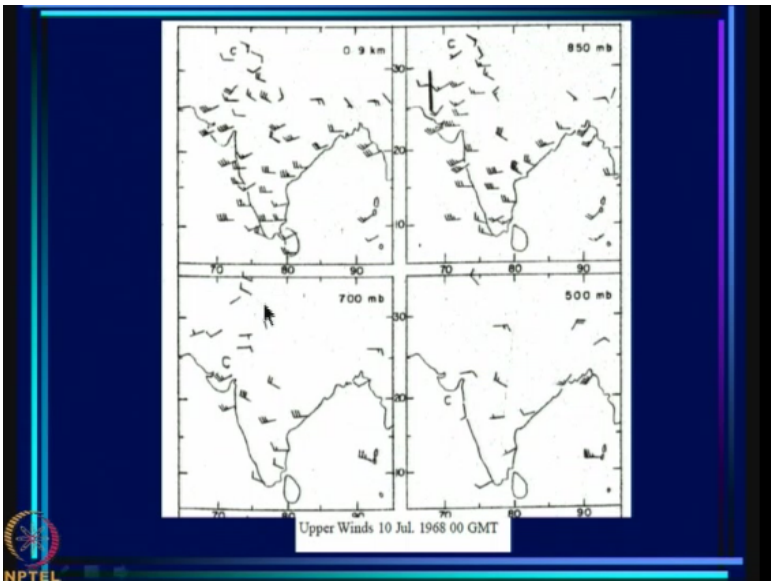

And these are the breaks phases and the active phases and now this is for the same day active day and what you see is very clearly is easterlies here and the vorticity is cyclonic over most of the region. The maximum westerlies are here and you (()) (18:01) cyclonic vorticity over the entire region.

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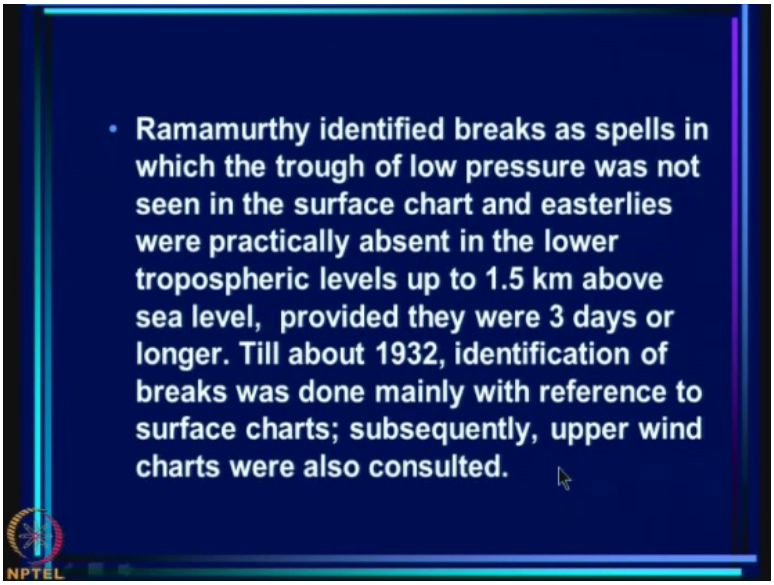

So, Ramamurthy identified breaks as spells in which the trough of low pressure was not seen in the surface chart and easterlies were practically absent in the lower tropospheric levels up to 1.5 kilometers above the sea level provided they were 3 days or longer. So such spells were called breaks only if they were 3 day or longer, 1 day or 2-day kind of spell in which these conditions were satisfied were not considered as breaks.

So he had in mind that these were longer time scale phenomena then 1 or 2 days and so provided they were 3 days or longer he called situation in which there were no easterlies on the surface chart and practically up to 1.5 kilometer he called them breaks. Now, till about 1932 identification of breaks was done mainly with reference to surface to surface charts only after that some upper wind chart became available and they were consulted.

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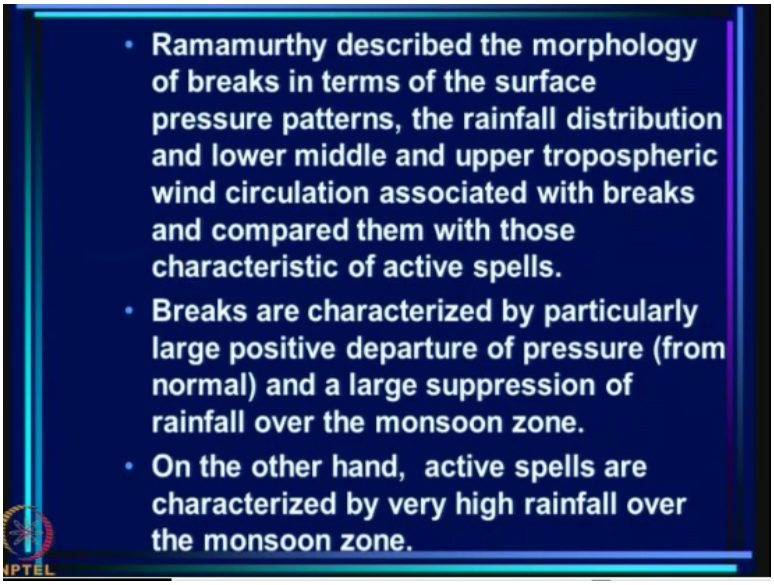

So, what Ramamurthy did is having defined breaks in a very specific way by saying there were days when no easterlies was seen on the surface charts or up to about kilometers in fact. He then went on to describe the morphology of breaks in terms of the surface pressure patterns, rainfall distribution and lower middle and upper tropospheric wind circulation associated with breaks and compare them with those characteristic of active-spells.

So, what he did was that he identified the breaks and the active-spells over a large period for which he had data and then he made composite of them to see what is a break composite and active composite for surface pressure patterns, rainfall distribution as well as circulation patterns that is how he got the morphology of the breaks. And breaks are in fact characterized by particularly large positive pressure departure that is departure from normal.

And a large suppression of rainfall over the monsoon zone. Whereas active-spells are characterized by very high rainfall over the monsoon zone.

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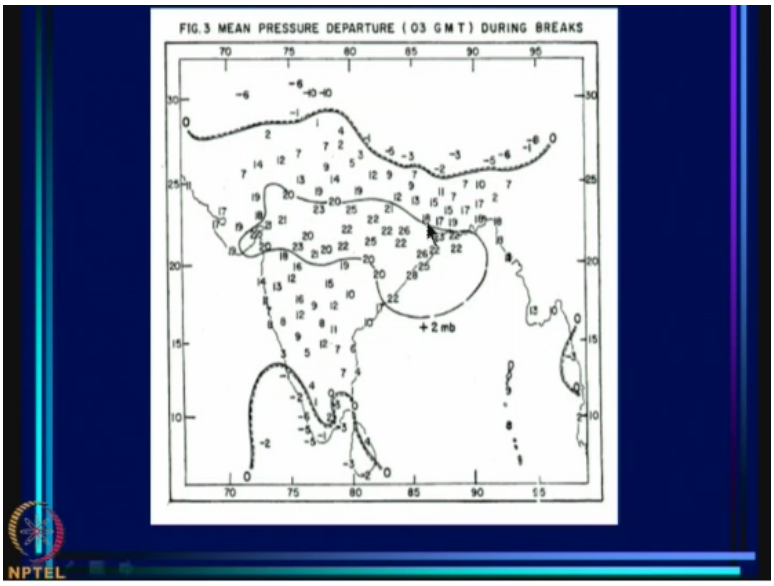

Now, this is a typical pattern for a break now remember is an average over several breaks and what you see is that the pressure departure from normal in this composite is more than 2 millibar which is a huge pressure departure over this region over the monsoon zone and it is in fact positive over all most the entire Indian region except for the foot hills of Himalayas and the southeastern peninsula. So, this kind of pressure departure is what is characteristic of break.

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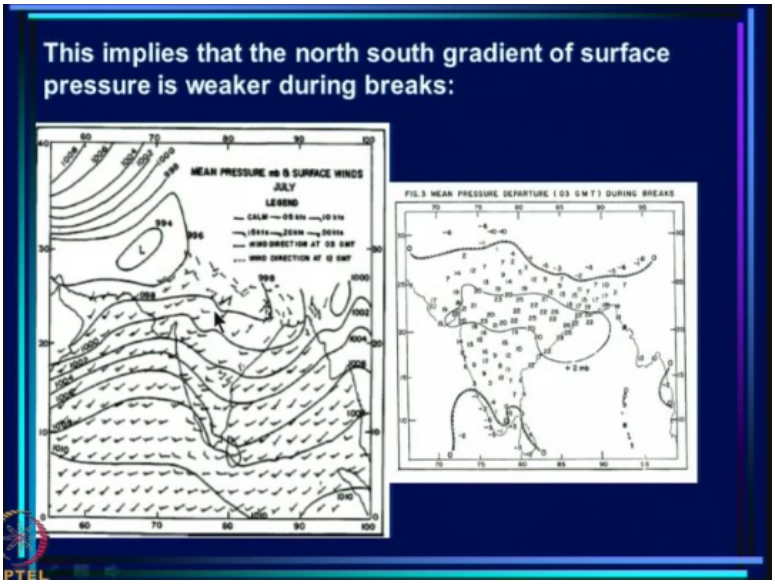

Now what this implies is (()) (20:58) see you know that in the normal you have a low pressure belt here. Now when you have a departure which is positive pressure anomaly here this means that the low pressure has become less intense. So, this low pressure belt that you have has become less intense because this positive pressure departure which is occurring right over here and so this means that the north-south pressure gradient.

