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

Lecture - 17
Seasonal Transitions- Part 2: Spring to Summer Transition

So I continue now with our discussion on the Seasonal Transitions. First the spring to summer transition. We have already talked in the last class about the nature of the seasonal transition and monsoon onset over Kerala.

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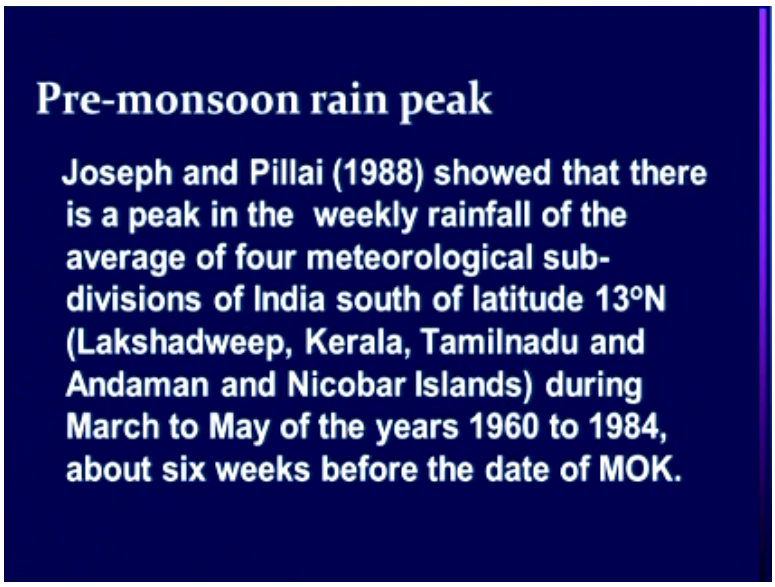

Now I continue first with the monsoon onset over Kerala. Joseph and Pillai showed that there is a pre-monsoon rain peak that there is a peak in the weekly rainfall of the average of 4 meteorological sub-divisions in South India which we see here.

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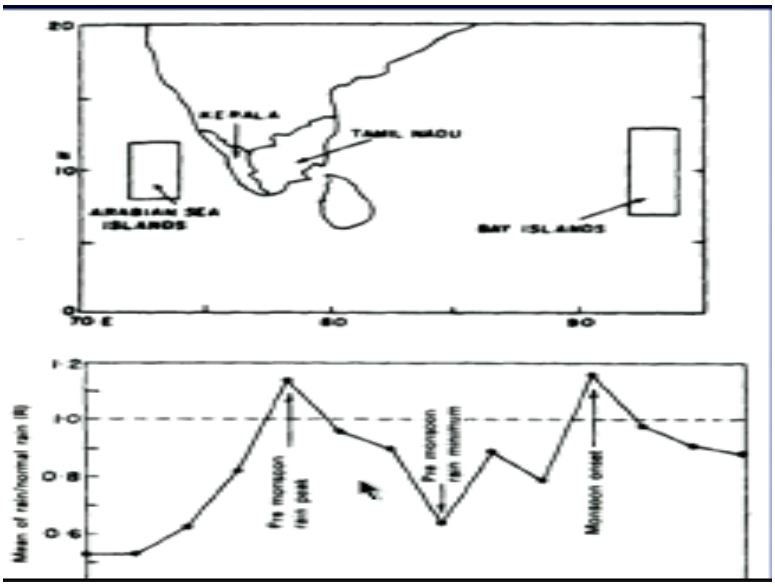

We see those 4 meteorological sub-divisions here these 4 all along about 10 degree north. So Arabian Sea Islands, Kerala, Tamil Naidu and Bay Islands. If we take sort of this (()) (01:08) and we do not rainfall over here because this is not land and the data is only land rainfall station. So they took average of rainfall of these 4 sub-divisions weekly rainfall and what did they find.

This is again relative to the monsoon onset date these are all composited. So if this is the monsoon onset then they find that our 6 weeks prior to the onset there is a peak in rainfall here and then the rainfall decreases and again increases during the onset. So the data they analyzed was of weekly rainfall average of 4 meteorological sub-divisions of India, Lakshadweep, Kerala, Tamil Nadu and Andaman and Nicobar Islands during March to May of the year 1960 to 1984.

And for those years about 6 weeks before the date of MOK we saw a peak there. This pre-monsoon rainfall peak is clearly seen in the composite of the weekly rainfall which we have seen here. So there is a very clear pre-monsoon rainfall peak about 6 weeks before the onset of monsoon over Kerala. Now they went further then that they actually tried to see whether you could predict.

Now this is of course the composite every year the dates of these will vary both the PMRP as well as onset and then one can ask the question is the onset date related to the date of the pre-monsoon peak and this is what they did.

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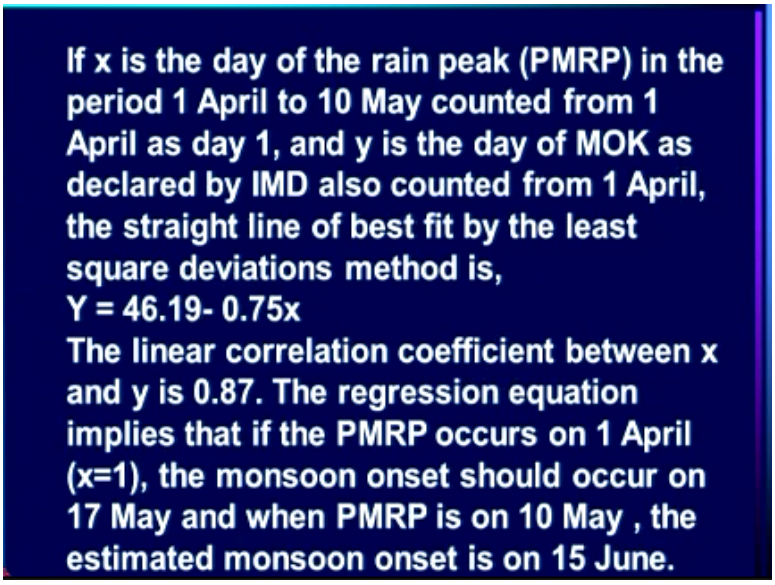

So they said if x is the day of the rain peak in the period of 1st April to 10th May counted from 1st April as day one and why is the day of MOK as declared by IMD and also counted from 1st April. So they are looking for a relationship between the day of the pre-monsoon rain peak and the onset over Kerala and date of onset over Kerala is Y and date of pre-monsoon rain peak is X everything is counted with one as 1st of April.

Then what they found is that they can get a straight line fit to the deviations although they have not actually shown the points. So one does not know how good the fit is, but it is probably very good because the correlation coefficient between x and y is 0.87. So the fit says Y=46.19-0.75 X. In order words, the monsoon onset over Kerala the date of MOK is actually linearly related when the pre-monsoon peak occur.

And the regression equation implies that if PMRP occurs on 1st April the monsoon onset should occur on 17th May, so that is more than a month and half later and PMRP is on 10th May the estimated monsoon onset is 15 June so that is just 35 days later. So this is the kind of results that have come and since y-x is depended on the calendar date. See it is already saying that if PMRP is too early in the year.

Then the system is not quite ready to have the onset of the monsoon within say 35 days, but if it occurs later in the year the system is ready.

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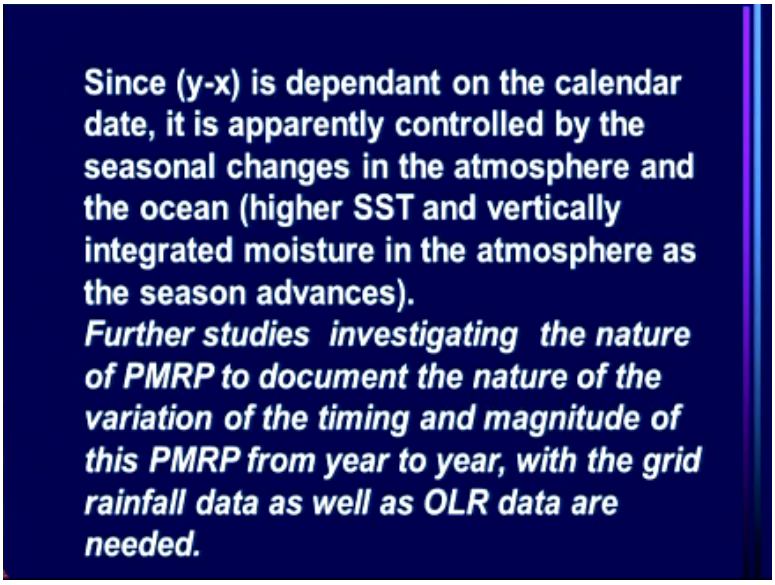

So since y-x is depended on the calendar date it is apparently controlled by the seasonal changes in the atmosphere and ocean that is higher SST and vertically integrated moisture in the atmosphere as the season advances. Now I think this needs to be perused a little bit further and in fact this goes as an input to the operational method later on developed by IMD in 2006.

But I think it is very important to have further studies investigating the nature of this PMRP to document the nature of the variation of the timing and magnitude of this PMRP from year to year. Now new data that are available grid rainfall data are available and OLR data are also available. So with these new data that are available it would be a good idea to get an idea of the pre-monsoon rain over this belt vis-à-vis what happens during the onset.

So this is a problem on which more works needs to be done.

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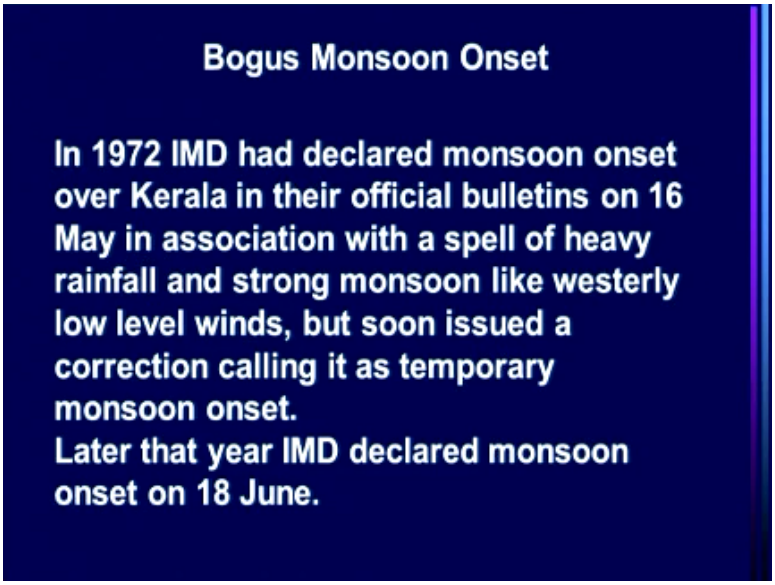

Now I mentioned Bogus monsoon onset in the last class and I will talk about that now. In 1972 IMD had declared monsoon onset over Kerala in their official bulletins on 16th May in association with a spell of heavy rainfall and strong monsoon like westerly low level winds, but soon issued a correction calling it as a temporary monsoon onset.

Later that year IMD declared monsoon onset on 18th June so that is quite bit later than the climatological date of June 1. So this was a late onset year in which there was a Bogus onset in 18th May.

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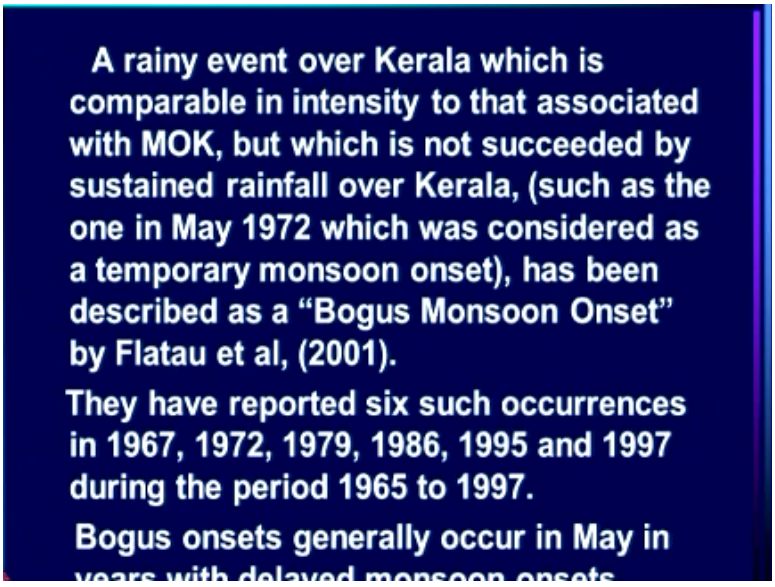

Now a rainy event over Kerala which is comparable in intensity to that associated with MOK, but which is not succeeded by sustained rainfall over Kerala such as the one in May 1972 which was considered as a temporary monsoon onset by IMD has been described as the

Bogus monsoon onset by Flatau et al. Now they have reported 6 such occurrences 1967, 1972, 1979, 1986, 1995, 1997 during the period 1965 to 1997.

So quite a few occurrences of bogus onset. Now bogus onsets generally occur in May in years we deal at monsoon onset. As I said 1972 was 18th June was the real onset which was 17 days' delay from the climatological MOK.

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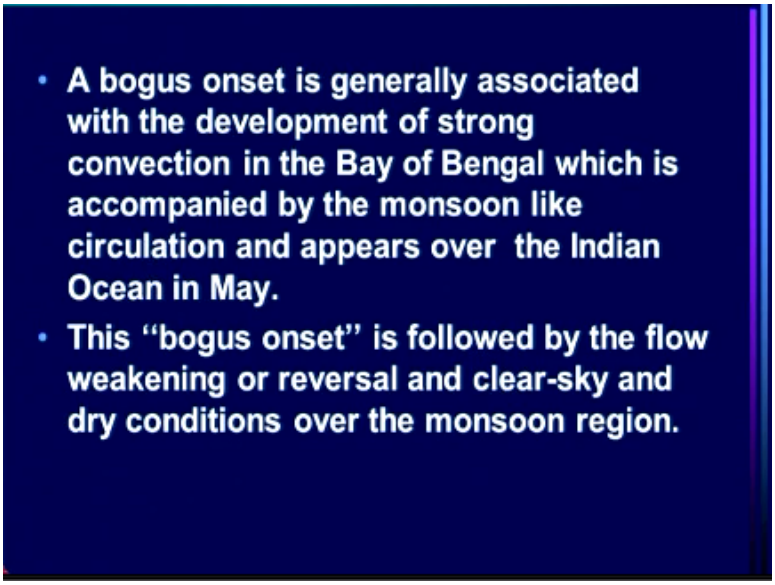

A Bogus onset it generally associated with the development of strong convection in the Bay of Bengal which is accompanied by the monsoon like circulations and appears over the Indian Ocean in May. This Bogus onset is followed by the flow weakening or reversal and clear-sky and dry conditions over the monsoon region. So this is the way Flatau et al describe it.

