The Monsoon and Its Variability

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Lecture - 03
Monsoon variability through the eye in the sky, seasonal variation of the surface wind and pressure

Now in the last lecture we have seen the nature of monsoon variability as analyzed from rainfall data today we will begin with looking at what monsoon variability looks like from measurements from satellites the eye in the sky and then we will look at the Indian monsoon on the seasonal variation of surface and so wind and so on and then develop the background required for understanding the various theories we have and mechanisms.

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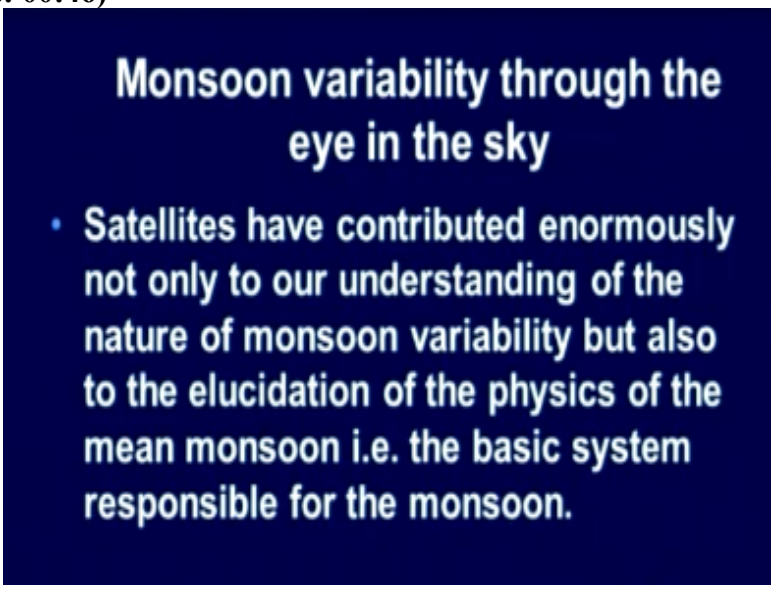

So, let us first look at monsoon variability through the eye in the sky in fact satellites have contributed enormously not only to our understanding of the monsoon variability but also to the elucidation of the basic system responsible for the monsoon you know the physics of the mean monsoon.

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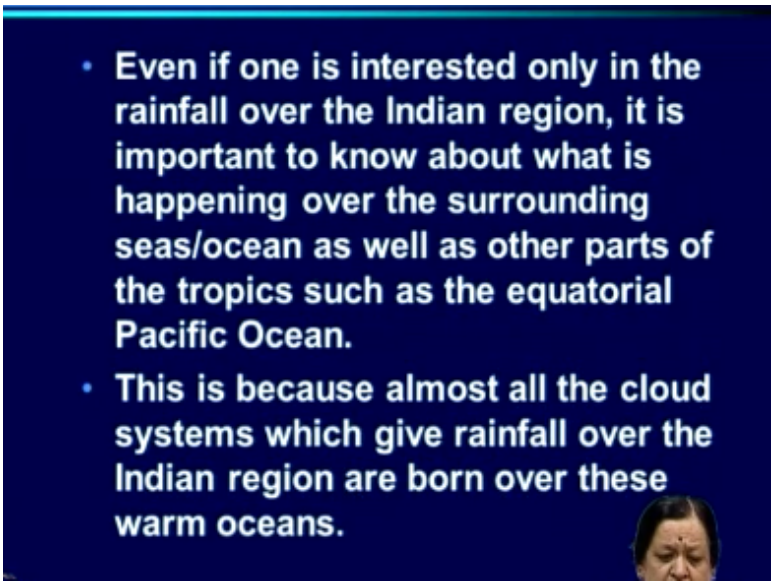

Now even if one is interested only in the rainfall over the land region that is only over the rainfall over the Indian region it is important to know about what is happening over the tropical oceans now why is that because almost all the cloud systems which give rainfall over the Indian region and actually born over the warm parts of the tropical oceans warm our Arabian sea, Bay of Bengal equatorial Indian ocean and equatorial Pacific Ocean and warm parts of West Pacific.