That exists between the southern hemispheric highs and this low pressure is going to be weaker during the breaks.

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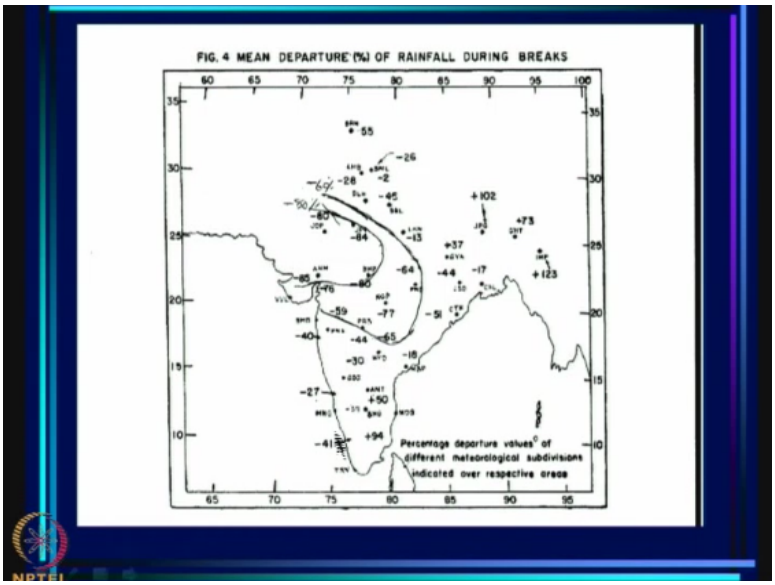

Now what is the mean departure of rainfall during breaks? This again Ramamurthy computed this is based on sub-divisional rainfall and actually about 80% deficit occurs here towards the north-western part the monsoon zone. 60% here so there are huge rainfall departures and they are in fact negative over most of the region please notice that even over west coast there is huge deficit in rain because 40% and 27% and 41% is very large amount of deficit.

In terms of quantum of rainfall because the mean rainfall here is very, very high. So, it appears that breaks are characterized of course by large deficit in the rainfall over the monsoon zone. But associated with it are also deficit in rainfall over the west coast.

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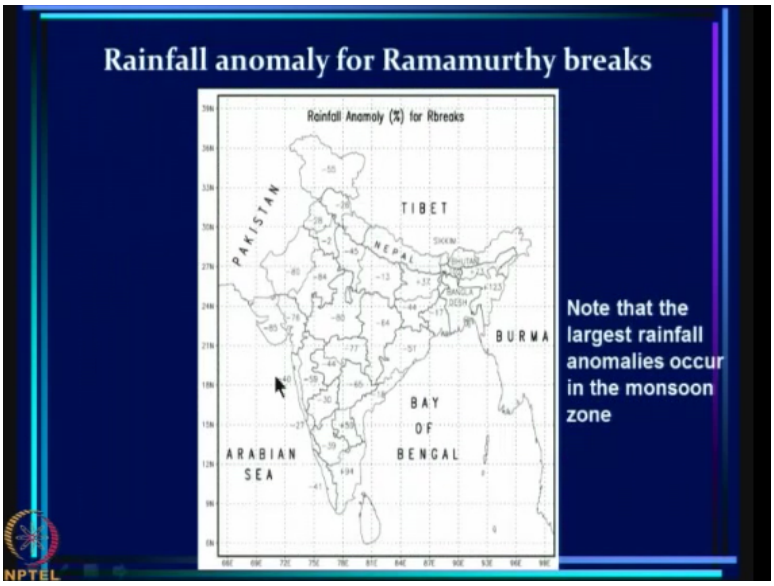

Now, this is all from Ramamurthy and if we look at the subdivisions which is what he used the data for then in fact you see that this is 80% and so on and so forth 84. So very, very large departure as we noted in this end of the thing and very large departures also over the west coast but not at large as over the north-western part the trough zone here. So, the largest anomalies occur over this region in the break.

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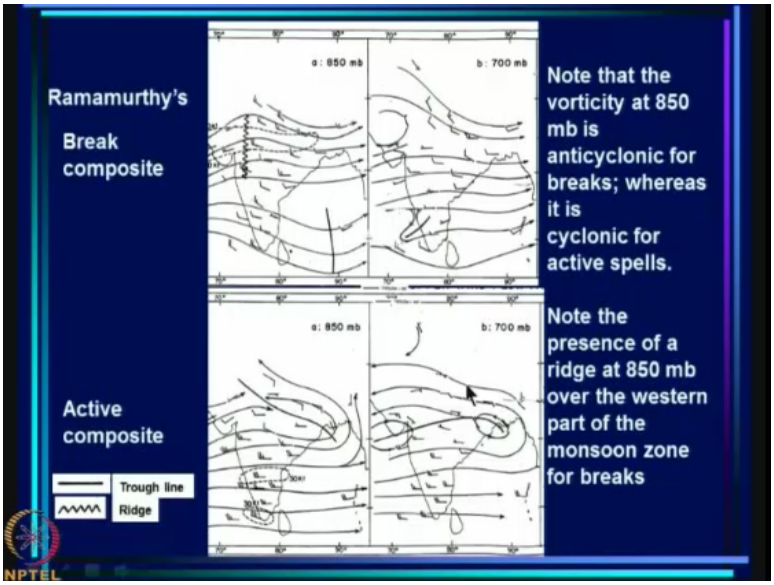

Now, what are the winds like in the breaks and this is again a very interesting composite here. This is the break situation and this is an active situation. This is 850 millibar, this is 700 millibar or HPA as we call it now. So, this is 850 HPA and 700 HPA for break situation and this is the

same for an active situation. Let us see first what happens at 850 millibar for a break situation? You can say that the winds are westerly throughout.

And furthermore they are very high here relative to here. So the vorticity is clockwise or anticyclonic over the entire region. As far as the pressure is concerned you see in fact there is a ridge here over the western part at 850 millibar and this presence of the ridge again will be mentioned in subsequent analysis of break situation and so please note it here. Now, 700 millibar also, there is no trough here at all.

In fact, the entire region is still anticyclonic vorticity as it is at 850. Now, look at the opposite case active monsoon. Active monsoon in fact the trough is here and we have a 700 millibar trough here so very active trough over the Indian region here and you have strong westerlies and relatively strong easterlies which means a high cyclonic vorticity above the boundary layer here. So remember this now high cyclonic vorticity.

Above the boundary layer is associated with large scale convergence and large scale ascent and can lead to heavy precipitation because of the deep clouds. Now, you see at 700 millibar a very clear trace of that trough here and this is why 700 millibar is considered a very key level to look at the system which is associated with moist convection in the tropics. So, these are the contracting cases which were presented by Ramamurthy.

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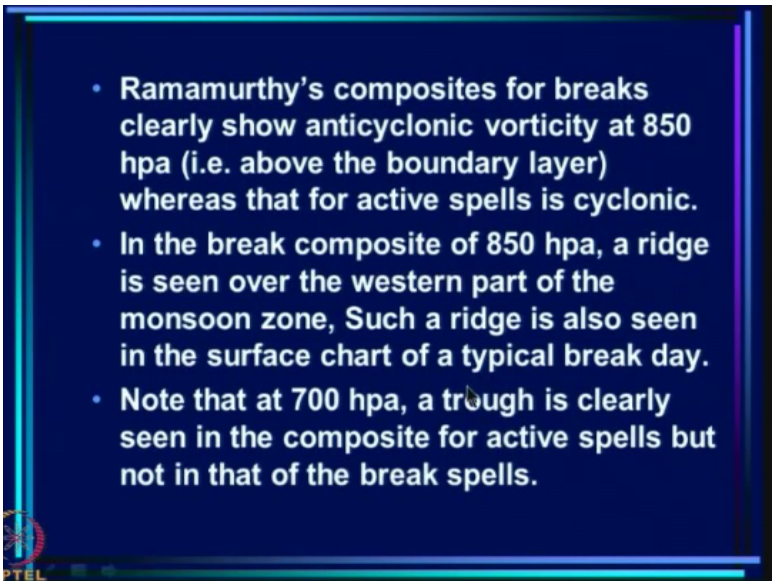

So, Ramamurthy's composites for breaks clearly show anticyclonic vorticity at 850 millibar that is above the boundary layer whereas that for active spells is cyclonic. In the break composite of 850 hpa, a ridge is seen over the western part of the monsoon zone and such a ridge is also seen in the surface chart of a typical break day. See, this is the ridge we are talking about. So, there is a ridge seen over the western part which is also seen for a typical break day.

We had seen it earlier. Now, as I pointed out at 700 hpa, a trough is clearly seen in the composite for active spells but in that of break spells. So, you have a trough very clearly seen here in the active-spell. But there is no trough over this entire region in the break-spell.

