The Monsoon and Its Variability
Prof. Sulochana Gadgil
Centre for Atmospheric & Oceanic Sciences
Indian Institute of Science – Bangalore

Lecture – 21
Active-Weak Spells and Breaks in the Monsoon - Part 2

We are discussing the fluctuations between active and weak-spells within the monsoon season and particularly the intense weak-spells which are called breaks. What we have looked at in the last lecture is how breaks have been defined traditionally and what are their attribute in terms of the patterns of pressure, wind, rainfall etcetera. Now, we try to start with slightly another approach in trying to define breaks in terms of rainfall over the monsoon zone.

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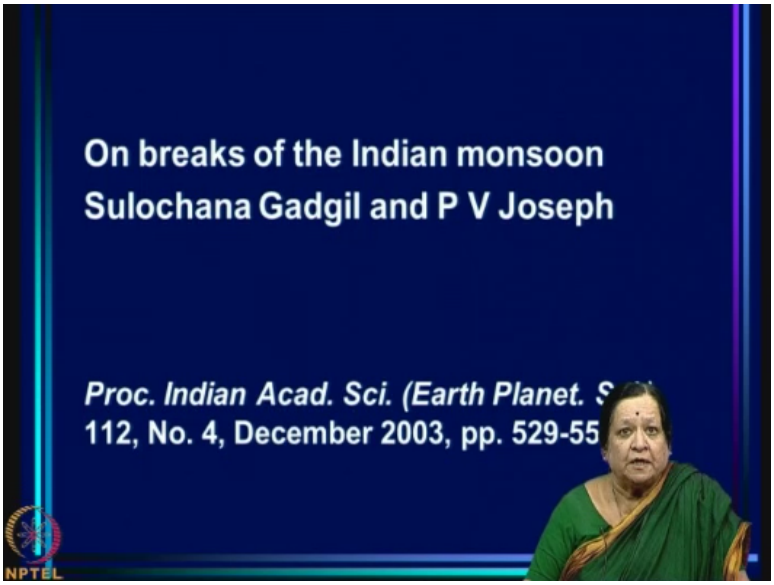

As I mentioned last time the traditional definition of breaks is on the bases of surface winds. Breaks are said to occur when there is no easterly winds in the surface wind charts over the Indian region. Now, what we would like to do is to define breaks in terms of rainfall because after all the original definition of active weak spells or as active weak-spells of monsoon as we understand it.

In fact, involve lot of rain and active-spells which Blanford's as you know called spells at the height of rains and intervals of drought as he called them which involved dry-spells or relatively dry-spells during the monsoon. So, it would be good to define breaks also in terms of rainfall and

this was done in a set of 2 studies first was by Gadgil and Joseph in 2003 and followed by Rajeevan and et al 2010.

So, let us discuss to begin with how we define breaks in terms of rainfall and what are the implications in terms of morphology of the breaks.

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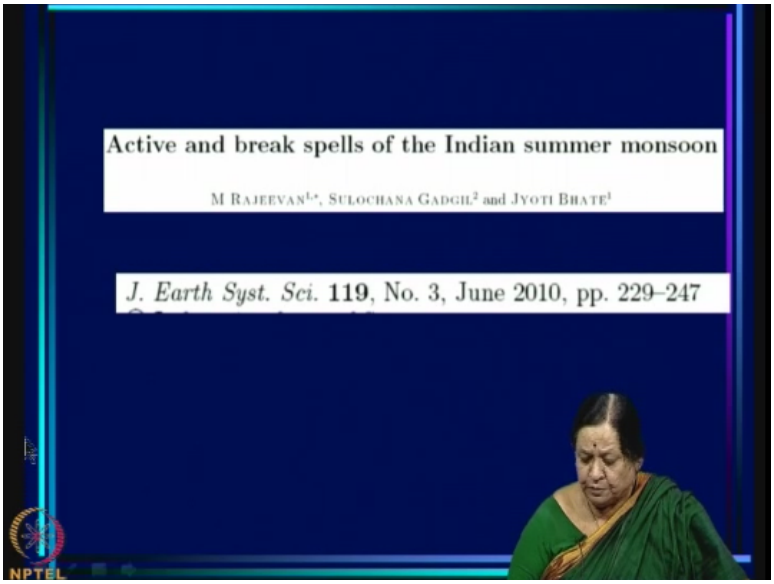

So that was the first paper and the second is Rajeevan and et al. in 2010 which also looked at the same thing.

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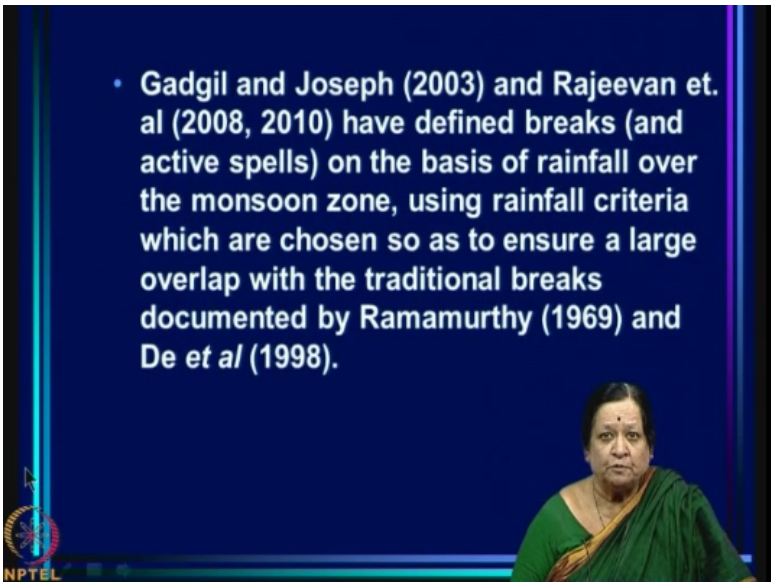

So, Gadgil and Joseph in 2003 and Rajeevan et al in 2008 and 2010 have defined breaks and active spells as well on the basis of rainfall over the monsoon zone, using rainfall criteria which are chosen so as to ensure a large overlap with the traditional breaks documented by Ramamurthy and De et al.

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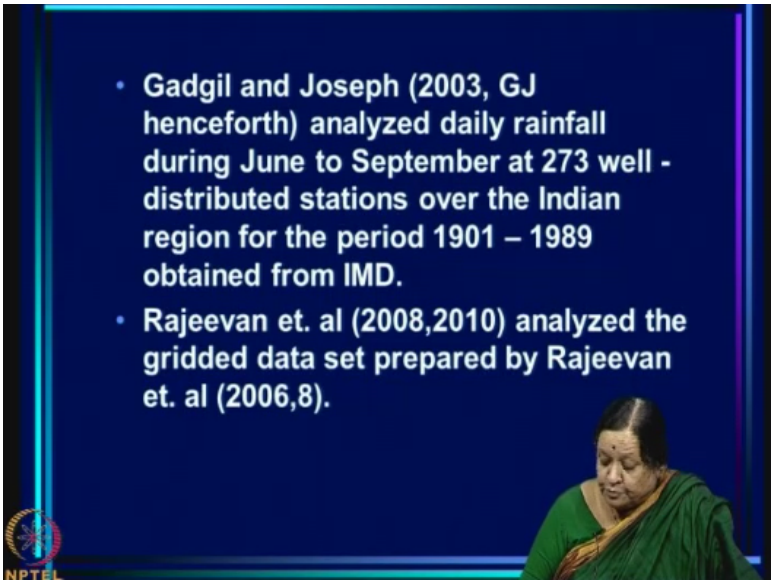

Now, why did they do that? Because there is a large body of literature pertaining to breaks defined in the traditional way and if there is a lot of overlap between the rain breaks as defined from rainfalls and these breaks then our understanding of these breaks one can use all the understanding gained from the large body of work that exists earlier. So, in fact they choose the criteria so that there was maximum overlap with the traditional breaks.

Now, the bases for Gadgil and Joseph work was that they had data for 273 well-distributed stations over the Indian region for the period 1901 to 1989 obtained from IMD. So, this was the bases for the work of Gadgil and Joseph. On the other hand, Rajeev and et. al had prepared in an earlier set of papers and presented in an earlier set of papers grid data for the Indian region. Initially, it was at 1 degree later on it was higher resolution at .5 degree. So, they used the grid data as the bases.

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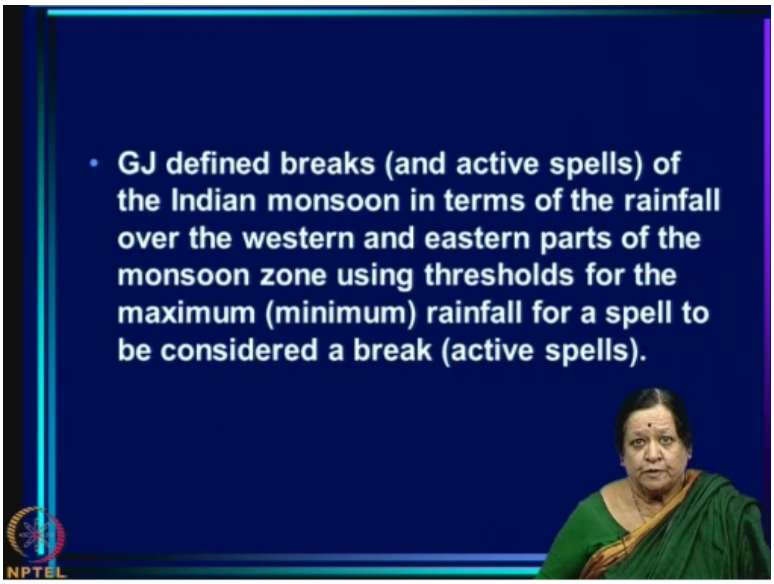

Now let me begin with Gadgil and Joseph and Gadgil and Joseph which I will hence forth say GJ defines breaks an active-spell of the Indian monsoon in terms of the rainfall over the western and eastern parts of the monsoon zone using thresholds for the maximum, minimum rainfall for a spell to be considered as a break or active-spell.

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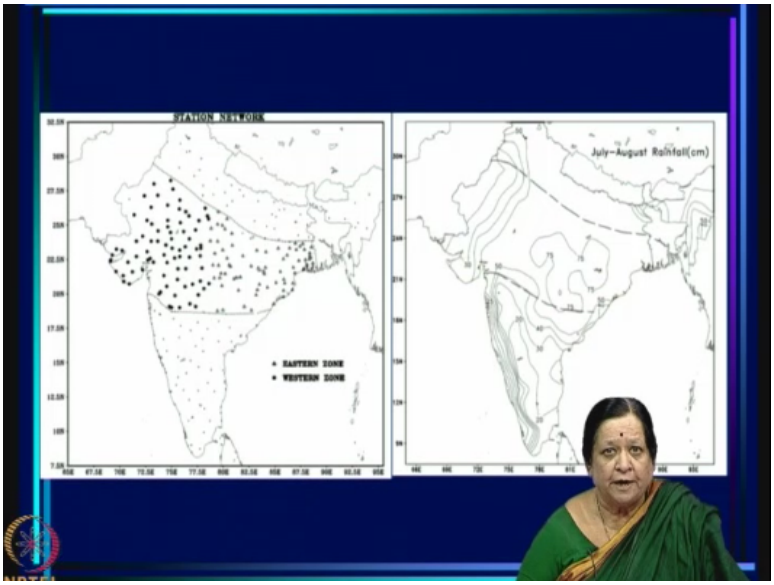

Now, this is the monsoon zone that you see and this is the ne2rk of stations that Gadgil and Joseph had at their disposal. What they did was to divide it into 2 zones, western zone and eastern zone. Now you see this is the mean rainfall over the monsoon zone and you can see that it is quite large over the eastern zone but smaller, much smaller over the western zone. So, now why did they have 2 zones?

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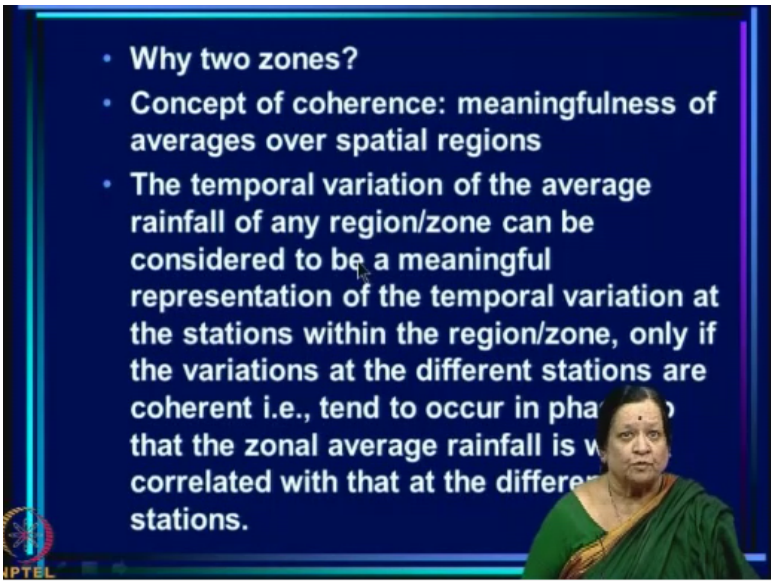

See when we are looking at averages over the region it is a good idea to take a region over which variations of rainfall at individual stations within a region are coherent. Otherwise, the areal average is not representative. To a give a simple example if half the fluid is boiling and the other half is resting over ice and we take the average temperature, that will be 50 degree. Now, that average temperature is not a very meaningful average.

Because part of the fluid is actually boiling and other part is very, very cold. So, it is not representative of any part of the fluid but it is an average. So, same way if we have a reason over which some of the stations have above normal rainfall and other stations have large deficit in rainfall and we make an average of over all those stations that average may be above rainfall or below rainfall depending on how many stations were above normal or below normal.

But that average will not be a meaningful representation of all the stations. This is why it is important to look at regions over which variations of rainfall are coherent. So, the temporal variation of the average rainfall of any region or zone can be considered to be to be a meaningful representation of the temporal variation of stations within the zone. So, we are saying is the average over the region.

Reasonable representation of what is happening at individual stations within a region. So, it can be considered to be so only if the variations at the different stations are coherent that is to say they tend to occur in phase so that the zonal average rainfall is well correlated with that at the different stations. So, it is important to ensure that and with the station data that we had it was not so for the entire monsoon zone.

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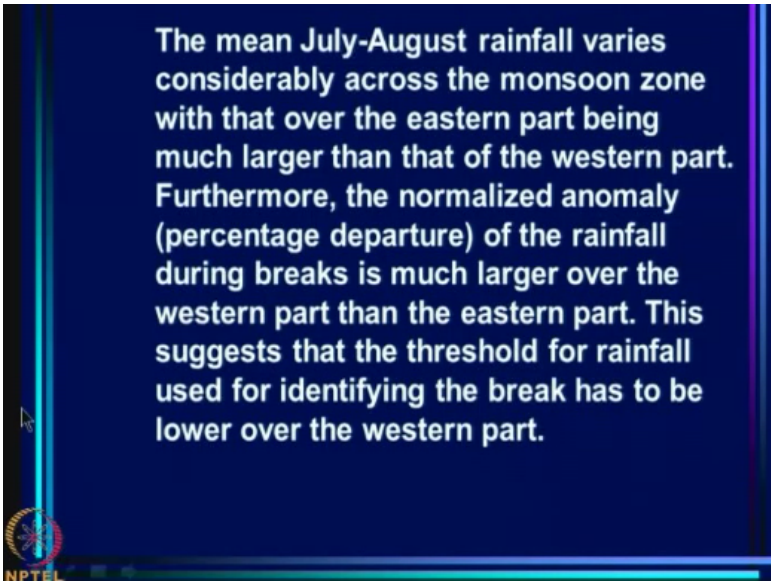

Now, the mean July, August as I have pointed varies considerably across the monsoon zone with that over the eastern part being much larger then that over the western part. Furthermore, the normalized anomaly which is to say the percentage departure of the rainfall during breaks. The picture from Ramamurthy we show earlier where it was seen that the percentage departure over northwest goes from 60% to 80% over parts.

Whereas over the eastern zone percentage wise it was smaller so this means that since the normalized anomaly of percentage departure of the rainfall during breaks is much larger for the western part then the eastern part. So, this suggest that the threshold for rainfall used for identifying the break has to be lower over the western part then the eastern part. Because the mean is also lower and the percentage departure is higher for breaks.

So, we need to have separate threshold for these 2 regions.