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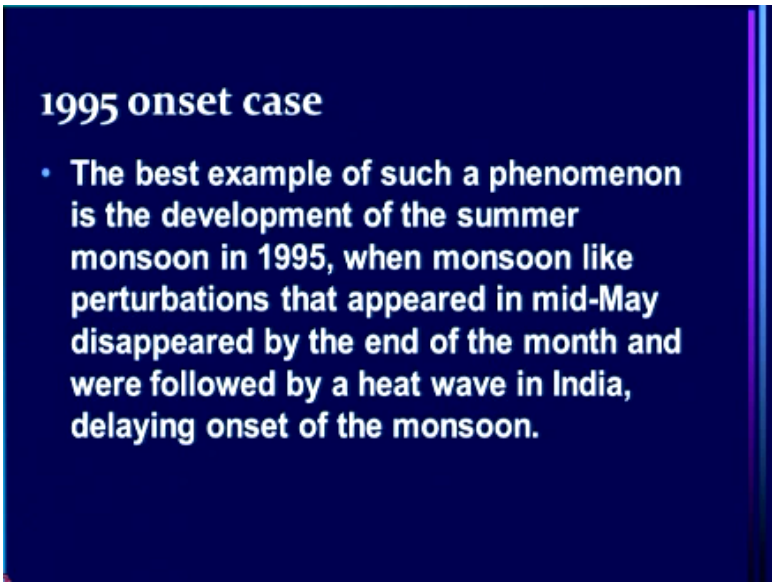

And perhaps the best example of a bogus onset is the case of 1995. The best example of such a phenomena is the development of the summer monsoon in 1995 when monsoon like perturbations that appeared in mid-May disappeared by the end of the month and were followed by a heat wave in India delaying the onset of the monsoon. Now this is the comment they make that the heat wave delayed the onset of the monsoon.

Now whether the heat wave delayed the onset of the monsoon or the onset of the monsoon was delayed by some other factors which led to a heat wave it cannot be really ascertained without a proper analysis of the evolution.

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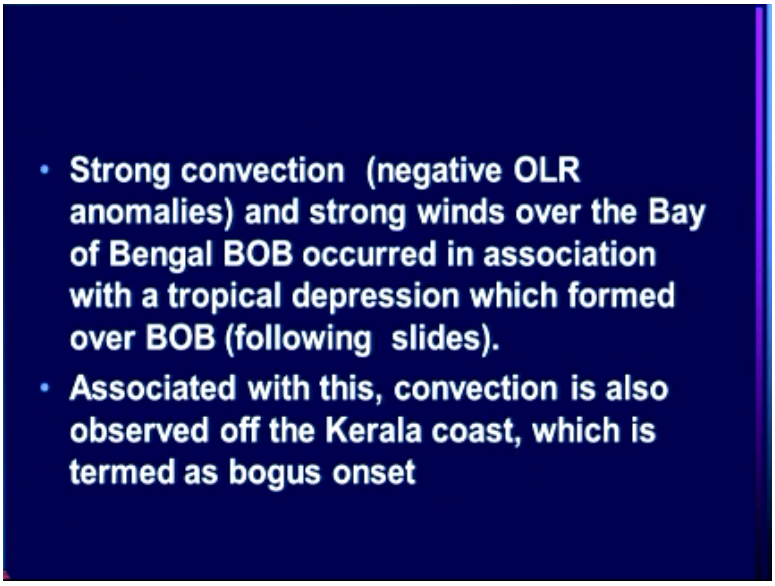

Now what happened during this Bogus onset. Strong convection that is to say negative OLR anomalies and strong winds over the Bay of Bengal occurred in association with a tropical

depression which formed over the Bay of Bengal as seen in the following slides.

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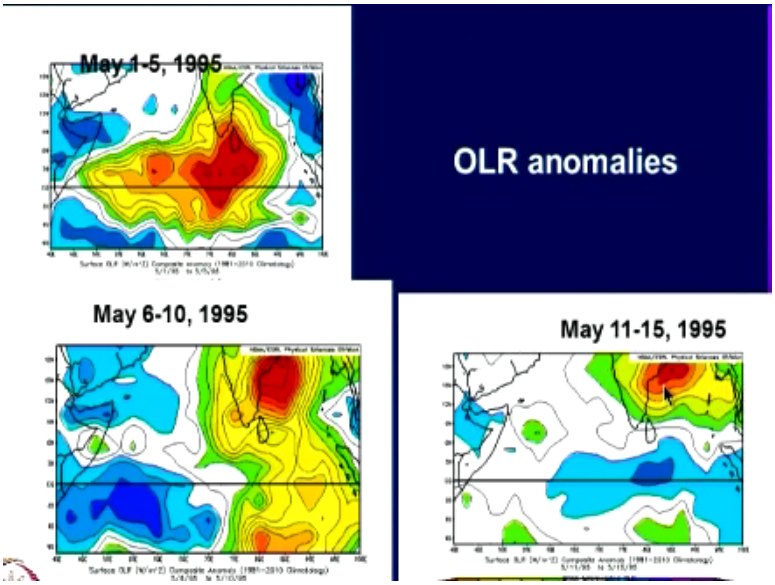

So this is May 1-5 and note that yellow and orange negative OLR anomalies. So this is where there is convection from May 1st to 5th and you can now see May 6th-10th what has happened is convection has disappeared here. It has moved eastward if you wish and formation of 2 systems. One going to the North, one going to the South in the 2 hemisphere and the northern one has intensified into a depression which you see again here.

Here the southern one has moved off this map and the northern one or May have disappeared and the northern one is a strong depression here May 11-15.

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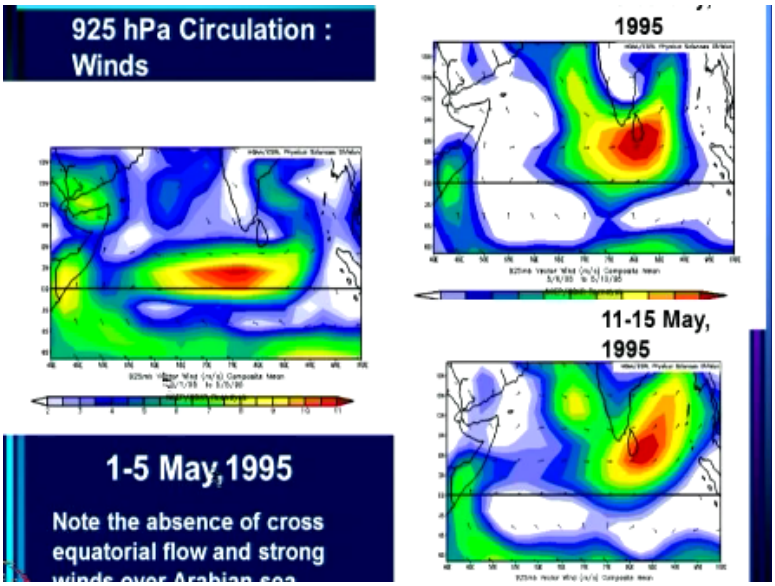

Now look at 925 hPa circulation which is available from the (()) (09:35) data and what you

see is that a strong wind here from 6th May to 10th May and you see the winds have move north the strong winds have move northwards and here 11 to 15th May again they spread more here over the Bay of Bengal, but we have to notice one thing. See these winds are strong here and remember that there was a convection, strong convection over here in this period.

Here it was actually convection was all over here and from 6th-10th May the convection was much more here and then here there was a depression here. So in association with that we got strong winds, westerly winds here, but notice the cross equatorial flow is still very, very weak. See here yellows are the strong winds and greens and blues are the weak winds. So you get strong winds in association with the depression, but it is not the change in the planetary scale because you do not get cross equatorial flow which is characteristics of the monsoon.

So what happened is after the storm passed away and weakened convection off the Kerala coast disappeared over South India dry conditions leading to heat waves prevailed. After the passage of the storm over BOB the wind strength also reduced substantially. So this is what is happening after the passage of the storm. So by 1620 the storm has passed away you see all these are blues there is some convection here, but rest of the thing there is no convection.

And you see the entire Indian region is dry and same thing is happening till towards the end of May and you see even May 21st-25th there is no convection. End of May, you see something is now happening over the South equatorial Indian ocean convection is building up here. Once the convection disappears from the Bay the winds also became relax. So the whole phenomena so to speak ended without leading to the transition to the monsoon season.

So this is why it was a Bogus onset.

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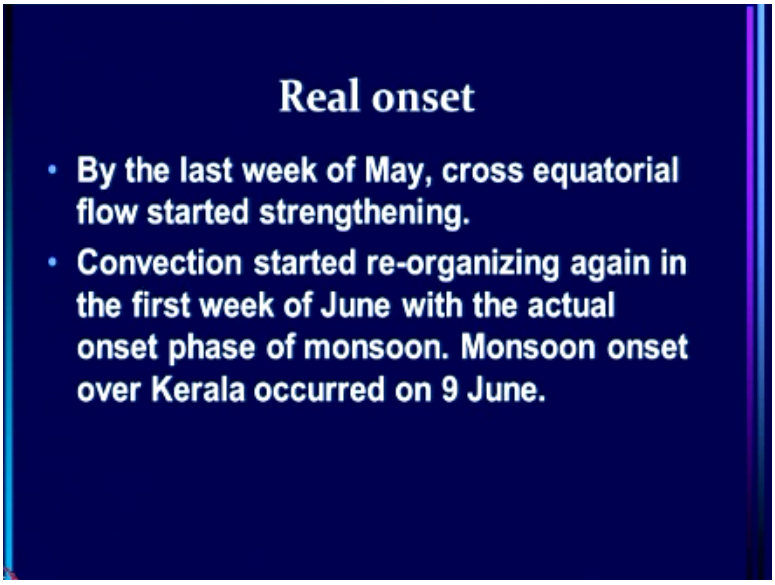

Now by last week of May cross equatorial flow started strengthening. Convection started re-organizing again in the first week of June with the actual onset phase of the monsoon. So now this is the last week of May and you see now the cross equatorial flow has started strengthening and you see these are the yellows are the stronger ones here it started strengthening here in the southern hemisphere and you see by 21st-25th May it is actually strong here also.

The strength is high here also and it has become even stronger and by end of May you see this entire region is very, very strong cross equatorial flow. So by end of May, the cross equatorial flow started strengthening by last week of May. Convection started re-organizing again in the first week of June.

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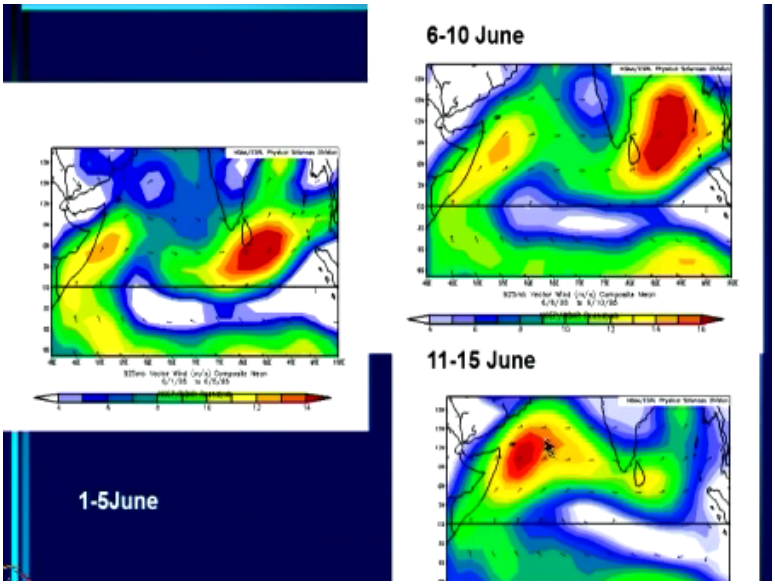

So let us look at the convection or this is still the cross equatorial flow and what we see is this is 1st to 5th June now it is becoming stronger in the northern hemisphere and by 11-15th June it has become extremely strong here and strong here as well. So this is the strengthening of the circulation.

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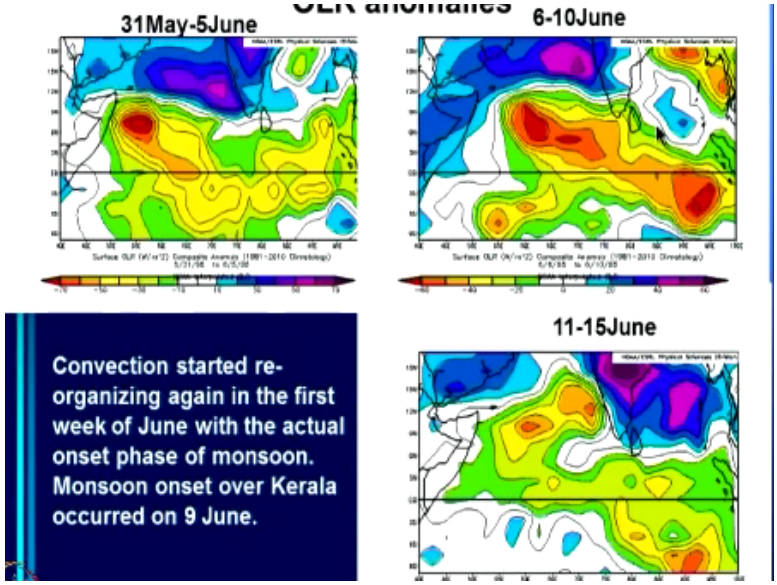

Now this is 31st May to 5th June you can see that there is a nice belt of deep convection over the equatorial region and part of the western equatorial Indian Ocean, very nice deep convection has formed here and 6-10th June of course you see northward movement of the deep convection here all along here and 11 to 15 June it has moved even further northward here.

So convection started re-organizing again in the first week of June with the actual onset phase of the monsoon and the onset occur towards the end of the 6-10 June period onset over Kerala occurred when actually you had a TCZ going across that region, but stretching all the way from the Arabian sea here.

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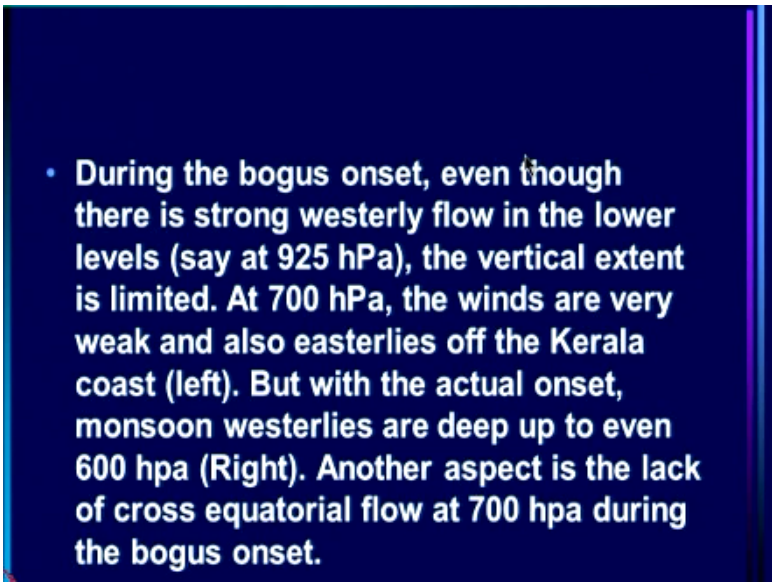

Now during the bogus onset even though there is strong westerly flow in the lower levels say at 925 hPa the vertical extent is limited. So at 700 hPa, the winds are very weak and also there are easterlies off the Kerala coast. But with the actual onset monsoon westerlies are deep up to even 600 hPa. Another aspect is the lack of cross equatorial flow at 700 hPa during the bogus onset.

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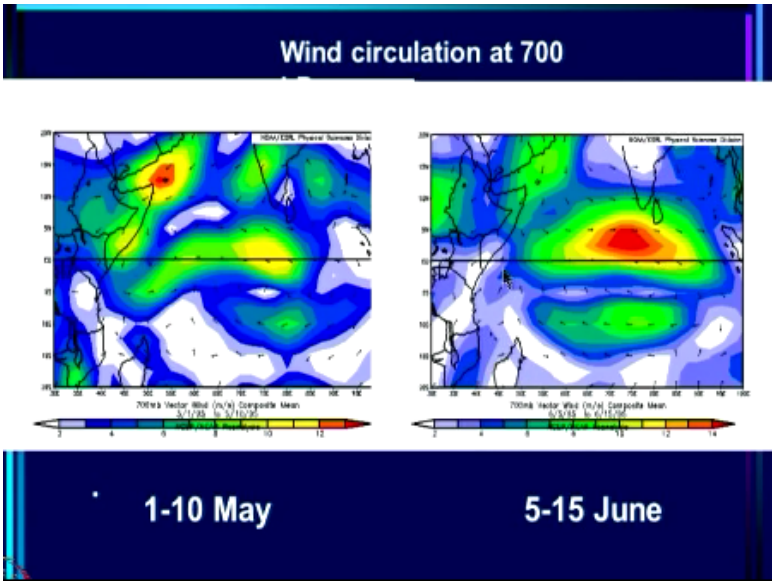

So if we look at wind circulation at 700 then you see there is no cross equatorial flow at all from 1 May to 15th May, but by June it has got established here.