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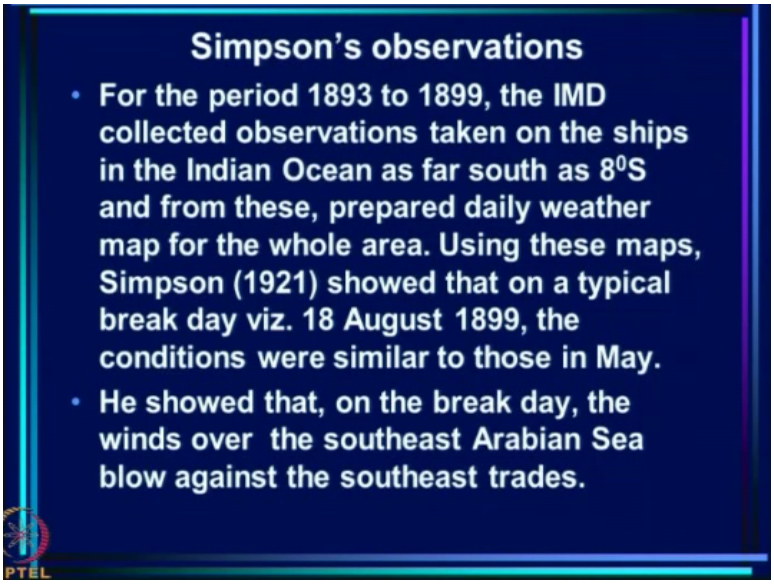

Now it is interesting that although we defined breaks by Ramamurthy's criteria because Ramamurthy was the first to do a very detailed study of break-monsoon actually even before Ramamurthy various people have written about breaks and in particular interesting are observations made by our friend Simpson about whom we talked because he had a theory of the basic system responsible for the monsoon.

He also shut down the land sea breeze model for the monsoon. So, in that same paper in fact Simpson talks about breaks as well and what is very interesting is that even in that era because the paper was published in 1921 even in that era people were keen to look at what is happening on the oceans around the region. So, Simpson says that for the period 1893 to 1899 the IMD collected observations taken on the ships in the Indian Ocean as far south as 8 degree south.

And from these prepared daily weather map for the whole area. So, for a 7-year period IMD had taken the trouble to collect observations from the ships and these were all ships of opportunity and actually prepared daily weather maps for the whole area that is including Indian Ocean up to 8 degree south. Now, using these maps Simpson showed that on a typical break-day namely 18 August 1899, the conditions were very similar to those in May.

He showed that, on the break day, the winds over the southeast Arabia Sea blow against the southeast trades. Now, this is very interesting because now he is talking of winds over the Ocean. So far in the definition we were only talking of winds over land. But he showed that in association with the break situation over land on the break day the winds over southeast Arabian Sea blow against southeast trades.

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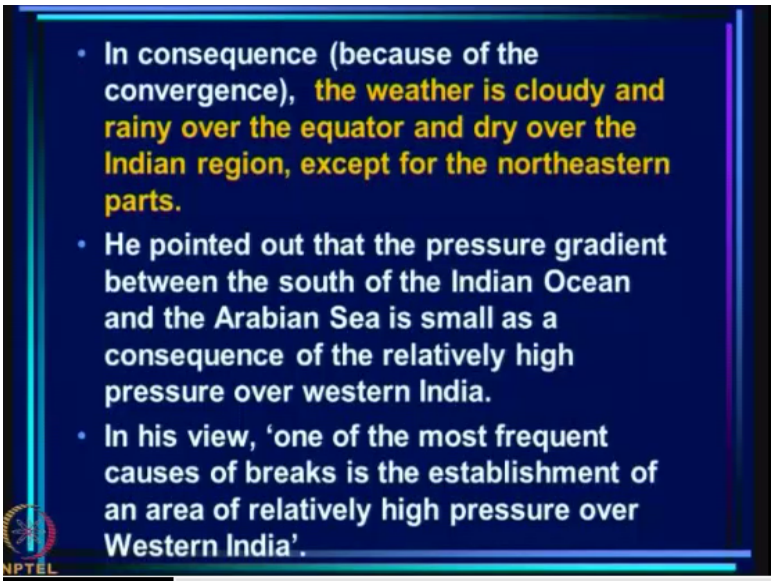

And in consequence so what happens is that there is convergence between winds over the southeast Arabian sea blowing towards the southeast trades. So there is a convergence over the equatorial region. This is what he pointed out and so in consequence he says that the weather is cloudy and rainy over the equator and dry over the Indian region except for the north eastern parts. So, this is very interesting he points out with perhaps the first analysis of observations.

On the Indian Ocean that during breaks it is cloudy and rainy over the equatorial region. We will come back to this later on. He also pointed out that the pressure gradient between the south of the Indian Ocean and Arabian sea is small as a consequence of the relatively high pressure over western India we have seen this from Ramamurthy analysis. And in his view, one of the most frequent causes of breaks is the establishment of an area of relatively high pressure.

Over Western India. Remember I have pointed out to you the ridge over Western India which is seen in surface charge as well 850 hpa on typical break days and is also seen very clearly in Ramamurthy composite of break monsoon. So, he says this is one of the most frequent causes of break.

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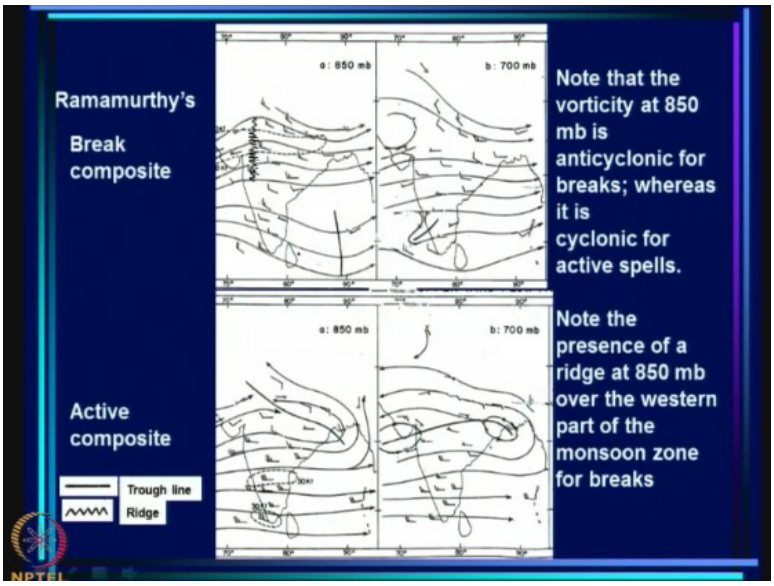

This presence of the ridge and in fact this is what I show here again this presence of the ridge in Ramamurthy's composite which he is talking about.

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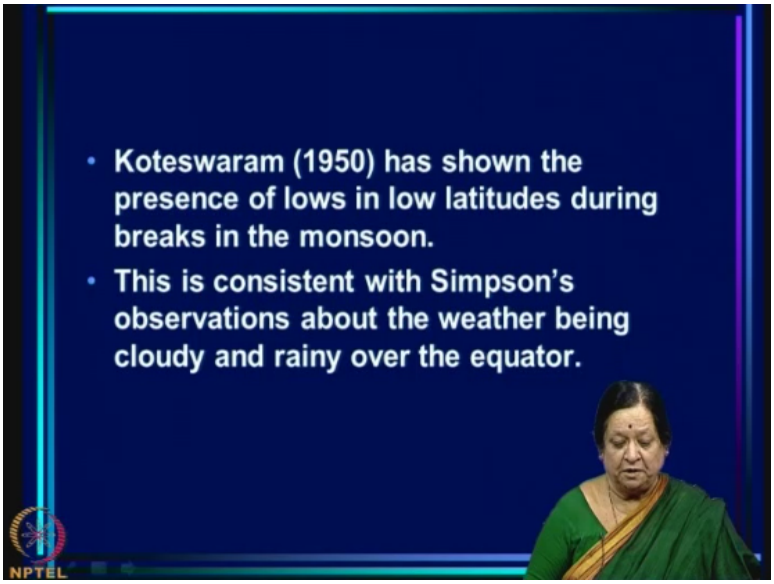

Now, there is another very interesting study by Koteswaram who has shown the presence of lows in low latitudes during he breaks in the monsoon. So, Koteswaram had also suggested that during the breaks in the monsoon the equatorial convergence zone becomes more active or the equatorial rain belt gets more rain. Now, this is again consistent with Simpson's observations about weather being cloudy and rainy over the equator during break.

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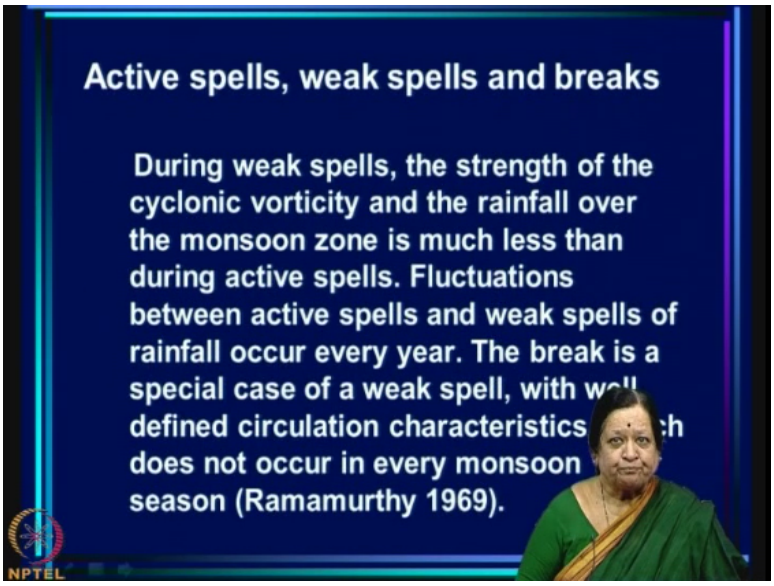

Now, we have to distinguish between active-spells, weak fspells and breaks as I have tried to show active-spells and weak-spells occur in every monsoon season and we have seen that before. In fact during weak-spells what happen is that the strength of the cyclonic vorticity and rainfall over the monsoon zone is much less then during active spells. So, it is not that the nature of the circulation changes.

