The Monsoon and Its Variability
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Lecture - 18
Seasonal Transitions-Part 3: Advance and Retreat of the Summer Monsoon

So we continue our discussion on seasonal transitions today. In the last class we have already talked about the onset over Kerala.

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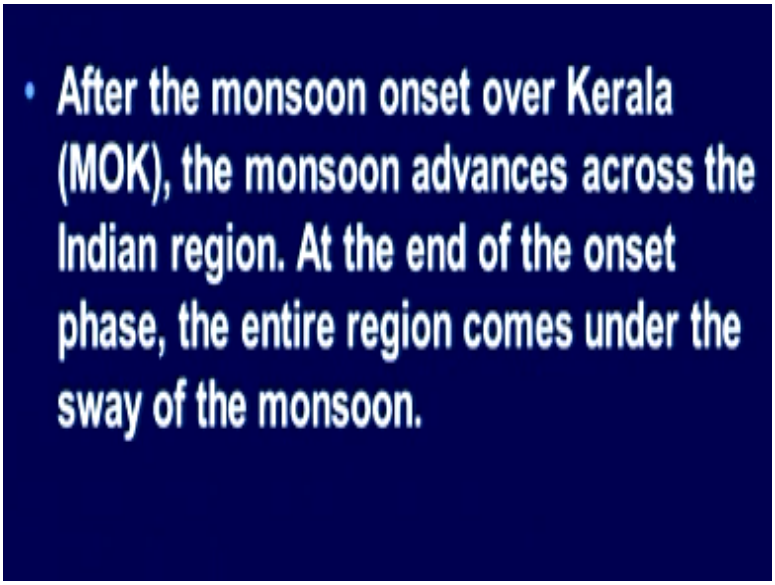

After the monsoon-onset over Kerala which is in short MOK the monsoon advances across the Indian region and at the end of the onset phase the entire region comes under the sway of the monsoon.

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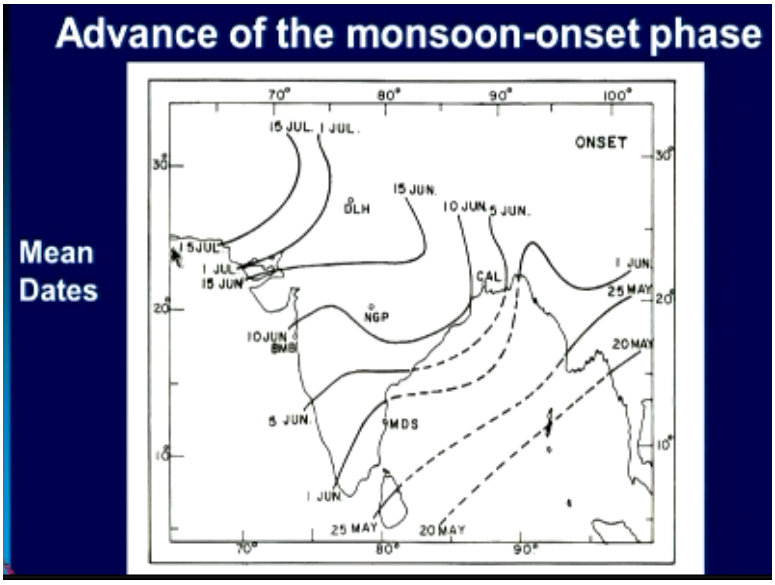

So you may recall these are the dates from India Met department of the onset dates over different regions this is the date this is when the monsoon-onset occurs over Kerala. After that there is during the onset phase it propagates northward as well as westward and eventually by 1st of July most of the region is under the sway of the monsoon this is 15th of July. So these are the mean dates calculated by India meteorological department.

By looking at the onset date, looking at the rainfall mean rainfall patterns and taking the centre of the pentad during which onset occurred as the onset date.

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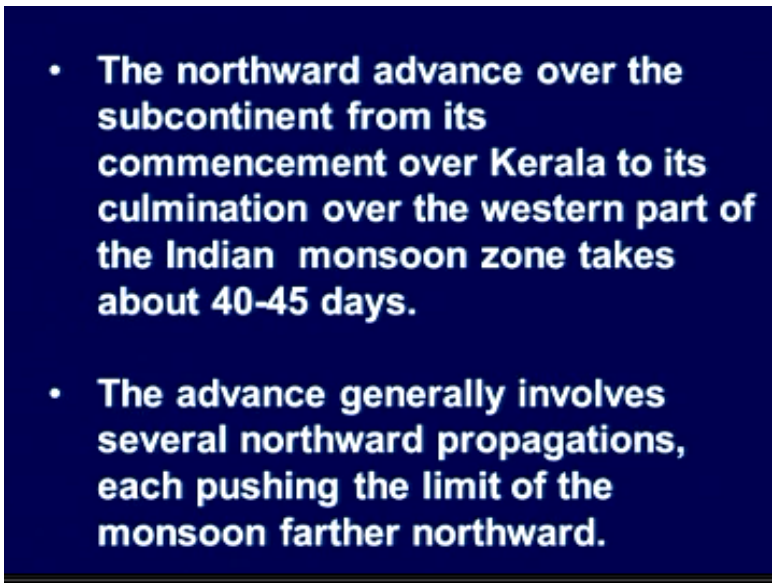

Now the northward advance over the subcontinent from its commencement over Kerala and its culmination over the western part of the Indian monsoon zone takes about 40 to 45 days as we have seen this is 1st of June and this is 15th of July. So the northward advance takes about

40 to 45 days and advance generally involves several northward propagations each pushing the limit of the monsoon farther northward.

Now we have already seen this when we looked at the satellite pictures of the cloud bands and how they propagate.

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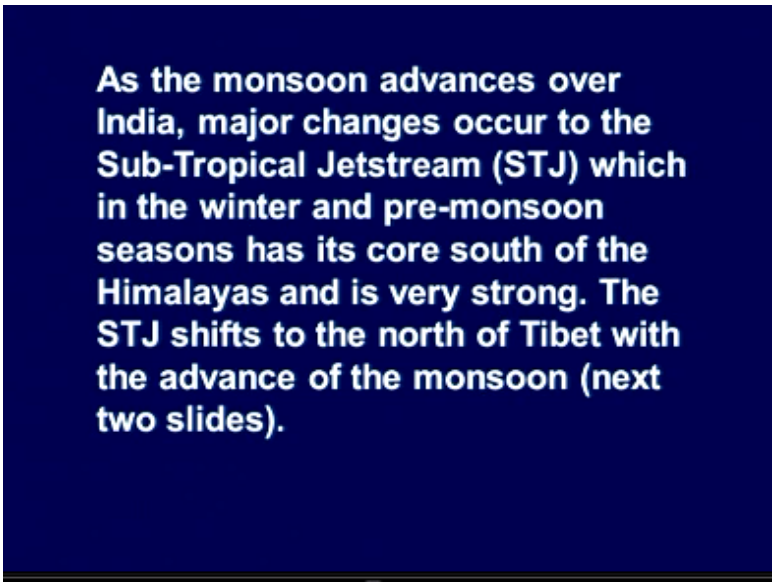

As the monsoon advances over India major changes occur in the Sub-Tropical Jetstream which in the winter and pre-monsoon season has its core to the south of the Himalayas and is very strong and this Sub-Tropical Jetstream shifts to the north.

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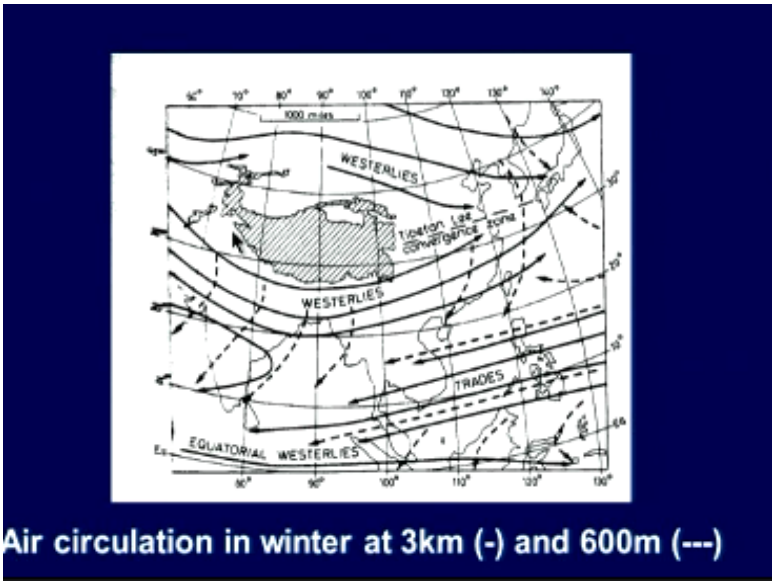

Now this is something we have seen when we saw the difference between the summer monsoon and the previous season. See in winter the Sub-Tropical Jetstream comes over us

and that is why Delhi is part of the mid-latitude weather regime in winter. So we have the Sub-Tropical Jetstream coming over us and this is the air circulation at 3 kilometers even a 3 kilometers you see very strong westerly winds this is the Tibetan plateau.

So the westerly jet the mid-latitude westerlies which penetrate over the Indian region the jets actually split part of it goes north of Tibetan plateau and part of it come south. Now why is there a split because this Tibetan plateau is 5 kilometers. So we are looking at winds at 3 kilometers they cannot penetrate the plateau so they have to go around here. And so you see these subtropical jet in winter comes like this.

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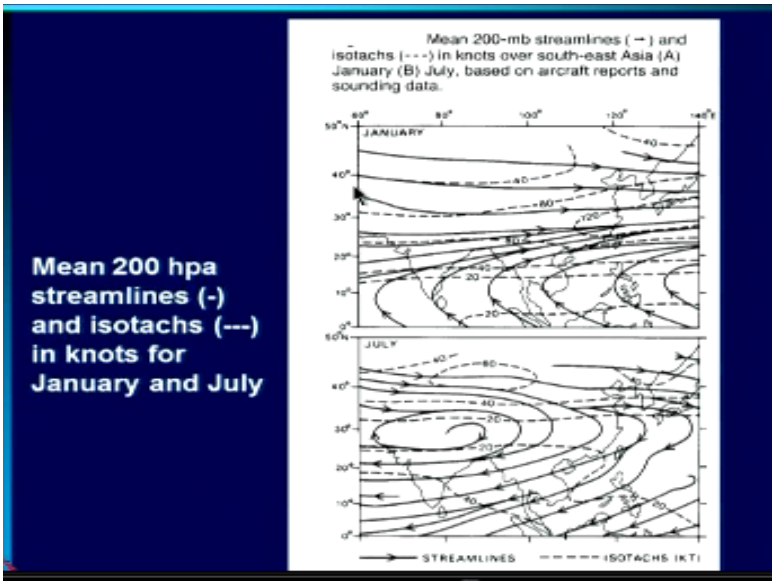

Now if we look at the Mean 200 millibar streamlines which is up in the upper troposphere for January then you will see that in January at 200 millibars also the winds are westerly. Now they are of course directly flowing over the Tibetan plateau which is lower than the 200 millibar level, so this is the westerly wind. What happens during the monsoon? What happens during the monsoon is that the westerly flows entirely to the north of Tibetan region?

And to the south we have easterly flow. This is the tropical easterly jet. In fact, what you have here is a sub-tropical ridge which we will talk about. So you get the formation of a sub-tropical ridge in the middle and upper troposphere. So this is high pressure now the lower pressure in the upper level is here. So naturally because of (()) (04:12) the winds will be easterly and this is the tropical easterly jet which was discovered by Koteswaram in 1950.

So we have a transition from purely westerly flow here to easterly flow. So the westerly flow

in the upper level get replaced by easterly flow during the summer monsoon.