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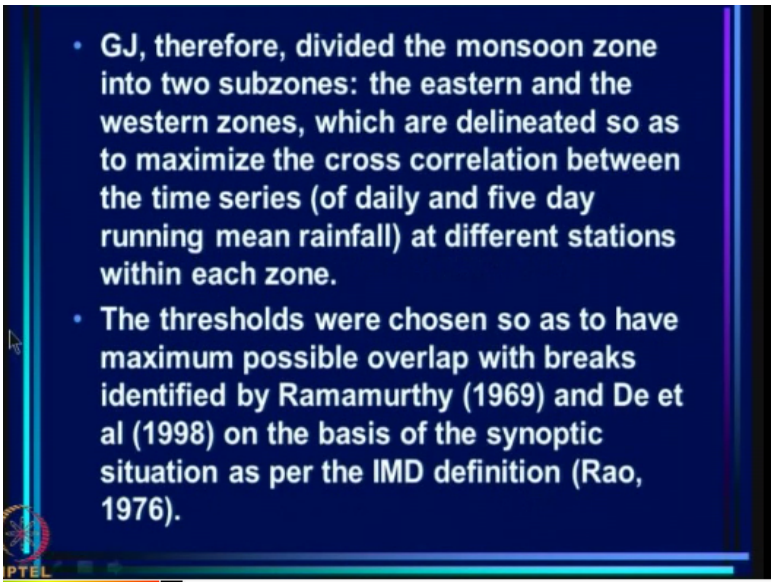

And GJ, therefore, divided the monsoon zone into 2 subzones: the eastern and the western zones which are delineated so as to maximize the cross correlation between the time series of daily and 5-day running mean rainfall at different stations within the zones. So, I am not going to get into details of that but the idea was to determine zones which are coherent with respect to variation of rainfall on daily and 5-day running mean scales which is the scale of interest here for inter seasonal variation. Now, with this kind of a constraint then they choose these 2 regions.

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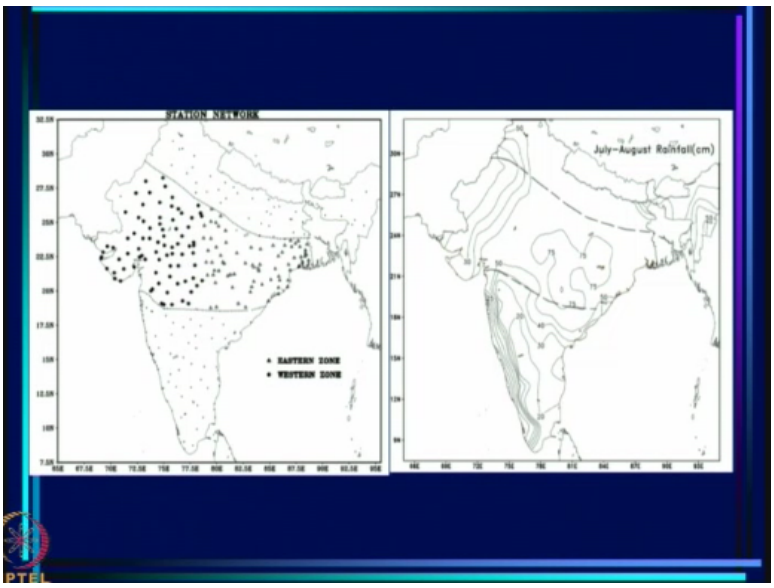

So, this is the western region and this is the eastern zone. Western zone and eastern zone and these are chosen such that the cross correlation between the time series at different stations within a zone are maximum. So, the boundary is determined so that each zone is coherent and

within the zone the cross correlation between any pair of stations times series at any pair of stations is significant.

So, this is this is how the zones were identified and then one had to choose thresholds for western zone and eastern zone so that one can define break days and active days. Now, as I mentioned before these thresholds were chosen so as to get maximum overlap with breaks identified by Ramamurthy for the period 1888 to 1967 and the later breaks up to 1997 identified by De et al and these were identified using the IMD definition of breaks.

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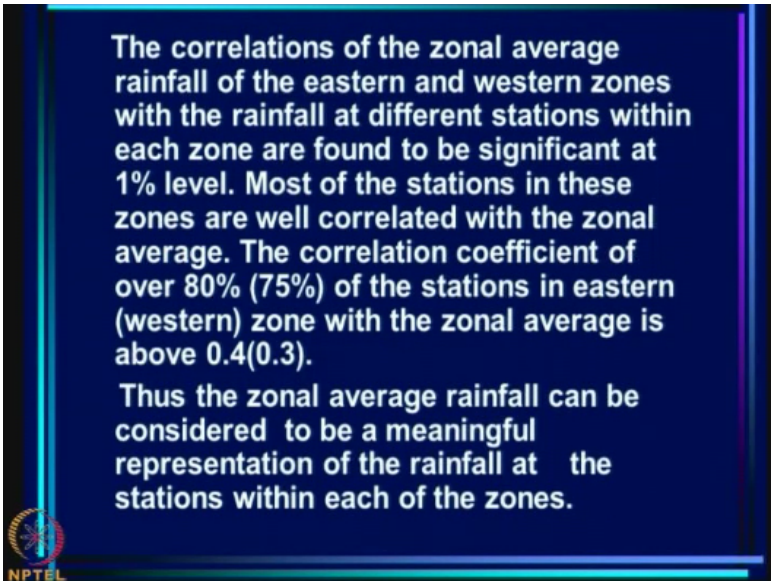

Now, we have seen that the correlation of the zonal average rainfall for eastern and western zone with the rainfall at different stations within each zone are found to be significant at 1% level. And most of the stations in these zones are well correlated with the zonal average and correlation coefficient of over 80% per 75% of the stations in eastern and western zone with the zonal average is above 0.4 or 0.3.

This is simply saying that the zones we have determined are coherent. And so the zonal average rainfall can be considered to be meaningful representation of the rainfall at the stations within each zone.

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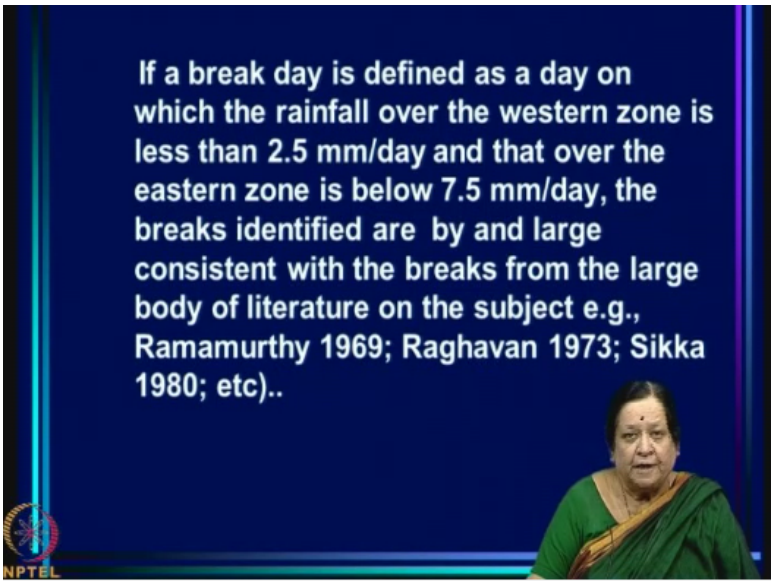

Now how do we define a break day? If a break day is defined as a day on which the rainfall over the western zone is less than a particular threshold and that over the eastern zone is also below another threshold, then it is a break day. Then we determine these 2 thresholds so as to get maximum overlap with Ramamurthy breaks and day breaks. Then we find that if we choose the threshold for western zone to be 2.5 millimeters.

And for the eastern zone to be 7.5 millimeters a day then the breaks we identify are by and large consistence with the breaks from the large body of literature on the subject such as Ramamurthy, Sikka and of course De et al and so on and Raghavan. So, these were determined these thresholds were determined primarily from the overlap thing.

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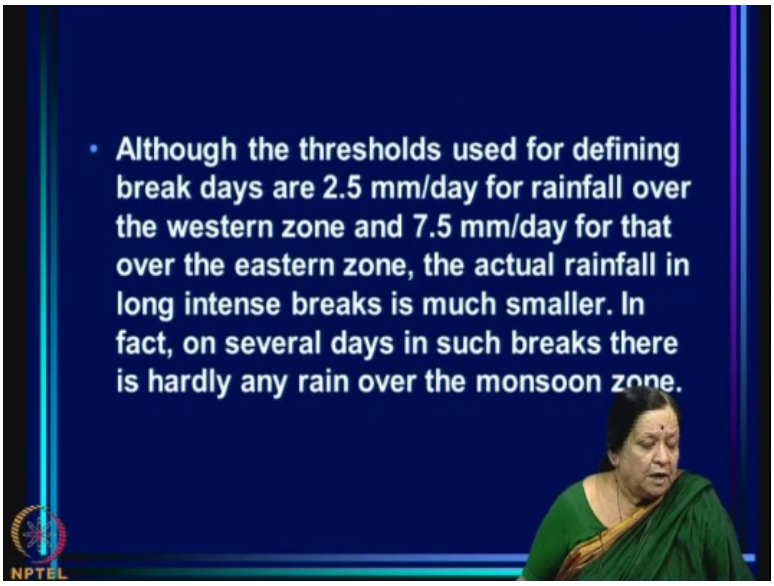

Now, I should mention that one may think oh, threshold of 2.5 millimeter a day that means there is still some rain on an average over the western zone during the break. But actually when we determine break days using these 2 thresholds the actual rainfall in long intense breaks is very much smaller than 2 millimeter per day. In fact, very often close to zero particularly particularly on the western zone.

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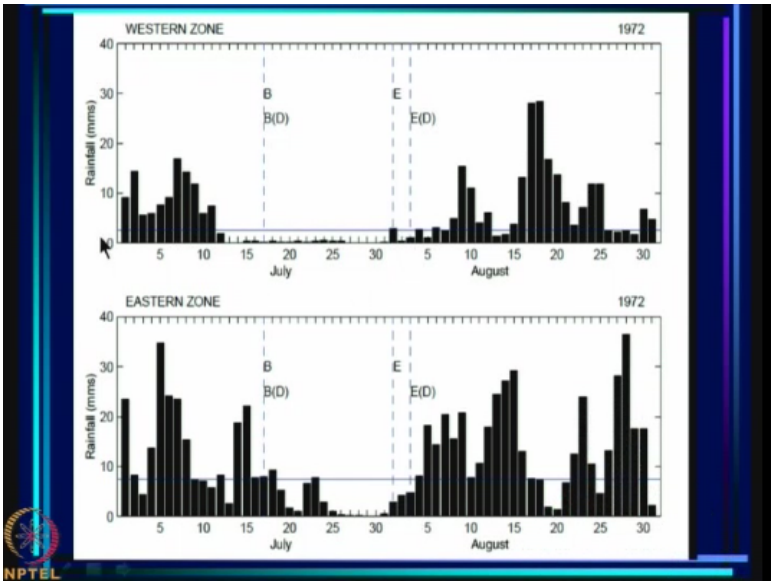

And I show you and example here. This is 1972 and this is the break of 1972 and you can see that this on the scale of 0 to 10 millimeters and you can see that actually there is hardly any rain over the western zone for a long period including few days preceding the break. And in the

eastern zone there is some rain in the initial part and actually almost zero rain towards the end of the break. This is when it has become intense. So, these are the thresholds here.

So, these are the thresholds that were imposed for defining a break but in actual the rainfall on those days during the break is very much smaller in fact very close zero.

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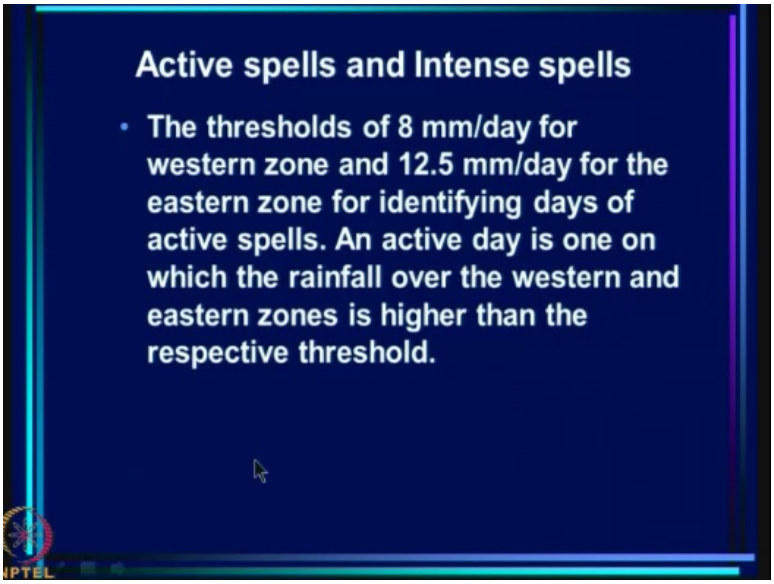

Now, how do we define active-spells and intense-spells? So, thresholds of 8 millimeter per day for western zone and 12.5 millimeter per day for the eastern zone were chosen for identifying active-spells. Now, an active day is one on which the rainfall over the western and eastern zones is higher than the respective threshold. So, western zone has to be higher than 8 millimeter per and eastern zone has to be higher than 12.5 millimeter per day for it to be an active spell.

So, active spell then we (()) (12:33) as one in which it is raining all over the monsoon zone. Both over the western zone as well as the eastern zone both the sub-regions of the monsoon zone it rains. And provided that the rain is high enough to be above the threshold for the averages then we call it an active day.

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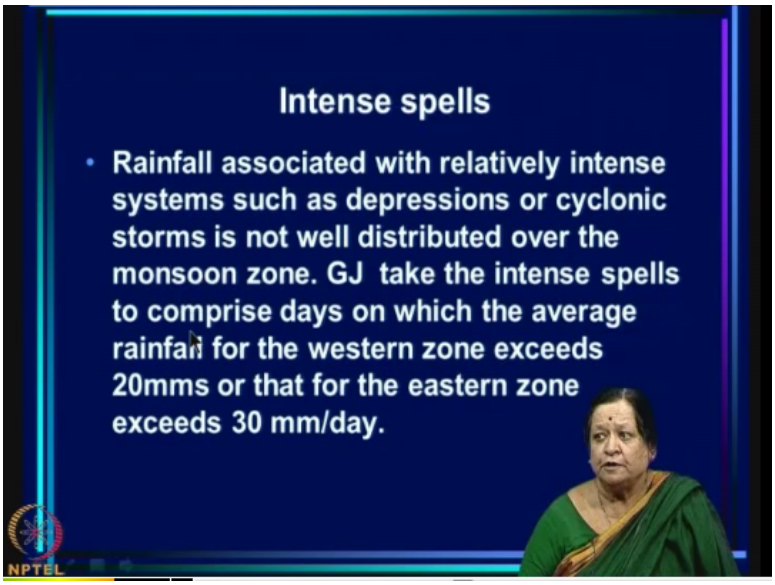

And continuous days with active days are called active-spells. Now, there are in addition to this active-spells in which the rainfall is occurring all over the monsoon zone. There are some days on which rainfall is associated with relatively intense system such as depression, cyclonic storms and so on. For these intense systems the rainfall is not well-distributed over the monsoon zone rather heavy rainfall occurs only in the region of influence of that system which is smaller than the monsoon zone on any day.

So, GJ take the intense spells to comprise of days on which the average rainfall for the western zone exceeds 20 millimeter or that for the eastern zone exceeds 30 millimeter. So, again they have 2 thresholds for it to make it as an intense category over the eastern zone it has to be more than 3 centimeters. For the western zone it has to be more than 2 centimeters but these 2 do not have to be simultaneously satisfied.

For intense rainfall criteria to be met. Intense spell can occur either over one or the other zone. So, this is how intense spells are defined.

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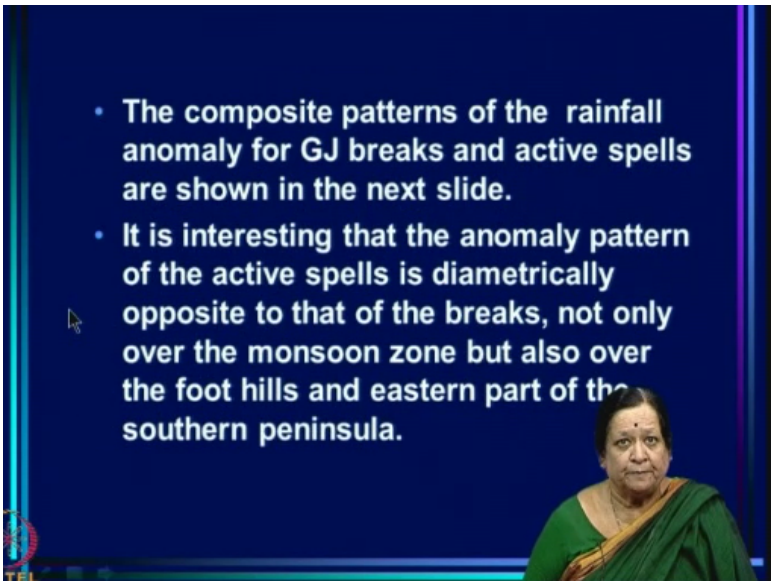

Now the composite patterns of rainfall anomaly for GJ breaks and active spells are shown in the next slide.