But the magnitude of the cyclonic vorticity above the boundary layer, magnitude of the large scale convergence and rainfall decreases during weak-spells vis-a-vis active-spell so fluctuations between active spells and weak-spells of rainfall occur year-after-year. Now, break is a special case of a weak-spell with defined circulation characteristics which does not occur in every monsoon season.

So, beaks as Ramamurthy defines them and our traditionally defined actually do not occur each and every year. But fluctuations between active, weak-spells are seen year after, year.

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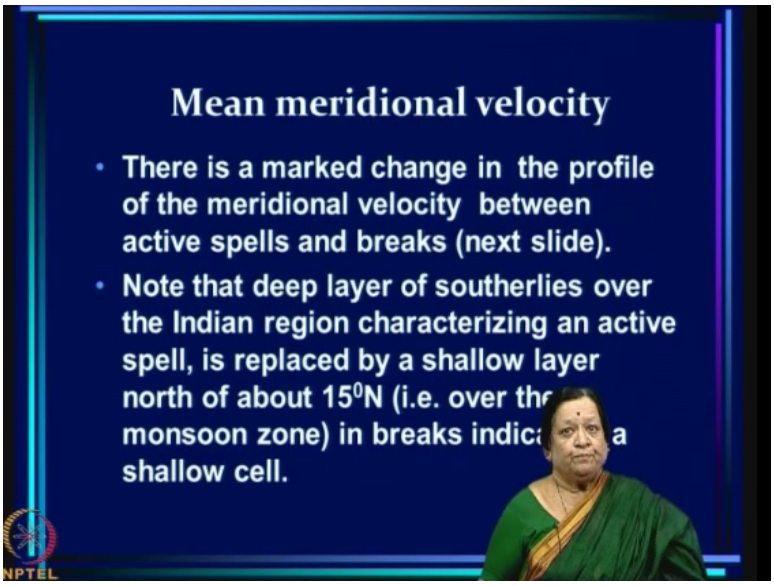

Now, what are active spells? You may recall that Blanford also remarked on how there is frequent generation of cyclonic vortices during what he called the height of monsoon range. So Murakami says active spells are characterized by a sequence of time-clustering partly overlapping, development of monsoon disturbances, cyclonic vorticity above the boundary layer. So, naturally these disturbances are associated with cyclonic vorticity above the boundary layer.

So active-spells you have a series of disturbances which are actually generated and which move along the monsoon zone. So, this is the definition of active-spells. On the other hand, the break-spell is characterized by a mark change in the lower tropospheric circulation over the monsoon zone with vorticity above the boundary layer becoming anticyclonic. Now, this again you have seen from Ramamurthy composite.

Now, there is another interesting way to look at these things and this is where looking at the mean meridional velocity because this gives an idea of the circulation in the latitude height dimension. Remember we talked of the Hadley cell which involved raising of air in the ITCZ and spreading towards higher latitudes and sinking beyond the ITCZ and then returning at low level to the ITCZ. So, this is one cell this is the Hadley cell.

Now, we try and see how cells are modified during the active and break conditions. So, let us see in the in the next one.

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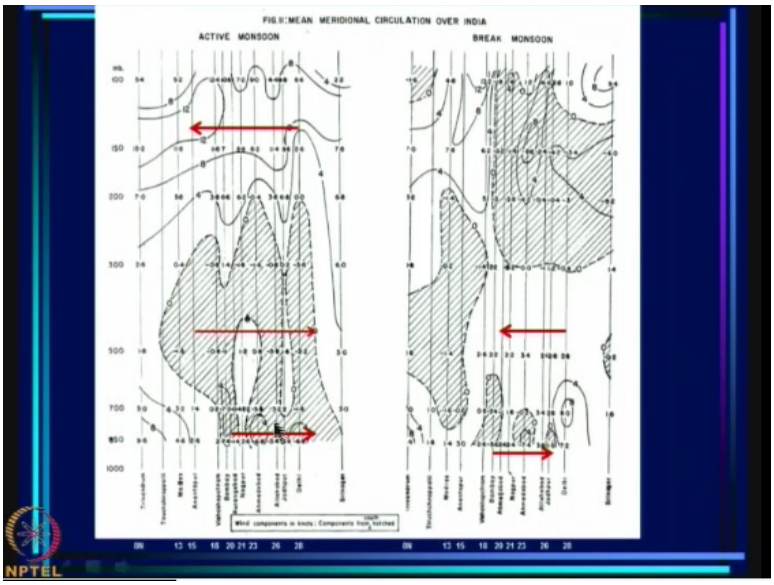

Now, this is actually from Ramamurthy. This is the active monsoon case and you know in those days what it did was to get an idea of how things vary with latitude. They would look very carefully on data at various stations going all way from Trivandrum to Srinagar here. So, this is roughly along say 75 or 80 degrees east. So, this is roughly along the central Indian longitudes and they do not worry about differences that arise from east-west displacement.

Rather they take the data of all the stations and then draw maps. For active monsoon and break monsoon how does the wind which is going north or coming from the north in which places does it occur? And what you see is over the Indian region which begins from Trivandrum but from Vizag onwards you have southerlies in another words wind is flowing from the south to the north in an active monsoon day and these southerlies are very deep.

In fact, even at 300 millibar you see the winds are coming from the south. So, there is a very deep layer in which winds are coming to the north to the monsoon trough zone and air rises here and in fact returns to equator in latitudes only in the upper levels that is beyond 200 millibar or so you have a deep cell in which this is at the lower levels air is going towards the north, towards the monsoon trough and at the higher levels it is coming from the north to the south.

So, this is a very deep circulation cell it is similar to what we consider of as a Hadley cell with the rising limb of the Hadley cell being here. This is the active monsoon situation but look what happens in the break monsoon? What happens in the break monsoon is very interesting the belt of southerly is here is restricted to only a very low level it does not even reach 700 millibar. So the belt of the southerly is up to about 2 kilometers or so.

So, air is moving north here and it is actually returning to the equatorial region here so you are getting a very shallow cell in the break monsoon which is totally different from the deep cell that characterize the active monsoon.

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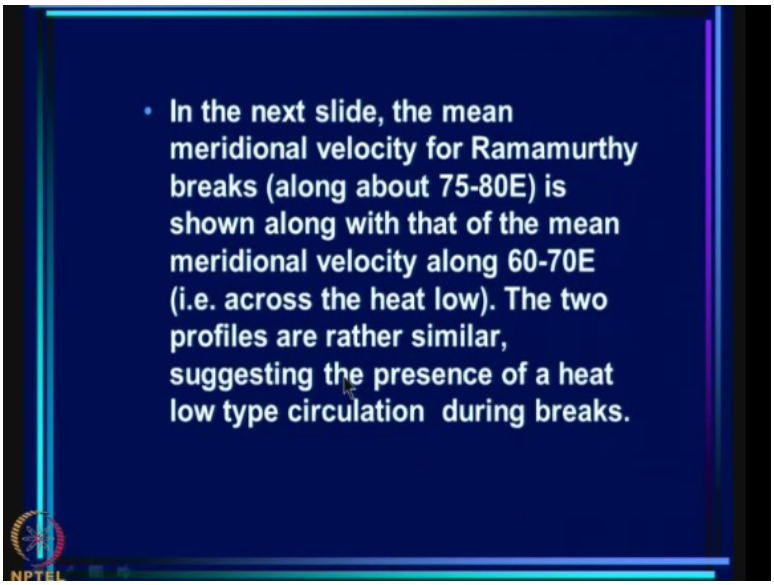

Again what we do now is to see what we have seen here, this is the break monsoon slide and in fact this circulation looks very much like the heat low that I described earlier. Heat low circulation remember actually the ascend never goes beyond 700 millibar and actually at 700 millibar and above there is descend and there is divergence. So the air is the cell is completed by circulation at 700 millibar towards the south and ascent only up to 2 kilometers or so.

This is a typical heat low kind of circulation and what we do is in the next slide compare these 2.