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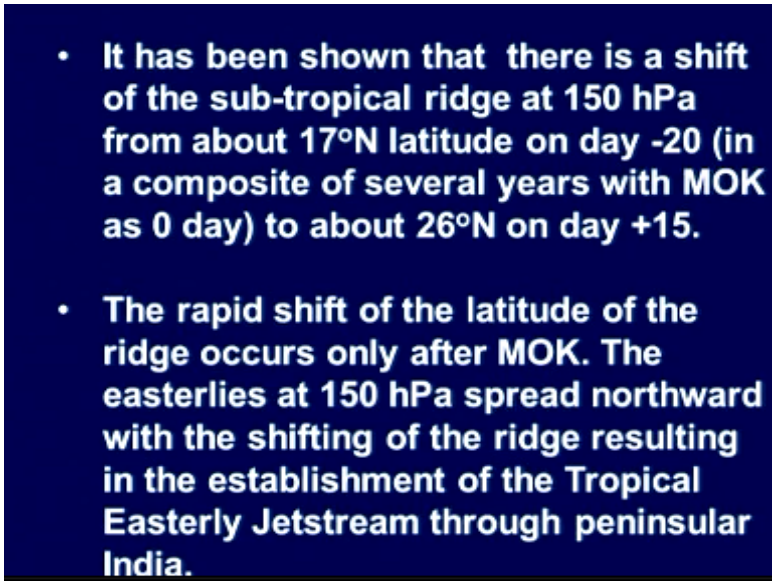

So it has been shown that there is a shift of the sub-tropical ridge at150 hPa from about 17 degrees latitude on day -20 in a composite of several years with MOK as 0 day to about 26 North on day +15. So he is talking now of this ridge. He saying that about 20 days before the onset of the monsoon if you look at the composite taking MOK as 0 day then on -20 it is around 17 and 5 days after the onset it goes to 26.

So you have, see this is the latitude here this is about 26 or so. So it comes to 26 from about 17. So you see the shift of the sub-tropical ridge before the monsoon. You have to remember that this high pressure region in fact marks the region where the pressure is low and you have a lot of convective clouds at the lower levels. Now rapid shift of the latitude of the ridge occurs only after MOK.

The easterlies at 150 hPa spread northward with the shifting of the ridge resulting in the establishment of the Tropical Easterly Jetstream through peninsular India. So we have the establishment of Tropical Easterly Jetstream. So this is an important feature and we will come to this when we talk of hiatus during the advance or temporary stalling of the advance of the monsoon which is observed in many, many years.

Now let us go back to the dates of onset and see that the onset over Mumbai, this is Bombay. Onset over Mumbai is around 10th June and this is 1st of June. So after the onset on Kerala the monsoon travels northward there is an advance of monsoon northward and by 10th of

June the onset occurs in Mumbai. This is the mean picture.

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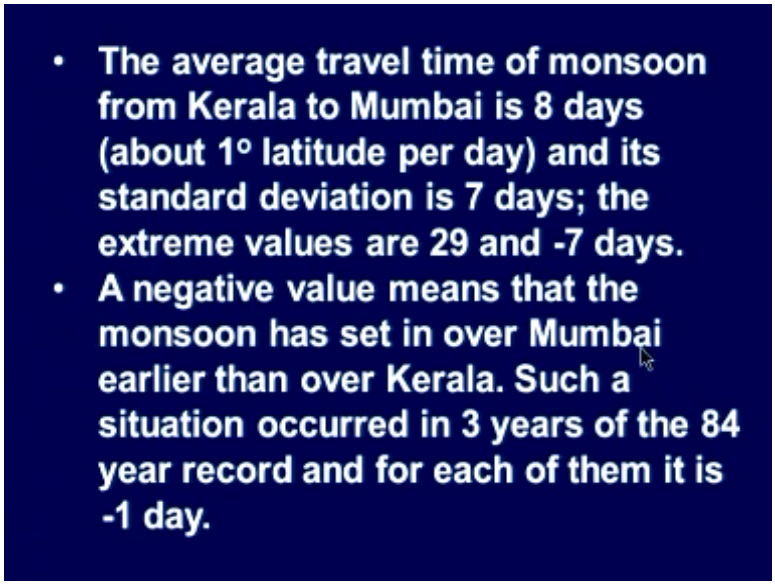

Now the average travel time of monsoon from Kerala to Mumbai is 8 days which is about 1 degree latitude per day remember that the average northward movement of the cloud bands that we saw also was about 1 degree latitude for a day. So this is the typical time of northward movement of cloud bands and its standard deviation is about 7 days. The extreme values are 29 and -7 days.

A negative value means that the monsoon has set in over Mumbai earlier than it does over Kerala. And such a situation occurred in 3 years out of 84-year record for each of them it is -1 day. So what we are saying is that instead of the monsoon first having an onset over Kerala and moving north. In 3 years what has happened is the onset occurs first over Mumbai and almost simultaneously within 1 day after that it occurred over Kerala as well.

But in general there is considerable variation of the time from when the monsoon-onset occurs over Kerala to that over Mumbai.

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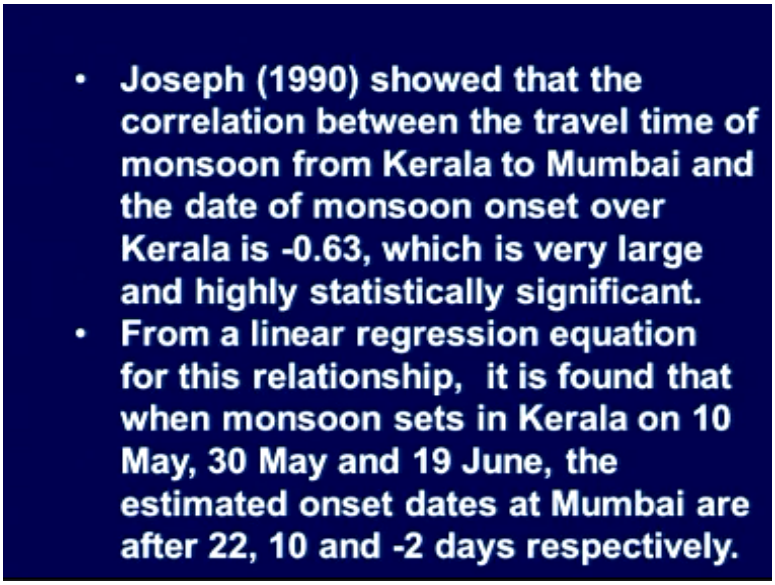

Joseph has done an interesting study in which he shows that the correlation between the travel time of monsoon from Kerala to Mumbai which means onset date of over Mumbai - onset date over Kerala what is the number of days. The travel time of the monsoon between Kerala to Mumbai and the date of monsoon-onset over Kerala is -0.63 which is very large and highly significant.

So what it is saying is later the monsoon-onset occurs over Kerala the shorter the time it takes for the onset to occur in Mumbai after that. So this is very interesting there is a negative correlation between the travel time of the monsoon from Kerala to Mumbai to the date of monsoon-onset over Kerala and Joseph actually fitted a linear regression curve to this relationship and he found the following.

That when the monsoon sets in on 10th May in Kerala which is very, very early. The estimated onset dates at Mumbai are 22, so it takes more than the average period of 8 days it takes 12 days. However, when the monsoon-onset occurs on 30th May then it takes only 10 days so < half of the time for the onset to occur in Mumbai and on a occasion when it occur in 19 June I believe this was in 1979.

Actually the monsoon-onset over Kerala occurred 2 days later which is on 21st June. So this is the way it happens and it was (()) (10:09) at first as to how this should happen.

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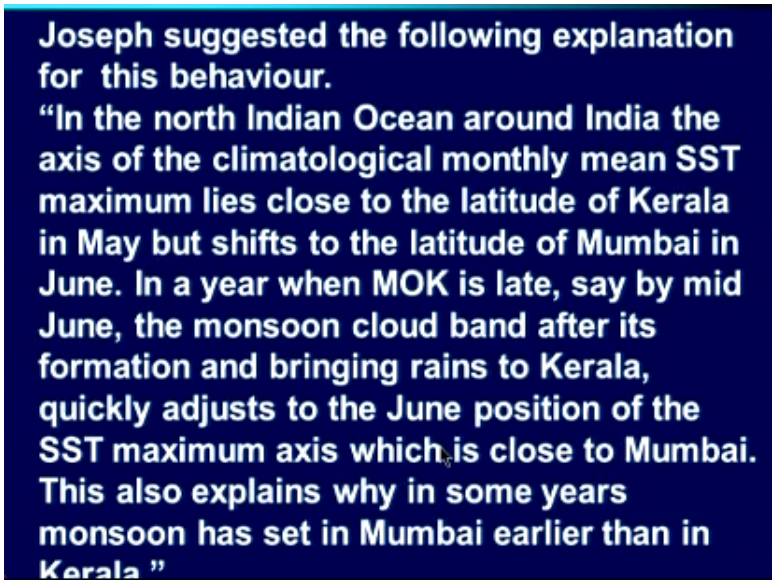

So Joseph has suggested the following explanation. He says that in the north Indian ocean around India the axis of the climatological monthly mean SST maximum lies close to the latitude of Kerala in May, but shifts to the latitude of Mumbai in June. So there is a shift in the axis of maximum SST from about Kerala which is 8 degrees to Mumbai which is about 19 degrees North.

So what happens is you have a shift in the SST from May to June SST axis of maximum SST so in a year when MOK is late and he does not say why it is, but he says in years when monsoon-onset over Kerala is very much delayed say by mid-June then the monsoon cloud band after its formation and bringing rains to Kerala quickly adjust to the June position of the SST maximum axis which is close to Mumbai.

So what happens is since the TCZ the Tropical Convergence Zone is favored to form over the region of maximum SST. When it is formed to the south of it quickly goes to the place where the maximum SST is and that is why the travel time is much shorter when the onset occurs towards the middle of June. This is the explanation given by Joseph. Of course one has to test this with model which has not been done.

Now so far we have talked of the onset over peninsula and how it occurs on the northward by means of northward movements of cloud bands or rain belts. Now over the monsoon zone the onset first occurs over the eastern part.

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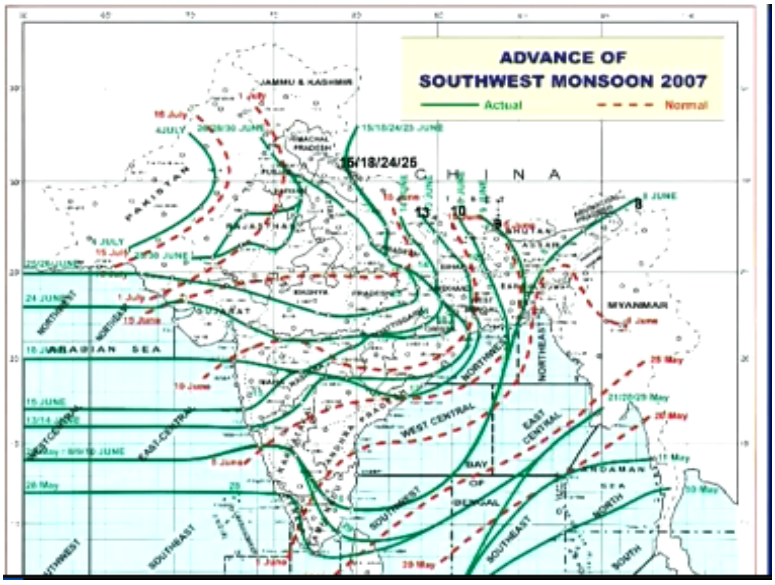

Let us take here the example of June southwest monsoon of 2007 and what you find is the lines in green correspond to the actual dates on which the monsoon-onset occur in 2007 and what you will see here is that this is the 8th June line then this is 9th June line which you can see. So on 9th June it has occurred over the eastern part first. Notice of course that after the onset over here which was somewhat early by 28th of May then the onset occurred at more and more northern latitudes.