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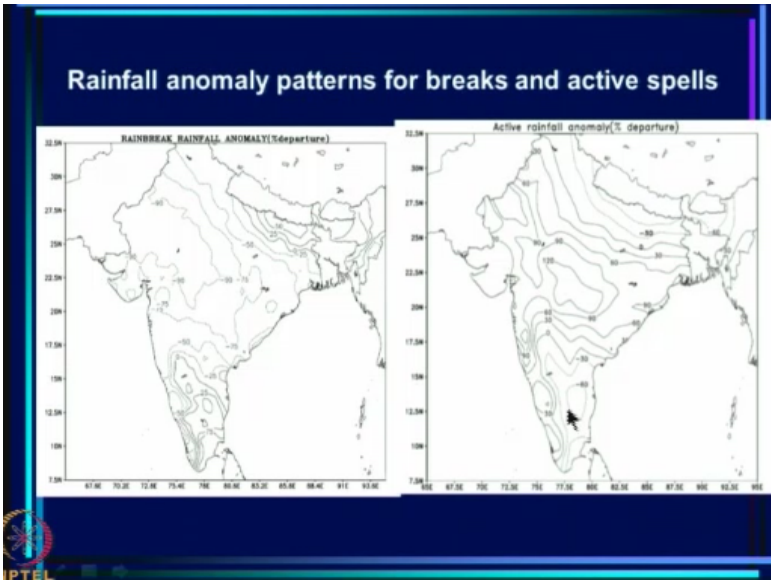

And what you see here primarily that for the break you have entirely negative anomalies here and active spells you have entirely positive anomalies here. You see also that over southeast part of peninsula there is a reversal of same. And over the foot hills of Himalayas also there is a reversal of same. So, in fact it is very interesting that given this definition that we have of the rain break what we get is actually 2 mirror images.

Active spell rainfall over the monsoon zone the anomalies is a mirror image of this one with all the signs of the anomalies changed to the opposite sign. So, negative anomaly here changes to positive anomaly here and you have positive anomaly here which changes to negative anomaly here and similar to for the foothills. So, this is an interesting point.

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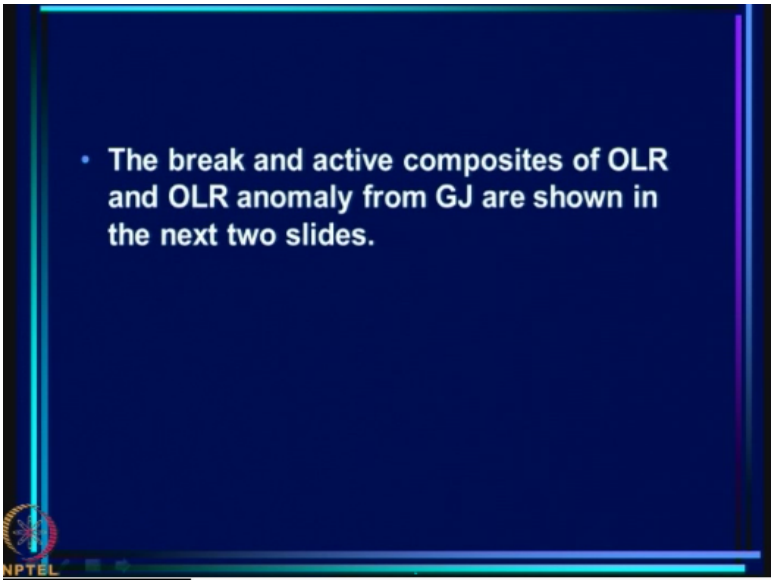

Now, the break and active composite of OLR and OLR anomaly are seen here.

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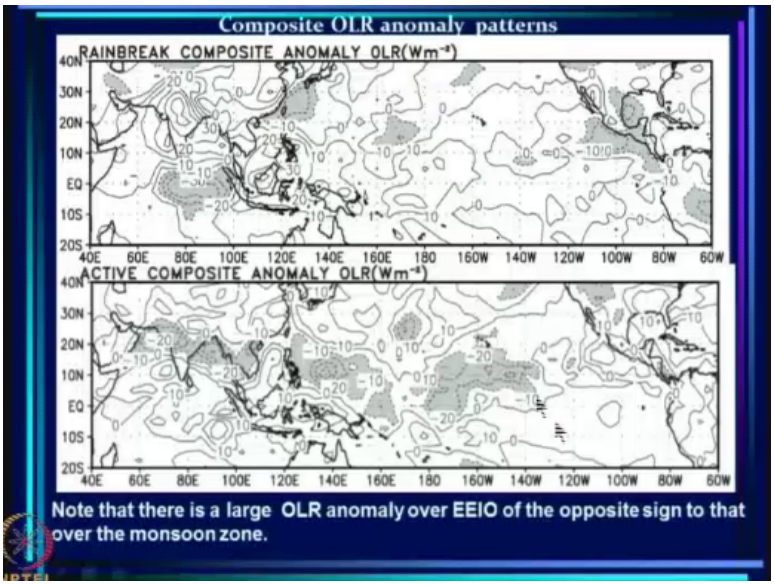

Now, first of all let us see the composite of the OLR anomaly. Let me remind you that outgoing long way radiation when it is low it means that the emitting surface is very, the cloud tops are very high and we have deep convection and rainfall. So, if we have a negative anomaly of OLR

this means there is going to be more rain. And positive anomaly means rain is supressed. So, for the break anomaly natural you see over the Indian region.

A huge supression of rainfall or a big positive anomaly. Notice that the west coast also has a similar sign here of the anomaly and let me just go back and point out here that even in for the break and active by and large the west coast anomalies are of the same sign as those on the monsoon zone. That is to say during active spells of the monsoon the west coast also tends to be active and during breaks the west coast also tends to have supressed rainfall.

But our criteria were based only on the monsoon zone. So, it so happens that the correlation is such that most of the time the west coast rain is in phase with the rain of the monsoon zone. This is something to remember. And now we look at the OLR anomalies and OLR anomalies show that very clearly. That during breaks the west coast also seems to have a break or supression of rainfall.

But the biggest signal is here over the eastern equatorial Indian Ocean here there is huge negative anomaly. This means that the convection is flaring up here. There is more rain here during breaks and let me remind you that actually this was pointed out by Koteswaram long ago that there is a formation of lows in the equatorial region and Simson also suggested that in fact the equatorial Indian ocean rainier during breaks. So, it is a manifestation of this that you see.

Notice that in fact corresponding to this positive OLR there is also a positive OLR here which means convection is supressed also over the west pacific but to its north it is enhanced here. And this has been called a quadrupole because you can see this and this are opposite signs. This and this are opposite sign. This is a quadrupole characterizing the break. Now, if we go to the active spell.

What we find is that the major feature namely out of phase variation with the eastern equatorial Indian Ocean is there. So, that when it is active here it is actually supressed over the eastern equatorial Indian Ocean as you see here. But you do not quite see any equivalent of a quadrupole

here and that is to say you do not see a mirror image of active and break signatures over the west pacific. It is somewhat more complicated than that.

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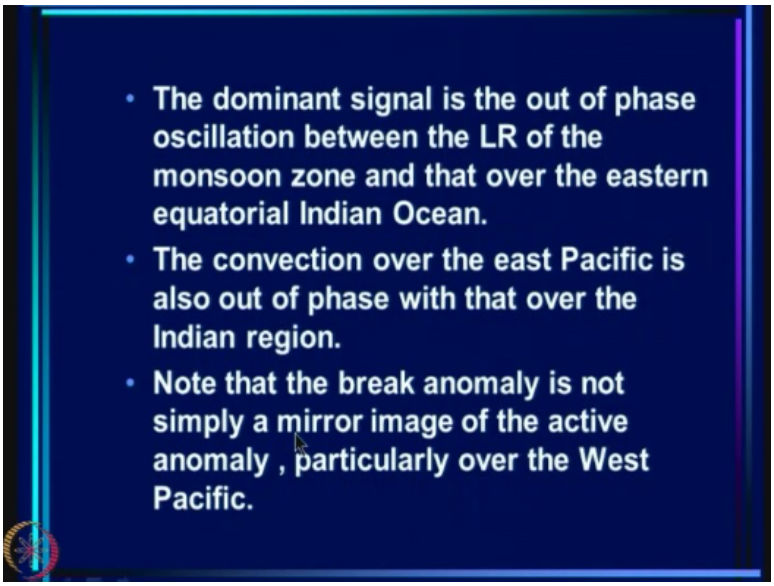

So, the dominant signal is the out of phase oscillation between the OLR of the monsoon zone and that over the eastern equatorial Indian Ocean. The convection over the east Pacific is also out of phase with that over the Indian region and this I should point out to you. See here this is the break anomaly is positive over the Indian region and notice that over east Pacific here it is negative.

And for the active phase exactly opposite holds when it is positive over the Indian region there is a signal here as well. So, it is interesting that when we wrote this paper here we did talk about the east Pacific but we did not emphasised this sea show in convection between Indian region and the eastern equatorial Indian Ocean. The importance of this eastern equatorial Indian Ocean downed on us only later on.

And then when we went back and looked at the composite low and behold it was very much there. I will come to this aspect of the link of monsoon to convection and the equatorial Indian Ocean in later lectures. But it turns out that the link is very strong. As I mentioned, note that the break anomaly is not simply a mirror image of the active anomaly particularly over west Pacific. Now, these are the OLR composite patterns.

So these are not anomalies this is the actual average OLR for break and for active. What you see for active what is done is only 240 onwards is plotted and within 200 regions are shaded. This is 240 comes to here in fact 255 has also been plotted but 240 is this contour here. This is 240 watts per meter square is considered as the limiting OLR that is to say OLR below 240 generally is associate with deep convection and rainfall.

And of course OLR below 200 is very much so and what you see is that during breaks we have rain over this region. And over the equatorial region but the eastern part not over the western part and of course Indian region is dry. Whereas during active case we have suppuration of rainfall over here you see very OLR here. Little bit of actually enhancement of rain over the western part.

So, there is convection seems to be in phase with rest and out of phase with the eastern equatorial Indian Ocean as I said we will come back to this point. Another interesting thing to see is that you look at the active composite it appears as if this TCG is in fact coherent right across or all the way from India up to the east Pacific here. This is a very interesting thing. So, active phenomena seem to be a have organization of convection. Over a very, very large scale compared to breaks.

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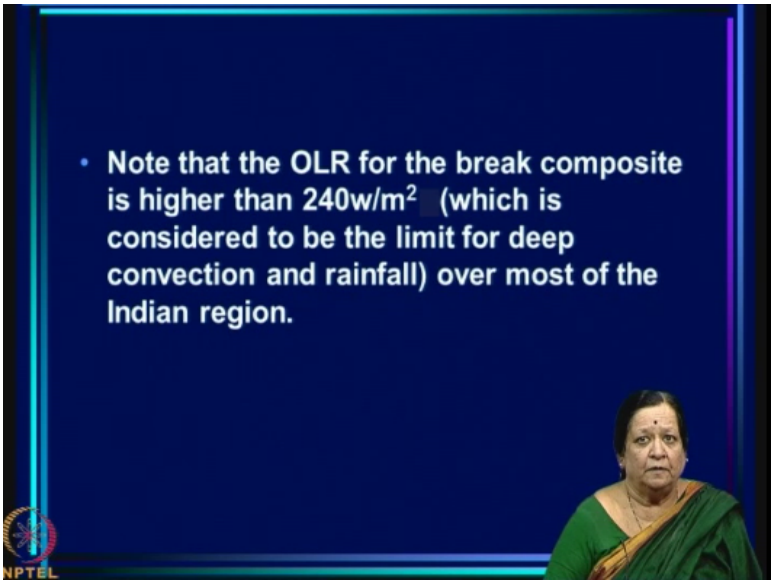

So, this is the interesting point we have to look at. Now, as I mentioned OLR for the break composite is higher than 240 watts per meter square which is considered to be the limit for deep convection and rainfall over most of the Indian region.

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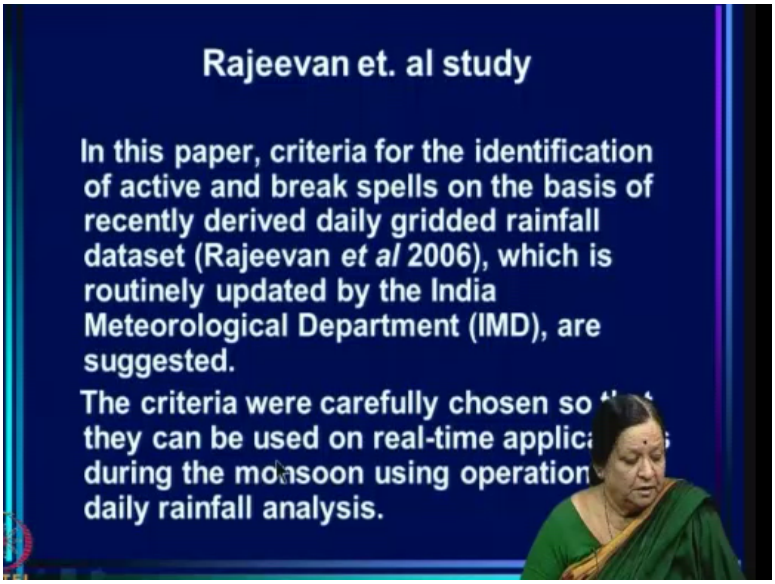

Now these are the main results that I mentioned from the Gadgil, Joseph study Rajeevan and De et al study is somewhat similar because in fact it is rather similar because it again tries to define thresholds such that there is maximum overlap with traditional breaks and it is also based on rainfall over India and particularly rainfall over monsoon zone. The difference is in the basic data set. So, in this paper as I mentioned here the criteria for the identification of active.

And break spells on the bases of recently derived daily graded rainfall data set. So, the basic data set they have used is the data set derived and that in fact presented by Rajeev and De et al in 2006. Rajeev was at IMD then derived by IMD which is a daily graded rainfall data set which we use to be 1 degree gridded and which is actually routinely updated by the India Meteorological Department.

So, using these data criteria for identification of active and break spells are suggested. And the criteria are carefully chosen so that they can be used on real-time applications during the monsoon using operational daily rainfall analysis. So, this is the value of this work that in fact

one can operationalized the definition of break and active spells by using the criteria they have suggested.

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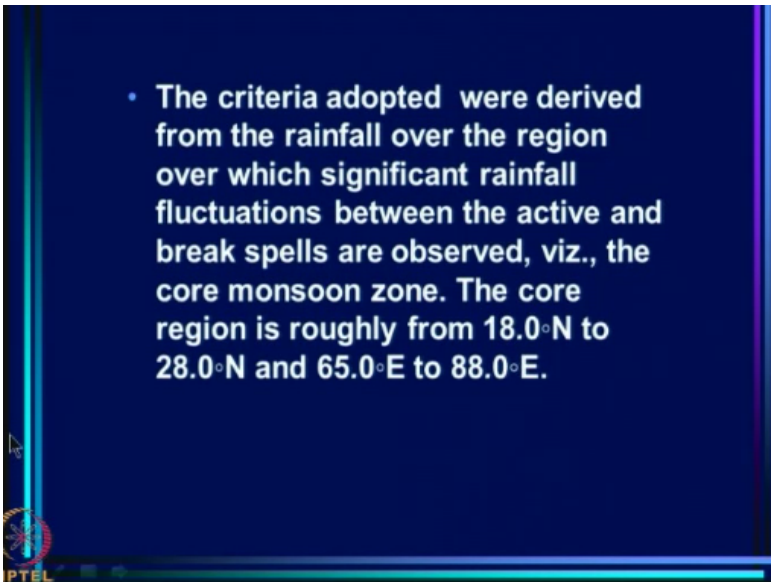

Now the criteria adopted were derived from the rainfall over the region over which significant rainfall fluctuations between active and break spells are observed namely the core monsoon zone. And this core monsoon zone is roughly from 18 to 28 and 65 to 88.