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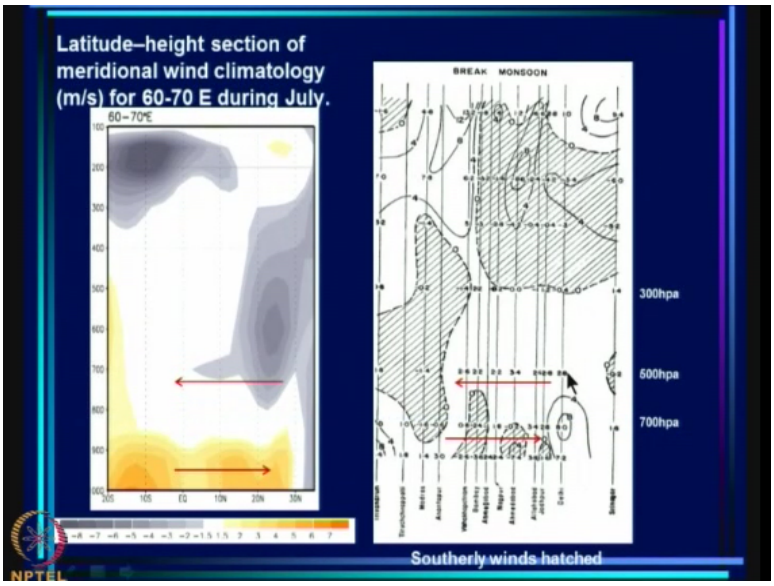

So what you see here is the break monsoon slide that you show this is the same one this is the shallow cell. But what you see here is now with modern data what we have plotted here is the latitude height section of meridional wind climatology so this is the mean for July. For 60 to 70 east remember the heat low is located in this region. The heat low over the north western India so take those longitudes and we look at the meridional circulation.

In fact, what we find is that the circulation is very similar to what we see in the break monsoon that you are getting us south. Southerly flow only up to about 2 kilometers or so and at 700 millibar in fact there is a return flow already so the ascend is restricted to below 700 millibar and you have a return flow here. So, this is the heat low circulation in the mean July pattern and this is the break monsoon.

So, the mean meridional velocity pattern of a break monsoon is very, very similar to the heat low.

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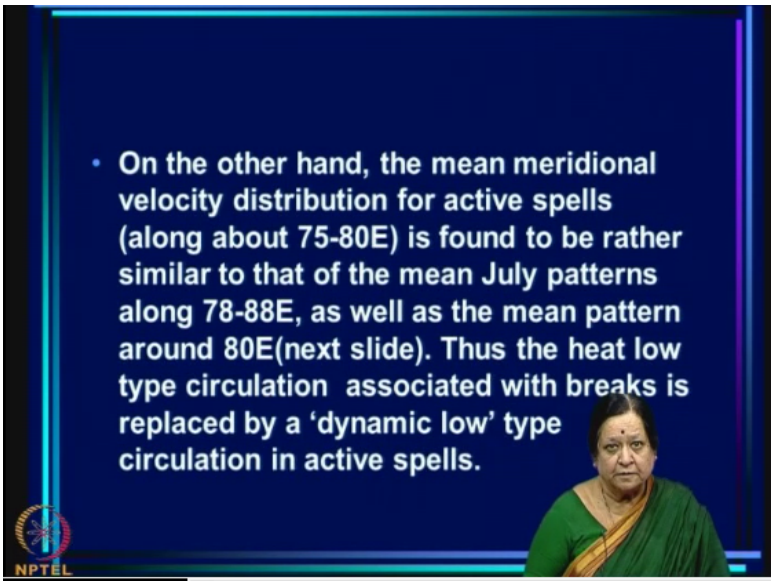

On the other hand, the mean meridional velocity distribution for active-spells is found to be rather similar to that of the mean July patterns as well as the mean pattern along 80 degree east. So, let us see now in the next one.

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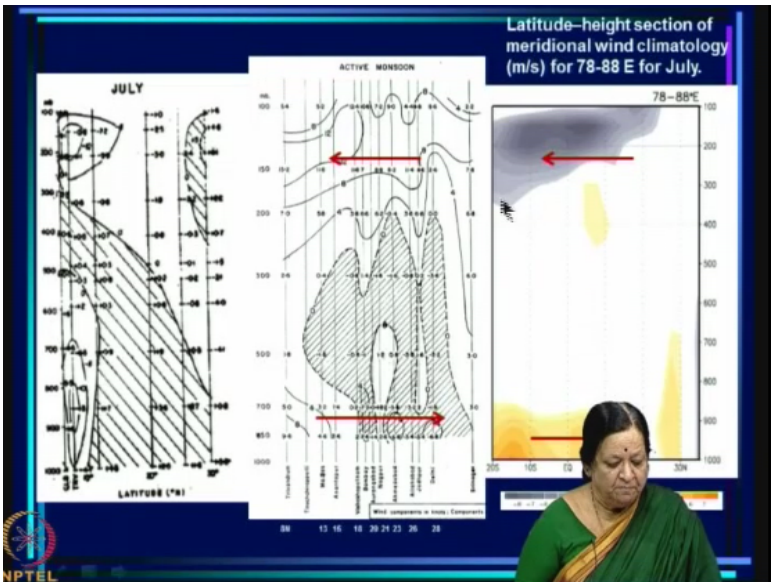

So, this is the active monsoon remember that is the deep cell with southerly extending way beyond 500 millibar also and ascend of air here and northerly that is the return current at this high levels here. Now, this is the latitude height section of 78 to 88 remember this is mean for July and this is where the CTCG axis is so this is the characteristic of the CTCG and what you see is in fact a very, very deep cell with southerlies here.

And northerlies beyond 300 millibar or so. In fact, this is the mean July picture again from IMD and that is similar to the July picture here. So active monsoon, the cell is very typical this is again like a Hadley cell and typical of the CTCG. Whereas break monsoon this meridional cell is very much like a heat low.

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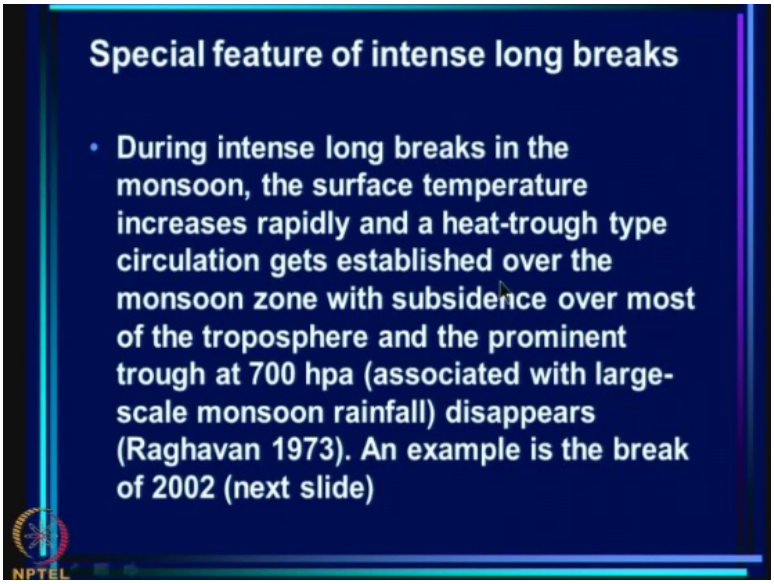

Now, let us see what is the special features of intense long breaks. During intense long breaks in the monsoon the surface temperature increases rapidly and heat-trough type of circulation gets established over the monsoon zone with subsidence over most of the troposphere and the prominent trough at 700 hpa associated with large scale rainfall disappears. This heat was first pointed out by Raghavan in 1973.

And what we are saying anyway the meridional circulation in the vertical plain for a break is like a heat low.

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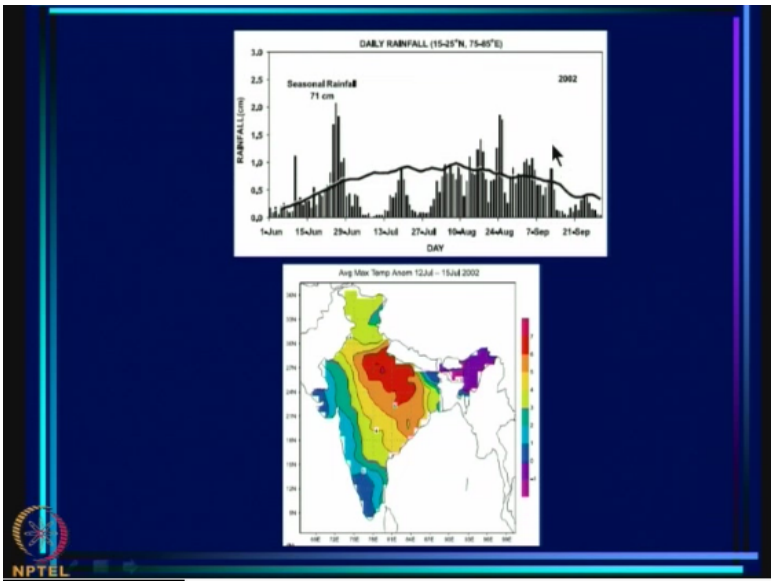

Now, what happens in intense breaks is and this is an example of the intense break that occurs in 2002 and what you see here is the average temperature anomaly for 12 July to 15 July and all the reds and yellows and so on are positive and what you see is that entire monsoon zone region is has positive anomalies in fact very large positive anomalies. And these are also positive anomalies but are not as large.

So, entire region is positive anomalies and this is something we experience whenever there is a dry spell things become very hot. Because the cloud free skye the incident radiation heats up the land. So, this is the case in which you have a genuine heat low with very large heating here sensible heating here and also structure like that of a heat low.