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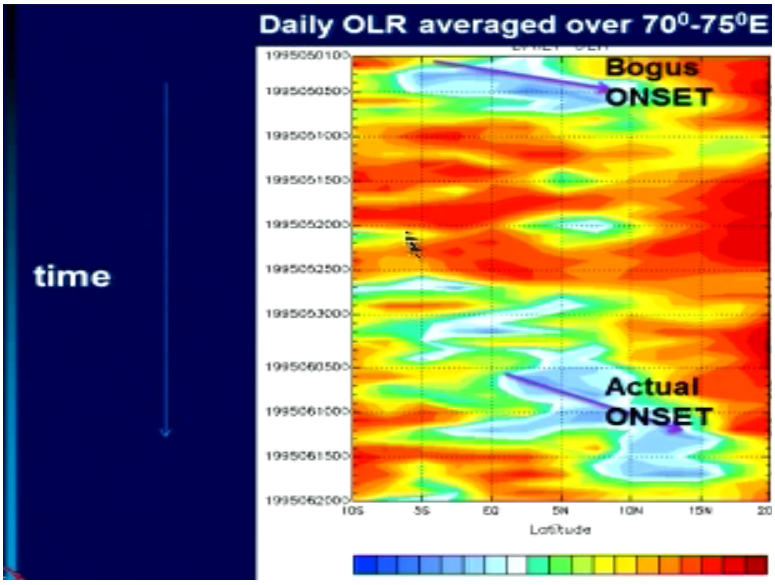

So let us look at what people call a Hovmuller diagram. This is the Daily OLR averaged over 70 to 75 degrees East remember this is just off the west coast of India and what you see here is from time is going downwards as shown that by the arrow there and this is 1st May so this is the Bogus onset remember now blue imply very low OLR here and see the low OLR region has actually moved northward all the way from about 5 south to 5 north.

Partly moved and partly expanded and this is when the Bogus onset occur. Remember tip of India is 8 degrees north so this is the bogus onset which occur. So the blues are the region of clouds that we watch, but see what happen after the Bogus onset just no deep clouds at all until almost 25th May. So this was the clear dry spell not only over Kerala, but over entire India and there was a heat wave as was described.

Then came the actual onset and that is a sort of a multiple propagation you see. One is here 30th May and soon after that another has begun here just north of equator and this is the one that has moved. So actually 9th of June was the onset date on which this rain-belt has come here. So this is the actual onset. So you see that between the bogus onset and the actual onset the system had changed completely.

This was dry hot region in between it was not just a weaker Tropical Convergence Zone.

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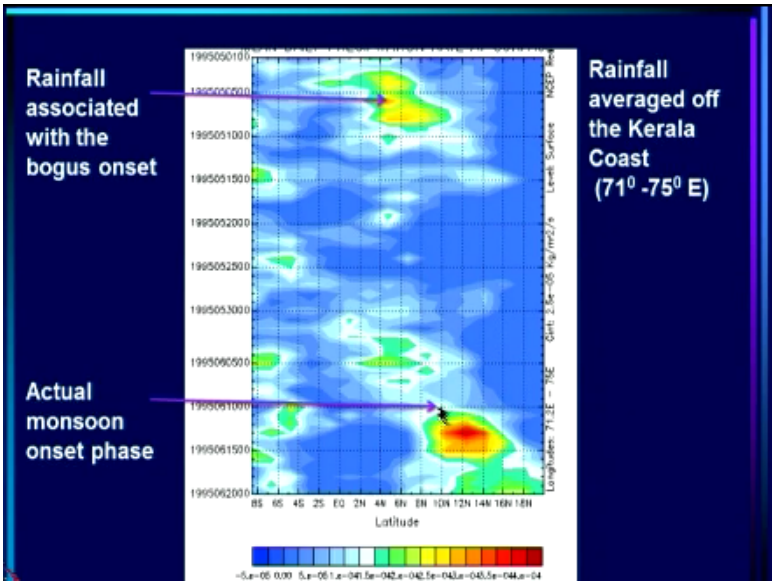

Now this is the rainfall associated with the bogus onset and you see it occurred with the Bogus onset and this is again averaged off the coast of Kerala 71 to 75 and again the real rain began only with the real onset around 9th of June.

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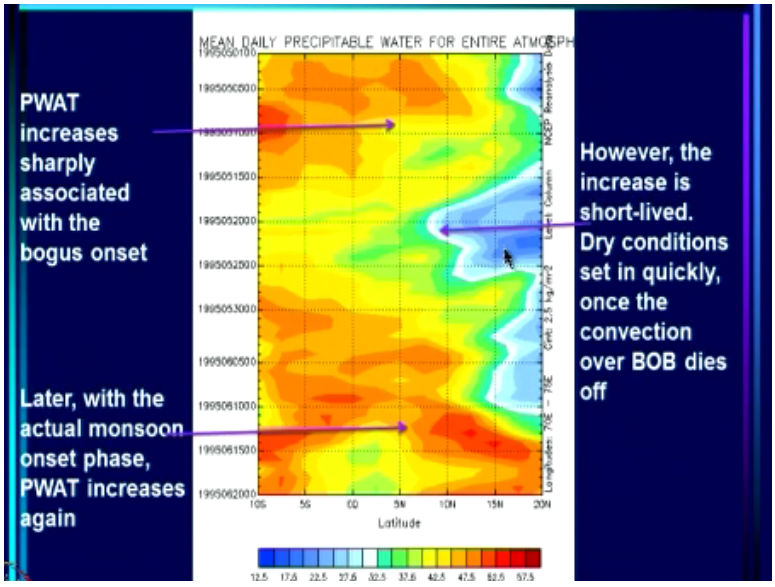

Mean Daily precipitable water for the entire atmosphere. So how much precipitable water was there. There again here we have to note that these oranges and yellows are the high precipitable water. Now PWAT increases sharply associated with the bogus onset this is in May here we are getting an increase in PWAT here, but it decreases. However, the increase is short-lived. See this whole thing is spread up to here.

But then it has retreated now north of 8 north we are somewhere here. So what has happened is Mean Precipitable Water over the entire atmosphere had increased in association with the

Bogus onset, but now it retreated and then it increased only with the real onset. So over this entire period it has retreated. So there is a very big gap between what seem like an onset and the real onset. This is PWAT started increasing with the real onset.

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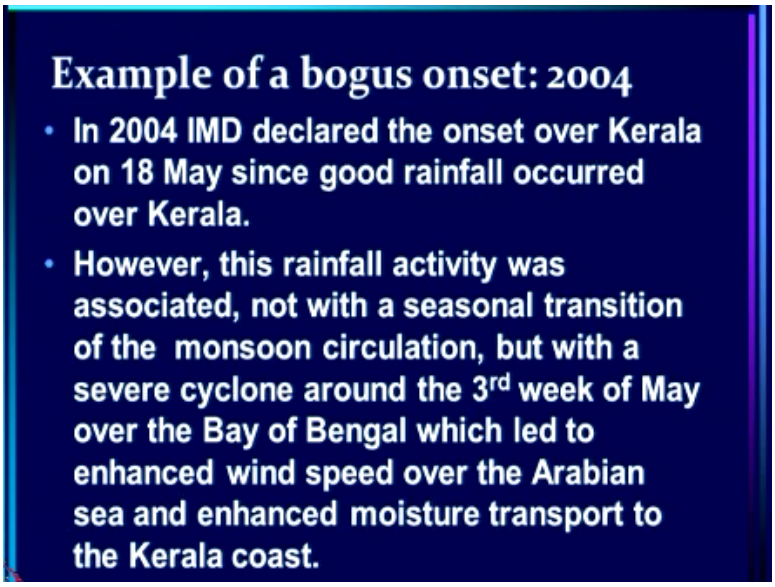

Now there was one more bogus onset in 2004 and it is perhaps this bogus onset that led to development of the objective methods for operational declaration of MOK. In 2004 IMD declared the onset over Kerala on 18th May since good rainfall occur over Kerala. However, this rainfall activity was associated not with the seasonal transition of the monsoon circulation.

But with a severe cyclone around 3rd week of May over the Bay of Bengal which led to enhanced wind speed over the Arabian sea and enhanced moisture transport to the Kerala coast.

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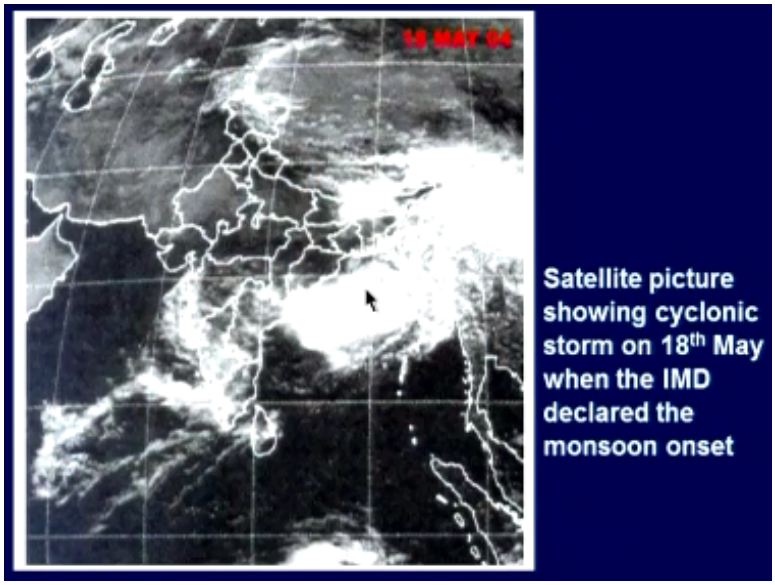

So this is the cyclone this is the severe cyclonic storm on 18th May when IMD declared the monsoon onset and why did they declare it you can actually see because of the influence of this storm here actually the winds have strengthened here and you see a band of deep clouds here. So you did get considerable amount of rain over Kerala, but it was not associated with the Tropical Convergence Zone here.

Rather it was associated with this cyclonic storm here and therefore it was not something that would last. So it was this storm that led to the enhanced wind speed over Arabian sea and enhanced moisture transport to the Kerala coast.

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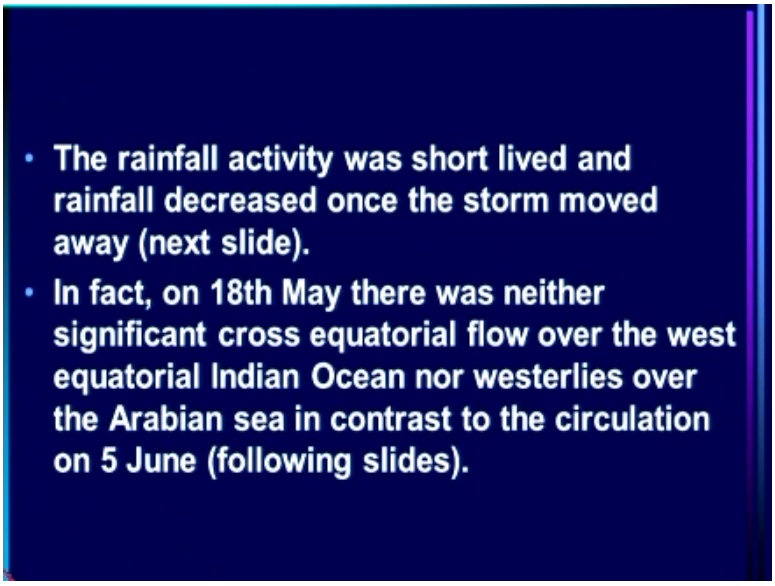

So the rainfall activity was short-lived and rainfall decreased once the storm moved away. So this is the rainfall activity over Kerala and you can see here it was absolutely nothing before

15th May it picked up on 16th May it peaked on 18th May and IMD declared the onset, but afterwards it sorts of hunger on for a few days, but decreased and then nothing at all for several days except for one day events till later on around in early June when the actual onset occurs.

So this is the rainfall and this is how the circulation looked for the period in which the onset was declared by IMD you see quite strong westerlies have occurred over Arabian sea, but the cross equatorial flow is not strong. Strong flow over the Arabian sea and Bay of Bengal in association with the cyclonic storm that was there. So very strong wind occurred, but not cross equatorial.

On the other hand, when the actual monsoon onset occurred in early June you see a very strong cross equatorial flow here and strong westerlies right along here. So this is the difference between the bogus onset and the actual onset.

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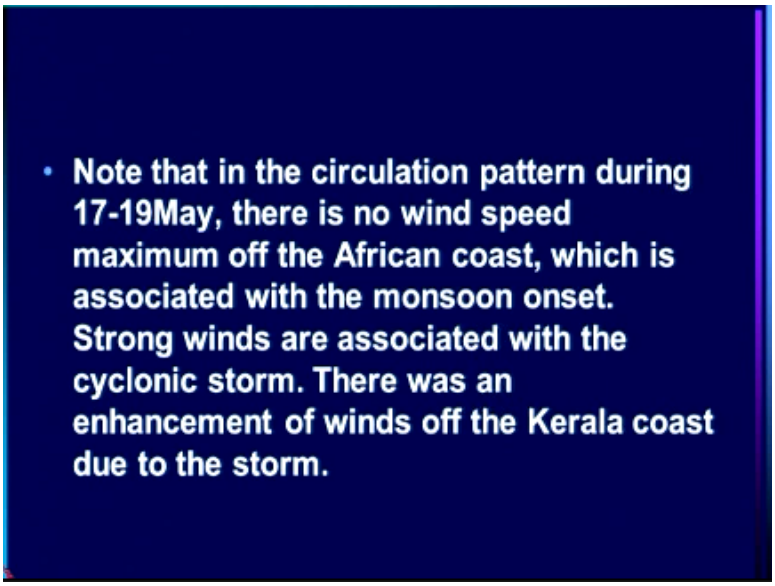

Note that in the circulation pattern during 17th to 19th May there is no wind speed maximum off the African coast which is associated with the monsoon onset. Strong winds are associated with the cyclonic storm. There was an enhancement of winds off the Kerala coast due to the storm which I pointed out.

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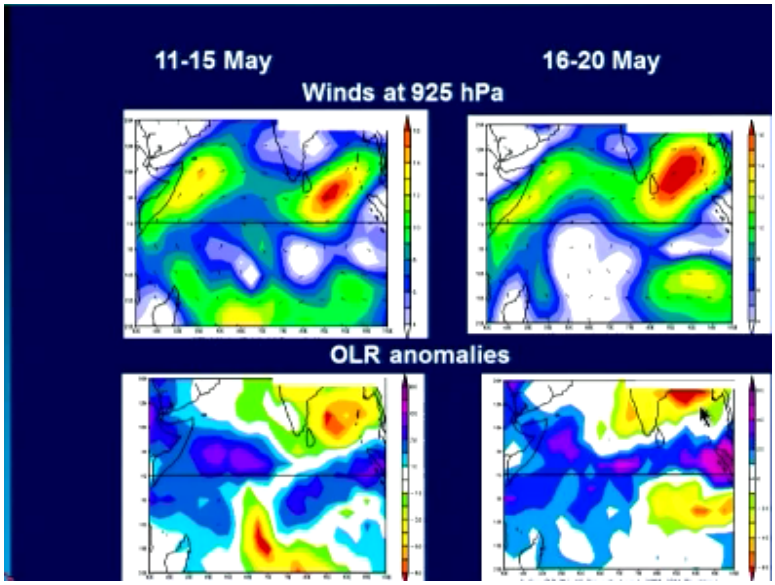

So now here we see the actual winds from 11 to 15th May and you see storm is developing and the winds are strengthening over the Bay here and some strengthening here and here the winds have become very strong here and these are the OLR anomalies and this is the development of the storm here and this is low and this is become a depression now. So we have a strong system here which also has led to deep convection over the Kerala coast because there are also strong winds here.