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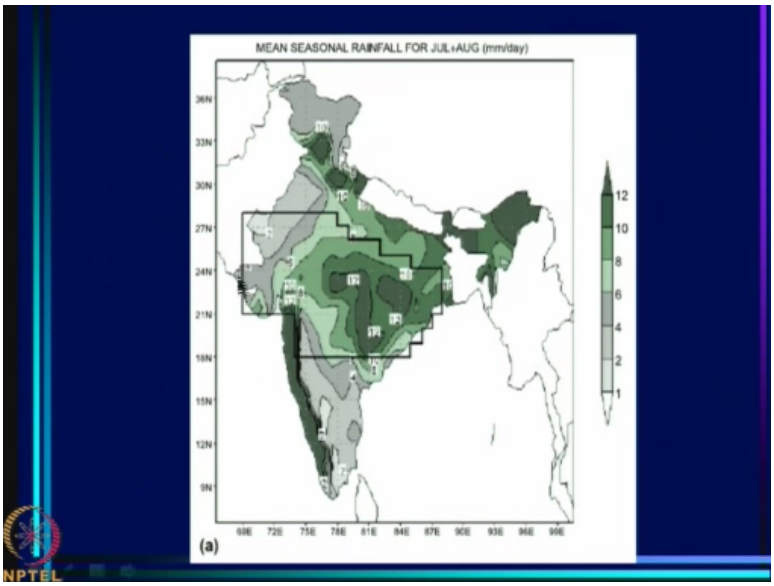

This is the core monsoon zone as you see plotted on top of July and August mean rainfall. So, this is where the rainfall is very high. Rainfall decreases as you go higher towards the northwest and this is the core monsoon zone within which the CTCG fluctuates primarily in the peak

monsoon months of July and August. So, data over this core monsoon zone has been used for defining active and break spells.

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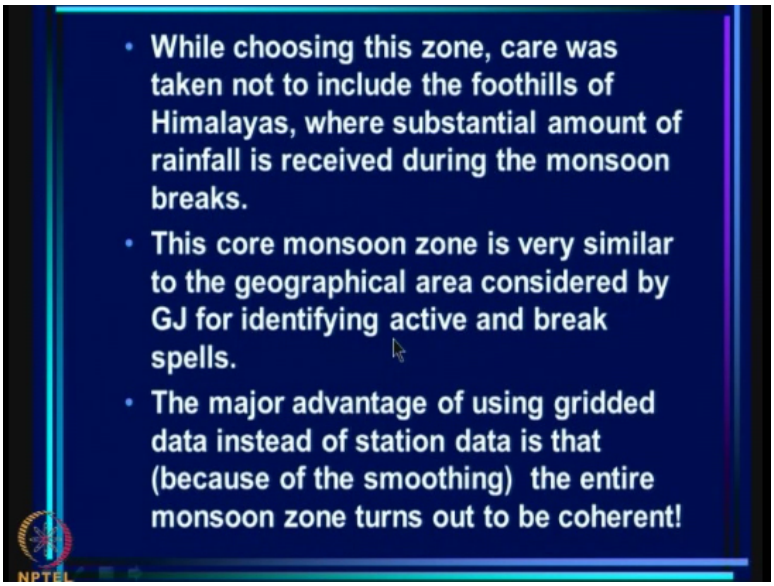

And while choosing this zone care was taken not to include foot hills of Himalayas where substantial rainfall is received during the monsoon breaks. Now, that we have seen earlier even in the break and active composite of Gadgil and Joseph. Now this core monsoon zone is very similar to the geographical area considered by Gadgil and Joseph for identifying active and break spells.

The major advantage of using gridded data instead of station data is that because of the smoothing the entire monsoon zone turnout to be coherent. So all the exercise that GJ had to do in determining coherent zones and determining separate thresholds for the 2 coherent zones is now not required.

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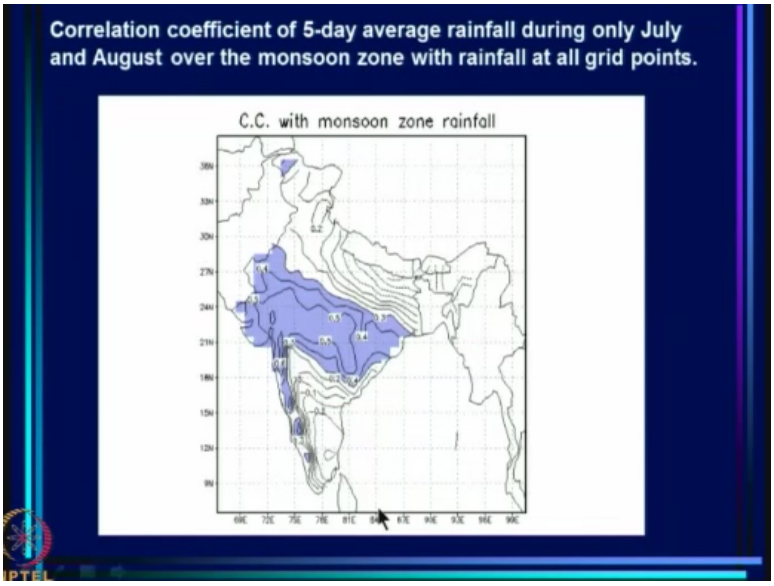

Because the entire monsoon zone becomes coherent and this is seen here this is the correlation coefficient of the 5-day average rainfall during July and August over the monsoon zones with rainfall at all the grid points. And so you see that the average rainfall for the monsoon zone is significantly co-related with all the grids in the monsoon zone and in fact is negatively correlated with rainfall over Himalayan foot hills and over the south eastern part of the peninsula.

Notice, also that it is positively correlated with rainfall over the west coast this is something we had noticed in the complexes as well. In the composites of breaks and active spells that Gadgil and Joseph had derived also. So, this correlation coefficient then shows that the average zone rainfall is significantly correlated with the rainfall over different grids.

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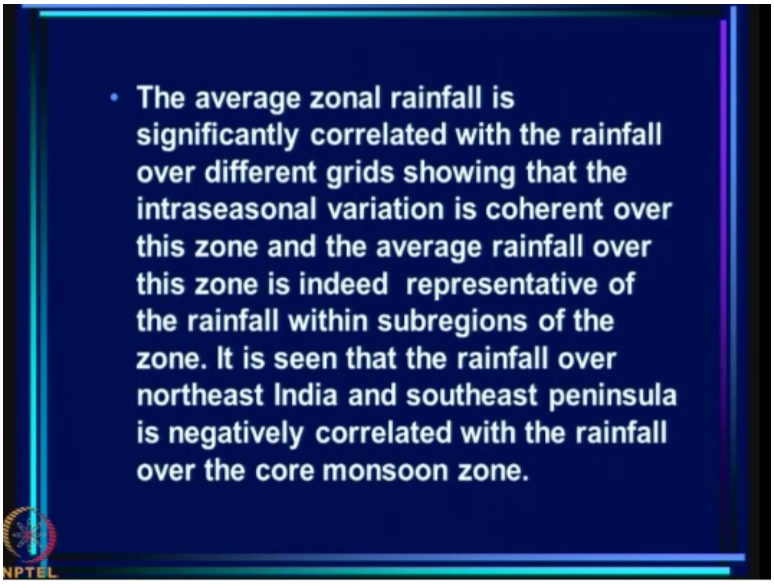

Showing that the intra seasonal variation is coherent over this zone and the average rainfall over this zone is indeed representative of rainfall within sub-regions of the zone. Now, it is seen that that rainfall over northeast India and south east peninsula is negatively correlated with the rainfall over the core monsoon zone as I have pointed out.

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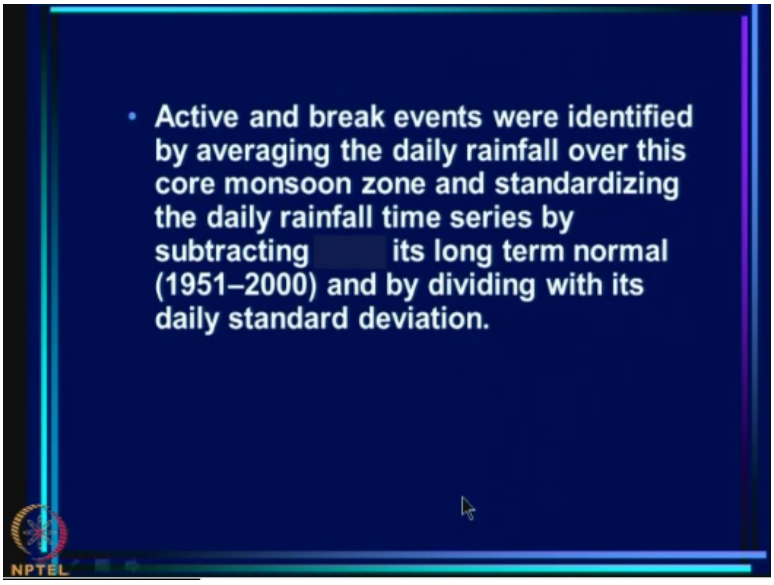

Now active and break events were identified by averaging the daily rainfall over this core monsoon zone and standardizing the daily rainfall type series by subtracting from its long term normal and by dividing with its daily standard deviation. So, first of all what one did was to identify the core monsoon zone make a time series of the rainfall over the core monsoon zone, daily rainfall.

Then make a time series of the anomalies by subtracting the mean and make it now standardized anomalies by dividing by the standard deviation.

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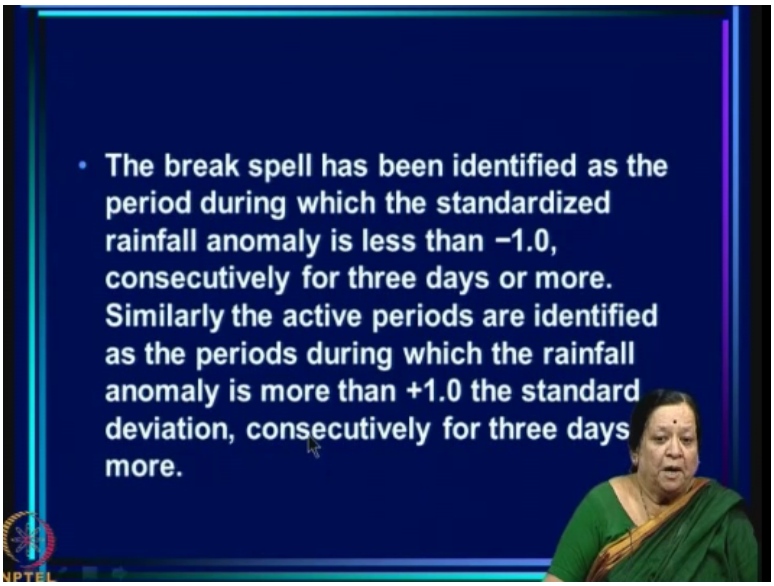

Now having got this how do we identify the break spell? It turns out that a very, very logical identification leads to very good results here. The breaks spells have been identified as the period during which the standardized rainfall anomalies is less than -1 consecutively for 3 days or more. That is to say that the rainfall anomaly is negative. It is deficit rainfall and larger in magnitude then the standard deviation that is when we call it a break day.

And if it occurs continuously for 3 days or more that's a break spell. Remember that Ramamurthy also had a lower limit of 3 days for the duration of the break. Now, similarly the active periods are identified as the periods during with the rainfall anomaly is more than +1 standard deviation. In other words, in active spells monsoon zone average rainfall anomaly is actually positive.

So that its rainfall is more than normal and larger in magnitude then one standard deviation that is when we call it an active day and it has to remain consecutively for 3 days or more for it to be called an active spell.

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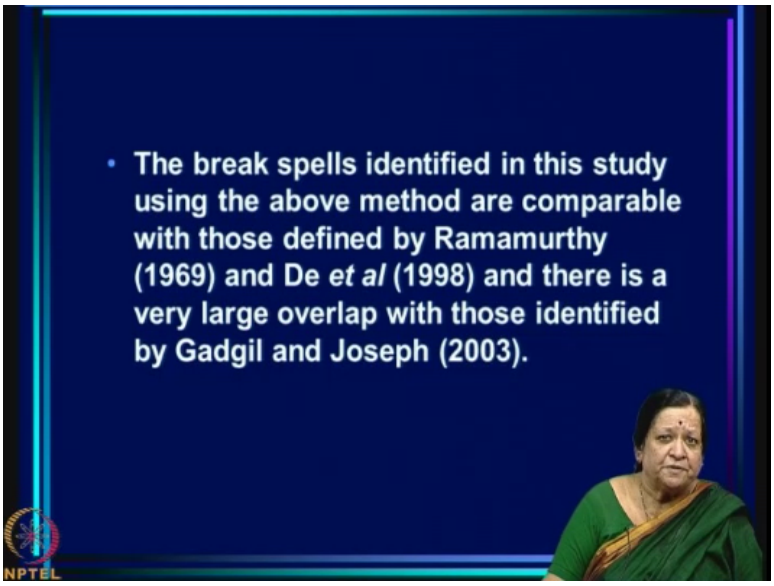

Now the break spells are identified in this study using the above method are comparable with those defined by Ramamurthy and De et al and there is an extremely large overlap with those identified by Gadgil and Joseph which is not surprising because after all the basic criteria used are very similar. It is the rainfall over the monsoon being deficit. So, in fact there is a very large overlap and details are in the paper of Rajeev and et al.

About how much overlap there is with Ramamurthy and day breaks and so on.

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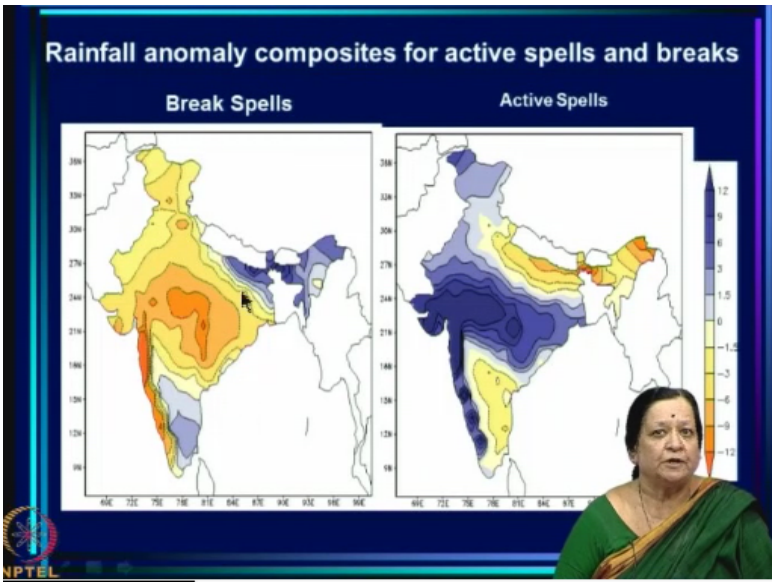

Now, these are the break spells and active spells composite figures and yellow and orange is negative anomalies and blues are all positive anomalies. You can see that in the break spells you

have a huge anomaly right across the monsoon zone. And in fact, a pretty large anomaly over the west coast as well. Whereas active spells you have exactly the opposite pattern and notice the opposite pattern over south east peninsula and the foot hills of the Himalayas.

These are really very much mirror images of one another. The break anomaly and the active anomaly from Rajeev and et al.

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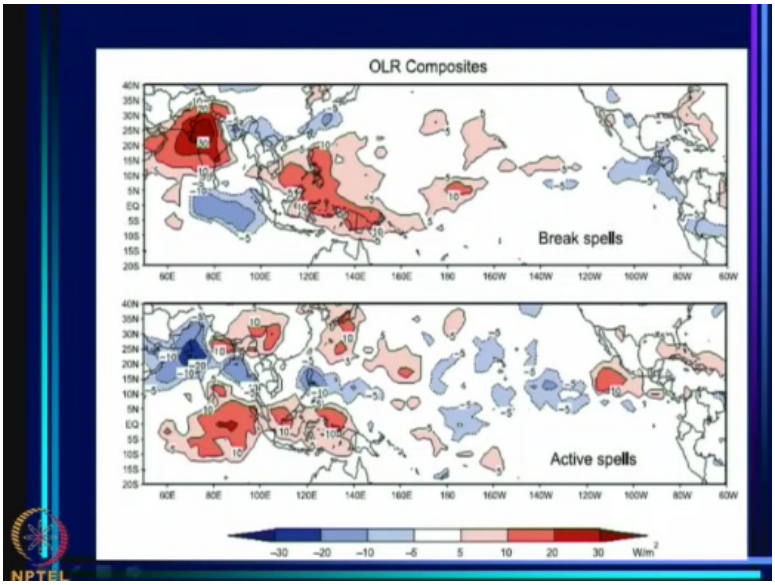

Again this is similar to what Gadgil and Joseph had found now these are the OLR composite for break spells and active spells and these are the anomalies. So, what you see is this is the break spell on top and you see supressed convection and rainfall over the Indian region and enhance convection or rainfall over the eastern equatorial Indian Ocean. Exactly opposite in active spells, active here and supressed here.

And this is the quadrupole that you can see +, -, + and - that you can see in the break composite. It is somewhat mixed up here in the active case. So, here again active is not a mirror image of the break composite over the west pacific.