So by 15th June we have onset here over the west cost of the peninsula and it is only by 18th June that the onset occurred over Mumbai. So here it is a clear case of northward propagation, but when you come to the monsoon zone which is this part of the region then what you see is on 8th of June you see it is here on 9th June it is here these are northern limits of the limit of the monsoon.

10th of June it is here, 13th of June it is here, 15th of June it is here. So you see a very clear movement from east to west over the monsoon zone and then after that it of course continues to move here. So this is there by 30th of June from 15th to 30th it has come here and then later on by 4th of July it has reached this destination. So the way the advance of the monsoon occurs is by northward movement up to this point somewhere around here.

And westward movement from here onwards. This is the way the advance of the monsoon takes place and you see that by this example here.

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- Over the monsoon zone, the onset first occurs over the eastern part (e.g. next slide for 2007). The onset over the western part is often a consequence of westward propagations of synoptic scale systems from the eastern part of the monsoon zone.
- There is considerable variation from year to year in the advance process. For example in 2009 the monsoon did not advance north of 18^0N until 21 June (following slide)

Now there is considerable variation from year to year in the advance process and we have seen this example before that in some years you know it takes a very long time for the onset to occur over the northwestern parts or further culmination of the advance phase.

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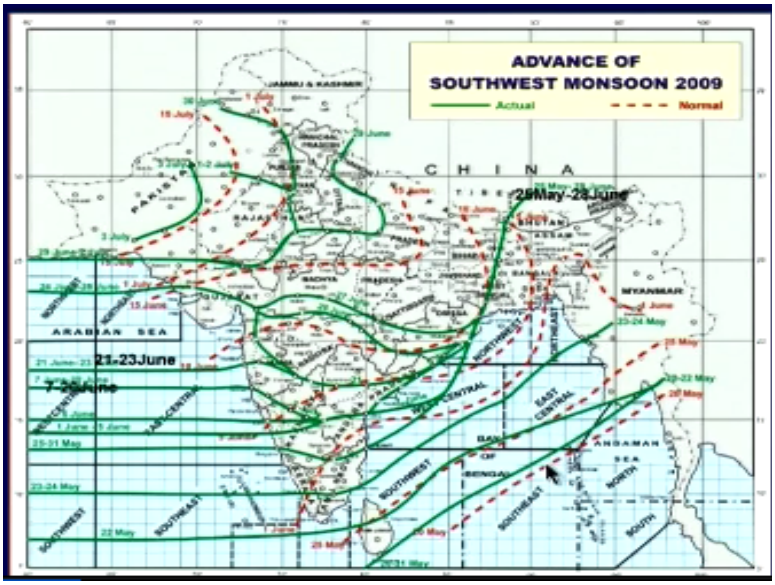

And an example I will show you is the southwest monsoon of 2009 and you will see what happen in 2009 the onset occurred very fast here. This is on 22nd May it has not yet occurred but 23rd May, 24th May onset has occurred over Kerala here and then it progressed quite well up to7th June. By 7th June it had reached the West Coast of Maharashtra so it has reached Konkan by 7th June.

Now from here also it had reached around here by 25th of May. But what happen after that is, that between 25th May and 28th June there was no movement here at all. So the monsoon

was just static here and here also from 7th June to 20th June it remained here and 21 to 23 it went there. So what has happened is that there is a big hiatus is what they will refer to it later. There is within the advance there is a short spell and not very short in fact almost 2 weeks long from 7 to 24 in which no advance has occurred of the monsoon.

So such things also happen that there is a lot of interannual variation and it is not as if there is a nice progression this way and progression this way to bring about the culmination of the advance phase.

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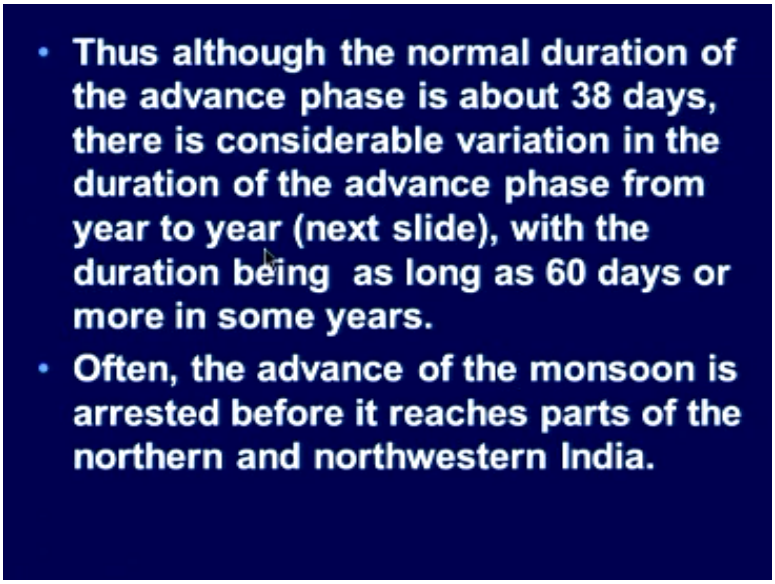

So although the normal duration of the advance phase is about 38 days there is considerable variation in the duration of the advance phase from year to year with the duration being as long as 60 days or more in some year.

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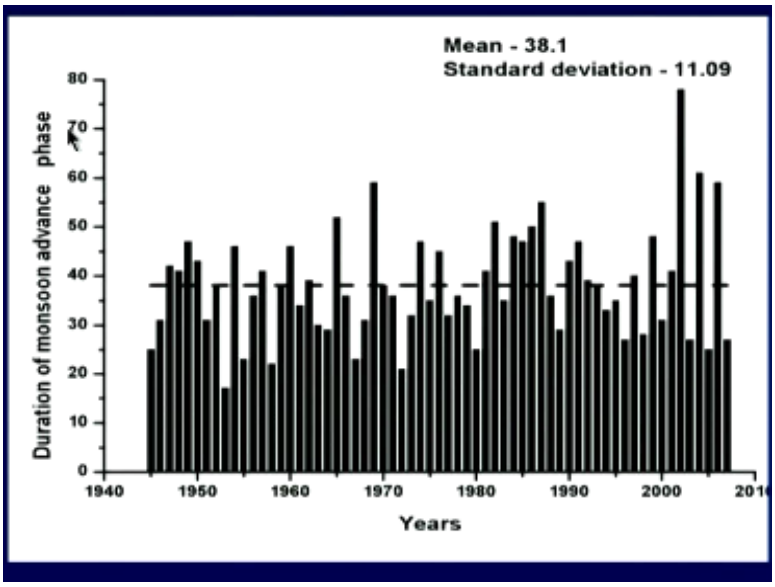

Now this is the duration of the monsoon advance phase and this is the normal of 38 days. You can see that there is considerable fluctuation in the duration of the advance phase and in 2002 which we will come to later in fact, it took a very, very long time more than 2 months from the monsoon-onset on Kerala to actually achieve the onset over the north western parts of the country.

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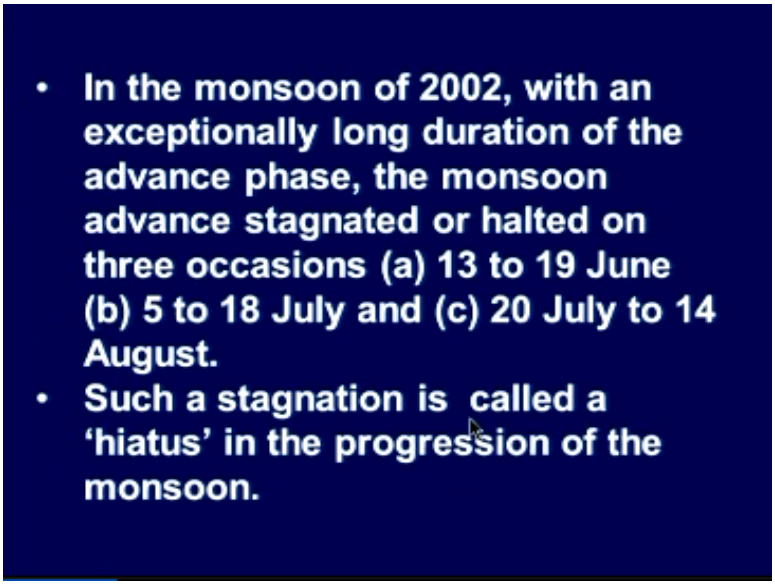

So in the monsoon of 2002, with an exceptionally long duration of the advance phase the monsoon advance stagnated or halted on 3 occasions 13th to 19 June, 5th to 18 July and 20th July to 14 August. Such a stagnation is called a hiatus in the progression of the monsoon. So such a hiatus occurs very often 13 to 19 June, 5th to 18th July and 20th July 14th August. So 2002 was full of inactive spells in which the onset phase did not progress at all so these are called hiatus in the monsoon.

Now there has been lot of studies of hiatus in the monsoon as well.

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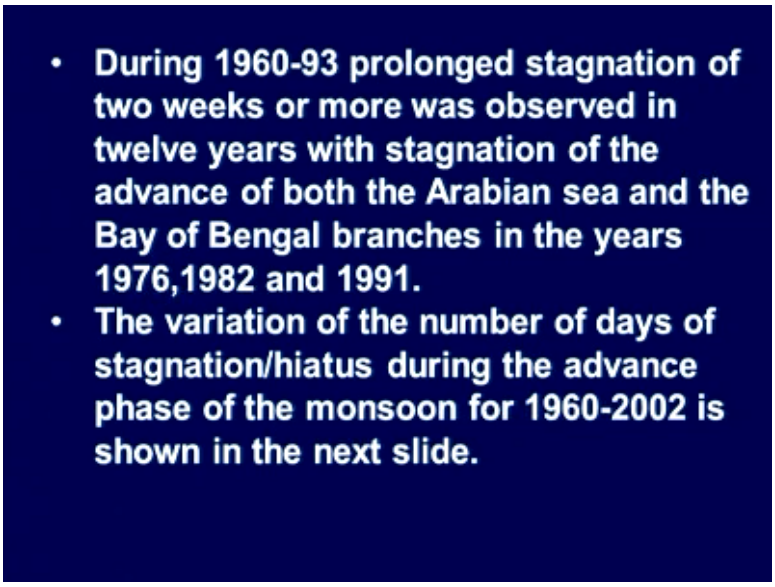

During 1960 to 1993 prolonged stagnation of 2 weeks or more was observed in twelve years with stagnation of the advance of both Arabian sea and the Bay of Bengal branches in the years 1976, 1982 and 1991. The variation of the number of days of stagnation or hiatus.

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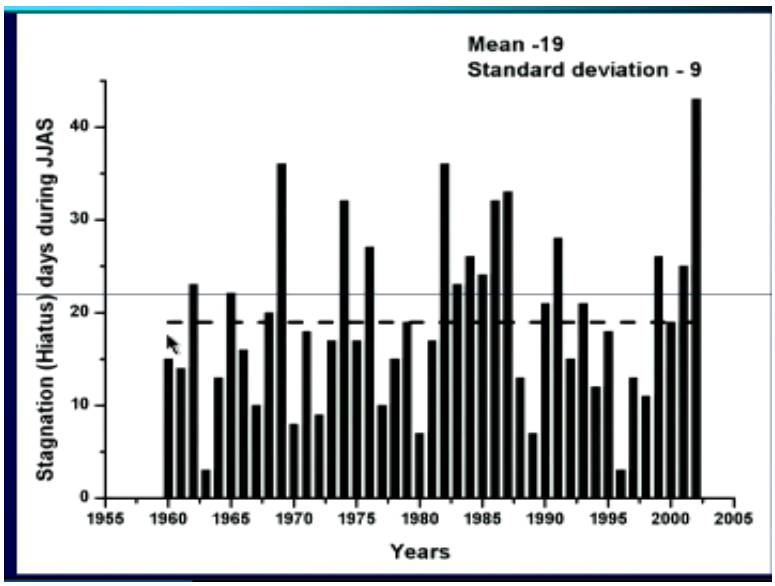

During the advance phase of the monsoon is plotted here and this is of course on 2002 which had a huge number and you have to remember here that this is not 1 hiatus, but it is sum of all such spells in which the monsoon did not progress in the advance phase over the years. So as you know in monsoon 2002, there were 3 such periods and combined they give this kind of a long more than 40 days of hiatus during the onset phase.