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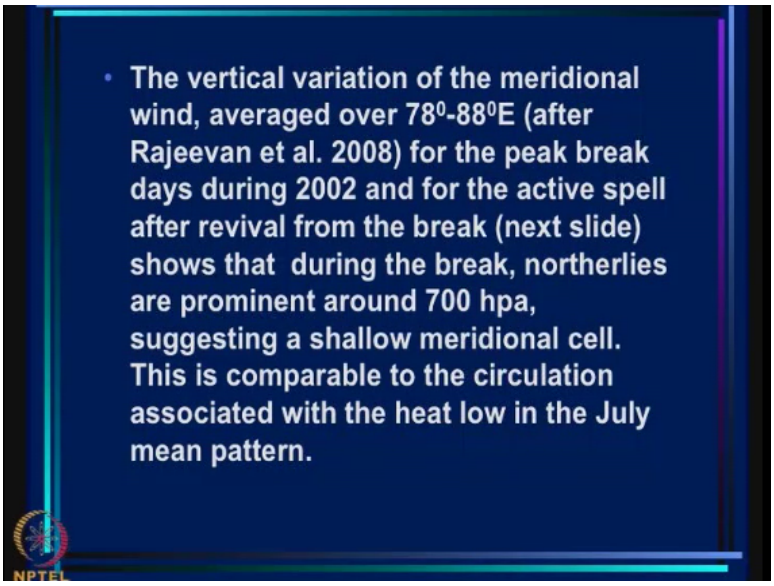

So, now we actually look at the structure what we have seen earlier was from break monsoon of Ramamurthy which was with earlier data. Now with modern data we can look at again at the meridional circulation for the break of 2002.

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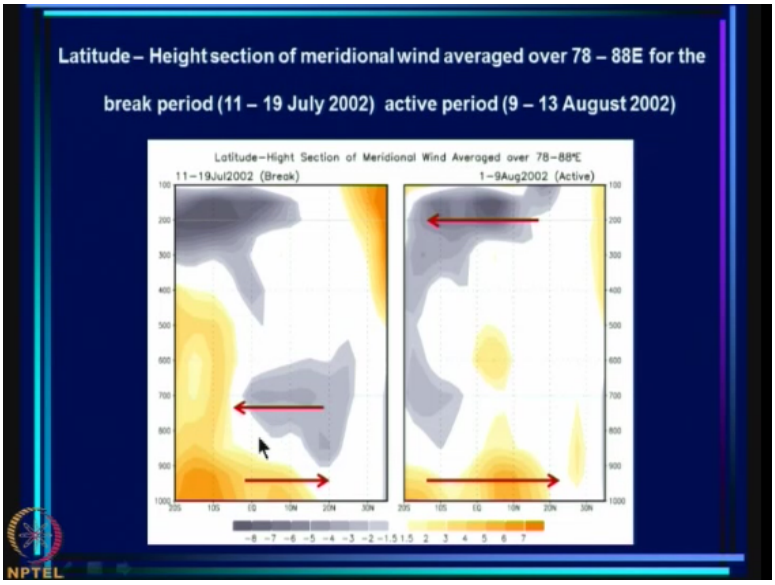

And what you see here is very interesting 11 to 19 July you see the shallow cell here and active monsoon again 1 to 9 August in 2002 you see a very deep cell here. So, this is very interesting that you get a transition from a heat low situation to a CTCG situation when you go from break to active. So, this is a very major transition that occurs.

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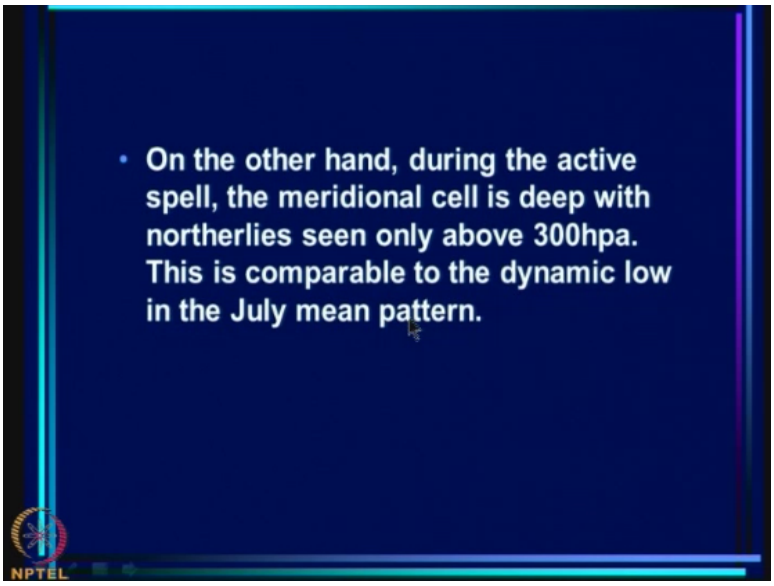

So, on the other hand during the active-spell the meridional cell is deep with northerlies seen only above 300hpa. So, this is comparable to the dynamic low in the July mean pattern. So, this is comparable to the dynamic low in the July mean pattern. This is the active situation, and remains over the same region this is the break situation. So, this is the CTCG and this is the heat low that you see. So, this is comparable to the dynamical low.

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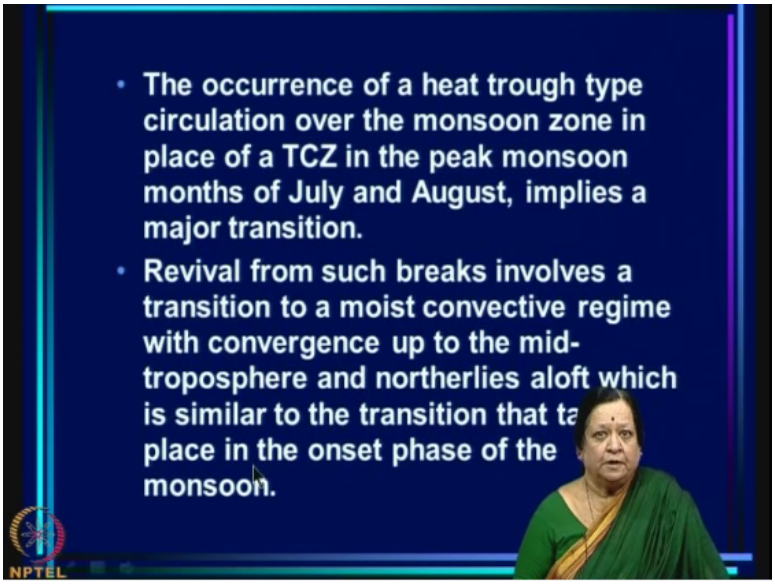

Now, the occurrence of a heat-trough that circulates over the monsoon zone in place of a TCZ in the peak monsoon months of July and August implies a very major transition. Now, revival from such breaks involves a transition to a moist convective regime with convergence up to the mid-

troposphere and northerlies aloft which is similar to the transition that takes place on the onset phase of the monsoon.

Now, as we see before the onset also in May there is heat-trough over the Indian region and the transition to having a CTCG over the Indian region takes place during the onset phase. So, revival from breaks such as these when you have a heat-trough again established over the Indian region involves a similar transition to that which is seen in the onset phase.

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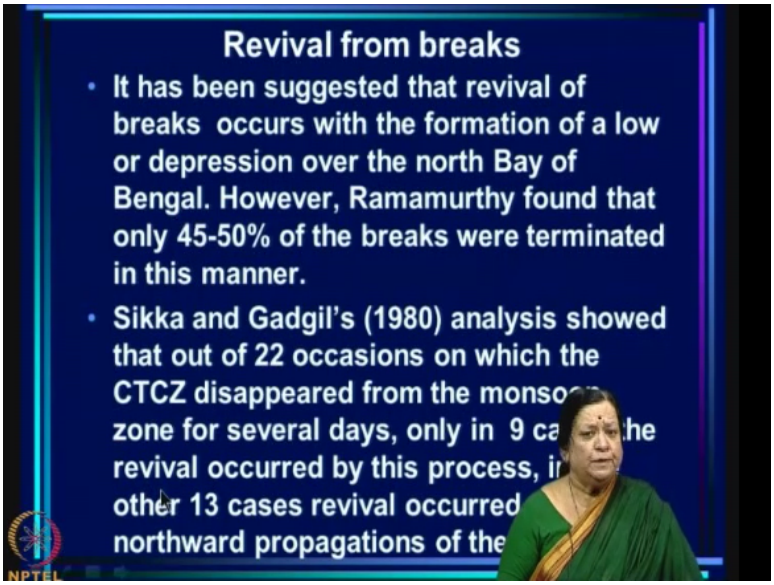

Now, we come to revival from breaks and this again it is amazing how comprehensive study of Ramamurthy has been in terms of looking at every facet of break not only describing the morphology but also describing the transitions. In another word how does the monsoon revive from breaks because remember breaks occur in the mid-season. So, it is not as if the monsoon has withdrawn for good it has to revival.

And it has been suggested that revival or breaks occurs with the formation of a low or a depression over the North Bay of Bengal this is what was traditionally believed. But Ramamurthy meticulously looked at all the breaks and how they were terminated and he said that only 45% to 50% of the breaks were terminated in this manner. So, only about half the breaks were terminated by having a genesis of a system over the north Way of Bengal.

Which then moves across the monsoon zone and revives the rain. In fact, Sikka and Gadgil's analysis showed that out of 22 occasions on which the CTCZ disappeared from the monsoon zone for several days, and this analysis is for 73 to 77 only 9 cases the revival occurred by this process, in the other 13 cases revival occurred with the northward propagations of the TCZ from the equatorial Indian Ocean. So, this is very interesting.