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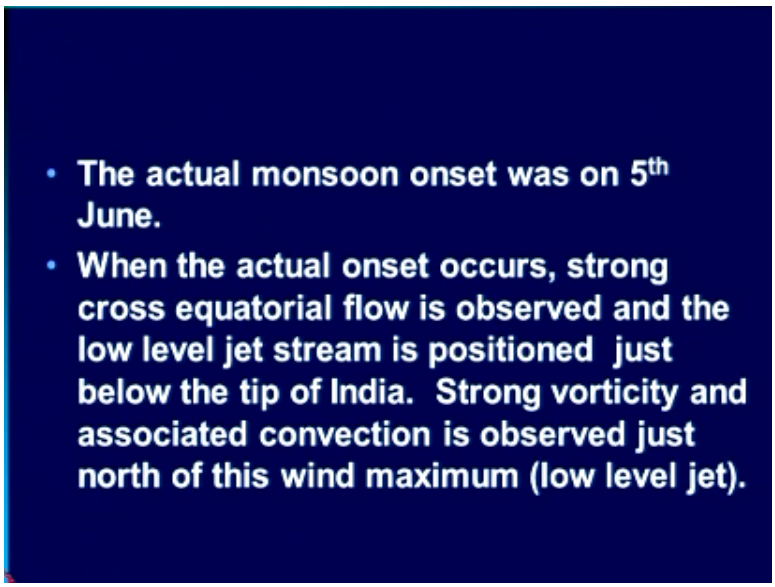

The actual monsoon onset was on 5th of June and when the actual monsoon occurs as we have seen already strong cross equatorial flow is observed and the low level jet stream is positioned just below the tip of India. So strong vorticity and associated convection is observed just north of this maximum which is the low level jet. So now you see what happens when you get the onset of the monsoon.

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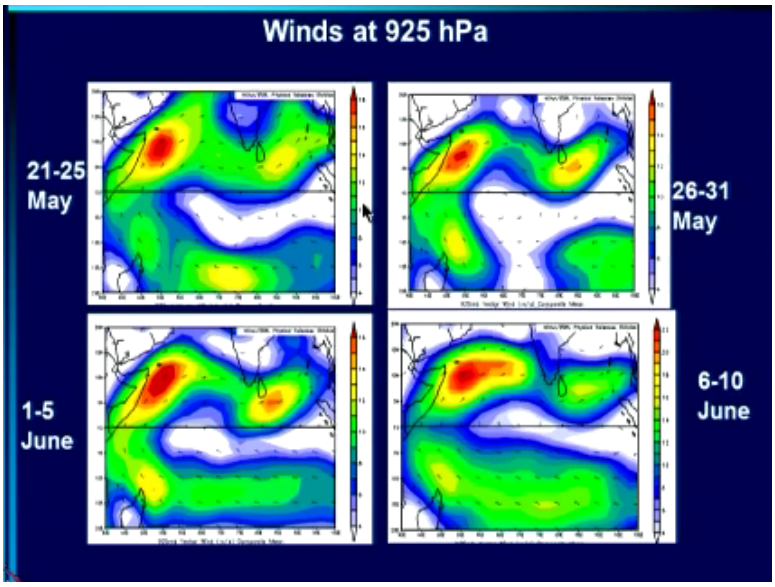

These are the winds again at 925 you see strong winds here and now strong cross equatorial current occurring this is before the real onset and you see strong winds here and here the vorticity is cyclonic which is what we need for the TCZ to appear there. See extremely strong cross equatorial flow has developed by 5th of June, 5th of June was the onset day and you have strong winds here and strong winds here.

And after the onset the Arabian sea westerlies have become even stronger here. So this is the signature of the real onset.

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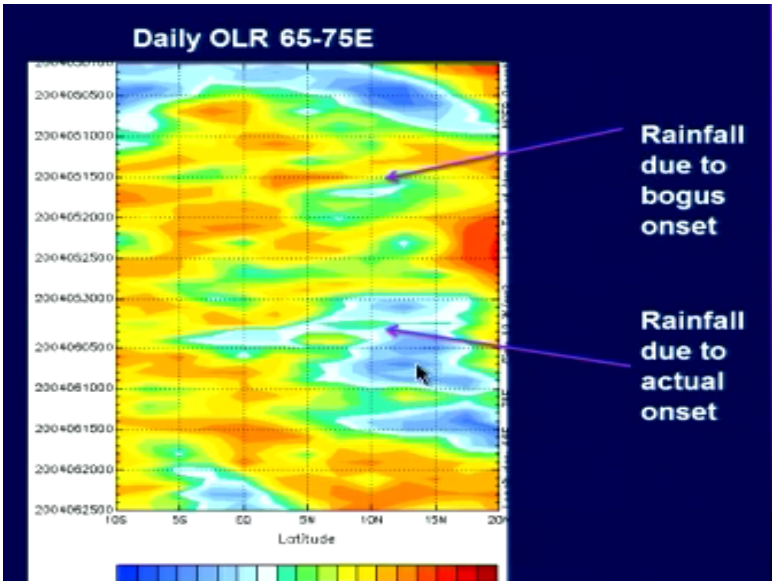

Now if we see the Hovmuller diagram then we see that daily OLR from 65 to 75 we see rainfall due to the Bogus onset here and this is 15th of May and this is the rainfall due to the

real onset and what you find is that see before the onset there was some rain to week rain and this is when it was declared as the onset on 5th of June and that is when rain persisted after that and actually moved northward. So this is the real onset daily OLR.

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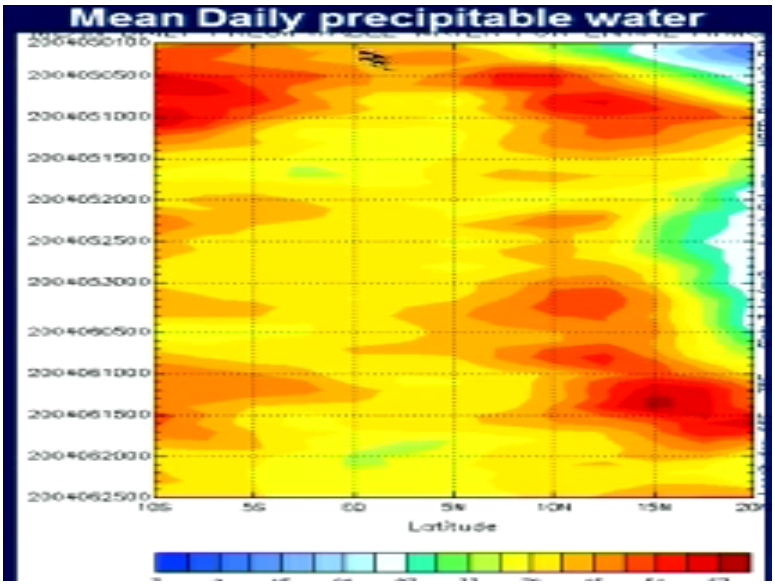

And this is the Mean daily precipitable water. You can see that it became very high during the bogus onset this is 10th of May this is when the depression was there precipitable water became very high, but then it ran southward and became much smaller and then started intensifying only in early June and from 3rd to 5th June you see an intensification here all over coast and in fact then you see the northward movement very clearly after the real onset.

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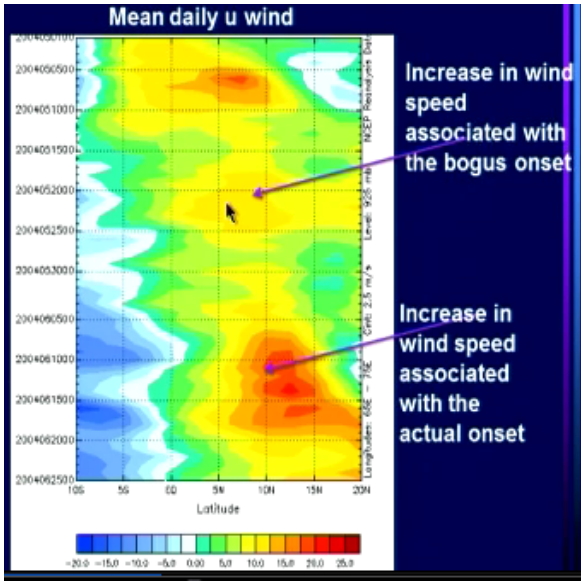

This is the Mean daily u wind and again you see a definite signature of the bogus onset and then this is the real onset when it increased this is from 65 to 75 east again. Now so far I have

been talking of bogus onsets, but to give a prospective let us look at a typical onset where we claim that there are no bogus onset have occurred.

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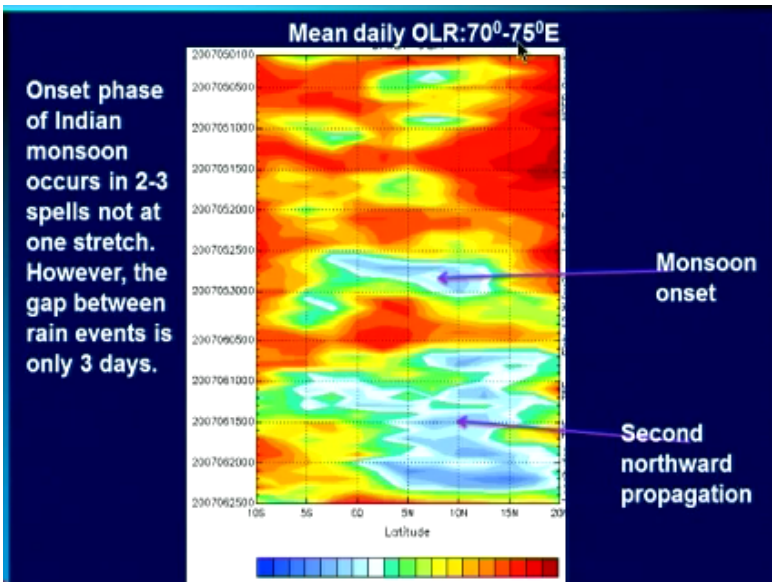

So if you look at Mean daily OLR from 70 to 75 again you see this is the monsoon onset, but the way the onset has occurred immediately after that you are not getting continuous rain rather very soon there is about gap 2-3-day gap and then again it occurs and then it more or less continuously rain here or there are deep convection continuously here. So when we look at it the difference between monsoon onset of this kind which we can say which has been called a multiple onset because it is not just one event.

But events in quick succession that are leading to the onset. This one (()) (25:50) and then again revived very soon. So this also there is a gap, but the difference is that the gap is only 2-3 days it is not more than 3 days. So onset can occur in 2-3 spells, but the gap between the spells is not very large when it is a regular garden variety onset and this is the thing.

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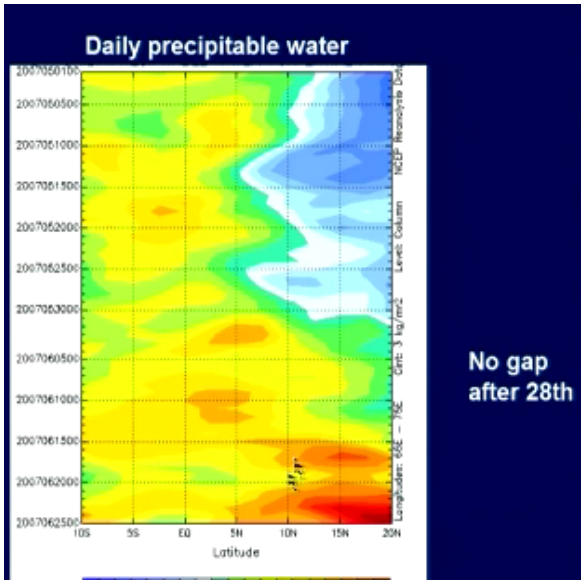

And in fact it should be seen that in the daily precipitable water there is no gap at all. In fact, it has just increased steadily and remained so. Here we got a bit of a gap, but this is when the monsoon onset occurred on 28th of May here which is around here this is when we decided that monsoon onset had occurred the IMD decided that and on 28th May you see already this has started moving northward.

That is to say the daily precipitable water was already increasing over the region and continued to increase throughout. This is Kerala coast continued to increase throughout, but much more so with the second events so to speak. Same thing with Mean daily wind mean daily wind also this is 30th. So it began to increase here and then continued to increase. So this is simply to say that it is in the nature of things.

That these systems cloud systems do not monotonically propagates from the equatorial region to the monsoon zone during the onset phase rather they get generated, they propagate up to a certain point they die another gets generated and again it propagates further northward and so on and so forth. So it is in the nature of things that it is not a single event that gives the onset phase of the monsoon.

But if it happens what appears like a first onset occurs many, many days before the real onset after which you get success in northward propagations and onset of the monsoon progresses northward properly then you call it a bogus onset. So there is not that much of a qualitative difference between the 2 it is just a matter of timing. This event is an isolated event a bogus onset is an isolated event.

Whereas during the real onset you can have several events separated by very small time scale of 2-3 days which lead to the onset and northward propagation of the monsoon. This has to be borne in mind.

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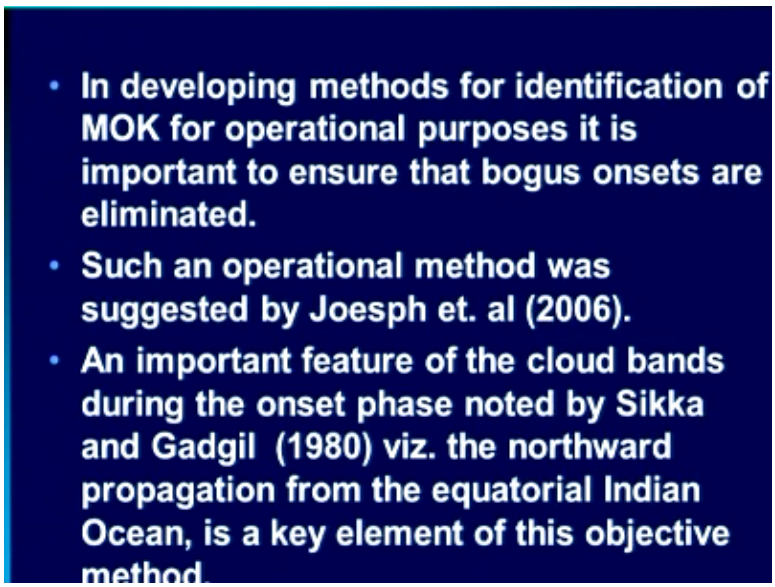

Now in developing methods for identification of MOK for operational purposes it is important to ensure that the bogus onsets are eliminated. Such an operational method was first suggested by Joseph et al and an important feature of the cloud bands during the onset phase noted by Sikka and Gadgil namely the northward propagation of the equatorial Indian ocean is a key element of this objective method.