But you see that even in other years there is a lot of variation. There are cases in which there is hardly any stagnation that occurred at all like this year of 63 and so on and so forth. Again here 96 there was hardly any stagnation, but typically you do have about 10 days of stagnation almost all the time and that is why the mean is of the order of 20 days or so. So you know it is not as if advance of the monsoon is a steady progression from south to north.

And from east to west rather it occurs in (()) (19:16) of spells and in between these spells there are times when it does not seem to progress and those are the hiatuses and having hiatus of some length is typical of the monsoon season. Now why does this hiatus occur?

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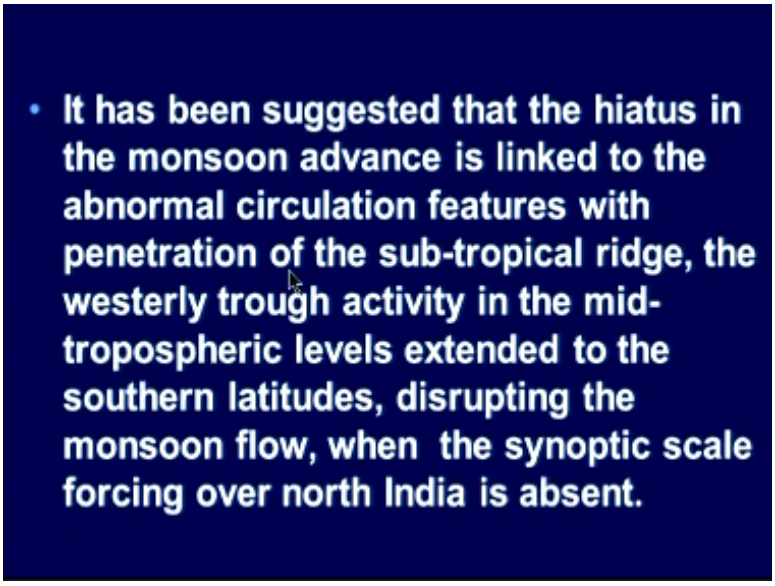

It has been suggested the hiatus in the monsoon advance is linked with the abnormal circulation features with the penetration of the sub-tropical ridge, the westerly trough activity in the mid-latitude levels extended to southern latitude disrupting the monsoon flow when the synoptic forcing over north India is absent. As I mentioned before in winter we have only mid-latitude flow over the region.

But what happens is and we have also seen that soon after the onset of the monsoon the sub-tropical ridge gets established, but if the sub-tropical ridge comes to the south then you have a problem because then you have mid-latitude influence in the monsoon and this is supposed to be one factors that lead to these hiatus events that we have observed.

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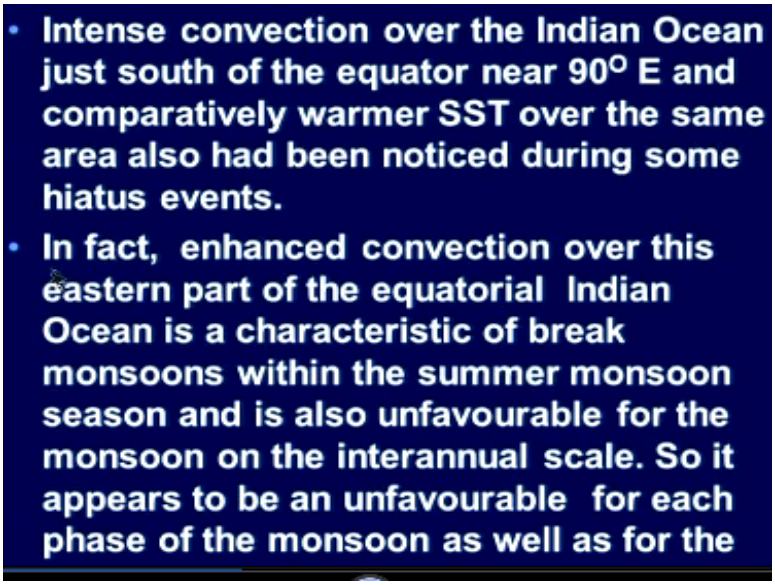

Another thing people have noticed is that intense convection over the Indian Ocean just south of the equator near 90 degrees and comparatively warmer SST over the same area also had been noticed during some hiatus events. So these studies of hiatus events also suddenly (()) (20:46) this region as being unfavorable. This is the region of the east equatorial Indian ocean which we refer to as EEIO Eastern Equatorial Indian Ocean.

And which plays a big role in major events such as Indian Ocean Dipole event and we will discuss this at length later, but this region convection over this region is found to be associated with hiatus events according to some of the researchers. Now in fact, enhanced convection over this eastern part of the Equatorial Indian Ocean is a characteristic of break monsoons which we will discuss in a later lecture within the summer monsoon season.

So after the summer monsoon is established towards the end of June, in July and August we get dry spells which are called breaks in the monsoon. Now it is found that this kind of convection over the same region is a characteristic of the breaks in the monsoon. So it is very interesting. It is also shown that such convection is unfavorable on the interannual scale also. So for the seasonal total also enhanced convection over that region is unfavorable for the summer monsoon over the Indian region.

So it appears that this region eastern equatorial Indian ocean convection over this region is an unfavorable factor for each phase of the monsoon that is to say for the advance of the monsoon, for the fluctuations in the monsoon during the peak monsoon months of July and August as well as for the seasonal rainfall as a whole. So this is a very interesting thing we

will have to follow it up later on when we discuss the physics of the monsoon.

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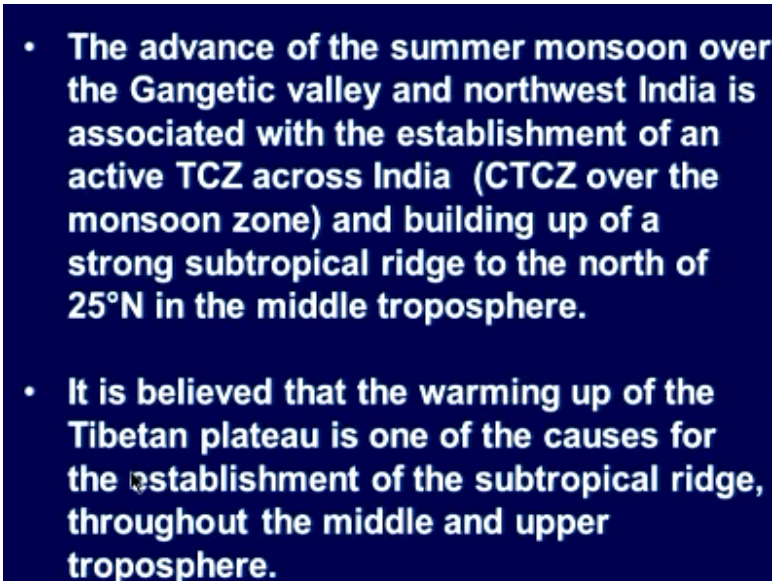

Now the advance of the summer monsoon over the Gangetic valley and northwest India is associated with the establishment of an active TCZ across India. That is the CTCZ over the monsoon zone and we have seen this before and building up of a strong sub-tropical ridge to the north of 25 degree north in the middle troposphere. So once you have an active continental Tropical Convergence Zone over the monsoon zone.

Naturally overlying this low pressure region with intense convection will be a high pressure region and this is the sub-tropical ridge that they talk about. So once the convection gets established, once the CTCZ gets established we have a very strong sub-tropical ridge to the north of 25 degrees north. It is believed that the warming up of the Tibetan plateau is one of the causes for the establishment of the sub-tropical ridge throughout the middle and upper troposphere.

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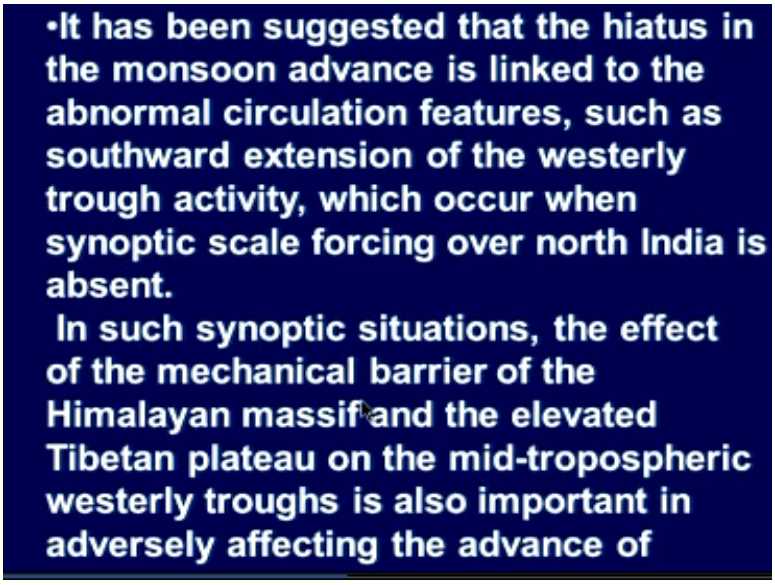

It has been suggested that the hiatus in the monsoon advance is linked to abnormal circulation features such as southward extension of the westerly trough activity which occur when synoptic scale forcing over north India is absent. So what we are saying is before the monsoon in winter months we have in fact mid-latitude circulation over the northern part of India. With the monsoon during the peak summer monsoon season this is totally pushed to the north of Tibet to the northern region.

But what they are saying is when there is very little synoptic scale forcing over the monsoon region that is to say when there is very little convection associated with the tropical system often what happens is even after the onset of the monsoon this mid-latitude system tend to penetrate. And it is suggested that in such situations the effect of the mechanical barrier of the Himalayan massif and elevated Tibetan plateau on mid-tropospheric westerly troughs also becomes important in adversely affecting the advance of the monsoon.

So what they are saying is that one goes back partly to the winter like situation and because of that Tibetan plateau would act like a mechanical barrier as we have seen it does in winter and the fact that it is an elevated heat source also has an important impact in adversely affecting the monsoon. So all the studies of hiatus suggest.

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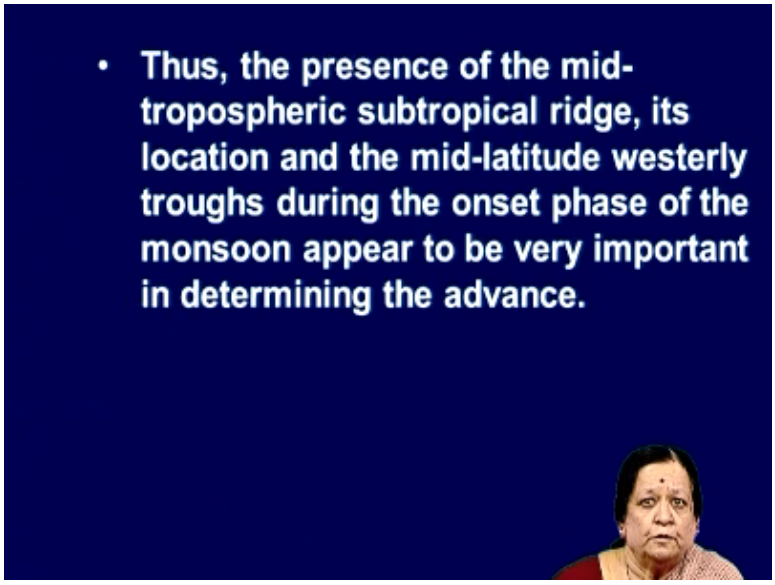

That the presence of the mid-tropospheric sub-tropical ridge, its location and mid-latitude westerly troughs during the onset phase of the monsoon appear to be important in determining the advance of the monsoon. So we know that the advance of the monsoon comprises cloud bands moving from south to north. Cloud bands generated over the equatorial Indian ocean.