Are the breeding regions if you wish for the cloud systems which actually give use rainfall?
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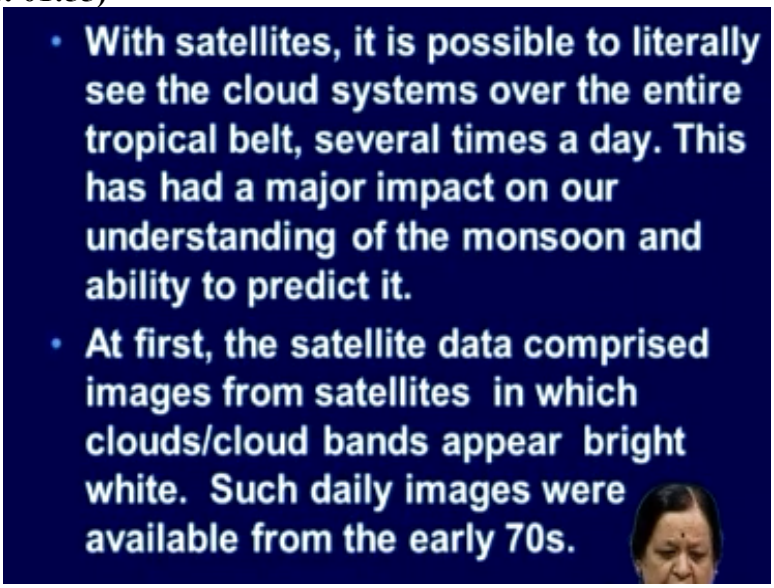

Now earlier without satellites we did not really have good data on what was happening over the oceans now with satellites it is possible to literally see the cloud systems over the entire tropical belt several times a day and in fact some of us do that we see it every day what is happening over the world this has had a major impact on our understanding of the monsoon and also Its

variability and I believe in the ability to predict various phases of the monsoon and its variability.

Now at first when meteorological satellites came in the data we had actually were images you know photographs taken by cameras from satellites and in these images, clouds appear as white blobs because a lot of sunlight gets reflected from the top of the clouds.

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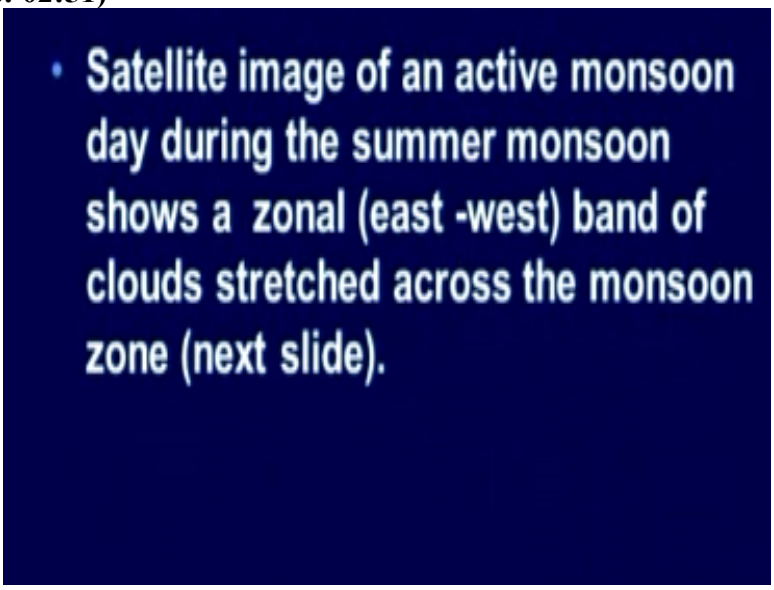

So now if we look at a typical image that we got in that time which is what we will see in the next slide it is an image of an active monsoon day a day on which a lot of rainfall occurred in the monsoon zone.