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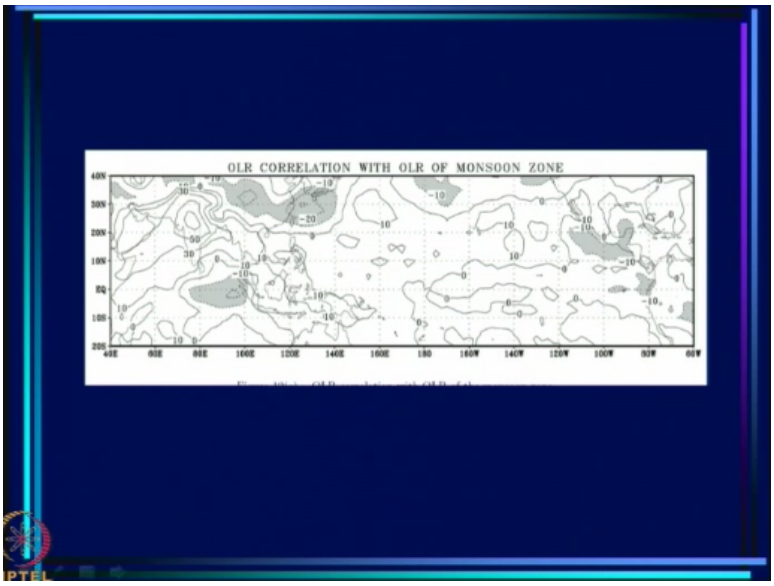

Now, if one looks as what is the correlation of OLR over the monsoon zone. So, far we have been looking at specific events breaks and active spells but if you ask the general question that on the 5-day scale or whatever. What is the co-relation of the OLR over the monsoon zone to OLR everywhere else then what you find is of course the OLR of the monsoon is highest here where the monsoon zone is positive?

But eastern equatorial Indian ocean has a negative OLR here and you also see a negative OLR here. So, the part of the quadrupole is very much there even in the OLR correlation and notice this outer phase oscillation with east Pacific is also there. So, it is in the general nature of things that on the intra-seasonal scale now in fact you have outer phase oscillation between the Indian region and the eastern equatorial Indian Ocean between the Indian region.

And the western Pacific, north western Pacific and also eastern Pacific. So, this is part nature of the beast if you wish. And later on when we look at links of monsoons to convection over ocean all these factors will come in.

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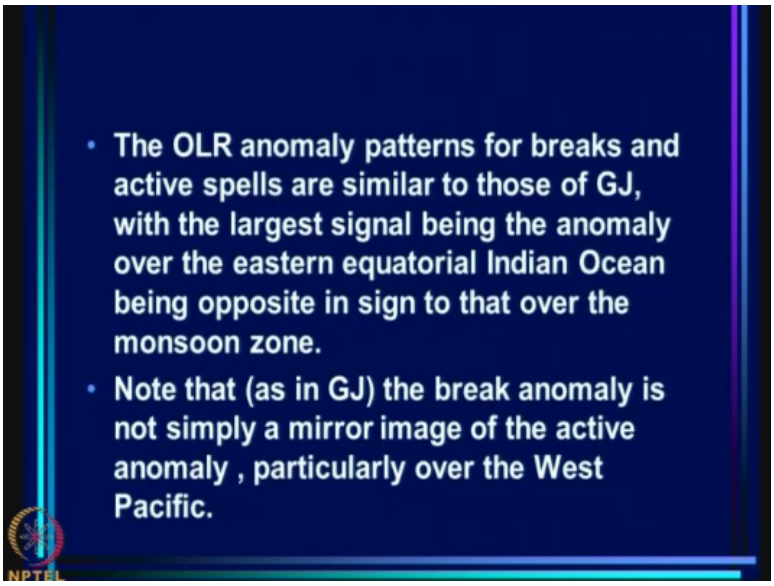

So, the OLR anomaly patterns for breaks and active spells are similar to those of GJ with the largest signal being the anomaly over the eastern equatorial Indian Ocean being opposite sign to that over the monsoon zone. Note that as in GJ the break anomaly is not simply a mirror image of the active anomaly, particularly over the West Pacific.

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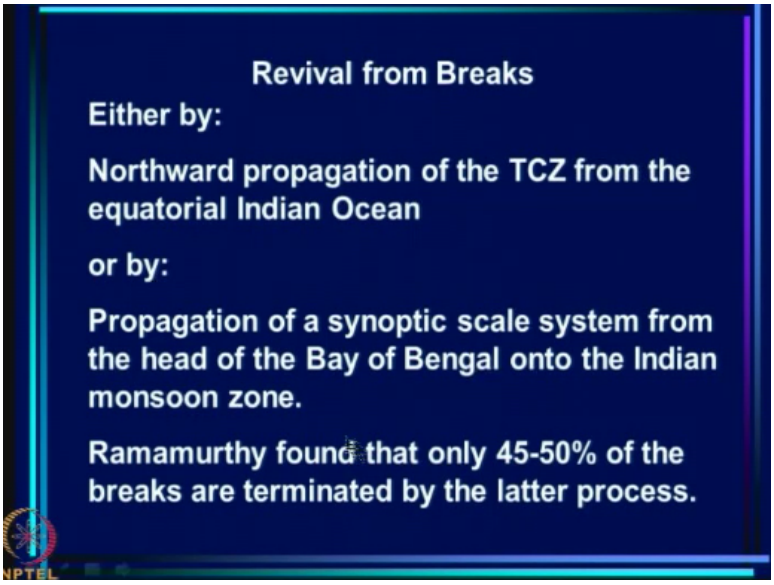

Now how does the monsoon revive from breaks? There have been 2 prior mechanisms have been suggested either by northward propagation of the TCZ from the equatorial Indian Ocean. And we show in fact in the earlier lecture that northward propagation of the TCZ from the equatorially Indian Ocean on to the heated subcontinent is the dominate feature of the TCZ as observed from satellites.

So, the northward propagations are certainly there and they play a role in the revival from breaks. Alternately, revival from breaks can also occur by genesis of a system over the head Bay of Bengal and its propagation across the monsoon zone. In fact, when Ramamurthy did his study only the later this synoptic scale system being generated in the headway and moving across the monsoon zone that was the only hypothesis proposed.

And Ramamurthy meticulously analysed all the data at hand and came to the conclusion that only about 45% to 50% of the breaks are terminated by this process. This suggest that almost half the breaks or even more are terminated by northward propagation of the TCZ from the equatorial Indian Ocean. But you can also see that the role of conventional erosions is very, very important in monsoon.

Once you get a break revival can only occur with genesis of convection over erosion and propagation on to a region either from the head way as in the second mechanism or from the equatorial Indian Ocean as suggested in the poleward propagation.

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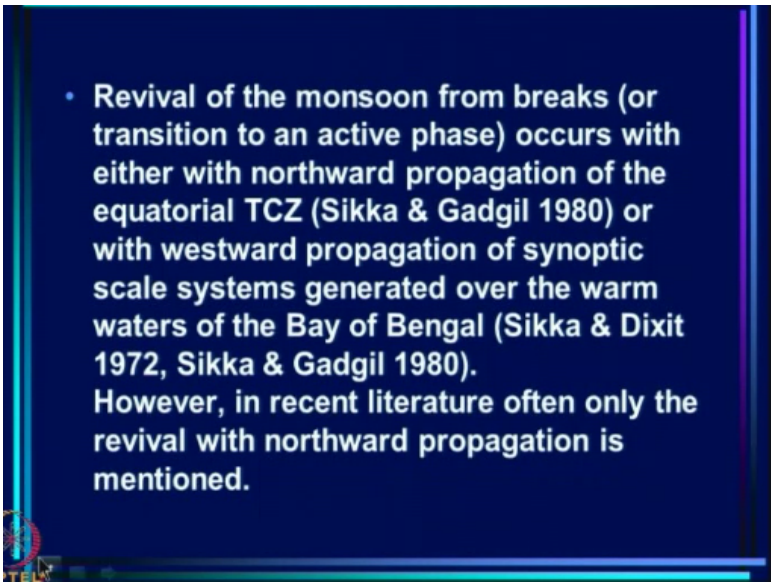

Now I will like to illustrate this revival of the monsoon from breaks or transition to an active phase occurs with either a northward propagation of the equatorial TCZ or with the westward propagation of synoptic scale system generated over the warm waters of the Bay of Bengal.

However, in recent literature people have got so carried way with northward propagations that often this other method which was originally the only hypothesis for revival is ignored.

The process by which you get genesis in the way of the headway and revival of the monsoon.

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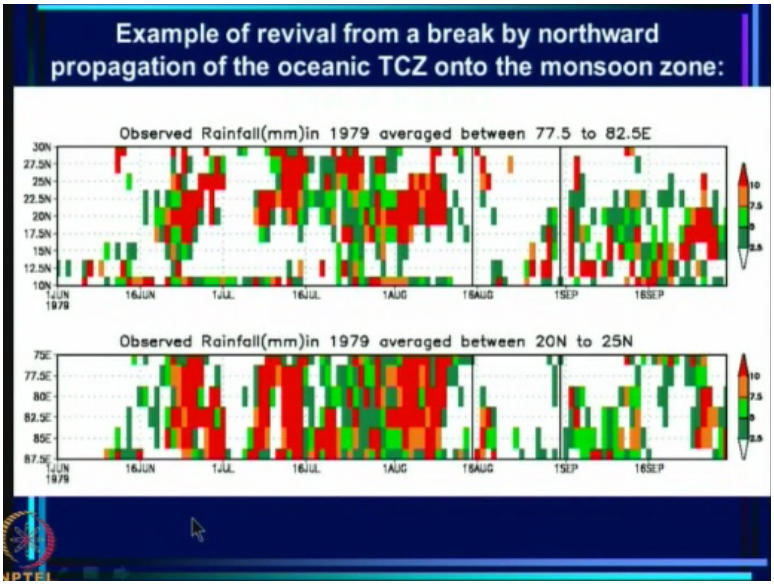

Now, I would to like to illustrate this by looking at rainfall over the Indian region so this is 10N this is 30N and these are dates and this is 1979 where revival occurred with northward propagation. So, what you see here is latitude going north these are the kind of images we had earlier 70, 80, and 90 degrees. But instead of clouds now this is rainfall and orange and red mean very heavy rainfall and lighter green is somewhat lower.

So, now if you look at 79 you can see this is the onset and then the system is sort of stable here. This is for central longitudes of India, 77.5 to 82.5 where there is considerable data available and then a break occurred here and during the break you see in the equatorial region systems are forming slowly moving northward and the revival occurs through this northward propagation here. So, this is the case of northward propagation.

You can ask the question was there any propagation from headway on the monsoon zone and the answer is no. The revival is entirely by northward propagation because if we look at the band average between 20 and 25 north. Now, we are looking at to see if there is any propagation either

towards the east or the west and we are beginning here with the longitude of the Bay of Bengal 87.5 that is near the Bay of Bengal.

And going westward and westward propagation would look somewhat like this on this map here and you see there is no westward propagation here during the break.

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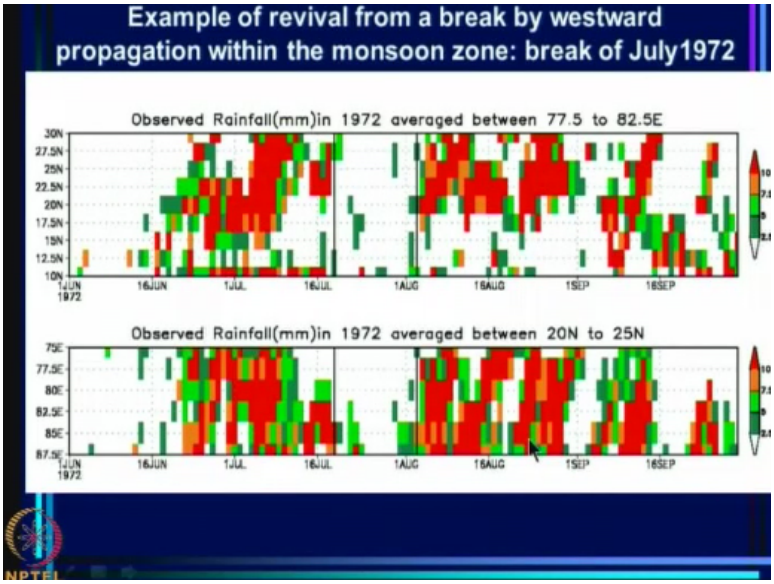

On the other hand, there is one case here in which you see that the propagation occurred primarily from the west to the east and that is this break here 72 average between 20 and 25 and you see that system this is the break here and the system formed here and moved over the head way.

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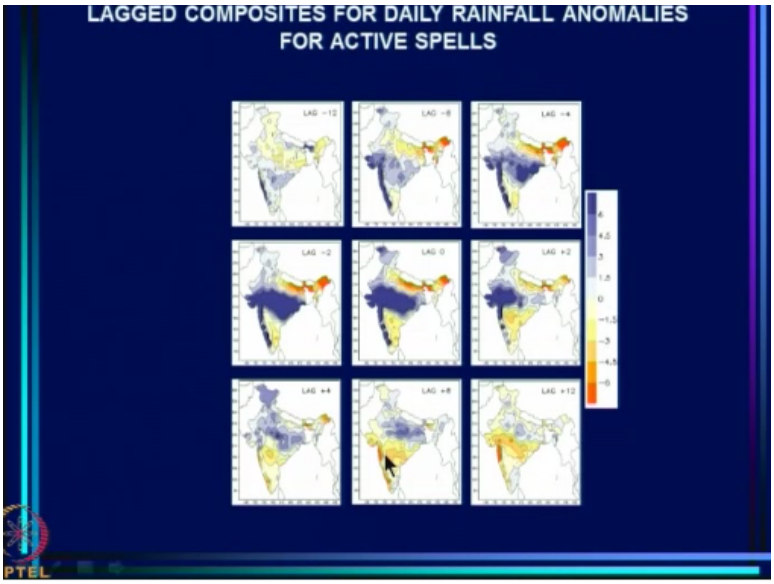

So, both these can be illustrated. Now I will not go into great detail on this but since Rajeev and et al had actually derived composites for breaks they could also derive lag composites. So, this is lag of 12 days ahead. 12 days ahead of the break day the centre of the break spells being taken as zero. So, this is -12, -8, -4 and you can see that about 4-days before the break already you see signals of negative anomalies over the monsoon zone here.

And now they are intensifying, interestingly here when you get this you also get the typical pattern of more rain over the foot hills and more rain over south east peninsula. Again lag of -2 it is more intense lag zero of course is the most intense and then this is +2, 2-days after the height of the break and you can see the whole system is weakening both the anomaly here as well as here are weakening and then finally.

What happens is here you see a spreading of the positive anomy of rainfall and that anomaly seems to move northward here and move further northward here and eventually it actually covers the monsoon zone. So, this seems to show revival by northward propagation and lagged. Similarly, one can look at lagged correlation with lagged composites for active spells, active spell what you find is that it goes towards the break mode.

Again beginning with the anomaly in the south east. So, in this scenario then the negative anomaly also propagates from south to north.

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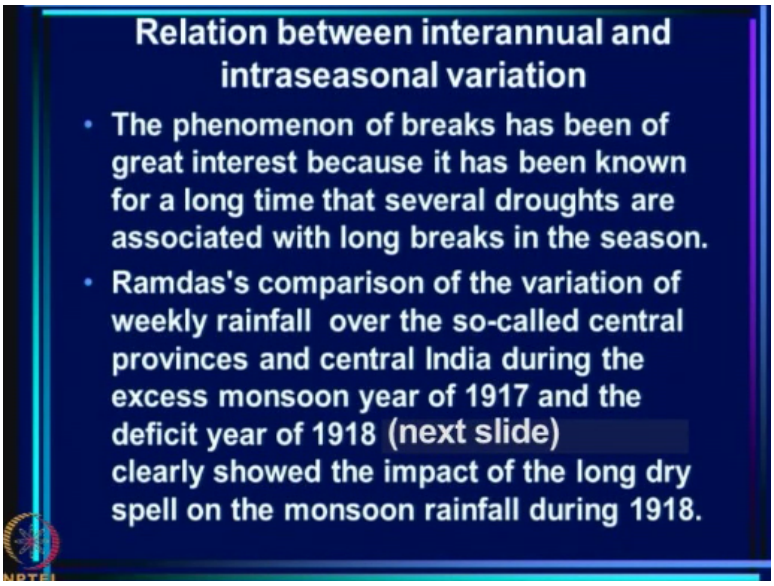

Another important thing to look at is okay, we are concerned with dry spells in the monsoon but do they actually matter in terms of the seasonal rainfall as a whole? All India seasonal rainfall June to September rainfall because these are breaks only during July and August that we have been talking about. Now, if fact the 2 are related because as I have shown you several examples for example the break of 72 which occurred in the drought year of 72.

And Ramdas has example of 1918 in which also there was a long spell and it was a drought year. So, phenomenon of breaks has been of great interest because it is being known for a long time that several droughts are associated with long breaks in the season. So, Ramdas has comparison let me remind you of the so called weakly rainfall over the so-called central provinces and central India.