Moving northward often in association with cloud system over the Arabian sea and Bay of Bengal and in addition to that we have westward movement of system generated over the Bay of Bengal across the monsoon zone. So the advance process in fact comprises genesis of clouds and cloud systems over a surrounding seas and equatorial Indian Ocean and there propagation onto the region.

Northward propagation of cloud bands and westward propagation of synoptic scale disturbances from the Bay of Bengal.

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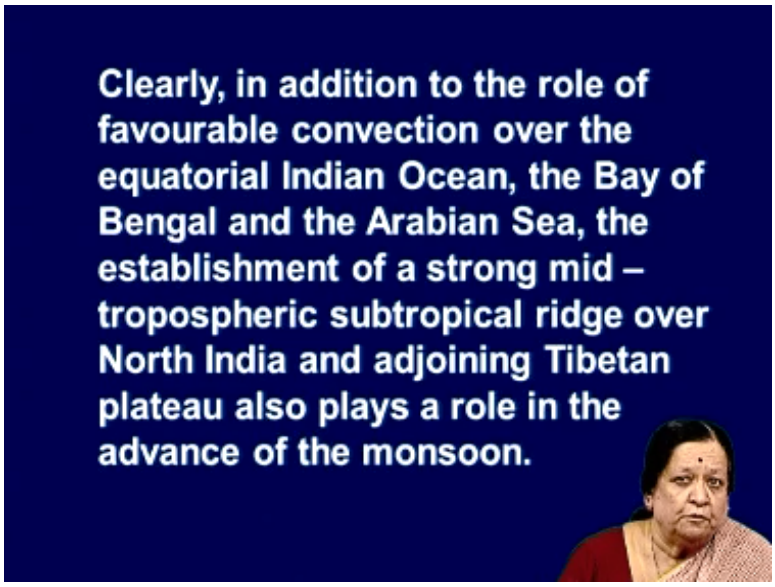

So clearly genesis of these cloud systems and their propagation play a very critical role in the advance phase of the monsoon, but now we have seen that from studies of the hiatus it appears that not only is it important to look at these genesis and propagation of cloud systems. It is also important to consider the look at the establishment of a strong mid-tropospheric subtropical ridge and adjoining Tibetan plateau because they also play an important role in the advance of the monsoon.

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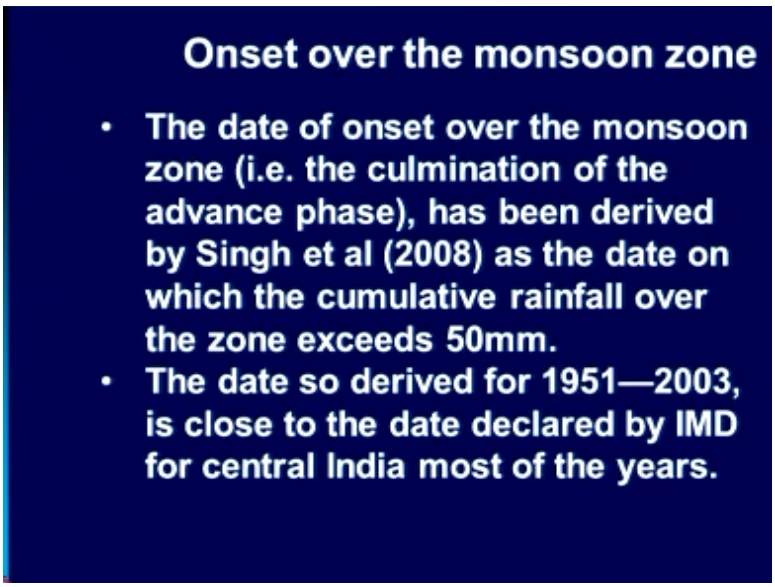

Now there has been a study an interesting study by Nityanand Singh and others over the monsoon zone. Date of the onset over the monsoon zone has been derived as the date on which the cumulative rainfall over the zone exceeds 50 millimeters. So he has used the threshold as in 1 day when the cumulative rainfall exceeds 50 millimeters he calls it the onset over the monsoon zone as a whole.

And he has derived these date of onset of the monsoon and remember that if one talks of onset on the monsoon zone as a whole. This means this is the culmination of the advance phase of the monsoon. Right this is the culmination of the transition from spring to summer monsoon.

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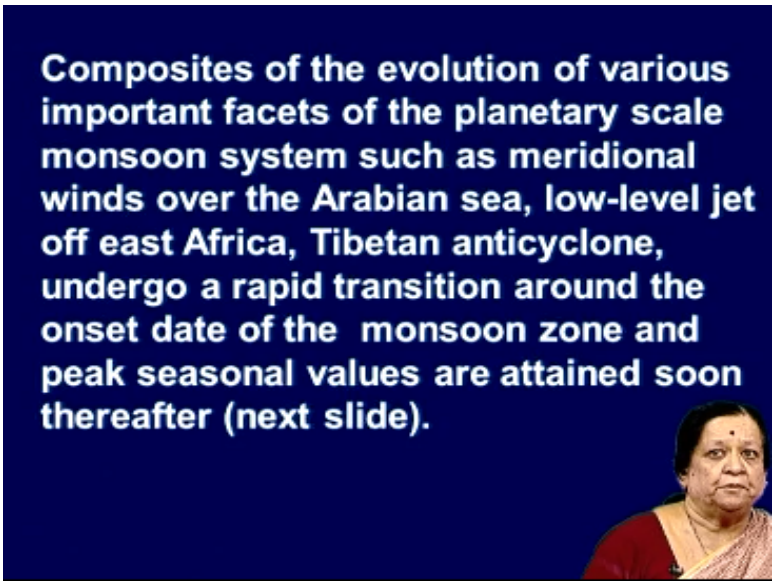

Now we should look at the composites that he has derived of various important facets relative to the onset date of the monsoon zone and the features he has looked at this meridional winds over the Arabian sea, low-level jet off east Africa. Remember these were important circulation features of the monsoon. Tibetan anticyclone which is the high which gets established over the Indian monsoon region.

All of these undergo a rapid transition around the onset date of the monsoon zone and peak seasonal values are attained soon thereafter.

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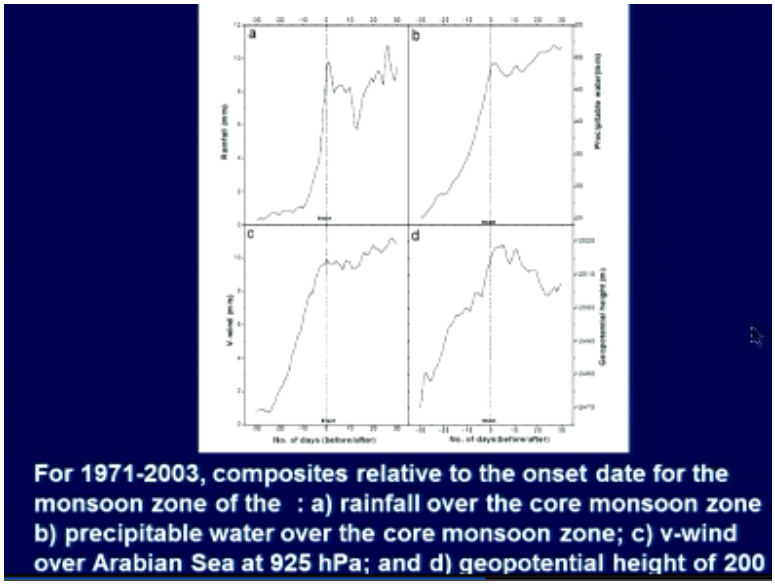

For 1971-2003, composites relative to the onset date for the monsoon zone of the : a) rainfall over the core monsoon zone b) precipitable water over the core monsoon zone; c) v-wind over Arabian Sea at 925 hPa; and d) geopotential height of 200

Now this is very interesting to see, what you see here A is the rain fall over the core monsoon zone and you can see that this is the composite now for all the years and this is the onset date. So what you see here is this is when his cumulative rainfall has exceeded 5. So this is the onset date, but you can say it not only exceeded 5. in the composite it almost hits 10 centimeters.

So the composite actually means a very sharp increase from a few days before the onset about 10 days before the onset it is < 1 millimeter cumulative rainfall and within the short time it attains something like 10 millimeters. So the rainfall becomes 1 centimeter here. So this is the rainfall then this is the precipitable water which also shows an increase. This is the v-wind field over the Arabian Sea.

And this is the geopotential height. So this is the 200 hPa level of the Tibetan plateau. So what you see is basically that if you look at the monsoon zone itself this onset date of the monsoon zone is a very important date because before that one talks of the spring kind of a situation and after that is the establishment of the summer monsoon with all the characteristic features of the cross equatorial flow being established over the Arabian sea.

And of this being precipitable water becoming high of course along with rainfall and the Tibetan high also being established at 200 hPa. So onset of the monsoon over the monsoon zone is therefore marks the culmination of the advance phase of the monsoon.

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Now we have seen earlier that there is hardly any relationship between the total summer monsoon rainfall over India and the onset of the monsoon over Kerala. Earlier onset does not mean more rain or later onset does not mean less rain as one would have thought if in fact it was a matter of stretching the season, but that did not happen. So the onset did not have much of a relationship.

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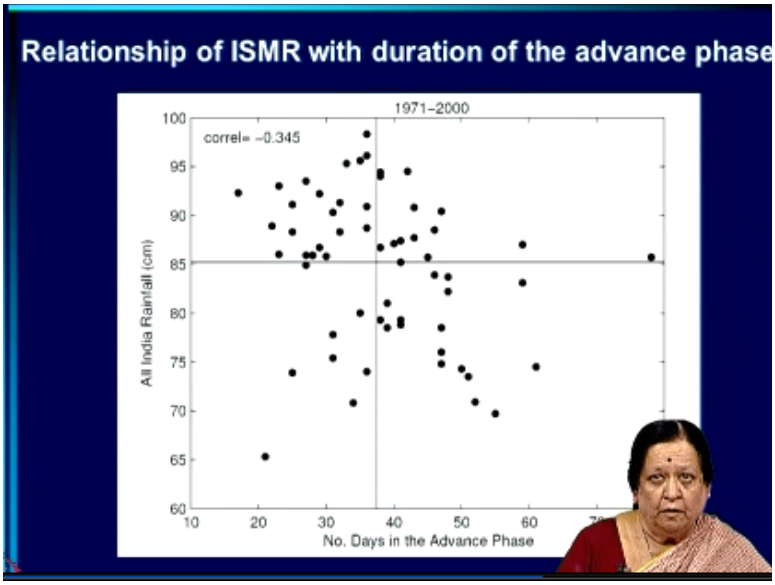

However, there is some relationship of the duration of the advance phase with ISMR. This is the all India monsoon rainfall here on the y axis and the number days in the advance phase here and what you see is that if the advance is very rapid that is this part, this is the average period taken for advance. So if it is faster than normal then the chance of getting higher rainfall is much higher than getting deficit.

So above normal rainfall the probability of above normal rainfall is rather high if you have a very rapid advance say in 30 days or so instead of 38 days then most of the points are above normal and very few points are below normal, but if in fact the advance takes normal or above normal then there is much less you can talk about whether you will get above normal or below normal rainfall.

So the relationship is there the correlation, is not bad, it is -0.34, but it is useful only partially one can say that if the advance is very fast then one is more or less guaranteed that the rainfall will not be below normal. The chance of a below normal rainfall is very small, but once it is beyond this then there is too much of a scatter to make too much sense of it and notice that even when the advance took as long as 80 days you still had normal rainfall.