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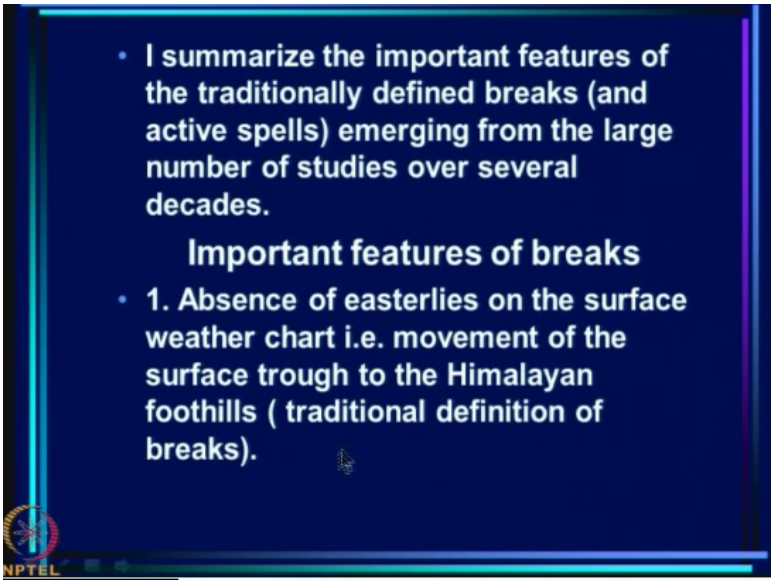

So, what are the important features of the traditionally defined breaks and active-spells emerging from the large number of studies over several decades and the first of course is the way breaks are defined by Ramamurthy and IMD definition of breaks also the same thing. So, absence of easterlies on the surface chart that is movement of the surface trough to the Himalayan foot hills this is the traditional definition of breaks.

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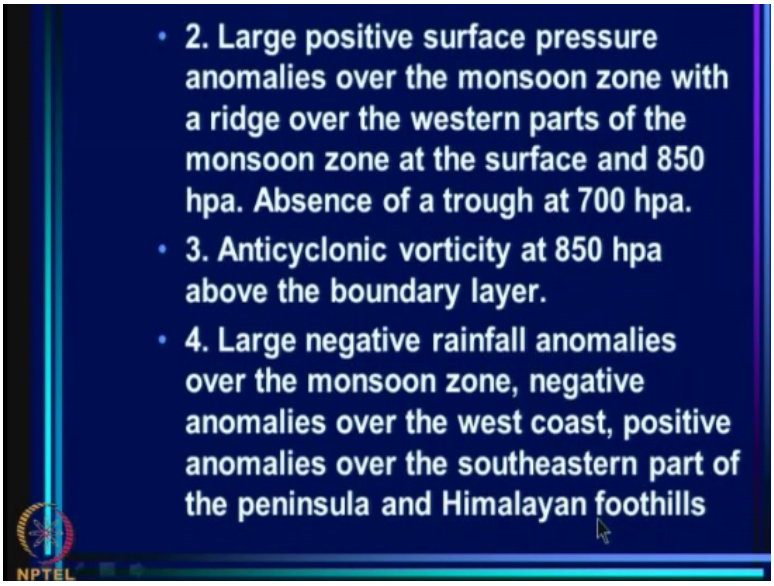

Then we have seen another characteristics is of course large positive surface pressure anomalies over the monsoon zone with a ridge over the western parts of the monsoon zone at the surface and 850 hpa. Absence of a trough at 700 hpa this is a very important feature because this also indicates that there is no moist convection during break period over the monsoon zone. Now, anticyclonic vorticity at 850 hpa above the boundary layer.

So, this implies that there would not be ascend at the top edge of the boundary layer and large negative rainfall anomalies over the monsoon zone, negative anomalies also over the west coast. But positive anomalies over south eastern part of the peninsula and Himalayan foot hills. So, this is the signature of the breaks.

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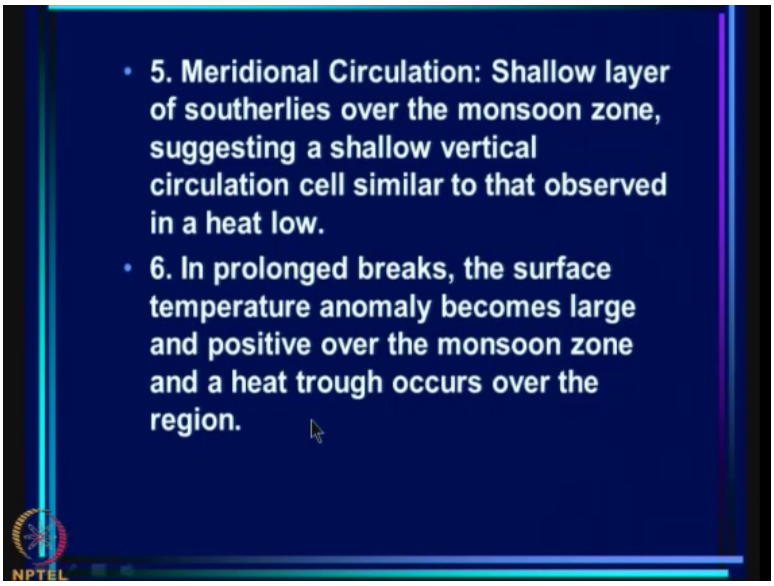

We have also seen that the meridional circulation for breaks is shallow layer of southerlies over the monsoon zone suggesting a shallow vertical circulation cell similar to that observed in a heat low. And in fact in prolong breaks the surface temperature anomaly becomes large and positive over the monsoon zone and a heat-trough occurs over the region.

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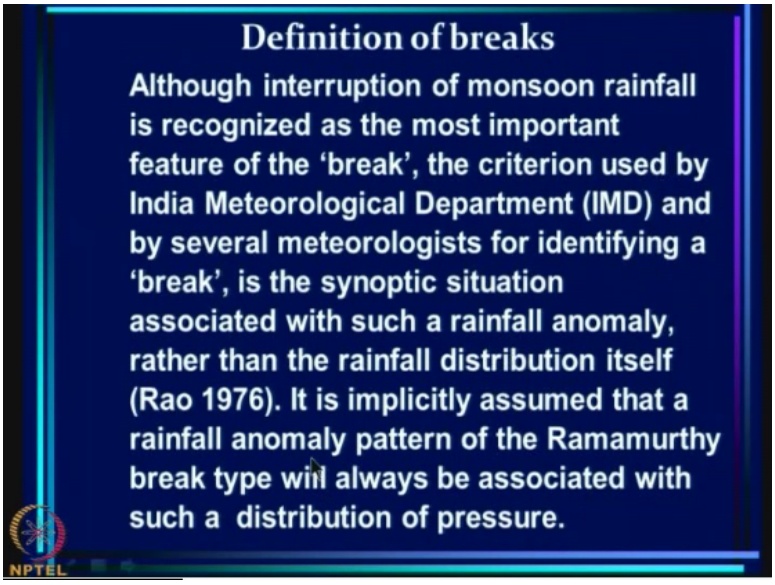

So, these are the major features of the breaks and so far we have been talking of breaks as defined by absences of easterlies on the surface weather charts. Now, although interruption of monsoon rainfall is recognized as the most important feature of the break the criteria used by Indian Met department and by several meteorologists for identifying a break is the synoptic situation associated with such a rainfall anomaly.

Because although Blanford talk of height of rain he does not talk of a synoptic situation and intervals of drought so he is talking of rainfall. And we all associate it break monsoon with a major negative rainfall anomaly. But the way break is defined it is on the bases of winds the synoptic situation associated with such a rainfall anomaly. It is implicitly assumed that a rainfall anomaly pattern of Ramamurthy break type will always be associated with such a distribution of rain pressure.

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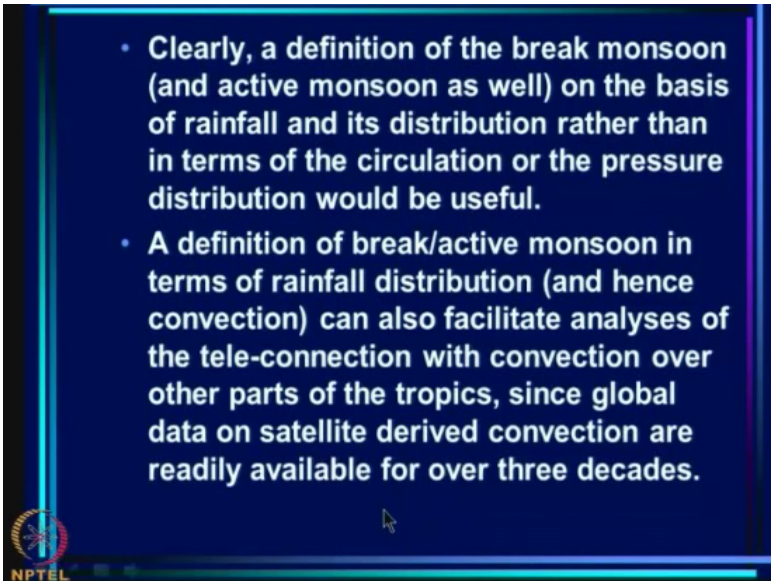

Now clearly it would be useful to have a definition of break monsoon and active monsoon on the bases of rainfall and its distribution rather than in terms of circulation and pressure distribution. So, a definition of break in active monsoon in terms of rainfall distribution and hence convection so we can also talk in term of how the OLR anomalies would be. Can also faciliate analysis of tele-connection with convection over other parts of the tropics.