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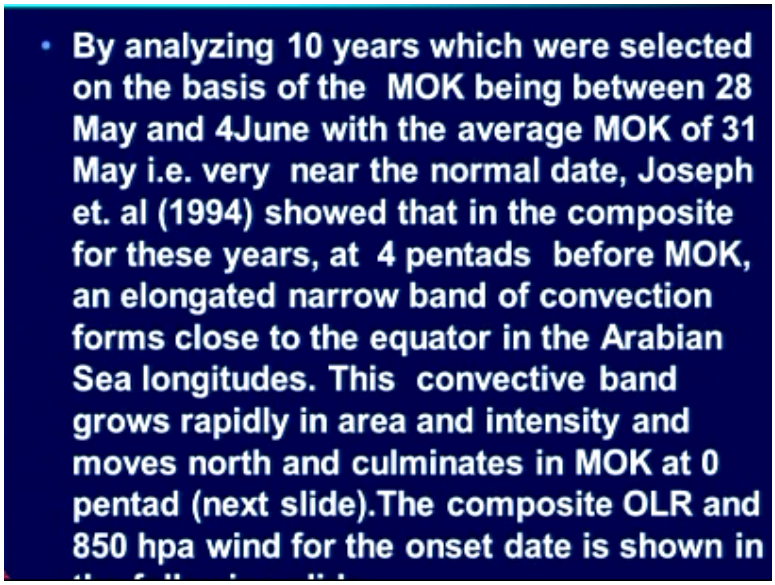

Now by analyzing 10 years which were selected on the basis of MOK being between 28th

May and 4th June. So these was specially selected years with the average MOK of 31st May that is very near the normal date. Joseph et al showed that in the composite for these years. Again the composite is made with their own specific onset date. So actually I am a bit puzzled as to why he took only 10 and not all the 31 years like Krishnakumar and Soman had done and so on.

But Joseph selected only 10 of these years when the MOK was very close to the average date and then did the composites and what he found was the following.

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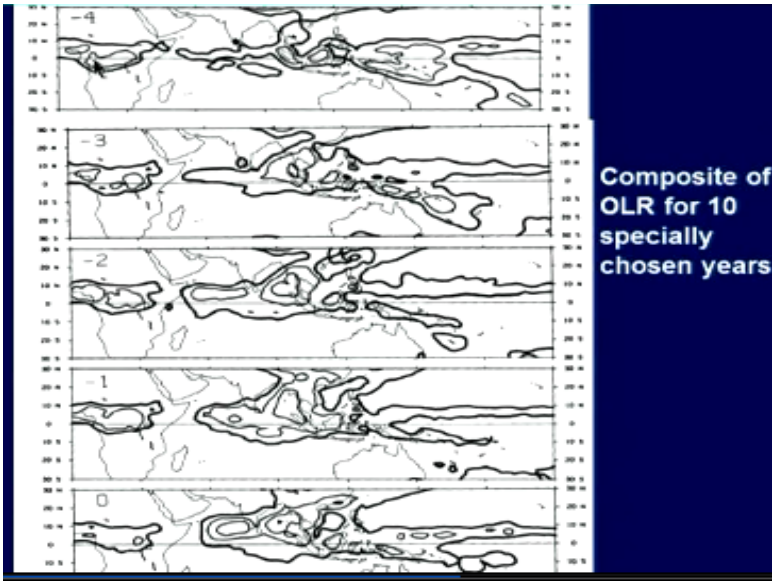

Now these are the composites for the different pentads. So this is -4 the top one this is -4 pentads that means 20 days before the onset and what you see is a nice band of convection extending all the way around the equatorial region. Now this happens at -3 that is to say 15 days before the onset and more or less same story and then you have 10 days before the onset it has intensified over the Bay here also between 20 and 15 also you see a definite intensification over the Bay and northward spreading over the Bay.

And -10 days also that continuous northward spreading and you see a blog over the South eastern Arabian sea and this is just 5 days before the onset when you see that almost the entire Bay have deep convection and you have a nice (()) (30:55) here with the maximum at the equatorial region and convection over the South East Arabian Sea as well and this is the onset of the monsoon when the actual intense convection is sitting over the tip of India here.

So these are Joseph composites for the 10 years that he chose and he says that as we have

seen 4 pentads before MOK and elongated narrow band of convection forms close to the equator in the Arabian sea longitudes. This convective band grows rapidly in area in intensity and moves North and culminates in MOK at 0 pentads. The composites we have already seen.

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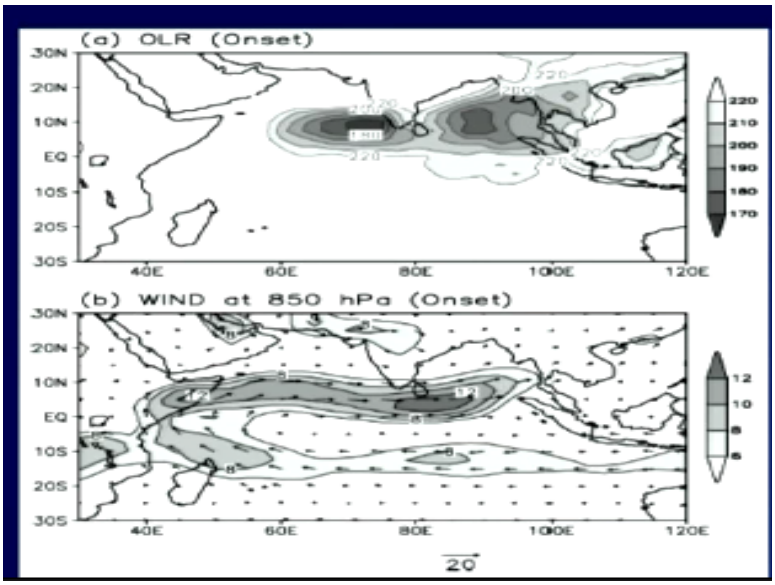

And from Joseph this 10 years' composites this is the onset of OLR and this is the wind at 850 hPa and you can see this is the low level jet here, but you do not see any vortex here. There is no cyclone or closed vortex here it is really the cyclonic vorticity because this is very strong and this is weak. So in the northern hemisphere you have a belt of strong cyclonic vorticity to the north of the axis of this low level jet.

So there is a belt of cyclonic vorticity, but there is no closed vortex here and this is the band, this is the TCZ associated with that.

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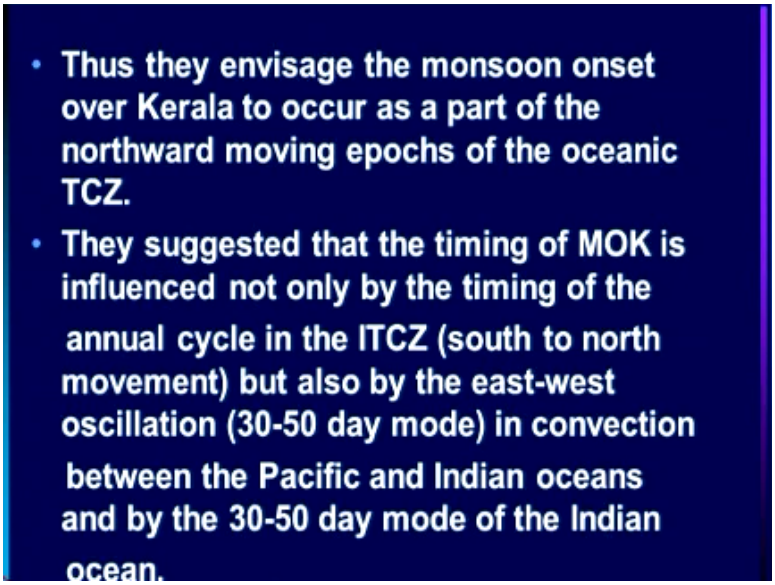

So thus the envisage that the monsoon onset over Kerala occurs as a part of northward moving epochs of the oceanic TCZ and they also suggest that the timing of MOK is influenced not only by the timing of the annual cycle in the ITCZ that is south to north movement, but also by the east-west oscillation that is 30-50-day mode in convection between the pacific and Indian ocean and by the 30-50-day mode in the Indian ocean.

So they are saying that the intra seasonal variation in the Indian ocean also plays an important role in deciding what is the monsoon onset over Kerala. Following the description of an onset vortex. Now you know in 1979 there was a major observational program called monsoon experiment, it was an international observational program and so for 1979 a large amount of data became available, lot of studies were therefore made of the monsoon of the 1979.

And we have already seen one of them which shows the sharp increase in kinetic energy with the onset of the monsoon. So for 1979 Krishnamurti wrote a very important paper showing that the onset occurred with a vortex of the coast of Kerala which we call the onset vortex.

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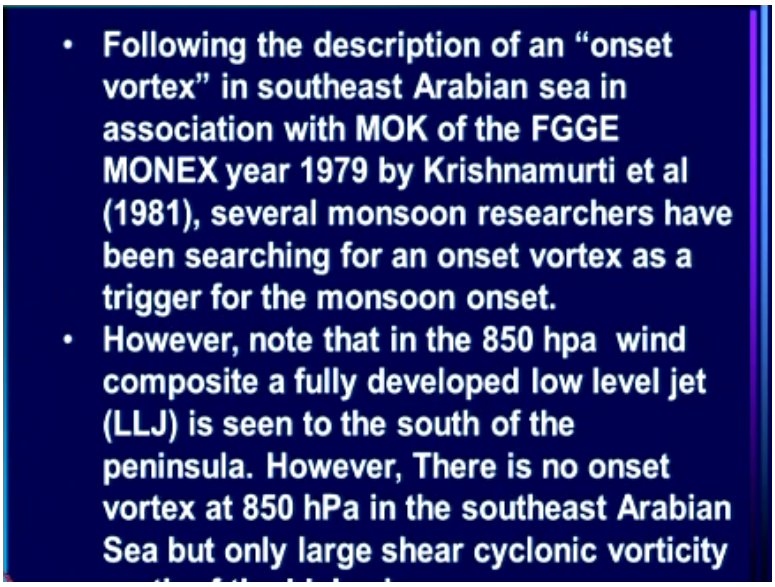

So following the description of an onset vortex is south eastern Arabian Sea in association with monsoon onset over Kerala the FGGE MONEX year by 1979 by Krishnamurti et al several monsoon researchers have been searching for an onset vortex as a trigger for monsoon onset. So they think that monsoon onset is as necessary facet of MOK, but in fact we see in the composite of Joseph that there is no vortex there.

And also there is no onset vortex at 850 hPa in the south east Arabian sea, but only large shear cyclonic vorticity not of the LLJ axis as I pointed out.

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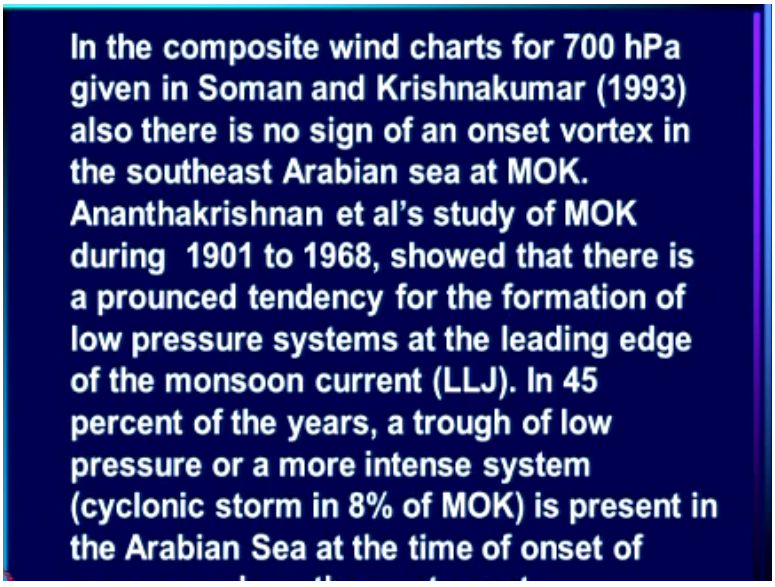

Now in the composite wind charts of 700 hPa given in Soman and Krishnakumar also there is no sign of an onset vortex in the southeastern Arabian Sea at MOK. In fact, Ananthakrishnan et al had looked at this possibility long ago they did an analysis of MOK during 1901 to 1968

and showed that there is a prounced tendency for the formation of a low pressure systems at the leading edge of the monsoon current which is the low level jet.

And in 45% of the years a trough of low pressure on more intense system cyclonic storm in 8% case is present in the Arabian Sea at the time of onset of the monsoon along the west coast. So there is a chance of about 1 and 2 or slightly < 1 and 2 of an onset vortex. So it should not be considered as a necessary facet of the monsoon over Kerala.

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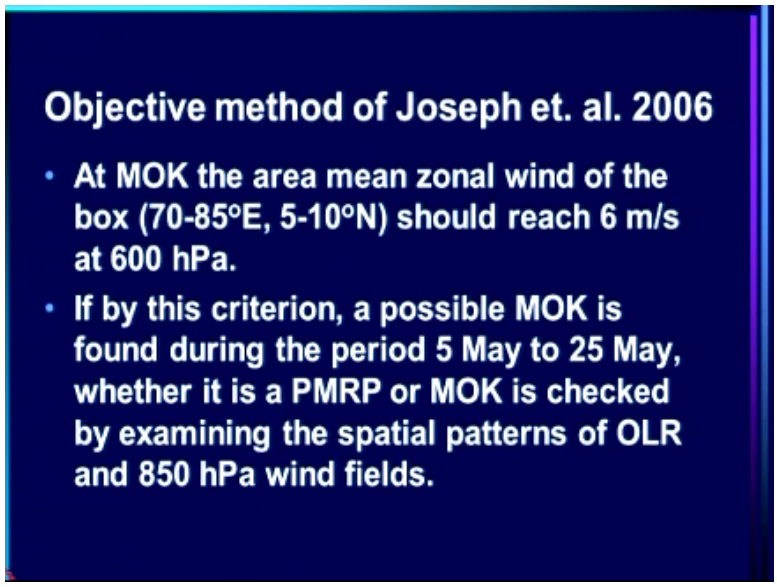

Now let me just describe to you what is the objective method suggested by Joseph he says this is an area of the south eastern Arabian sea mean zonal wind at that should reach 6 meters per second. If by these criteria a possible MOK is found during 5th May to 25th May then you should check whether it is a PMRP or MOK by examining spatial patterns of OLR and 850 hPa winds.

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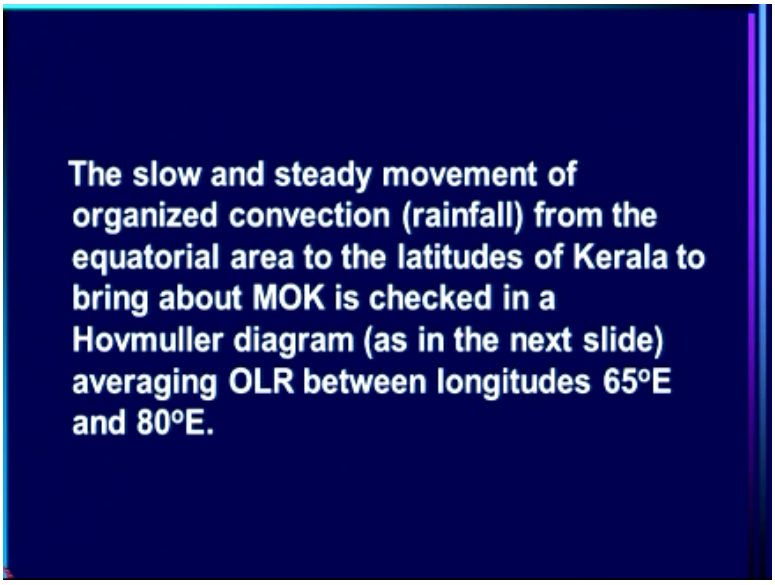

And slow and steady movement of organized convection from the equatorial area to the latitudes of Kerala to bring about MOK is checked in a Hovmuller diagram as in the next slide.