So the relationship with the duration of advance when the duration of advance is close to the average or above it is very poor with ISMR.

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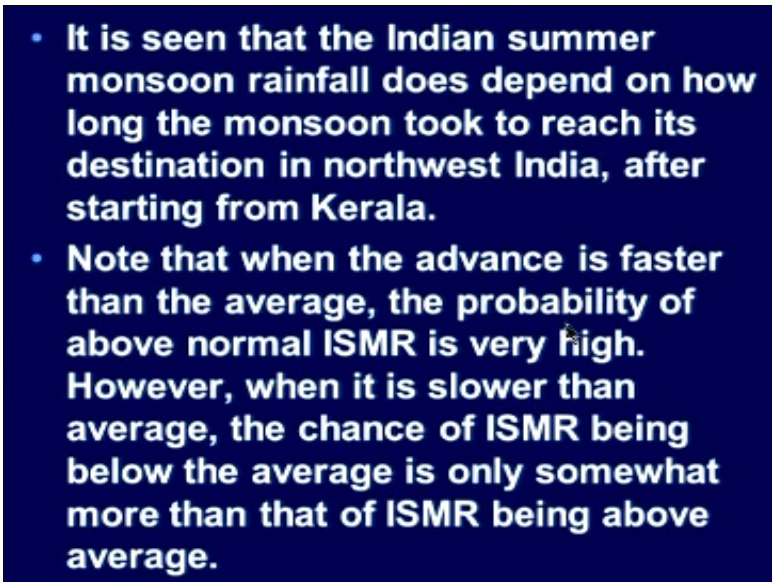

So the Indian summer monsoon rainfall does depend on how long the monsoon took to reach its destination in northwest India after starting from Kerala. Note that when the advance is faster than the average the probability of above normal ISMR is very high. However, when it is slower than average the chance of ISMR being below the average is only somewhat more than that of ISMR being above the average.

So with this now I come to the end of discussion of the transition from spring to summer and if you look in the literature you find that most of the studies address the question of monsoon-

onset over Kerala which is the first time it makes it up its appearance over the Indian region.

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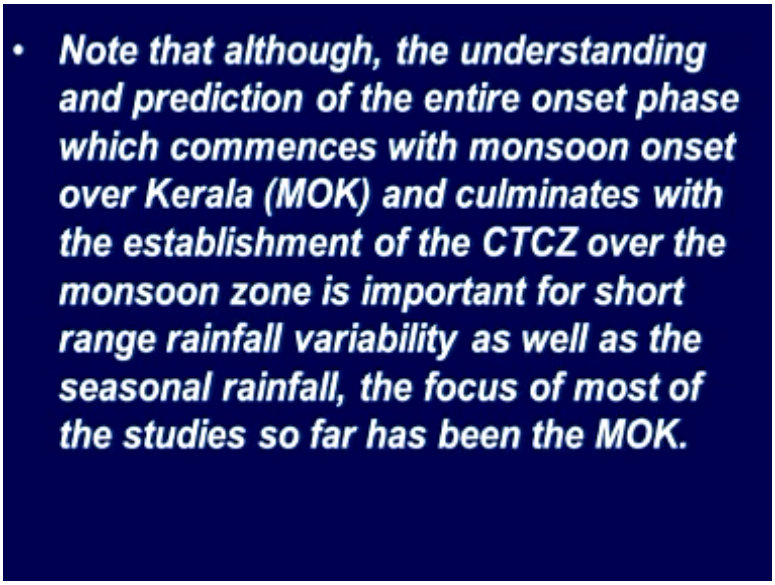

So although the understanding and prediction of the entire onset phase is important. This onset phase which commences with monsoon-onset over Kerala and culminates with the establishment of the CTCZ over the monsoon zone is important for short range rainfall variability as well as the seasonal rainfall. The focus of most of the studies so far has been on the monsoon-onset over Kerala.

So this is the lacuna that one should now try and address and it is very important to understand the variability of the advance phase and in fact if one is worried about all India rainfall it is more important to understand why the advance occurs faster in some years than in others if we want to say something about the all India summer monsoon rainfall.

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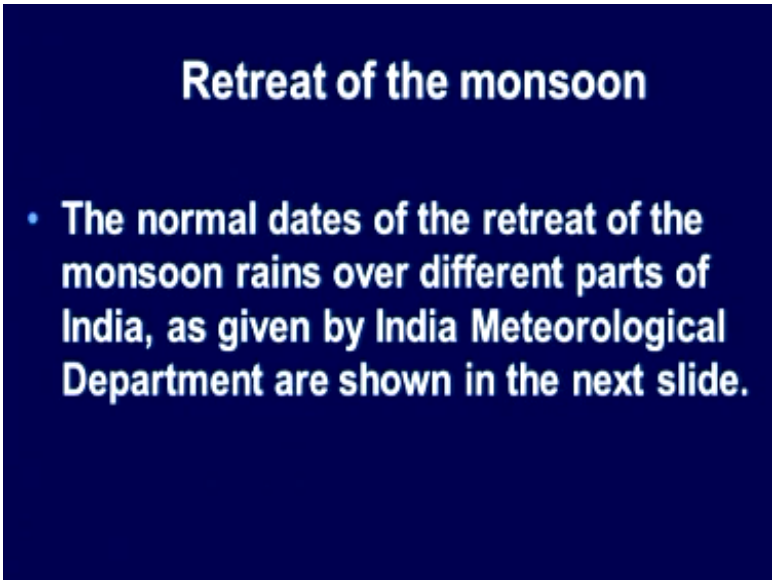

Now I come to the retreat of the monsoon. Now I must mention that the retreat of the monsoon is also called the withdrawal of the monsoon both words means the same thing.

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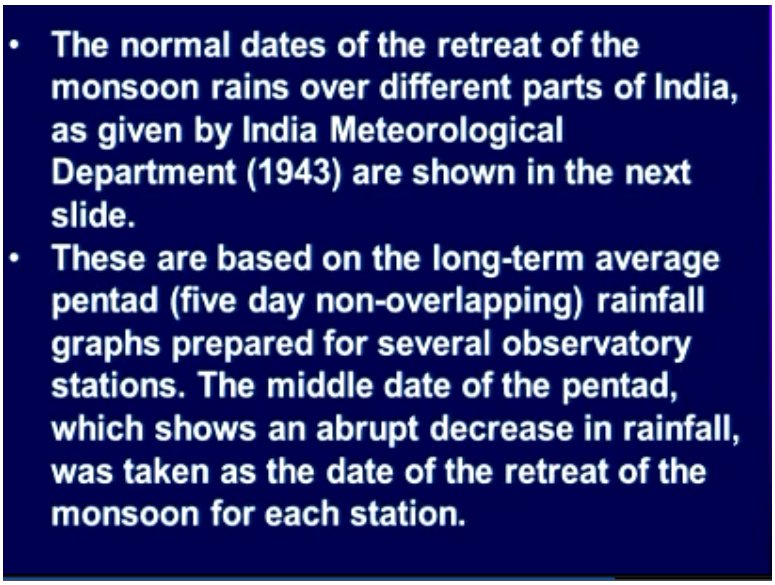

The normal dates of the retreat of the monsoon rains over different part of the country are given here and let me just tell you how they are derived. Again like onset the normal dates of the retreat of the monsoon rains over different parts of the India is given by India Met Department are based on the long-term average pentad rainfall graphs for several observatory stations.

So what they do is to have mean 5-day rainfall graphs and the middle date of the pentad which shows an abrupt decrease in rainfall is taken as the date of retreat of the monsoon for each station and middle date of the one that shows an abrupt increase in rainfall is taken as

the onset. So this is how IMD calculates the onset. Remember this is all based on the mean rainfall patterns.

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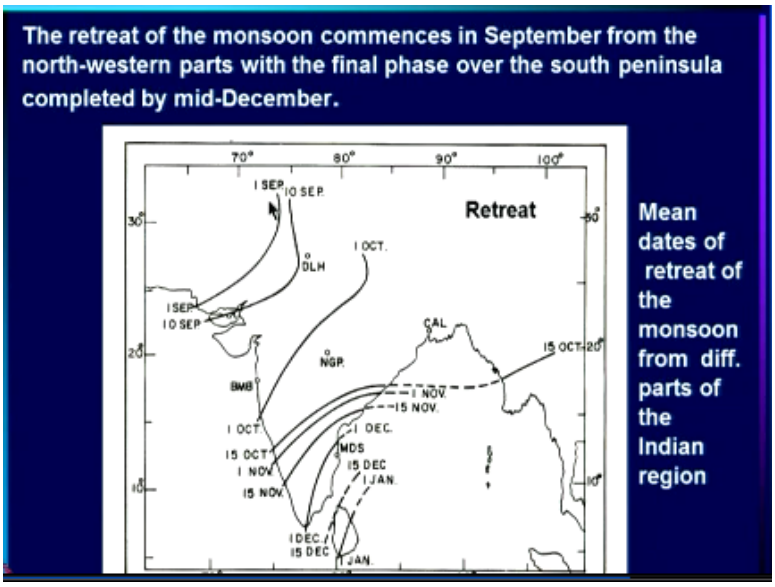

So the retreat of the monsoon is here it commences around 1st September from the north-western parts and keeps retreating. And finally phase over the southern south peninsula is completed by December. So now we have these are the mean dates of retreat you can see that by end of September this is 1st of October. So by end of September it has retreated from a very large part of the monsoon zone and by 15th of October it has retreated from about 15 north or so.

So totally from this part Gangetic plain monsoon zone and it has come well to the South and then it keeps on the rainy season continues towards this end with the final retreat of the monsoon rains only occurring in December from the Indian region.

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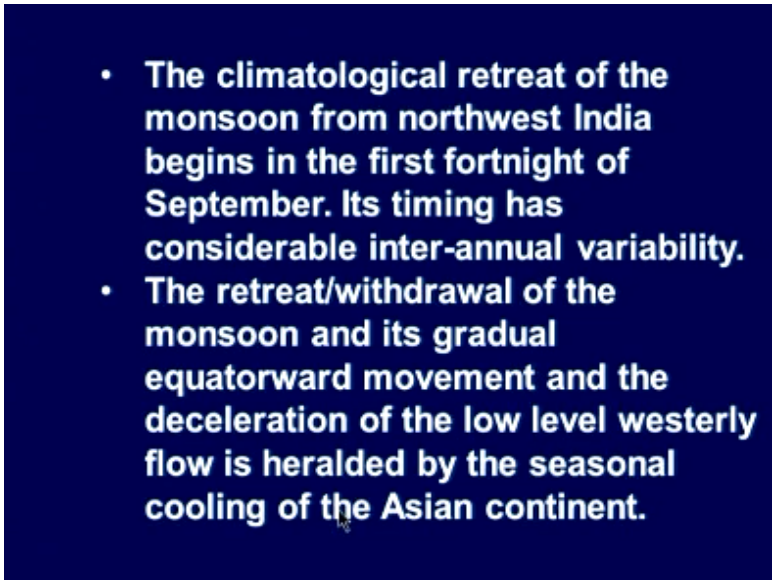

So the climatological retreat of the monsoon from northwest India begins in the first fortnight of September. Its timing has considerable inter-annual variability. The retreat/withdrawal of the monsoon and its gradually equatorward movement and the deceleration of the low level westerly flow is heralded by the seasonal cooling of the Asian continent. See after October in November, December this part begins to start cooling.

So this is accompanied by the retreat of the monsoon.