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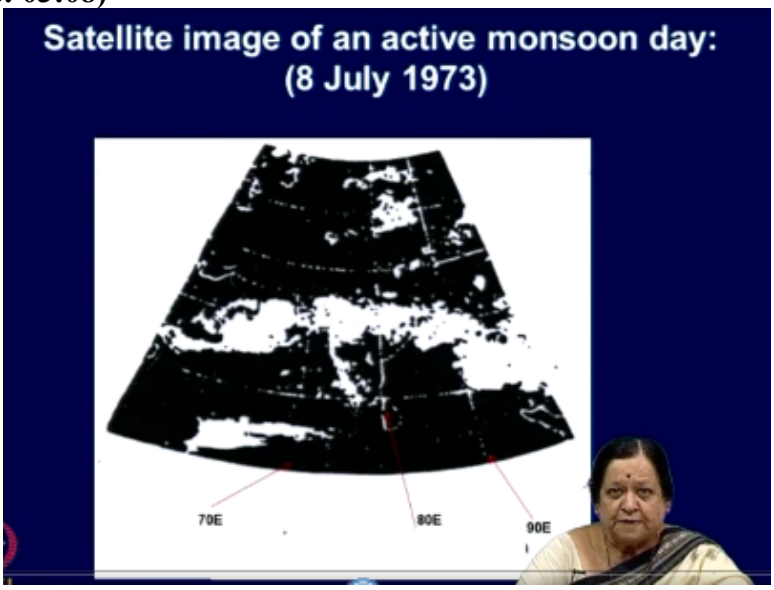

It happens to be 8th of July 1973 so what you see here is what the satellite actually generated it is a satellite image it is an image of the Indian region and what you see is an east west band of

cloud over India it extends all the way from west of India over the Arabian sea extends over India and you can see it continuously extends eastward as well so this is a big planetary scale cloud-band sitting on us.

And over Indian region and you can see that it is sitting on the monsoon zone please note the Indian longitude use what we can call Indian longitudes are 70 degrees east which is the longitude here 80 degrees east which is considered to be the central longitude of India that is these one and 90 degrees east which is the longitude here that cuts across the bay okay and goes to the head bay.

So, these three longitude we consider are the Indian longitudes and we will focus our attention on the variation of the clouds over the Indian region.

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Now in fact the very first study of you know how these clouds vary from day to day which was based on such satellite imagery actually reveal several new features which are particularly important in what the seasonal transitions such as the onset phase the retreat phase as well as the fluctuations between active spells and break are the variations within the season okay and this study was carried out by an eminent monsoon meteorological Sikka and myself.

And the paper was published in 1980 now this very first study of the daily variation kind of imagery that you saw what we did was we looked at the extent of the band at those three longitudes I showed you 70,80 and 90 the Indian longitude okay and looked at how the cloud extend over the Indian longitudes varies from day to day and it actually revealed many new

features that were unanticipated.

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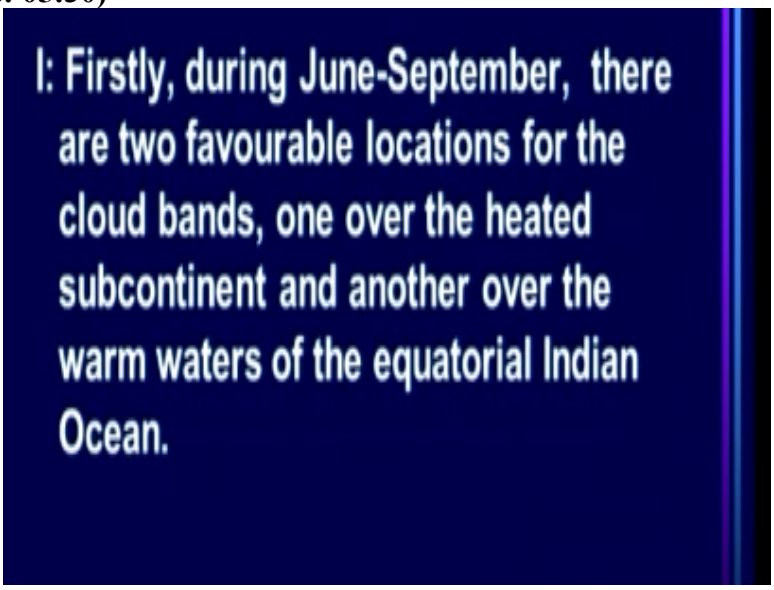