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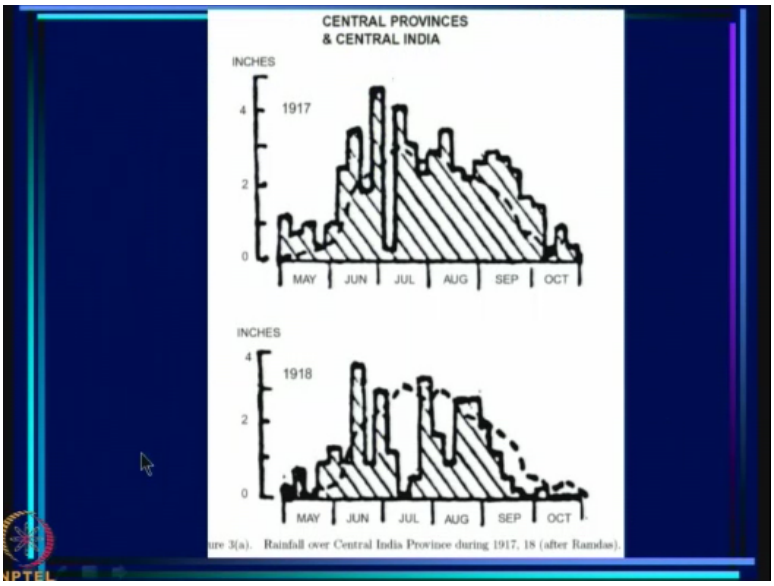

Which I again bring here you see this is the break and there was a drought in 1918. So this is the long break there.

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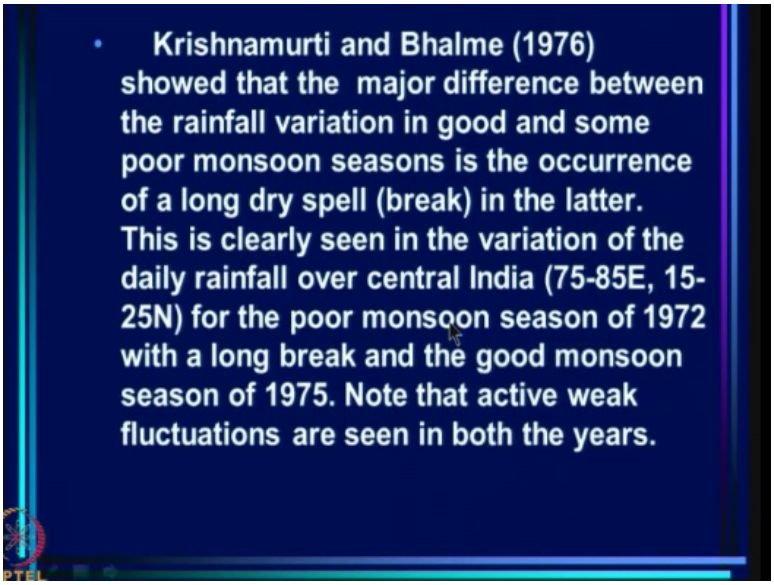

Now Krishnamurti and Bhalme also showed that the major difference between the rainfall variation in good and some poor monsoon season is the occurrence of a long dry spell or break in the later.

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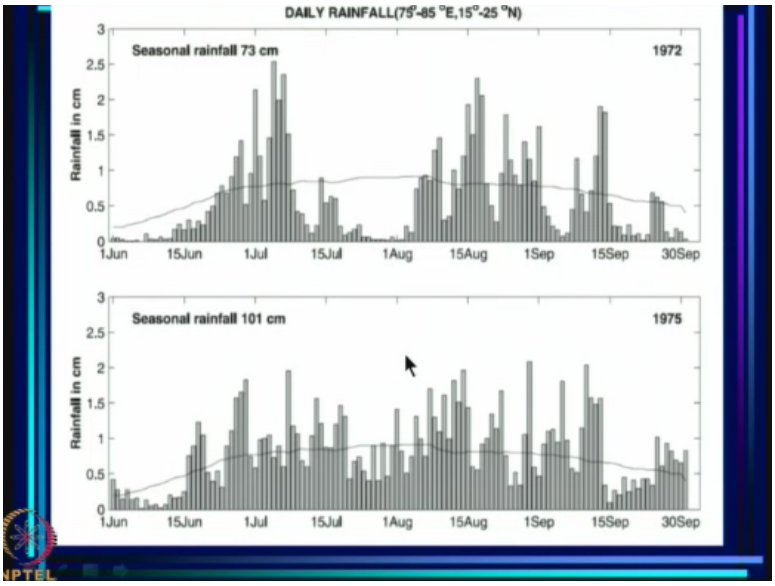

And this you see in the picture of 72 in which the seasonal rainfall this is the all India seasonal rainfall was only 73 centimeter. It was a very major drought and a very good monsoon year of 75 in which the seasonal rainfall was 101 centimeter. Remember the mean is 85 centimeter so this was very much higher than normal. And you can see that the difference between these 2 is not so much in the active spells.

In fact, the active spells seem even higher in 72. But it is in the presence of this big break which occurred in 72.

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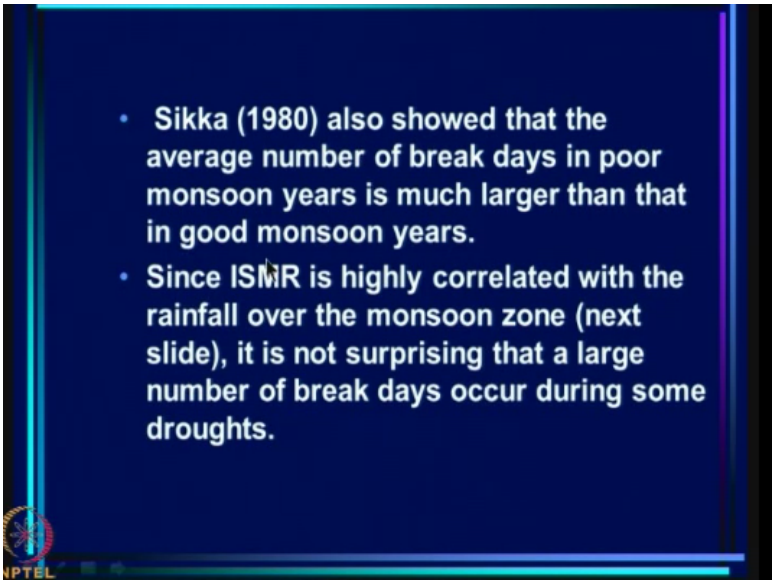

Now Sikka also showed that the average number of break days in poor monsoon years is much larger than that in good monsoon years. So, since ISMR is highly correlated with rainfall over monsoon zone it is not surprising.

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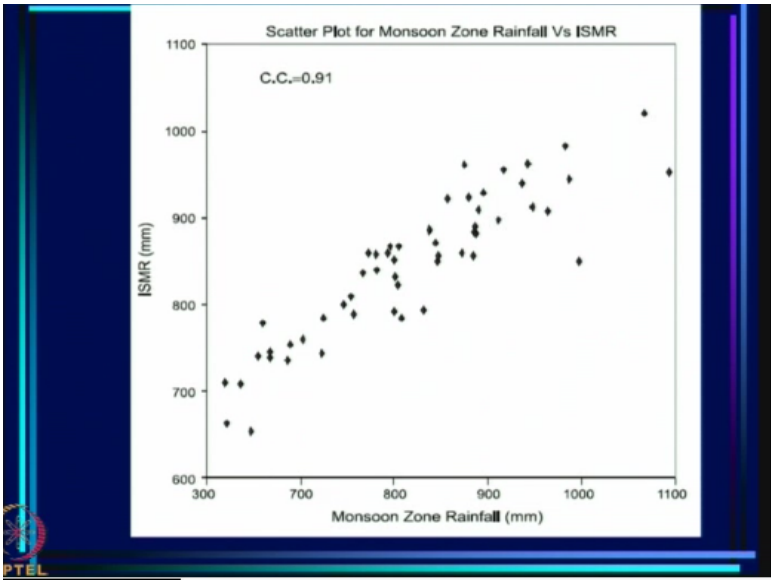

That this happens so this is the all India summer monsoon rainfall and this is the monsoon zone rainfall. And the co-relation overwriting 90-years is extremely high. You see how well the 2 are related the correlation coefficient is .91. So, it is not surprising that a major deficit over the monsoon zone will be associated with a drought of the all India monsoon rainfall.

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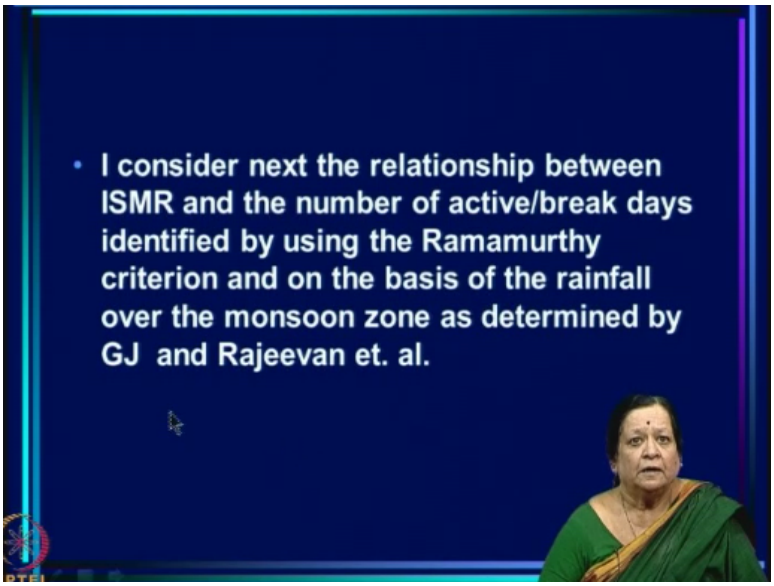

So, now let us see the relationship between ISMR and active break days identified by using Ramamurthy criteria and on the bases of the rainfall over the monsoon zone as determined by Gadgil and Joseph and Rajeevan et. al.

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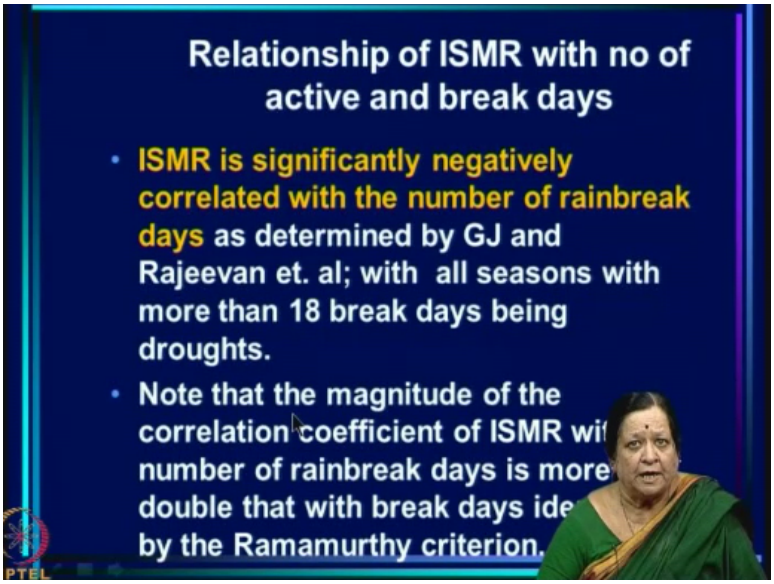

Now what is the result? That ISMR is significantly negatively correlated with the number of rain break days as determined by both GJ and Rajeevan and also by Ramamurthy. But the correlation with Ramamurthy breaks is much smaller.

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So, here you have these are the rain break days of Gadgil and Joseph and this is the all India monsoon rainfall and as the number of rain break days' increase in fact the rainfall does decrease

very much. But when the break days are within a certain limit you can see there is a huge spread here. So, it is true that long breaks are generally associated with droughts but you see here there are some long breaks in which there was no drought.

The rainfall was reasonable so it is not a one to one correspondence. In fact, very few things in metrology are one-to-one correspondence. It is a complex system but the correlation is significant it is -.4 so we can say that the intra-seasonal variation is related to interannular variation with a significant correlation between all Indian summer monsoon rainfall and the number of rain break days.

Same thing holds as of rain break days but you see the correlation is less than half. The magnitude of the correlation coefficient is less than half of what you get with rain break days. So, this is a better indicator of what will happen in the years as well.

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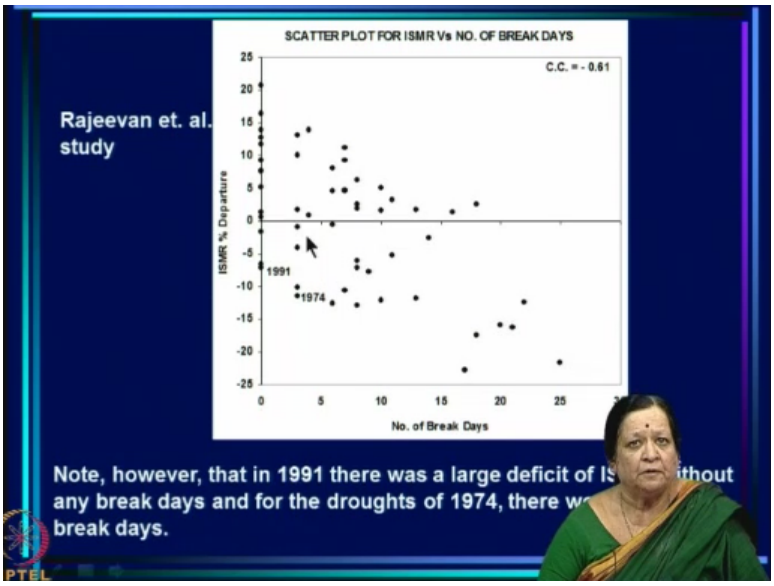

Now, if you took the Rajeevan et al thing also again we have a very good correlation in fact it is higher. It is -.61 but notice that even here in a year like 1991 there was a huge deficit of all India monsoon rainfall it was 8% or so and yet there was not a single break day zero break days. And similar 74 was a very, very high deficit very intense drought and only 5 break days. So, there are problems in looking for high co-relations.

When the number of break days are small there is spread but when you go beyond say 18-days or so then a drought is guaranteed if the break prolonged beyond that. Another example of the 99 kind of case where you have all most no breaks but deficit rain in fact occurred.

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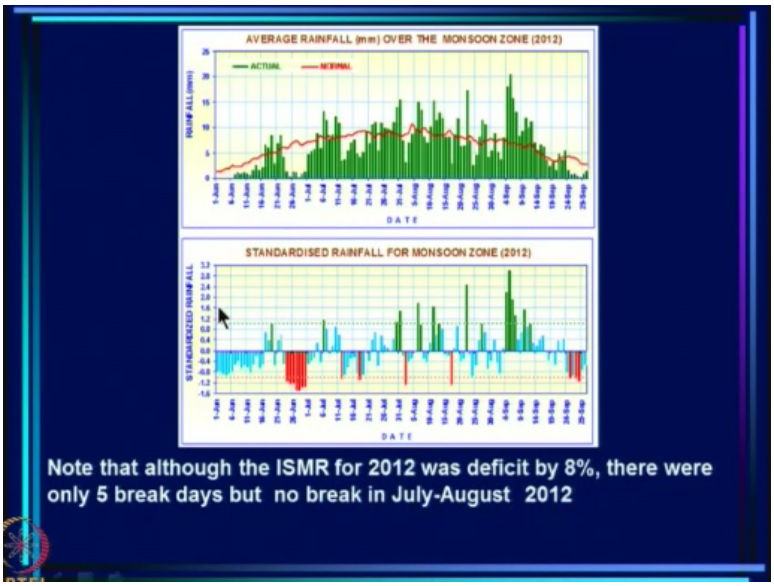

Now what you see here when I mentioned Rajeevan and et al I said they have defined things so that they can be operationally determined and indeed operational values of the monsoon zone rainfall actual as well the normal are available at the IMD website in Pune and this is what you see for 2012. This is the average and this is what happens the green bars are what happen in 2012 and this is the anomaly and whenever the anomaly magnitude is larger than 1.

If it is deficit it is red and if it is excess, it is green. So, what happens is in June there was a lot of deficit towards the end of June, very large negative anomalies occurred over the monsoon zone. But in July and August if you see there are only 4 or 5 days of rain breaks and they are all relatively, they are all scattered. There is no break spell as such. So, this is an interesting result but the point is that with definite criteria defined by Rajeevan and another.

One can actually monitor that occurrence of breaks on a year-to-year bases with the IMD data.