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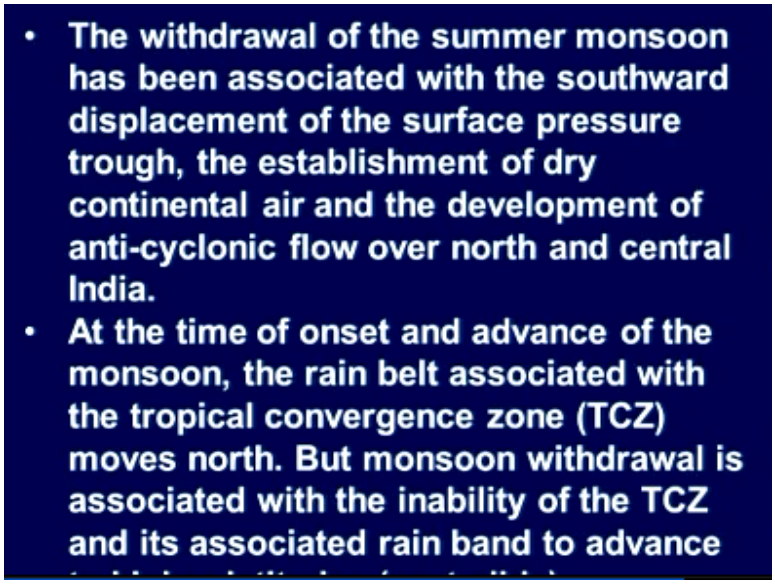

The withdrawal of the summer monsoon has been associated with the southward displacement of surface pressure trough. The establishment of dry continental air and development of anti-cyclonic flow over central India. So now they are talking of withdrawal of the summer monsoon and the not the entire monsoon. Remember what IMD has drawn is

if you like the withdrawal of the rain giving system.

And that takes a long time that takes till December, but we have divided in to rainy season. So summer monsoon withdrawal occurs over this region by about early October and so one talks of central India the surface low pressure trough will move southwards from there and you get an establishment of dry continental air and instead of having cyclonic flow you get anti-cyclonic flow over the central part of India.

At the time of onset and advance of the monsoon the rain belt associated with the Tropical Convergence Zone moves north, but monsoon withdrawal is associated with the inability of the TCZ and its associated rain band to advance to higher latitude.

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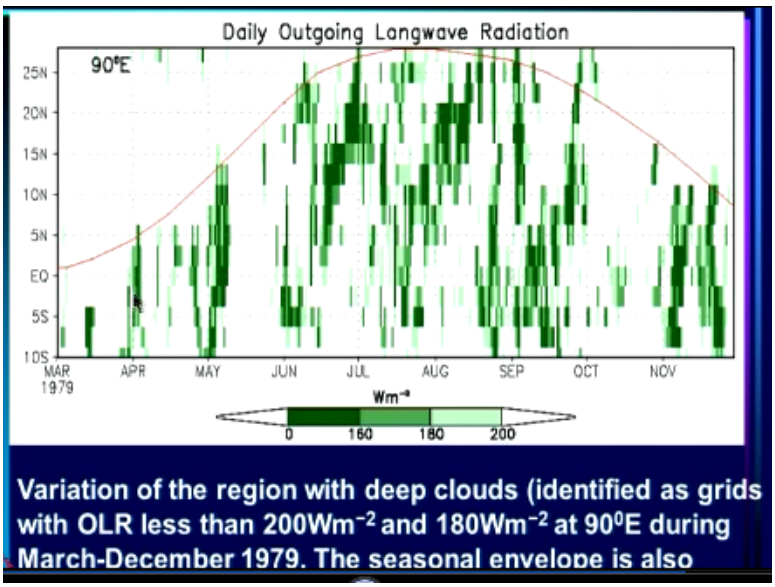

Variation of the region with deep clouds (identified as grids with OLR less than 200Wm^{-2} and 180Wm^{-2} at 90^{0}E during March-December 1979. The seasonal envelope is also

We have seen this before at the time of onset each successive northward moving band moves further and further northward. At the time of retreat or withdrawal it is not as if things start moving southwards not at all. The genesis is still around the equatorial region. It is just that the culmination occurs more and more southward or the band cannot move as for north as it used to before.

So the culmination of the propagations occurs at a much more southerly latitude during the retreat. So this is an interesting feature again which we had pointed out earlier that before the satellite era people used to think that just like you have the northward movement of the rain belt you would have southward movement of the rain belt during the retreat of the monsoon, but actually if you look at cloud bands it is northward movement which culminates at a lower

and lower latitudes with successive northward propagation.

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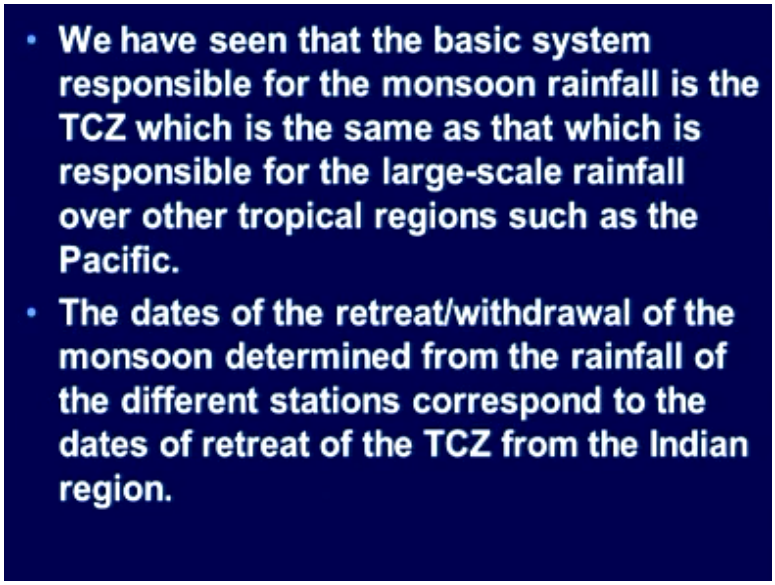

Now we have seen that the basic system responsible for the monsoon rainfall is the TCZ which is the same as that which is responsible for the large-scale rainfall over other tropical region such as the pacific and we have also seen that it is the same system that gives us rain irrespective of whether we are in the southwest monsoon or in the northeast monsoon. The so called southwest or northeast or the summer monsoon or post monsoon.

Now the dates of retreat or withdrawal of the monsoon determined from the rainfall at different stations.

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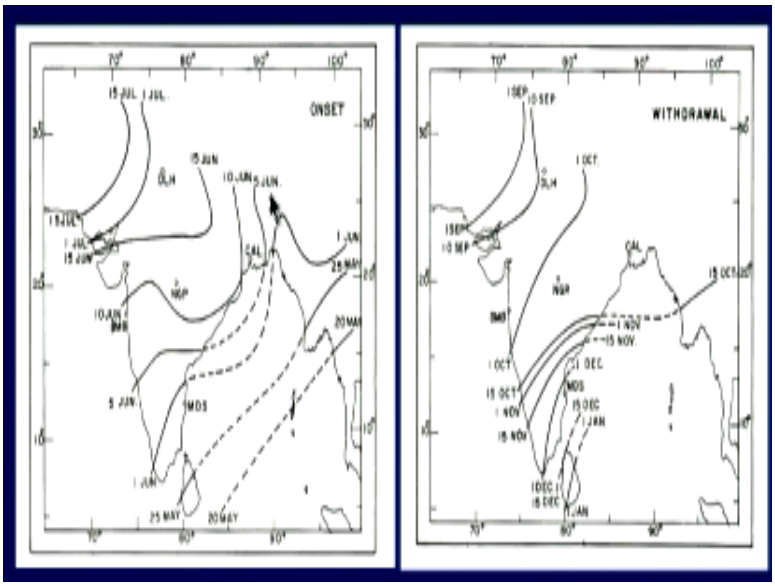

Actually this is again from IMD we have looked at these onset and withdrawal. So this

corresponds actually to the onset and retreat of the TCZ from the Indian region. So we have dates of retreat or withdrawal of the monsoon determined from the rainfall of the different station correspond to retreat of TCZ. So the TCZ retreats from this region which means the TCG which gets generated to the south no longer reaches these higher latitudes.

But actually reaches only up to here and then only up to here and so on and so forth. So the retreat corresponds to retreat of the Tropical Convergence Zone from our midst. At any place the period between the onset and the retreat of the monsoon can be considered as the rainy season. And the mean rainy season can be derived from the dates give by IMD for the onset and retreat.

So given that we have onset of the monsoon and retreat here one can actually derive what is the mean rainy season over any part.

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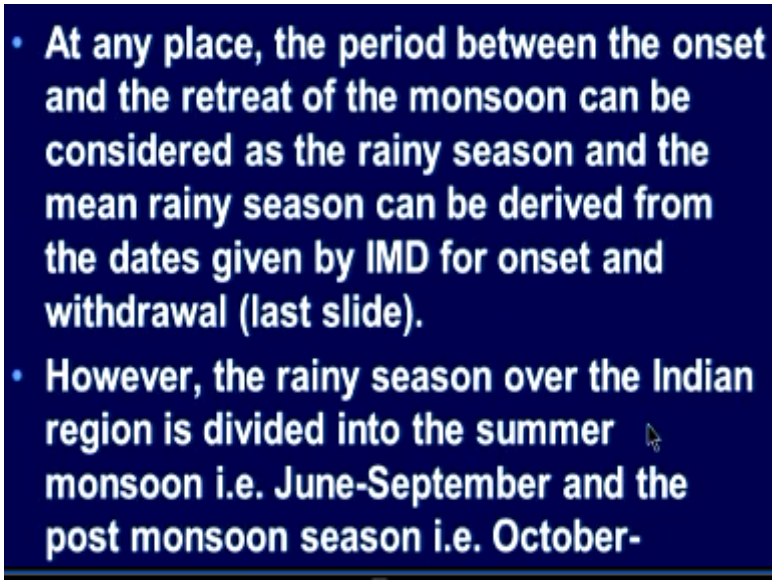

However, the rainy season over the Indian region is divided into summer monsoon and post monsoon season and as we mentioned in the first summer monsoon most of the flow is from the southwest, most of the winds is from the southwest. So it is also called a southwest monsoon.

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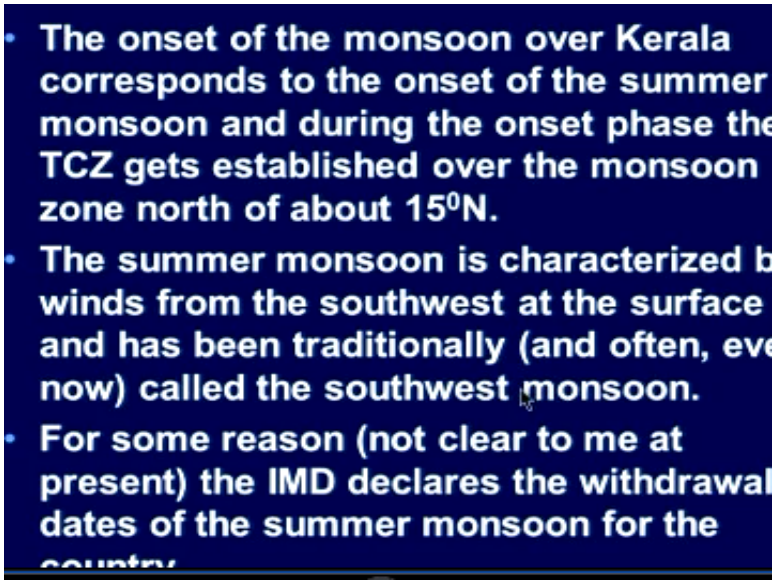

So the onset of the monsoon over Kerala corresponds to the onset of the summer monsoon as well as the onset of the monsoon as a whole because that is the first season and during the onset phase the TCZ gets established over the monsoon zone north of about 15 North. The summer monsoon is characterized by winds from the southwest at the surface and has been traditionally and even now called the southwest monsoon.