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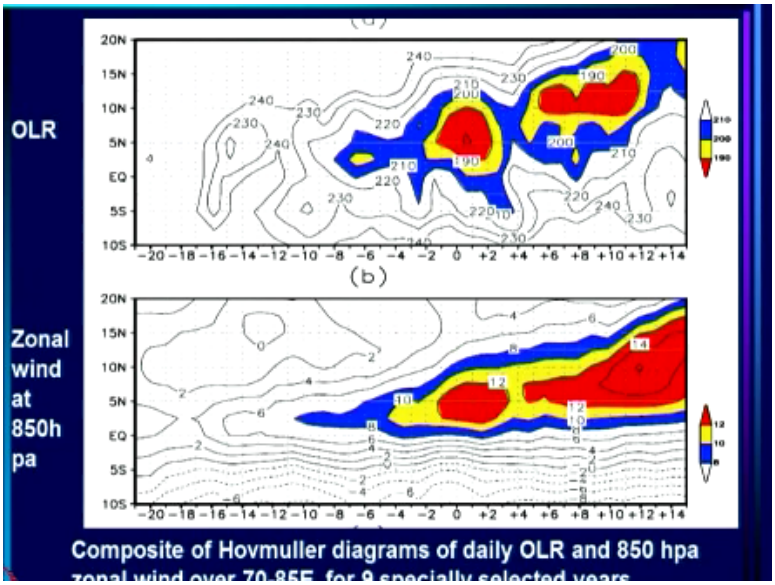

These are things that he plotted. These are again composites of those trends especially selected years and what you see here is a very clear northward progression of the low OLR region with the onset and you see here a northward progression of the wind also intensification in northward progression of the wind as well. So you should check to what extent this kind of patterns has exist.

So this is the method he suggested, but as you can see it is not very simple to adopt and what IMD did was actually combine few of Joseph ideas, few of Ananthakrishnan and other ideas

and they did not work. Rajeevan and Soman analysis of their onset phase.

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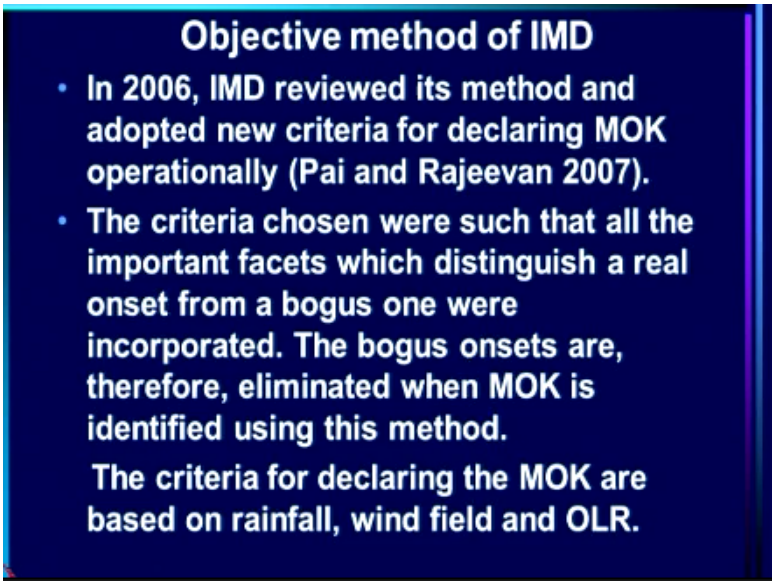

And then they came upon these criteria. Criteria to determine an operational definition of MOK which can be used for operational purposes objective definition which can be used for operational purposes. The criteria chosen were such that all the important facets which distinguish a real onset from a bogus one were incorporated. So that by the time the formula did this people knew how to remove a bogus onset.

How to distinguish between a bogus onset and a real one. So they used the criteria such that bogus onsets were eliminated and the criteria are as follows.

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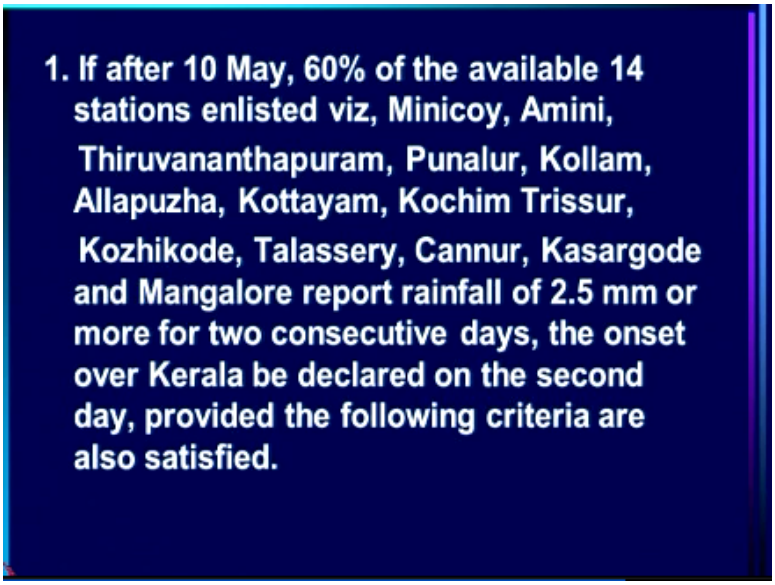

Again if after 10 May 60% of the available 14 stations enlisted get some rain the onset over

Kerala can be declared on the second day provided.

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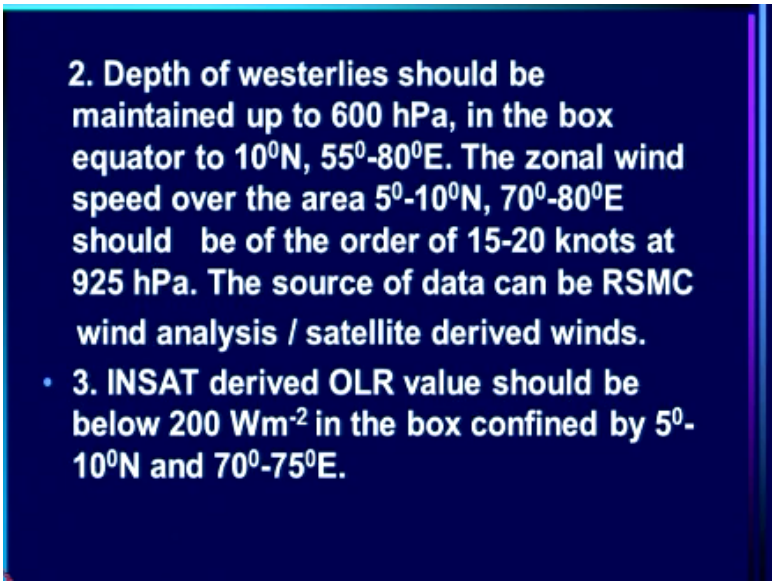

And this is where all the other conditions come. Depth of the westerlies should be maintained up to 600 hPa in the box equator to 10 North 55 to 80 East. So there is a big box they have defined in which the westerlies should be deep and the zonal wind speed over the area 5 to 10 North and 70 to 80 East should be of the order of 15 to 20 knots at 925 hPa and they have also specified which source can be used.

Then they are say INSAT derived OLR value should be below 200 watts per meter square in the box by 5 to 10 North and 70 to 75 East. So they have specifically listed conditions under westerlies, conditions on OLR in addition to rainfall and they have succeeded in eliminating the bogus onsets and how do we know that because they have applied the method from the point at which satellite data became available up to now.

And they have shown that bogus vortices of the bogus onset of the time 1995-2004 were actually eliminated in their objective assessment and that is in the Mean OLR pattern that they get. So this is somewhat different because this is the pattern not of selected years, but all the years between 1988-2007. So this is the IMD operational method for assessing monsoon onset over Kerala.

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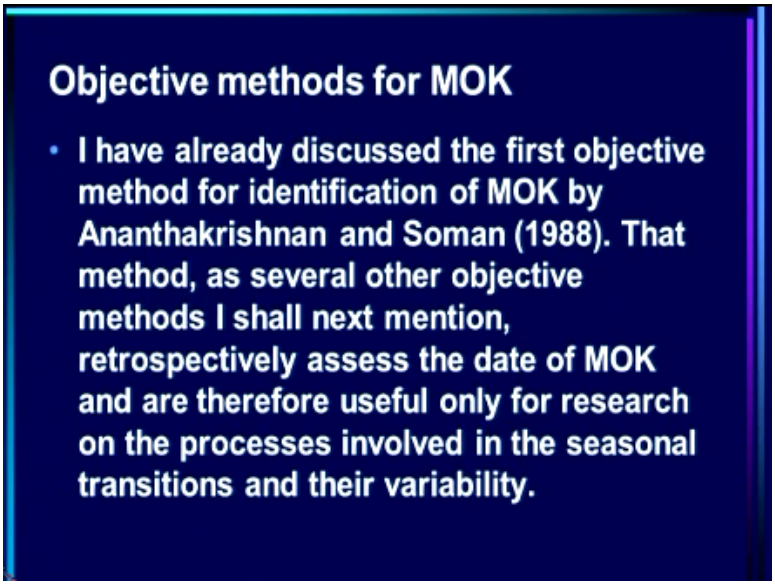

Now I consider other objective method which have been proposed. Now I have already discussed the first objective method for identification of MOK by Ananthakrishnan and Soman and this method has several other objectives methods I shall next mention. In fact, retrospectively assess the date of MOK and are therefore useful only for research on the processes involved in the seasonal transition and their variability.

So this method is not meant for operational declaration of monsoon onset over Kerala.

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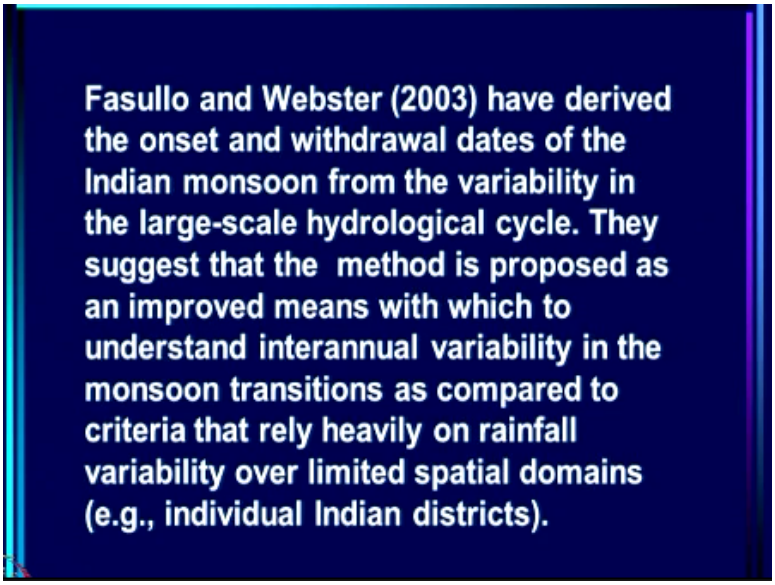

So Fasullo and Webster have derived the onset and withdrawal dates of the Indian monsoon from the variability in the large-scale hydrological cycle. They suggest that the method is proposed as an improved means with which to understand interannual variability in the monsoon transitions as compared to criteria that rely heavily on rainfall variability over

limited spatial domains that is individual Indian district.

Now this is what I commented on earlier. They think that Ananthakrishnan and Soman criteria identifies onset only over limited regions, but the way Ananthakrishnan had done a very deep study of all the data available up to that point and so the criteria for rainfall he adopted although the rainfall was only over South and North Kerala were such that they were signatures of large-scale system.

And not of rainfall which occurred on only small spatial regions. So this is I think misunderstanding that these people had, but in any event.

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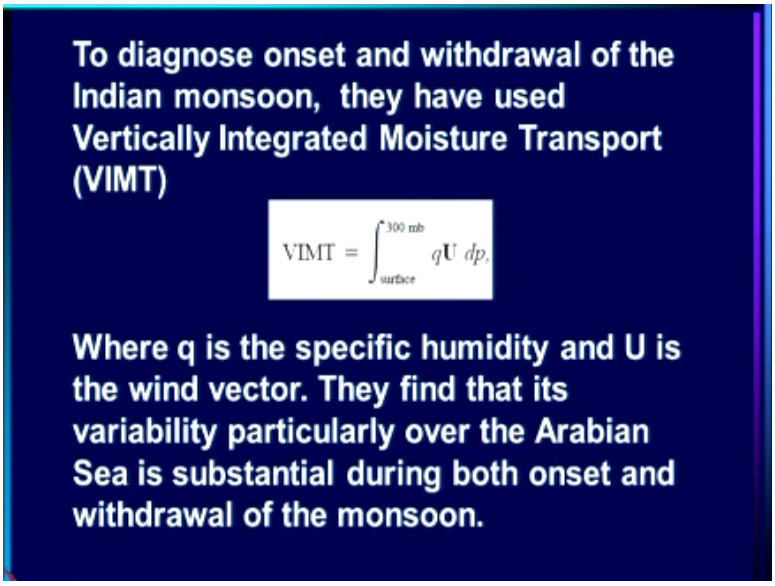

So what they do is to diagnose the onset and withdrawal of the Indian monsoon they have used Vertically Integrated Moisture Transport which will be integral between surface and 300 millibar of qU dp that is to say q is the specific humidity and U is the vector wind. So vertically integrated transport between surface to 300 millibar is what they have used and they find that the variability is very high over Arabian Sea and substantial during both onset and withdrawal of the monsoon.

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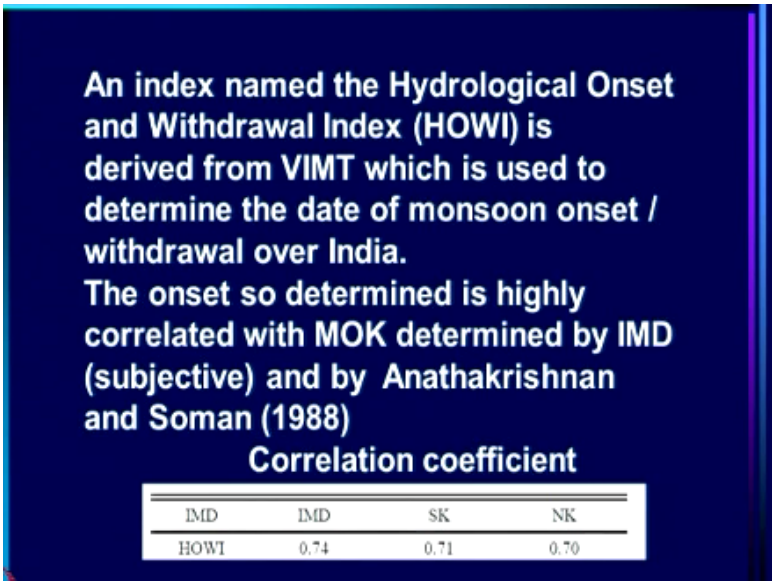

An index named Hydrological Onset and Withdrawal Index is derived from VIMT which is used to determine date of monsoon onset and withdrawal over India. The onset so determined is highly correlated with MOK determined by IMD subjective and by Ananthakrishnan and Soman. And this is what I said that although these people think that there is the largest scale onset than that identified by Ananthakrishnan and Soman the 2 are highly correlated.