Firstly, we found that during the summer monsoon there are two favorable locations for the cloud-bands okay and you will see that in this picture but if we go back okay one favorable location is over the Indian region which is the heated subcontinent in this time and another favorable location you see a kind of glimpse here is the equatorial region so cloud the cloud-bands of the kind you are seeing have a high propensity to occur either here or here.

Or we say there are so there are two favorable locations for the cloud-bands one over the heated subcontinent and another one of warm waters of the equatorial Indian ocean.

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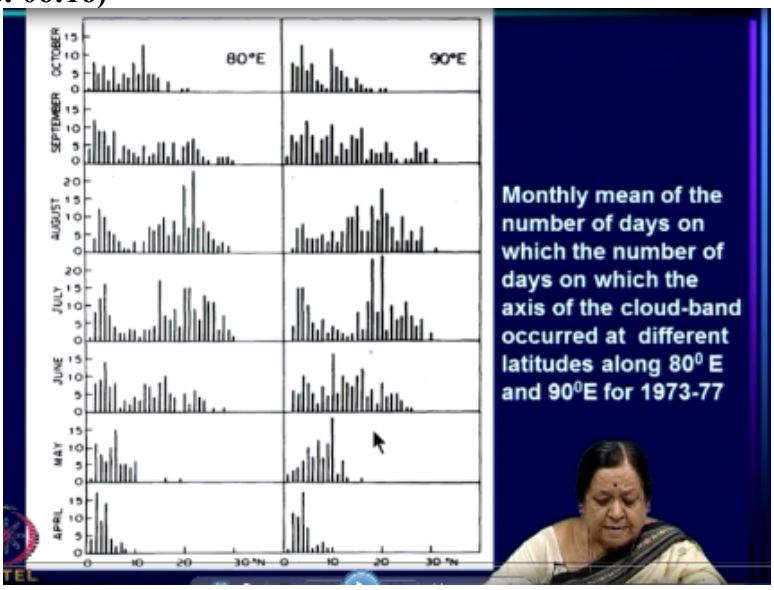

Now this is reflected the fact that it is a by model distribution that the cloud-bands then took are

two places is reflected here now this is again from the original paper that I talked about Sikka Gadgil paper and what you see here is the monsoon mean of the number of days on which the axis of the cloud occur differently latitudes along 80, 90 degrees east.

So 80 degrees remember the central longitude of India and we have to say what this shows are the number of days on which the cloud-band occurred here so let us look at June for example or begin with April you can see that most of the time the cloud vanish to the south of 10 degrees north remember the southern tip of India is 8 degrees north so in April you almost never get over Indian region any clouds very very few.

And over the bay you do get some clouding in April remember 90 degrees is the longitude that cuts across the bay now this starts spreading northward in May and in June while still you have higher chance of clouding in the equatorial region you also start getting substantial chance of clouding in the northern parts right up to 20 north and beyond and that is to say right up to Bombay and north of that.

Now similar distribution here if you see in July and August which you remember were the peak monsoon months' monsoon in July and August you see were to be consider by model distribution over the Indian longitude that is to say there is a mode here and there is another mode yet and between the two modes the chance of having close is very small so this mode is over the equatorial Indian ocean and this mode is over the heated continent around 20 north.