Since global data on satellite derive convection are now readily available for over 3 decades.

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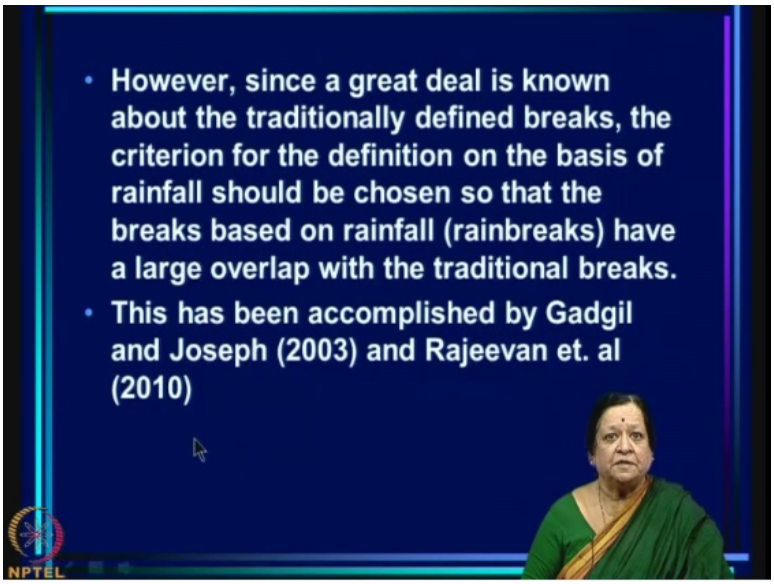

However, since a great deal is known about the traditionally defined beaks, the criteria for the definition on the basis of rainfall should be chosen so that the beaks based on rainfall which we can call rain breaks have a large overlap with the traditional breaks. Now, these actually have been accomplished in 2 recent studies one is by Gadgil and Joseph in 2003 and another by Rajeevan and another in 2010.

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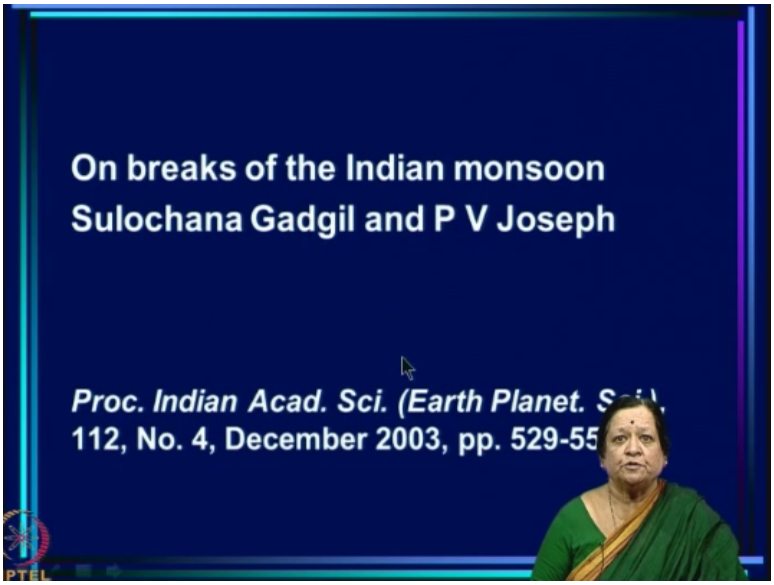

So, this is the paper on breaks of the Indian Monsoon by Gadgil and Joseph in 2003.

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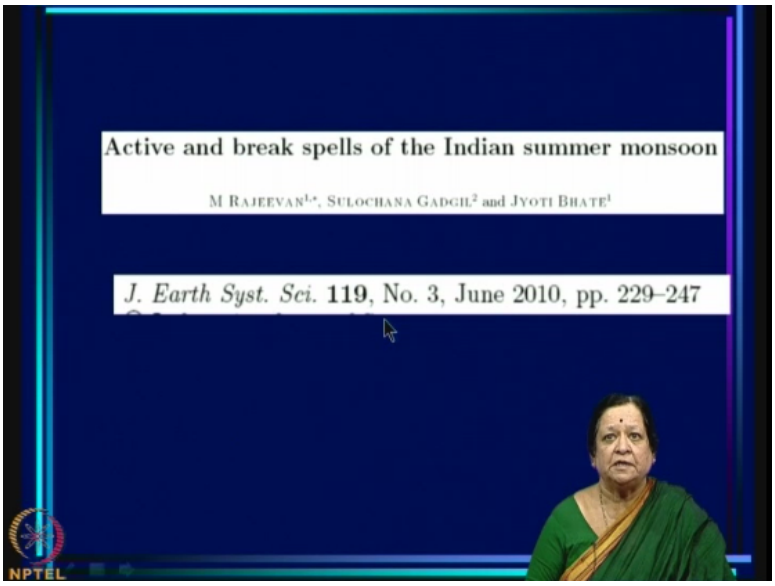

And this is the paper that appeared in the same journal in 2010. Active and break spells of the Indian summer monsoon.

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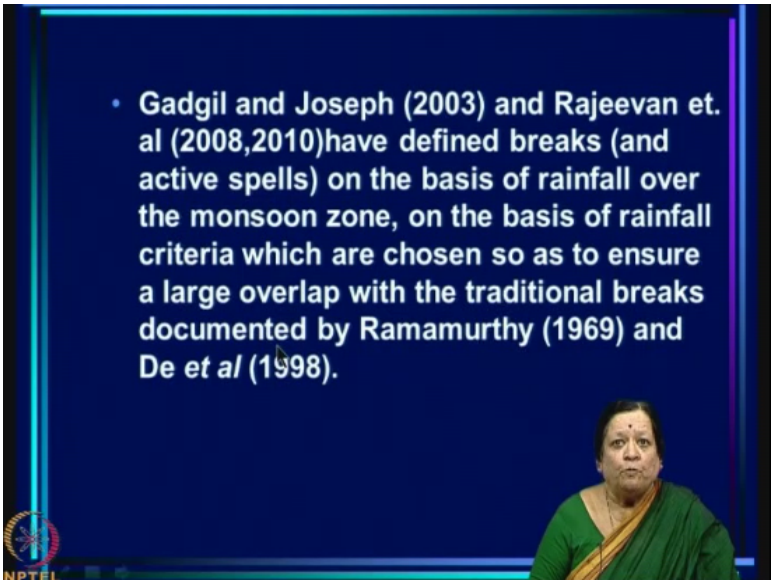

Now, Gadgil and Joseph have defined breaks on the bases of rainfall over monsoon zone. Remember we have emphasized that traditional definition really involves conditions primarily over the monsoon zone. So, they have also defined breaks on the bases of rainfall over the monsoon zone. On the bases of rainfall criteria which are chosen so as to ensure maximum overlap with the traditional breaks documented by Ramamurthy and De.

See between Ramamurthy and De traditional base has been documented from 1888 to 1997. So, if we use rainfall data then we should be able to check to what extent breaks defined using rainfall with criteria that has chosen overlap with those of Ramamurthy and De and in fact that is what they have done.

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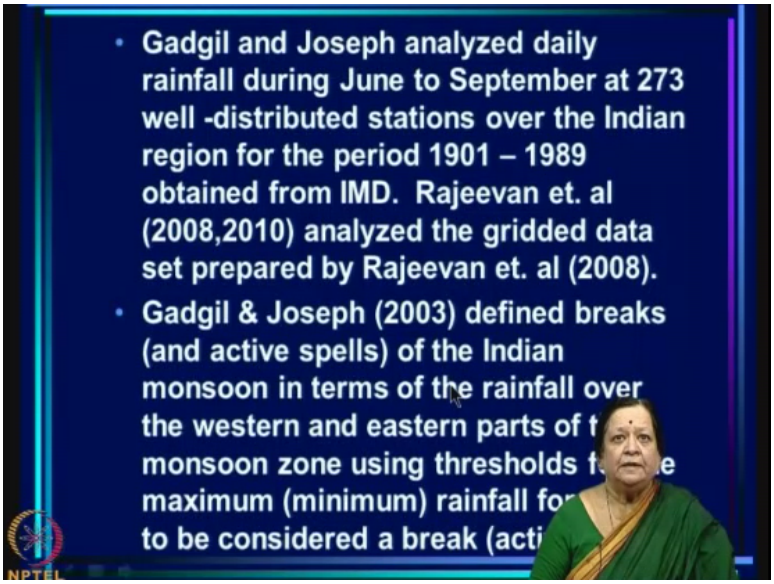

And in fact at this point I want to stop this lecture and from the next lecture we will look at what happens when we define breaks in terms of rainfall and we will also confirm that the characteristics morphology that was identified by Ramamurthy and others to what extent is it also the morphology of the rain breaks and so on. And then look at a large number of definitions of breaks by many scientists.

Because for some reason the word break monsoon or breaks has become extremely since the 80's and everybody seems to have their own definition of break. We will look at implication of that vis-a-vis the rain breaks also in the next lecture. Thank you.