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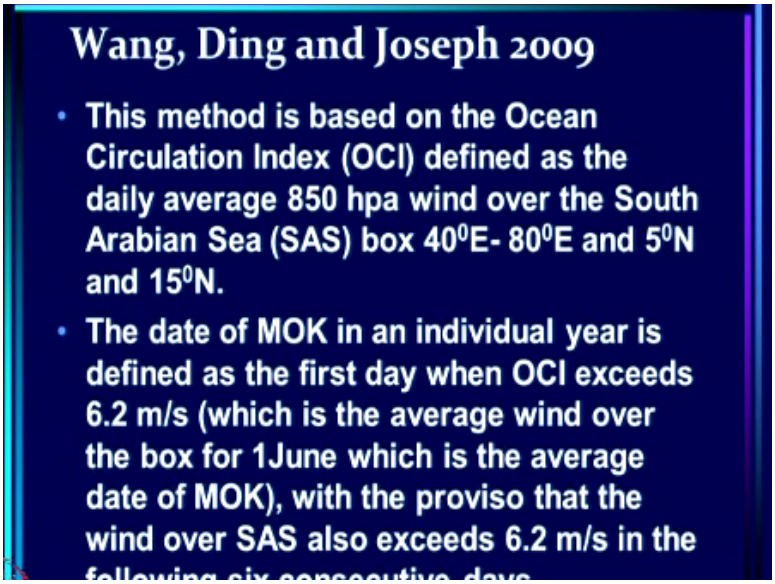

Then there is an another by Wang, Ding and Joseph and this is based on only circulation and they define Ocean Circulation Index as daily average of 850 hPa wind over the box 40 to 80 East 5 to 15 North. So this is from the Arabian Sea right up to central longitude of India and 5 to 15 north is again latitudes of peninsula. The date of MOK in an individual year is defined as the first day.

When OCI exceeds 6.2 meter per second which is the average wind over the box for 1st June which is the average date of MOK with the proviso that the wind over SAS exceeds 6.2 meters per second in the following 6 consecutive days. So this is the criteria based on OCI.

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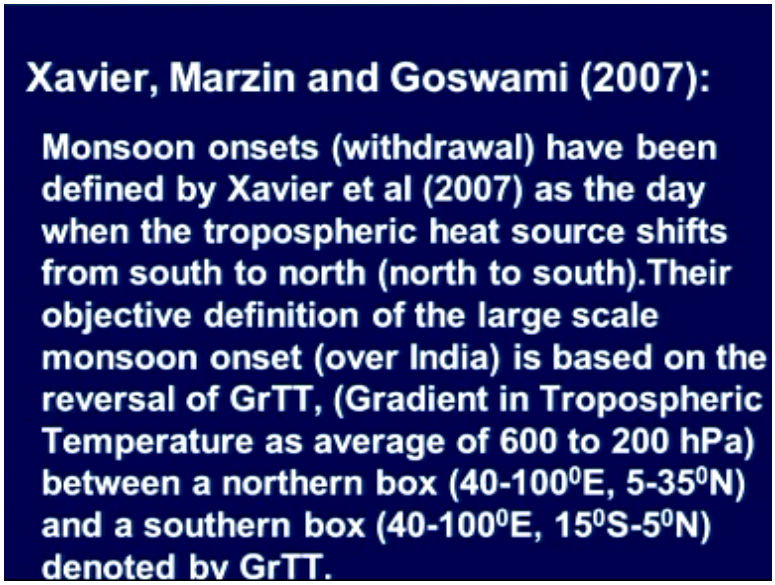

Then Xavier, Marzin and Goswami has suggested another criteria which I mentioned briefly when I showed you Ananthakrishnan results as the day when the tropospheric heat source shift from south to north that is to say the TCZ shifts from south to north. Their objective definition of the large-scale monsoon onset over India is based on reversal of GrTT Gradient in Tropospheric Temperature as average of 600 to 200 hPa over a rather big box 40 to 100 East, 5 to 35 North.

So this was all the way from the Arabian Sea in all across the Arabian Sea and the Indian region and the Bay of Bengal and a Southern box which is 40 to 100 East and 15 South to 5 North. So this is an entire equatorial region and part of the southern hemisphere as well and this is what they denote by GrTT.

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The onset date (GrTT onset) is defined as the date when GrTT changes sign from negative to positive and withdrawal date when the change is from positive to negative.

A characteristic of the large scale onset of the Indian summer monsoon is an abrupt increase in the kinetic energy (KE) of the low level monsoon flow (Krishnamurti, 1985).

The onset date GrTT onset is defined as the date when GrTT changes sign from negative to positive and withdrawal date when it changes from positive to negative. A characteristic of the large scale onset of the Indian monsoon is an abrupt increase in the kinetic energy over a similar box.

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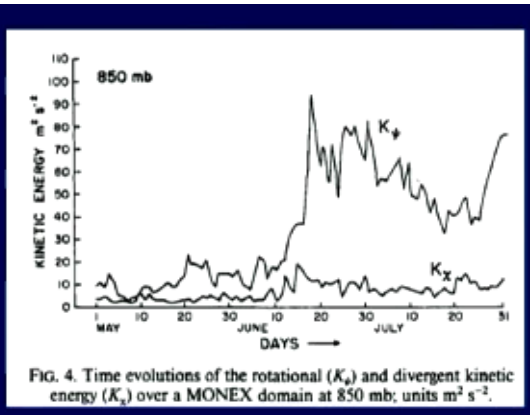

FIG. 4. Time evolutions of the rotational (K_ψ) and divergent kinetic energy (K_χ) over a MONEX domain at 850 mb; units $m^2 s^{-2}$.

The day of abrupt increase in the KE of 850 hPa winds averaged over a large region (40-100^{c}E,5-15^{0}N) above a threshold value of 40 m^2s^{-2} and persisting for 5 consecutive days is taken as the KE onset.

And that is what we have seen earlier. Again this is 40 to 100 East and 5 North to 15 North. So this is exactly the box that Krishnamurti had taken which these people have taken also Xavier et al. And what you see we have seen this before this is the kinetic energy onset which occurs very abruptly soon after the monsoon onset over Kerala.

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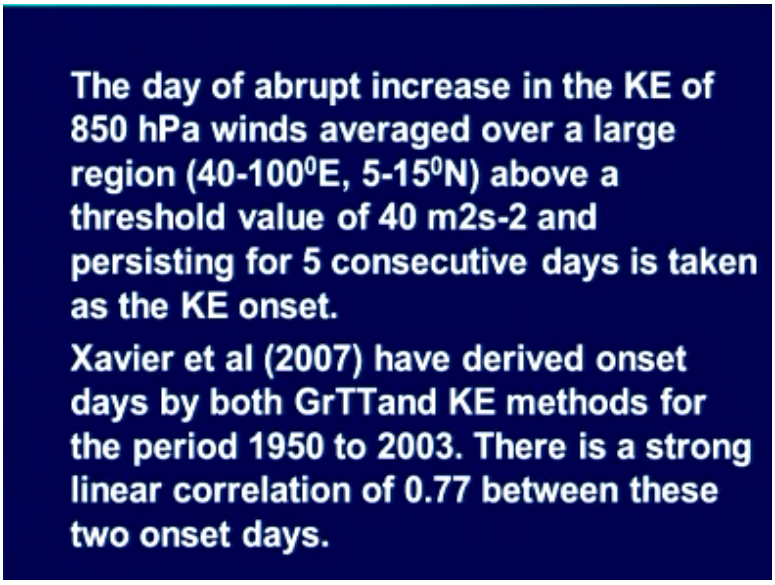

And in fact the day of abrupt increase in the kinetic energy averaged over this large region above a threshold of 40 meters per second square persisting for 5 consecutive days is taken as KE onset. Xavier et al have derived onset days by both GrTT and KE methods for the period 1950 to 2003 and they find not surprisingly because they are looking at features of the same box circulation and temperature variation that the 2 are highly correlated.

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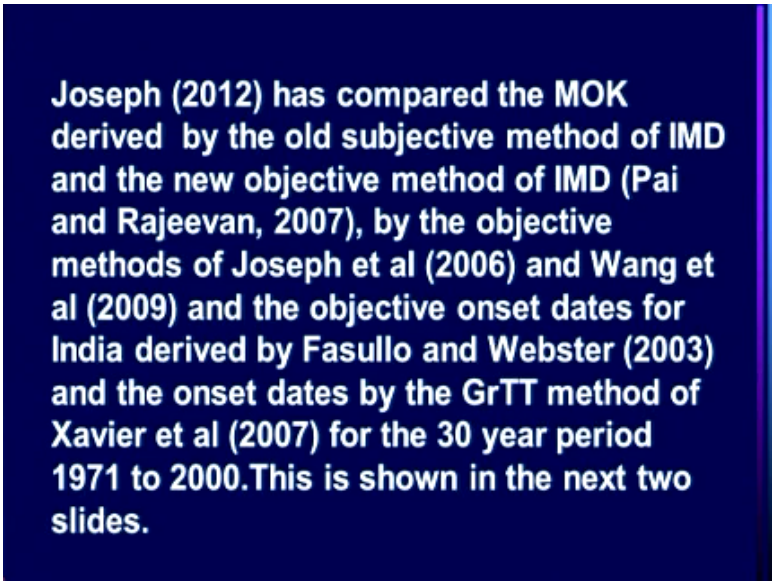

Now Joseph has compared MOK dates derived by the old subjective method of IMD, the new objective method of IMD and objective methods of Joseph et al, Wang et al and objective of Fasullo Webster as well as Xavier et al all of them.

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Table 6.2: Dates of onset of monsoon during 1971-2000 - See description of onsets in the text
(Dates are with respect to 01 May. 15 means 15 May, 40 means 09 June)

Year	IMD (Subjective)	Dates by Objective Methods				
		IMD (Objective)	Joseph et al (2006)	Wang et al (2009)	Fasullo and Webster (2003)	Xavier et al (2007)
1989	34	35	35	21	34	19
1990	19	18	16	17	19	16
1991	33	33	33	33	36	31
1992	36	36	37	39	43	41
1993	28	34	35	29	36	30
1994	28	28	28	30	34	29
1995	36	41	37	39	42	32
1996	34	40	42	33	36	26
1997	40	43	52	46	51	36
1998	33	34	34	37	40	36
1999	25	22	22	19	43	22
2000	32	32	32	15	29	18
Mean	32.33	33.23	33.96	32	37.03	28.9
S. D	6.12	7.13	8.1	8.11	7	6.48

And I will not dwell on this, but it is therefore for anybody to look at in detail and by and large these are things it may be of interest to see just one or 2 of those years. Look of 95 in which the subjective IMD and remember IMD subjective also when there is a bogus onset after that they correct they realize it was bogus and then they declare the onset at some other date. So it is not they retain the bogus onset date as it is.

So IMD objective, IMD subjective and all the other methods are rather close as you can see Joseph et al, Wang et al, Fassullo somewhat later, but Xavier et al is earlier. So by and large you will see that none of these methods now have bogus onset so it is not problem one needs to worry about particularly when we are doing retrospective analysis and by and large there is agreement in word some people call onset over India and other call MOK.

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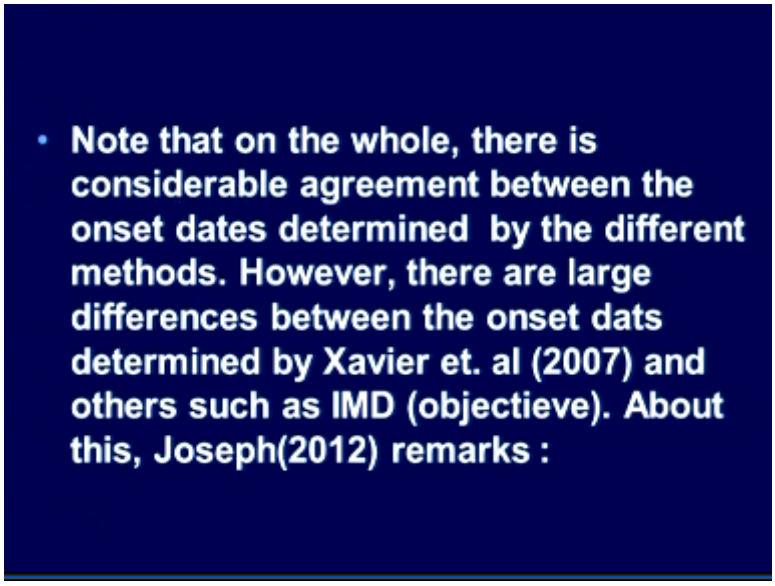

On the whole there is considerable agreement between the onset dates determined by the different methods. However, there are large differences between the onset dates determined by Xavier et al and others such as IMD objective.

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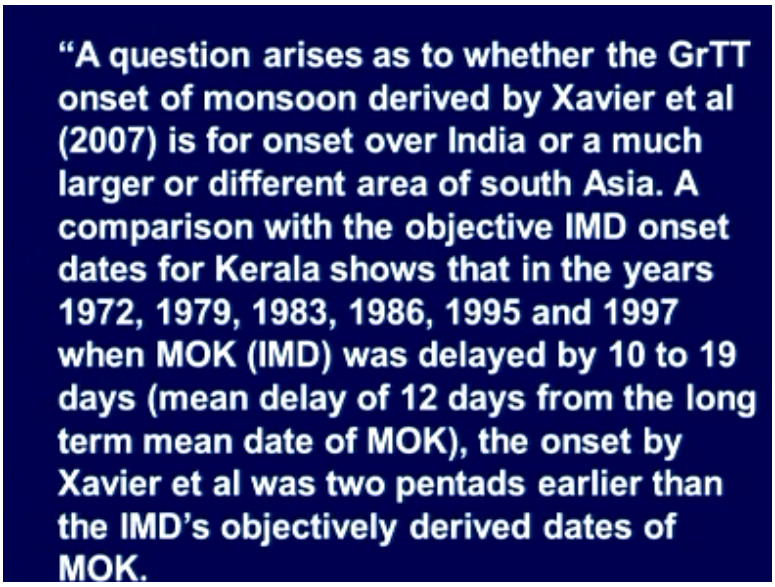

And about this Joseph has done an analysis and he raised the following question. Question arises as to whether GrTT onset of monsoon derived by Xavier et al is for onset over India or a much larger or different area of South Asia. A comparison with the objective IMD onset dates for Kerala shows that in years like 1972. 1979. 1983, 1986, 1995 and 1997 when MOK IMD was delayed by 10 to 19 days which is very long delay.

Remember the standard deviation is 7 days. The onset by Xavier et al was 2 pentads earlier than the IMD's objectively derived dates of MOK. So this is much closer to climatological dates so this is big error for several years

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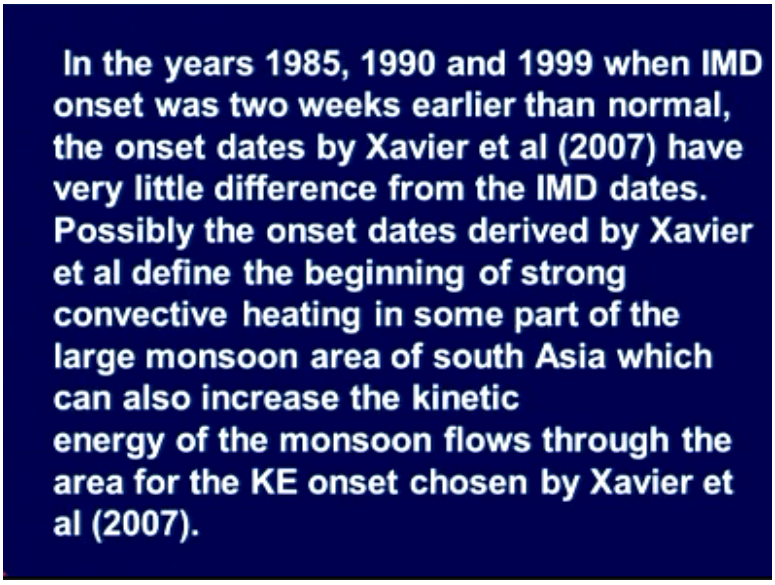

And in the year 1985, `1990 and 1999 when IMD was 2 weeks earlier than normal onset dates have little difference from IMD dates. So it appears that possibly the onset days derived by Xavier et al define the beginning of strong convective heating in some part at the large monsoon area of South Asia which can also increase the kinetic energy and the monsoon flows through the area of kinetic energy onset chosen by Xavier et al.