Of course the distribution is not very sharp it is in fact spread out and the chance of having clouds all over right from 80 north or so 25 to 30 north is quite high same story for August same story for July here but in August the Bay of Bengal the equatorial clouding has become less likely and so on so this is the by model distribution this is what we call the oceanic cloud-band and this is the continental cloud-band.

And they are separated if you wish by this in no mans land you know by these regions by the region between these latitudes around 10 north when that is not likely to be the cloud-band occurring so if we now make an average over if we now make an average over this part and call it as northern one and this part and call it a southern one when there are two distinct modes and otherwise look at the average of this distribution then what we get is.

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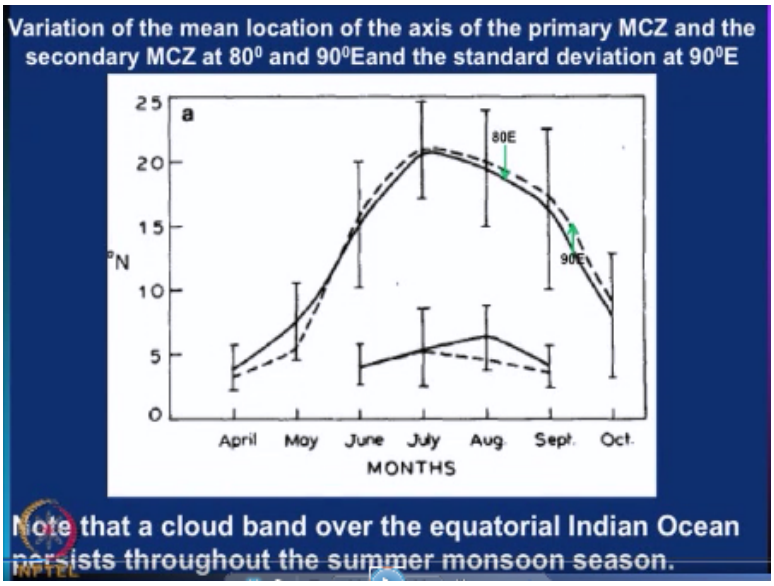

How does the location of the cloud-band vary with season vary from month to month okay so what you have here that is both 80 degrees and 90 degrees and sticks around it just indicate the spread or the standard deviation so what you see is in April and May the cloud-band is located the mean cloud-band is located south of India south of 8 degrees north of course it has a tendency to appear sometimes towards the north.

But the mean is located south of India, now it comes over India by June. It is around 15 degrees north it is just north of Mangalore and Bangalore then by July it has reached this destiny it has reached over the monsoon zone the center of the band is around 20 north August it remains there and September also it remains there. So monsoon zone starts from around 15 north and you see that June, July, August, September there is the band is there.

So you see a very clear northward movement of the band okay this is the northward movement during the onset phase of the monsoon and and this is the peak monsoon monsoon this is the retreat which looks like a southward movement if you look at monthly picture but north that when we look at the ocean bend this is the average over south of about say 7 degrees north or so then the ocean bend persists throughout June, July, August, September.

So, there is a band over the continent and there is a band over the ocean okay this is a very interesting feature and a somewhat unique feature of this part of the tropics. So, we have 2 locations where the cloud-bands can occur one is over the Indian region heated plains of India and the other is over the equatorial Indian ocean and throughout the main monsoon summer monsoon and monsoon of June to September the ocean band is also present if you look at the

monthly picture.