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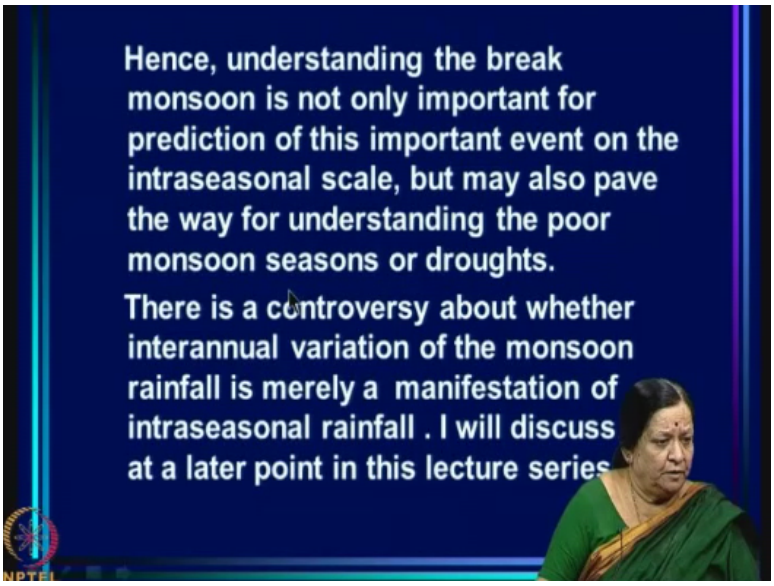

So, given the relationship of intra seasonal variation with inter annual variation understanding the break monsoon is not only important for prediction of this important event on the intra-seasonal scale. But also may pave the way for understanding the poor monsoon seasons of droughts. Now, there is a controversy about whether inter annual variation of the monsoon rainfall is merely a manifestation of intra-seasonal rainfall.

I will discuss this at a later point in the lecture series.

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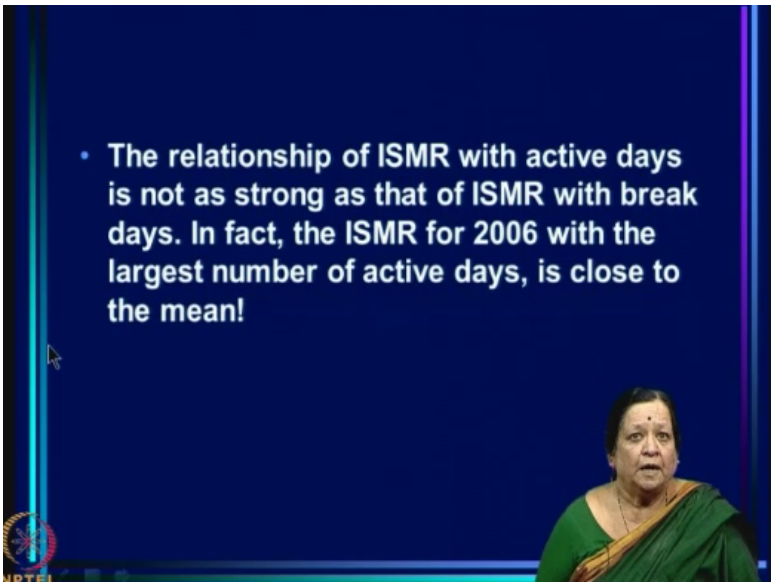

Now let us look at the relationship between active days and ISMR. So, far we have said that the relationship of ISMR with break days is strong what about with active days? The relationship of ISMR with active days is not as strong as with break days and in fact this is what is show here.

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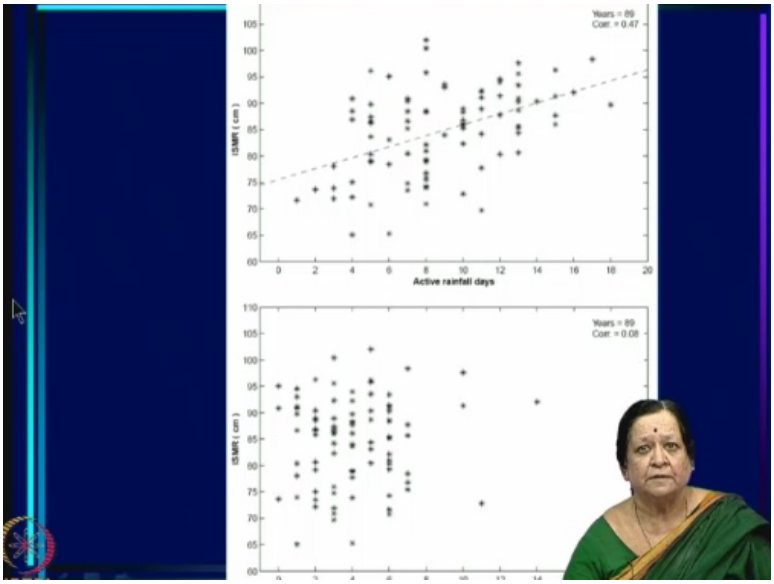

This is what is show here you see here this is from Gadgil and Joseph. These are active rainfall and notice also the relationship to intense rainfall days. They had determined also intense rainfall days and in fact the correlation between intense rainfall days is almost zero. This ties in with the fact that Sikka has shown that the all India monsoon rainfall really does not depend on the number of depressions or these strong events which give these intense rainfall days.

It actually depends on laws which gives much more distributed rainfall over the monsoon zone. Now active of course there is a positive correlation but it is not as large as the breaks.

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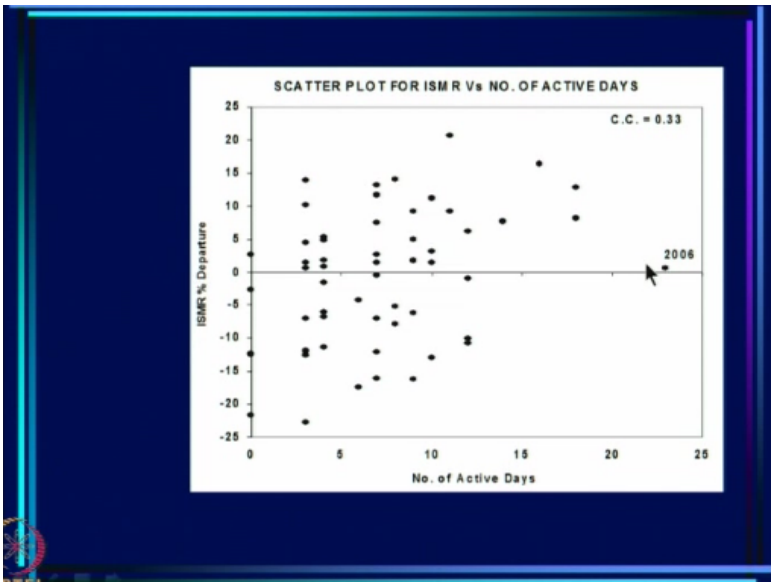

And this is the co-relation for Rajeevan and De et for some reason co-relation with active is somewhat less than that for Gadgil and Joseph. But notice here 2006 which has actually maximum number of active days is just a normal monsoon zero ISMR departure. So, this relation is not so strong.

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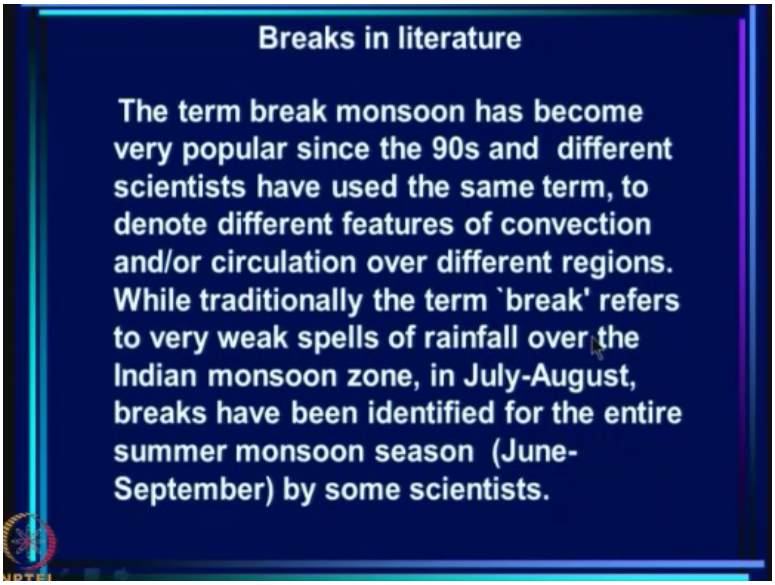

So, then we have actually looked at all the major features of the breaks and we find that the rain breaks defined by Gadgil and Joseph which are very similar to the rain breaks defined by Rajeevan and et al and rain breaks by Rajeevan and et al are in fact such that one can operationally monitor them with the data available at IMD and as these breaks have a very large overlap with breaks defined in the traditional way.

So, basically traditionally of course the breaks were defined with disappearance of easterly winds on the surface wind charts and so on. Now, when we define it on the bases of rain breaks that is to say rain over monsoon zone we are getting very, very similar results except a better correlation with ISMR. Now, what has happened is that the term break monsoon has captured the imagination of a lot of scientist.

Well I do not know precisely why? And so much so that different scientist has used the same term to denote different features of convection and or circulation over different regions. So, while traditionally the term break refers to very weak spells of rainfall over the Indian monsoon zone in July and August breaks have been identified for the entire summer monsoon season by some scientist.

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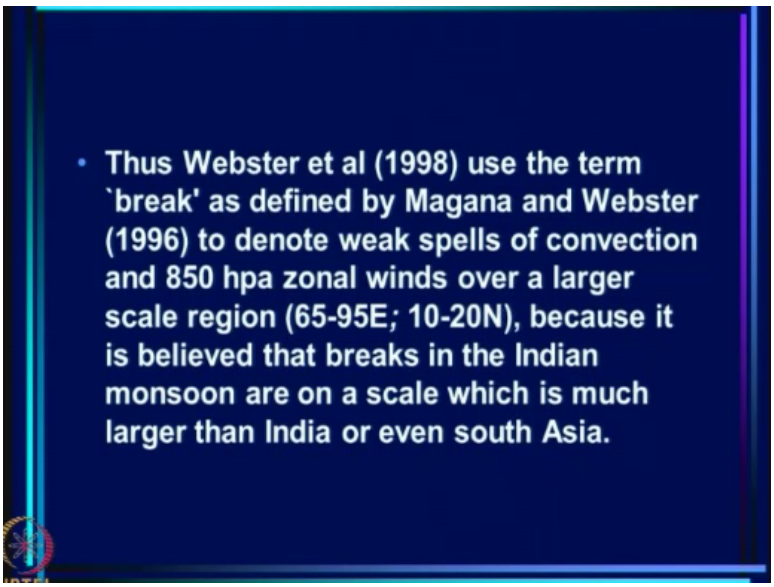

And there are many examples of this which I could give for example we are concerned only with the monsoon over India but Webster et al look at the work done by Magana and Webster in which they take a very large region 65 to 95 and 10 to 20 north and use 2 criteria one is weak spells of convection. So, OLR is involved as well as 850 millibar zonal winds over this region. And both those are taken to indicate breaks.

Because it is believed that break in the Indian monsoon are on a scale which is much larger then India or even south Asia.

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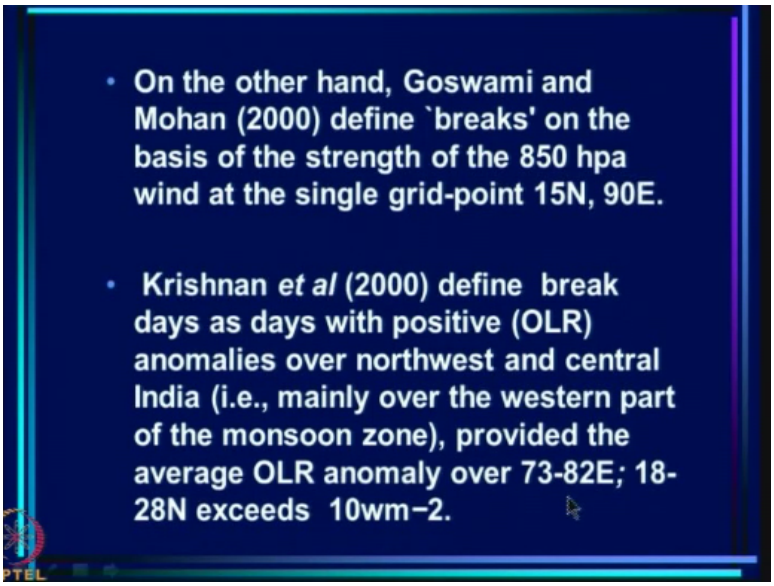

Now, on the other hand Goswami and Mohan defines breaks on the bases on the bases of the strength of 850 hpa wind at the single grid-point 15N and 90E. and Krishnan et al defines break days as days with positive OLR anomalies over north west and central India provided that the average OLR anomaly exceed 10 watts. So, each one has their own definition of breaks.

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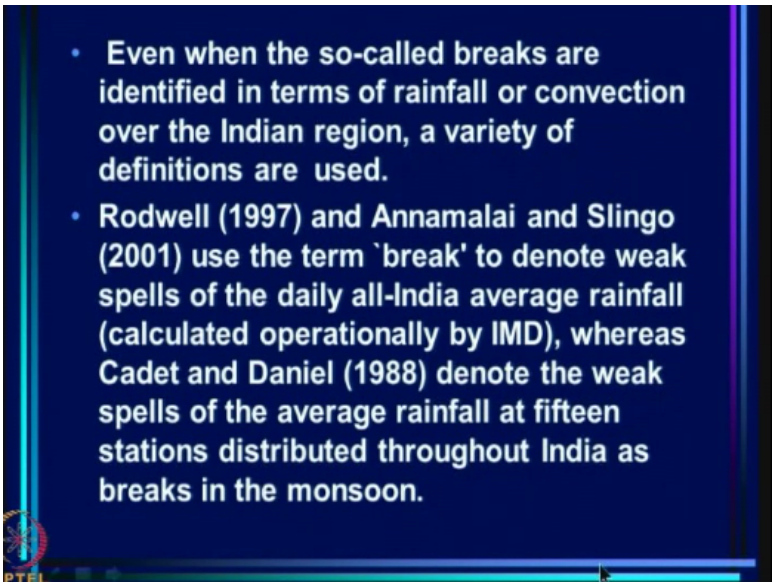

And even when the so-called breaks are identified in terms of rainfall or convection over Indian region a variety of definitions are used. So, Rodwell and Annamalai used the term break to

denote weak spells of all India average rainfall calculated operationally by IMD. Whereas Cadet and Daniel have some 15 stations over which they take the average rainfall and denote weak spells of that as breaks.

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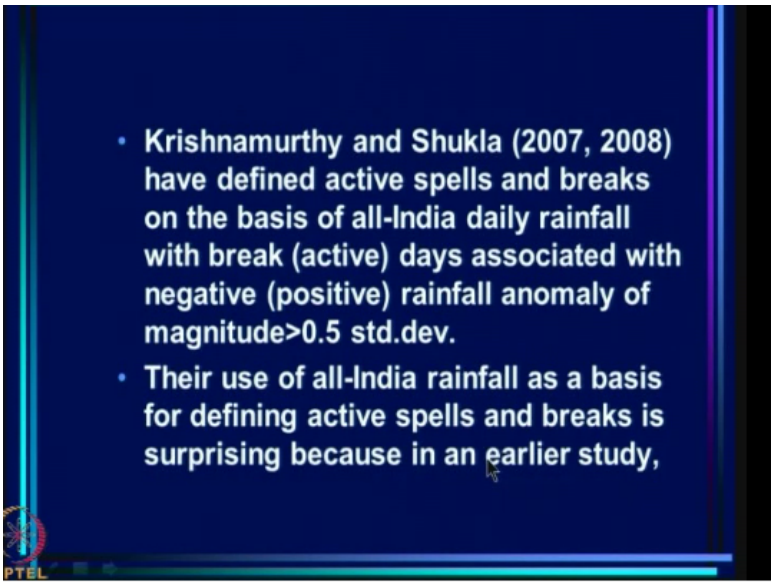

The point is all of them used the word break monsoon at the same time what they referred to are different criteria for definition of breaks. Now, Krishnamurthy and Shukla have defined active spells and breaks on the basis of all-India daily rainfall with break days associated with negative anomaly of magnitude greater than .5. Now, this is very peculiar that they themselves have used all-India rainfall.

We have seen that the monsoon zone rainfall is negatively correlated with rainfall over the foot hills of Himalayas as well as the south eastern region. So, all India average on a daily scale does not make much sense because the (()) (50:16) are not coherent. And this actually, support of this came from their own study earlier.