For some reason which is not clear to me at present IMD declares the withdrawal of the summer monsoon or the southwest monsoon for the country. So while the mean dates of IMD for withdrawal of the monsoon correspond to the end of the rainy season as a whole for that part of the country. IMD also declares the end of the summer monsoon which is part of the rainy season.

And it is not clear to me whether that is a useful thing to do or not, but let me talk about what is actually done.

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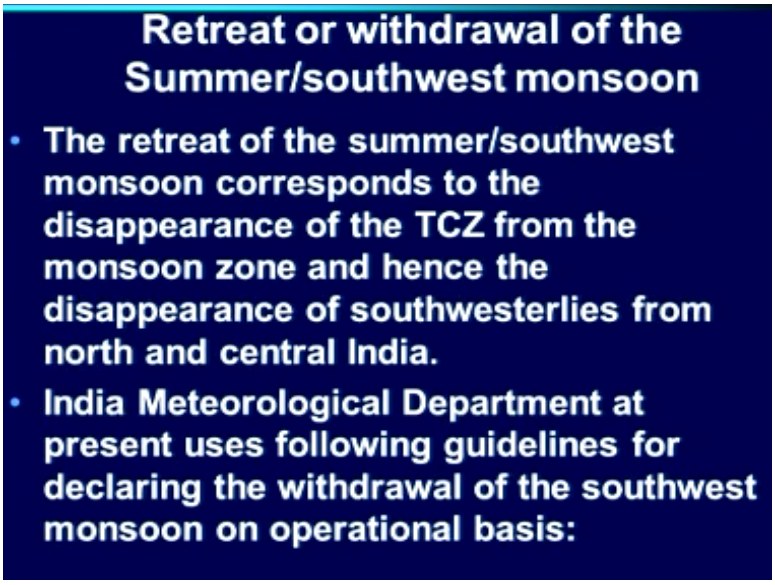

So the retreat of the summer or southwest monsoon corresponds to the disappearance of the TCZ from the monsoon zone and hence the disappearance of south westerlies from north and central India. So India Meteorological Department at present uses the following guidelines for declaring withdrawal of the south west monsoon.

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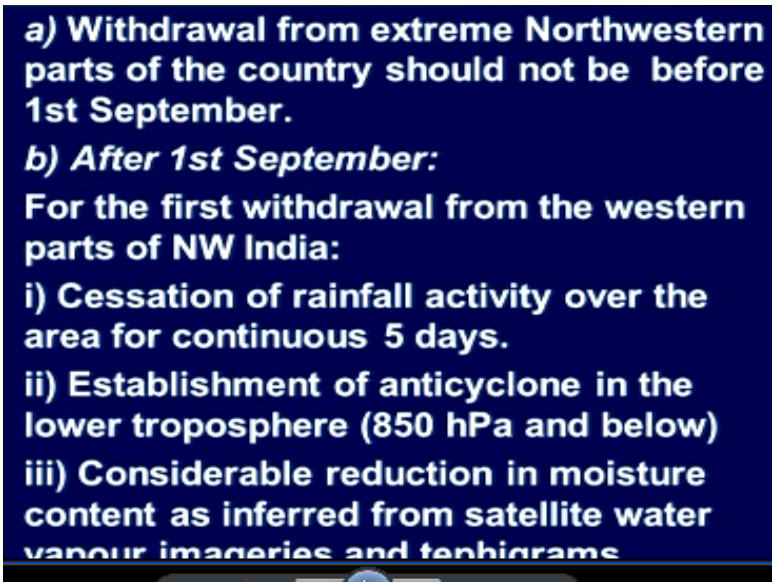

So withdrawal from extreme Northwestern parts of the country should not be before 1st of September. So this is an instruction for operational declaration of withdrawal of the south west monsoon. So they say even if you feel that the conditions look like the monsoon as withdrawn you should not do it before 1st of September. After 1st September for the first withdrawal from the western part of northwest India there are many criteria they look at succession of rainfall of rainfall activity.

Establishment of anti-cyclone in the lower troposphere this is over the monsoon zone and considerable reduction in moisture content as inferred from satellite data.

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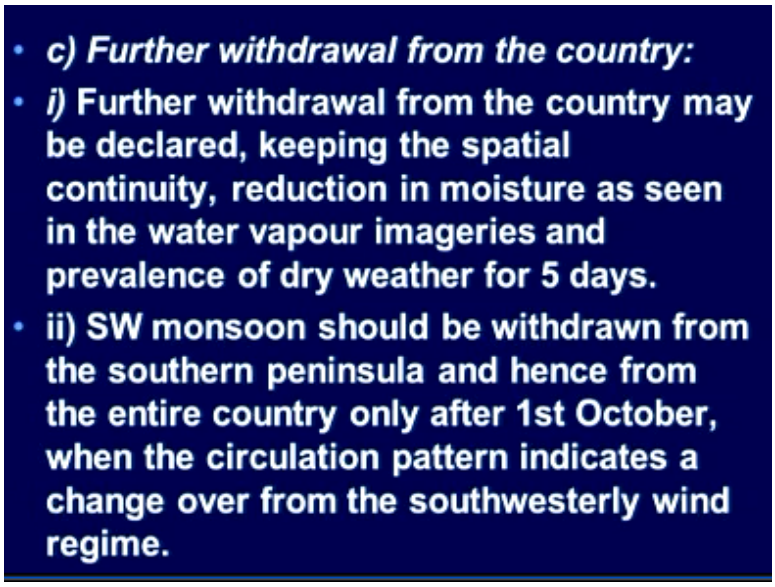

Now for further withdrawal of the country they say may be declared keeping the spatial continuity, reduction in moisture as seen in water vapour imageries and prevalence of dry weather for 5 days. And they say southwest monsoon should be withdrawn from the south southern peninsula and hence from the entire country only after 1st October when the circulation pattern indicates a change over from the southwesterly winds.

So only when the winds become northeasterly should you declare this. Now I must mention here that this is the very interesting terminology that IMD uses they feel that they are the players who actually bring on the monsoon or withdraw it which is an amusing thing. So they say southwest monsoon should be withdrawn what they mean is of course it could be declare that the southwest monsoon is withdrawn.

But it is very amusing way of putting things, but which IMD uses has been using for decades.

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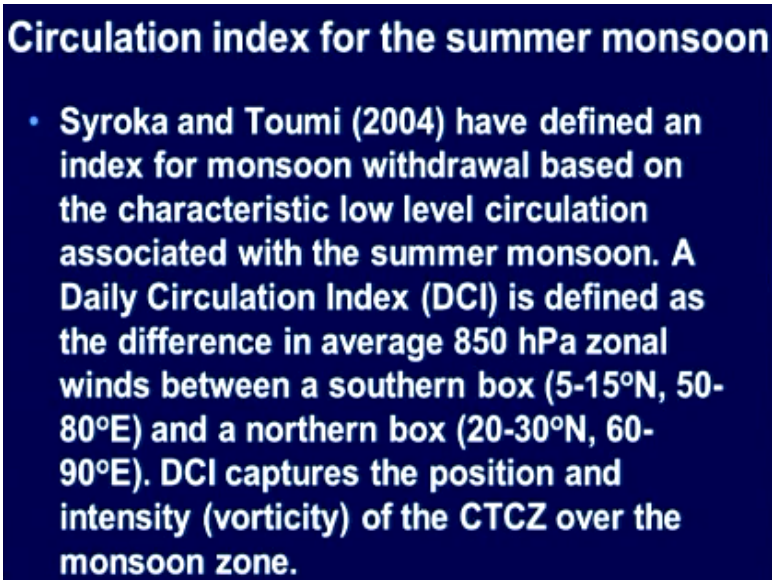

Now since people were interested in summer monsoon some work has been done on how does one define the duration of the summer monsoon and there are 2 Japanese who have define an index for monsoon withdrawal based on the characteristics low level circulation associated with the summer monsoon and this is a Daily Circulation Index which is defined as the difference in average 850 hPa zonal winds between a southern box and a northern box.

Southern box centered around 10 North and a northern box centered from 20 to 30. So what this is capturing is we have seen earlier that during the southwest monsoon there is shear between the westerlies to the south and easterlies to the north and what this index is capturing is the shear vorticity above the boundary and we have to note that during active phases of the monsoon the shear vorticity is cyclonic.

For the mean monsoon as well this shear vorticity is cyclonic and remember that vorticity is closely linked to organized rainfall. So if one has to use a circulation index it makes sense to use 850 millibar vorticity as the index and that is what they do and what they say is.

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- The date of monsoon withdrawal is taken as the first of seven consecutive days for which the smoothed DCI is negative.
- The withdrawal dates of the Indian summer monsoon (southwest monsoon) for the years 1958- 2000 (next slide).
- The mean date of withdrawal is 19 October with a standard deviation of 14 days (almost double that of MOK). The earliest withdrawal date is 23 September 1994 and the most delayed one is 23 November 1998.

That the date of monsoon withdrawal is taken as the first of 7 consecutive days for which the smoothed DCI is negative. So this vorticity has to change from cyclonic to anti-cyclonic with the withdrawal of the summer monsoon and so they look at the vorticity from about 10 to 20 North, 20 to 30, 5 to 15 vis-à-vis 20 to 30. So over that band they are looking at the shear vorticity which is the dominant component of the vorticity and they look at the data to determine when it becomes negative.

And it should not be just a day or 2 of fluctuation of vorticity, but it should be a permanent transition to a withdrawal state and so they wait for 7 days and only the first of 7 consecutive days for which the smoothed DCI is negative is taken as the withdrawal date.

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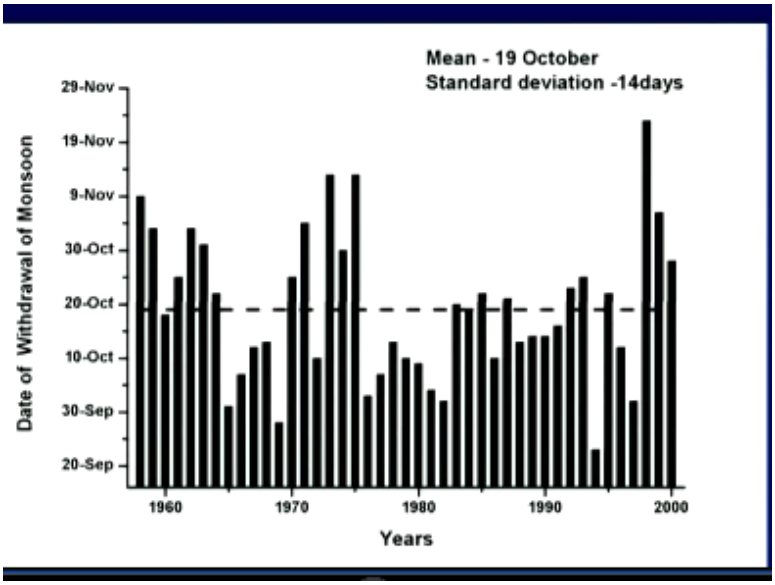

And the withdrawal dates that they derived as shown here. And you can see the withdrawal of

the southwest monsoon or the summer monsoon dates are here and the latest is sometime in November, but the mean date is about 20th October. So 20th October is the date of the withdrawal of the southwest monsoon from the country by this definition.

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Now I will start a discussion on the rainy season over the Asian monsoon region and the variation of rainfall profiles. So remember here we have been talking of mean rainfall and we have also said that the patterns of mean rainfall vary across the country from places like Chennai or southeast peninsula where maximum rain occurs in October, November to places over the Indian monsoon zone like Chaibasa and so on where the maximum occurs only in July, August and the rain is restricted to June to September.

So we have already seen that there is a great deal of variation in the patterns. Now there have been some studies of monsoon rainy season defining what a monsoon rainy season is and looking at its variation over the Asian region as a whole and circulation. There have also been studies of determining regions over which the rainfall variation patterns are similar. The monthly mean rainfall profiles are similar.

I will talk about both of those in the next set of lectures.