So there is some differences between them.

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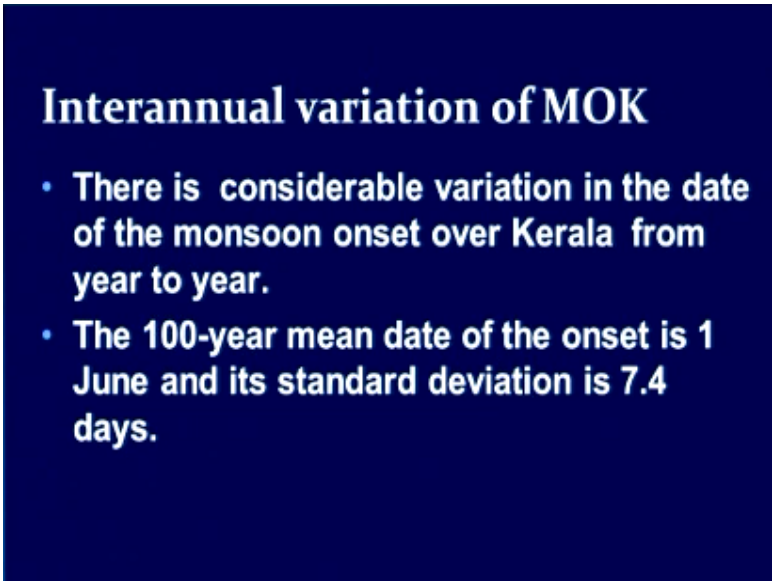

So much about the determination of monsoon onset over Kerala. Now we know there is considerable variation in the date of the monsoon onset over Kerala from year to year.

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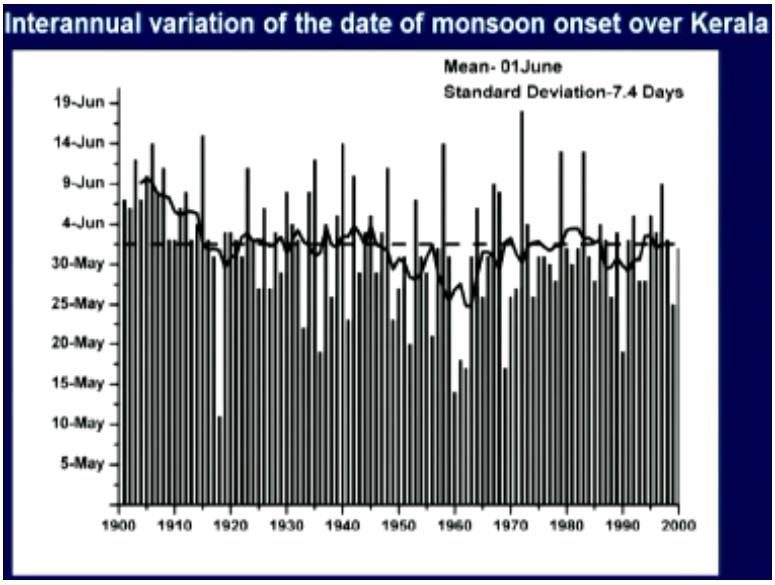

And we have seen this picture before. This is the variation of the monsoon onset date and you can see there is a considerable fluctuation from year to year and if you look at these are the number of years this is the histogram then you can see that 31 to 5 is the highest probability and within 1 week before and 1 week after most of the events are covered, but you do have chance of (()) (48:47).

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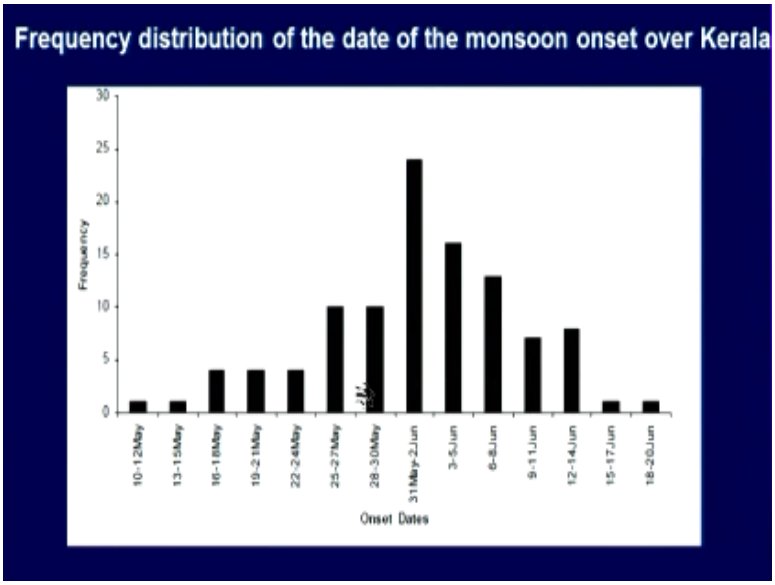

So this is the frequency distribution of monsoon onset over Kerala again.

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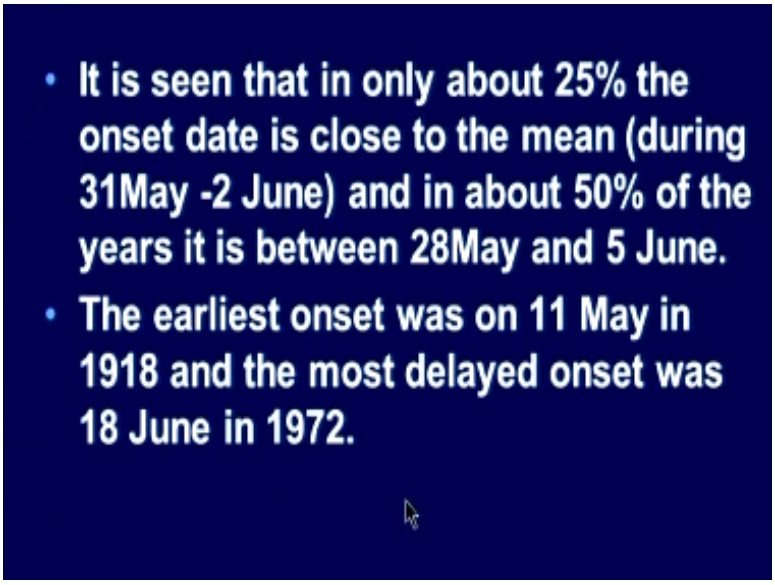

And you see that only about 25% of the onset date is closed to the mean that is 31st May to 2 June and in about 50% of years it is between 20th May and 5th June. So within a week of the actual date 50% occurs. Earliest onset was on 11 May 1918, but we know this may have been a bogus onset and we do not have data for that time and most delayed was in 18th June in 1972.

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Now in India when we consider the onset of monsoon over Kerala which is the commencement of the rainy season as a very important event. So it is pertinent to ask the question to what extent does the performance of the monsoon over the country as a whole depend on when the season commenced.

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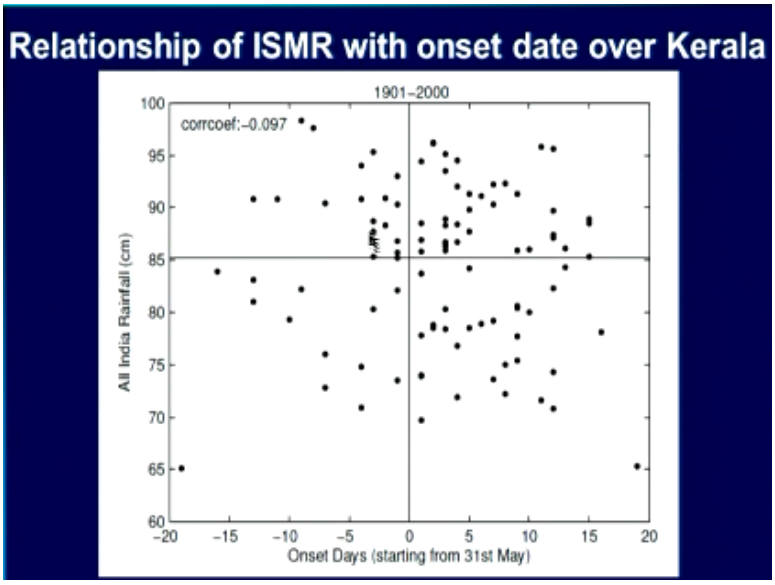

Actually there is very little relation between ISMR which is the All India Summer Monsoon Rainfall and the onset date as you can see the points are all over and the correlation - 0.097 which is close to -0.1. There is some negative correlation which says late onset will give less rain, but a correlation is very small 0.1 means it experience hardly any variance. So it is seen that ISMR is not related to the onset date over Kerala.

In fact, 2 cases of onset close to the 20 days before and after the mean date the ISMR was close to one another. You see here 20 days before and 20 days after and in one case this is 20 days after and in both cases the ISRM is similar. So just goes to show that there seems to be very little relationship.

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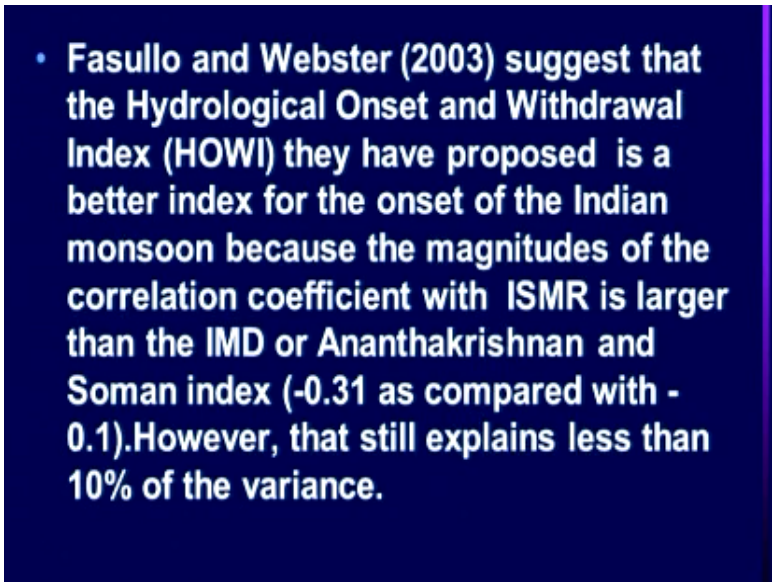

But Fasullo and Webster suggest that their onset is better related. Now I do not have this (())

(50:54) they have not produced one, but what they find is that their correlation is -0.31 whereas for the same data period if they look at correlation between Ananthakrishnan and Soman MOK and ISMR it is about -0.1, but still -0.31 experience < 10% of the variance and it is not clear who is right.

Because we do not know in the real system whether there is any relationship between inter annual variation of ISMR and the date of onset. So it is not clear that it is related at all in fact at this point the evidence points to the fact that there is very little relationship between ISRM and the onset date of the monsoon.

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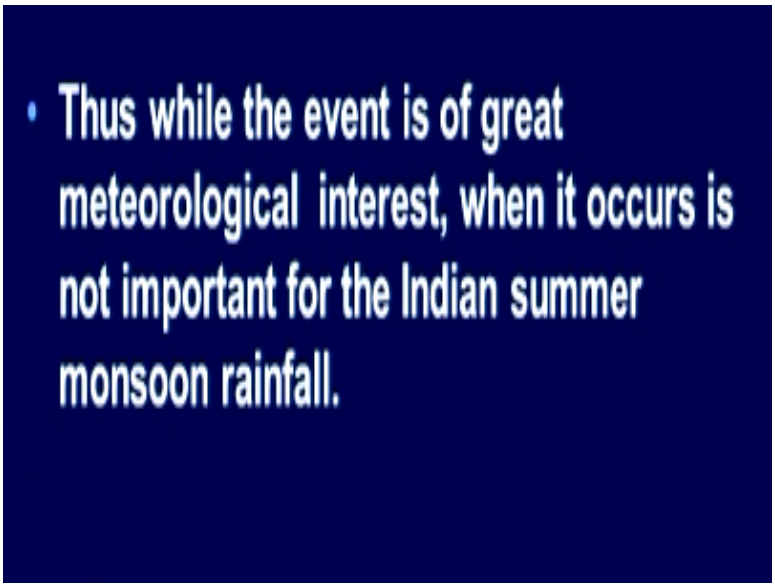

Thus, while the event is of great meteorological interest when it occurs it is not important for the Indian summer monsoon rainfall.

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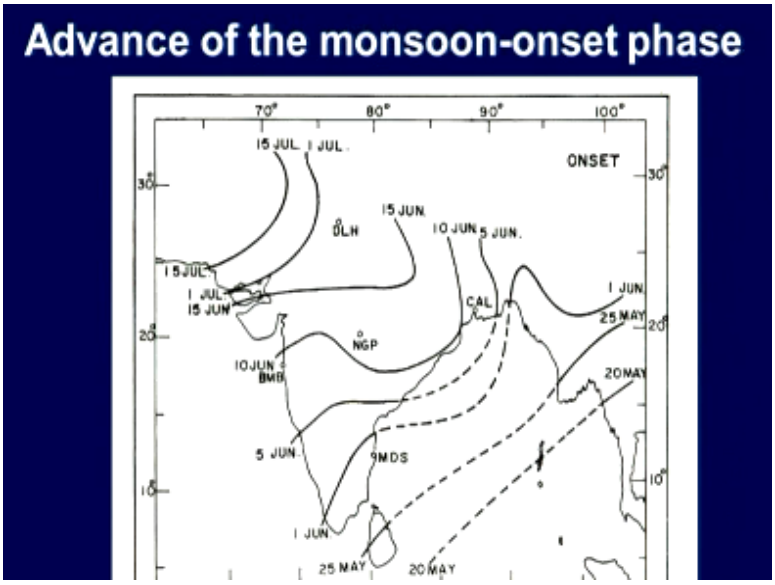

Now after this we will consider the advance of the monsoon we have so far focused on MOK because large number of studies are on the onset over this part the beginning of the onset phase of the monsoon. Now in the next lecture I look at how the monsoon advances and also the retreat of the monsoon at the end of the monsoon season after the TCGS fluctuated in the peak monsoon months over the monsoon zone.

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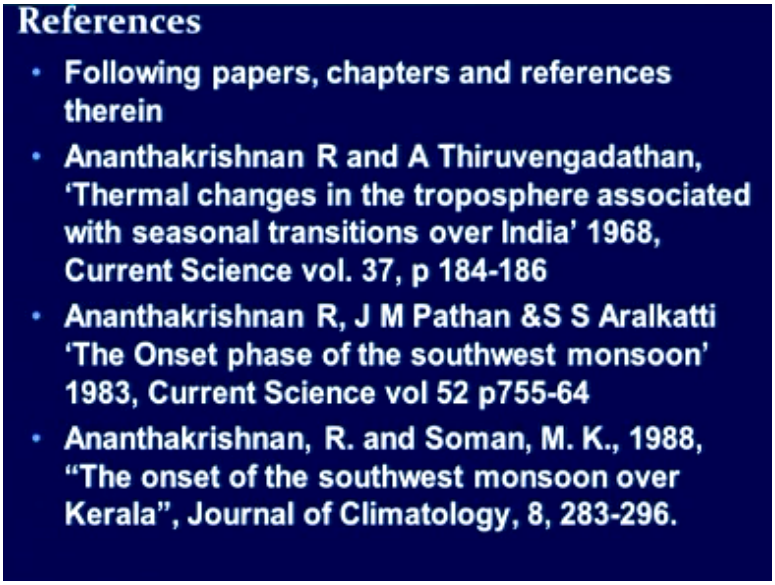

These are the references and there are many and they are relevant for the previous lecture as well as this one. Thank you.