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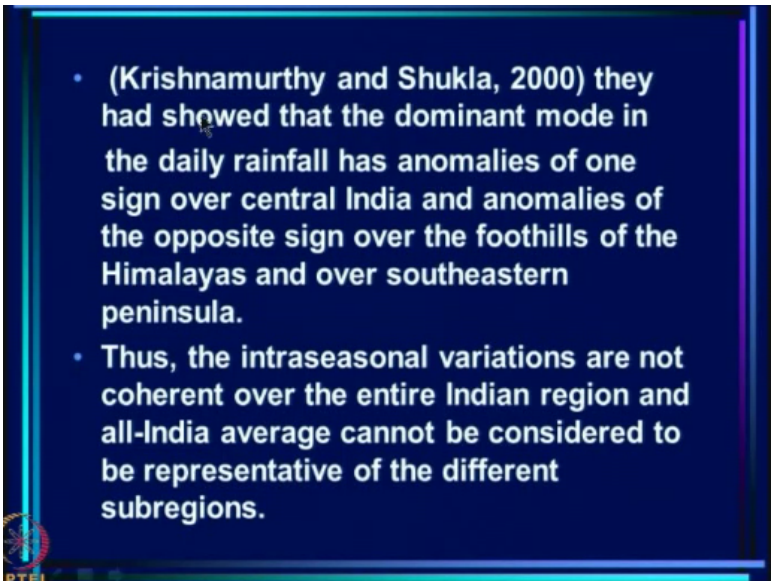

Because this Krishnamurthy and Shukla had shown that the dominant mode in the daily rainfall as anomalies of one sign over central India and anomalies of the opposite sign over the foothills of the Himalayas and over southeastern peninsula and yet they insist on taking an average over all India. So, all though the intra seasonal variations are not coherent any way.

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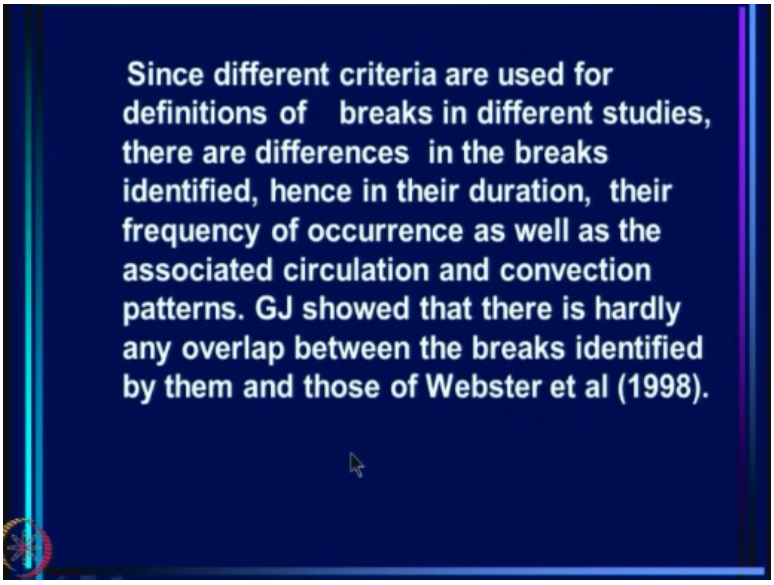

So many such criteria are used and since different criteria are used for definition of breaks in different studies there are differences in the breaks identified hence in the duration. Their frequency of occurrence as well as the associated circulation and convection patterns. So, GJ showed that there is hardly any overlap between breaks identified by them and those of Webster et al which means there is hardly any overlap between the traditional breaks also.

And Webster et al. So, Webster et al breaks are something that are different from the breaks that are recognized as breaks of the Indian monsoon by the meteorologist over a large number of years.

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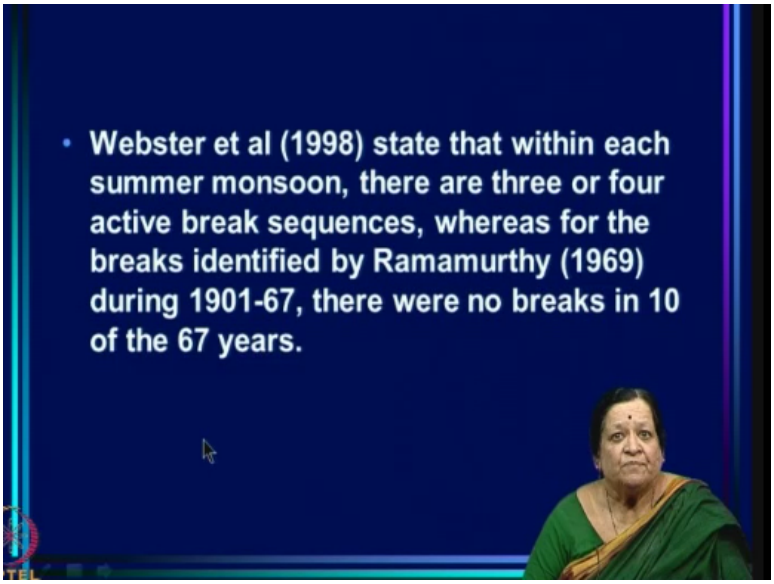

See the second thing that state is that within each season there are 3 or 4 active break sequences. So they are really talking of weak spells so that you have active weak fluctuations and we have seen every year there are many active weak fluctuations beginning from June ending in September. So, Ramamurthy breaks however do not occur every year they occur only in some years for example during 1901 to 67 there were no breaks in 10-years.

So it is not a phenomenon that you see every year we have seen in the plot that for several years there was zero break days. So break is a very special weak spell but what Webster and others are referring are general weak spells.

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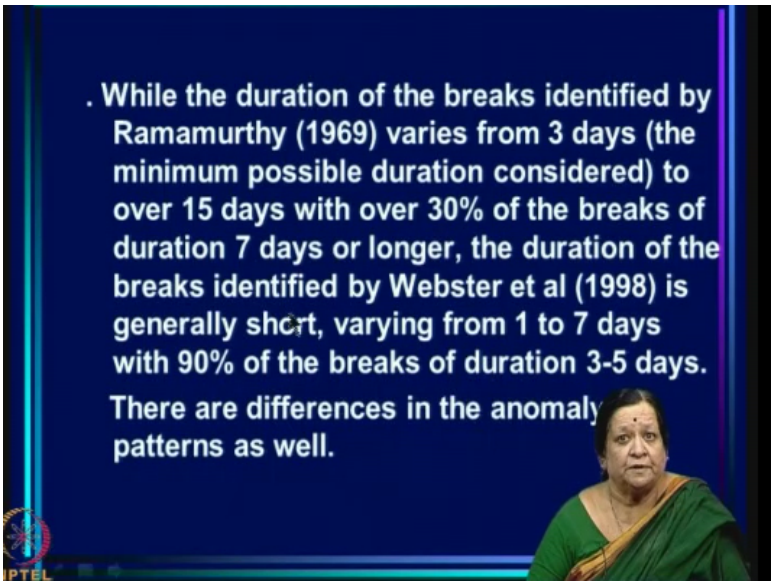

And the morphology of those weak spells may be very different. So, while the duration of breaks identified by Ramamurthy varies from 3 days to over 15-days with over 30% of the breaks of duration 7-days or longer. So, there are lot of long breaks in Ramamurthy breaks. The duration of breaks identified by Webster et al is generally short varying from 1 to 7 days with 90% of the breaks of the duration 3 to 5 days.

So, these are really weak spells from which the monsoon over the large region that they call monsoonal in fact revives. In fact, they are looking at a different beast when they talk of breaks and one has to be aware of that.

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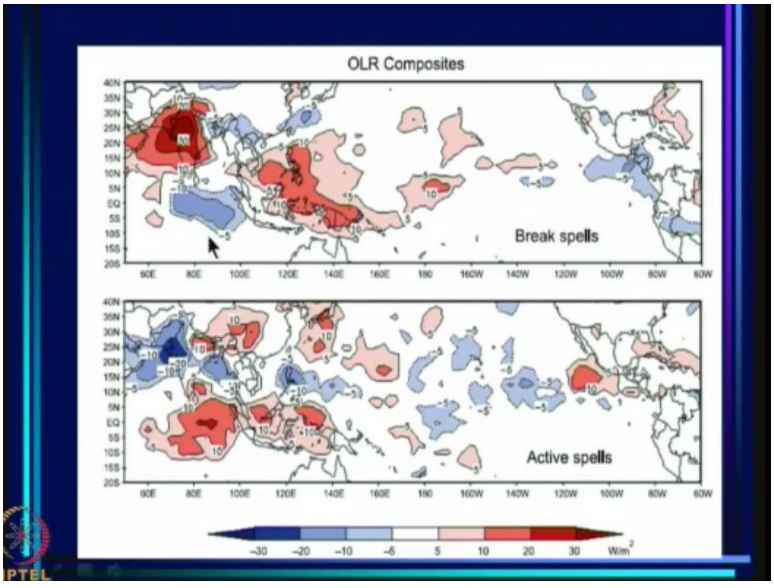

Now, we can look at the OLR composite. This is the one you have seen earlier this is from Rajeevan et al this is the break and this is the active spell.

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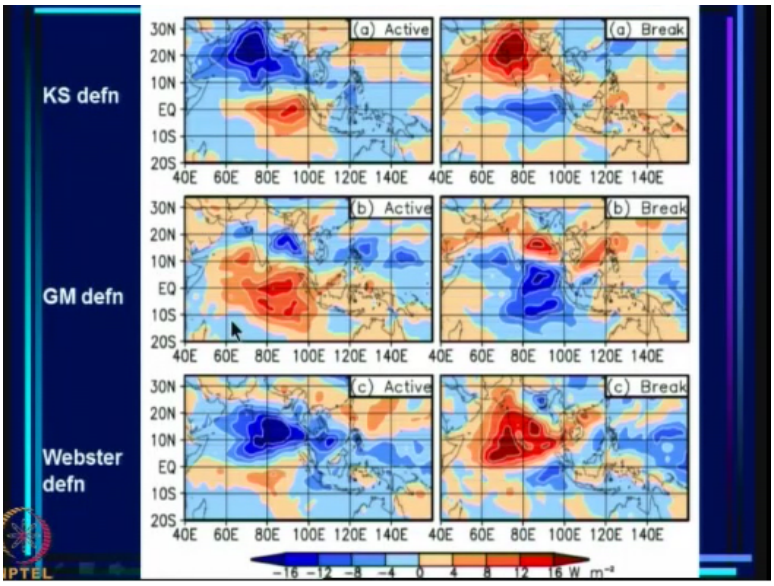

And if we look at the composites from different definitions this is Krishnamurthy and Shukla but let us look at Webster to begin with. This is his active spells and this is his weak spell you find that during the break in fact he does get enhancement over the equatorial region. But it is over the entire equatorial region not just over the eastern see particularly in the active spell is when he is getting active thing over the eastern equatorial Indian region.

So, you know this is the same sign of anomaly for both the cases. This is very different from the kind of things that we have seen earlier. Now, if we look at Goswami break you find this is the Goswami active one and this is Goswami break and you find Goswami break involves actually lot of rain all over here over the eastern Indian Ocean it is realistic. But also over the west coast and so on.

But we had seen that west coast tends to go along with monsoon zone. So what happens is basic features of the breaks identified and studied over the years are not present here. So they are looking at different facet of the system when they talk of breaks.

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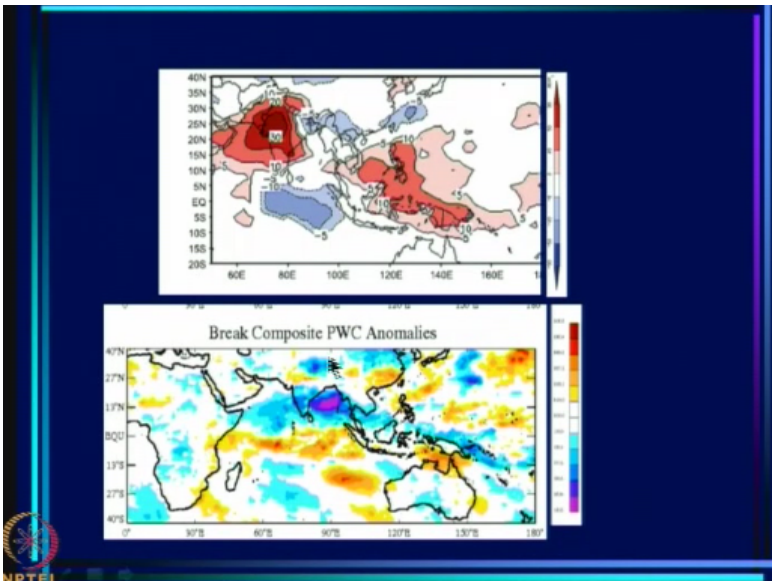

And this is the precipitable water content anomalies from Webster and you can see this is the break situation where you have very much less water here and very much more water here. So, the entire equatorial ITCZ is enhanced, convection is enhanced. Whereas what we had found was eastern part is enhanced and the western part is also slightly supressed.

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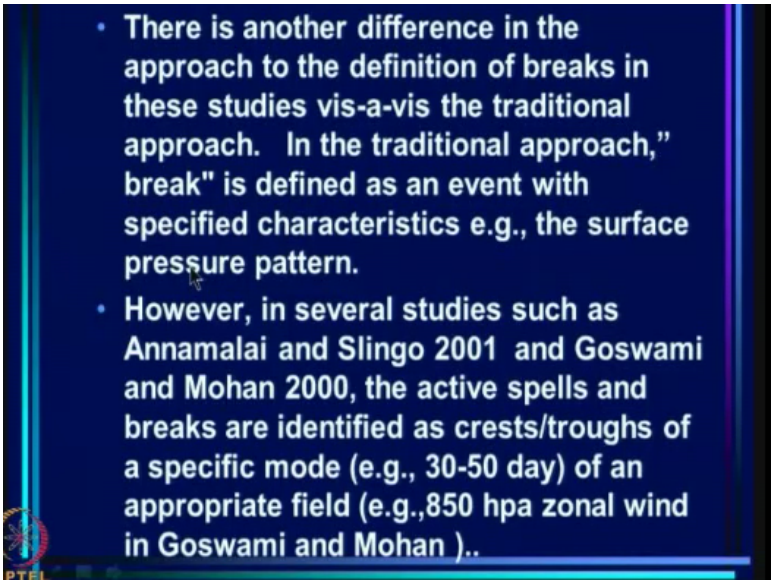

So, you are getting very different anomalies and I will not dwell on this or I may just mention that while we have talked of breaks and active spells as events. You know there is an approach in which they look at modes so they will filter for a 30 to 50 days' mode and so on and they look for active spell as a crests and a weak spell as a trough of the amplitude of that mode.

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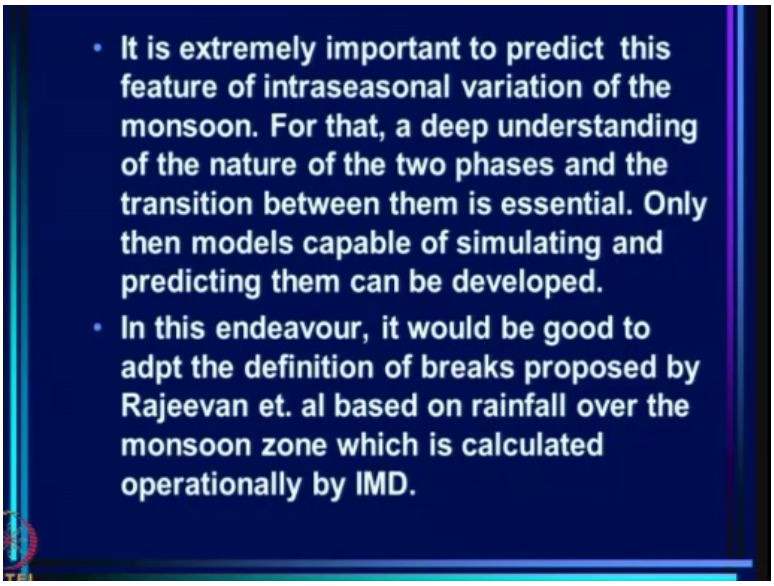

So, that may not translate into actual days. So, there are many differences and one has to be very careful in seeing how they define break before using whatever they have learnt about breaks their process and so on and so forth. So, I think it is extremely important to predict this feature of intra seasonal variation of the monsoon and for that a deep understanding of the 2 phases active spells, weak spells and breaks and the transition between them.

Is essential only then models capable of simulating and predicting them can be developed. In this endeavor it would be good to adopt the definition of breaks proposed by Rajeevan et al based on rainfall of monsoon zone which is calculated operationally by IMD. So, this is the suggestion then if you go on redefining the term break then it will be of foolish chase because we do not know what we are trying to understand or predict.

It is better to use this definition which can also be used operationally and try and then understand how the breaks occur. How the transition occurs from the break to active spells and vice versa and try and see if we can incorporate that understanding into model so that they can predict these very important events. Thank you.