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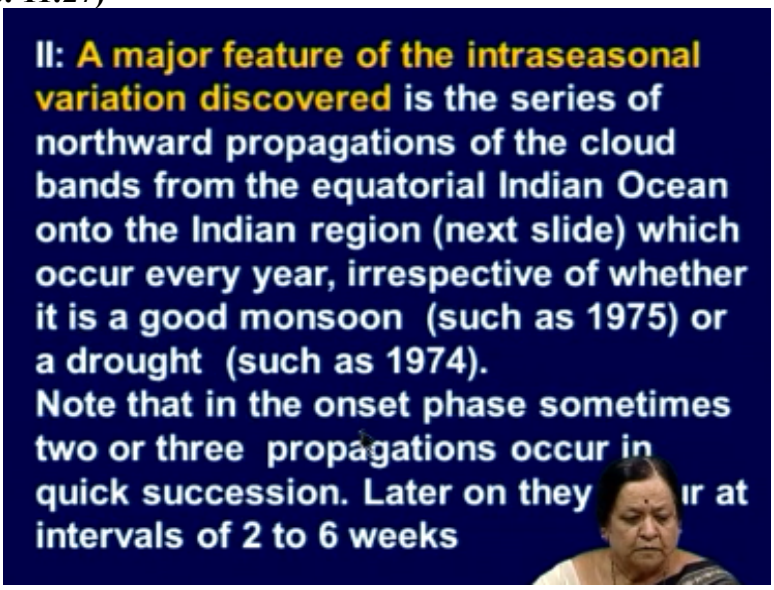

But if you now look at the daily picture you will see that in fact at both the locations the bands fluctuate I will come to that when we look at the next feature so that in this very first study of the satellite imagery of our region major features of intra-seasonal variation was discovered this is a new feature which was discovered in this study.

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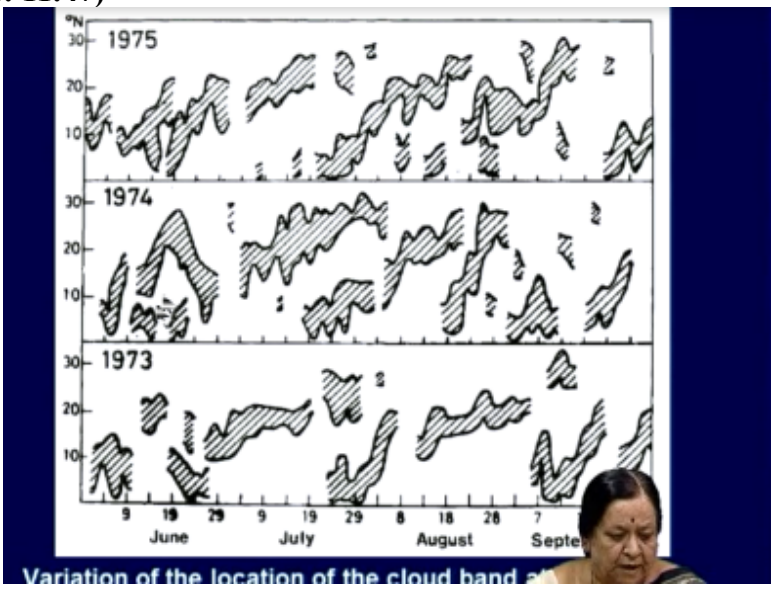

And this feature is shown here and I will go back to the description after you see the picture what you see here is where the cloud-band is at 90 degrees east so we are sitting on the longitude that cuts across the Bay of Bengal and we are asking the question on this particular day in 1973 where is the band so on this particular day 1973 the band is located around 10 north similarly in 1974 also it is located at around 10 north and even 1975 also.

So we see how does the location of the band vary from day to day when we are fixed at 90 degrees east which is the longitude here that cuts across the Bay of Bengal which is the central longitude of our monsoonal region so what you see is there are these northward propagations you see that seems to get generated in the equatorial region and moves northward and these occur at different intervals for example in 75 you got backward moment.

And the band seem to die here having reached the Indian region having reached monsoon zone over the Indian region. Another band appeared, and it moved northward and then it continued to move northward over a gap after a few weeks and the band appeared over the equatorial region and moved north and again moved north so this is northward propagations are something that we observe year after year.

So, what is the variation of the cloud-band like location of that cloud-band like in after year that cloud-band gets generated in the equatorial region and moves northward. How frequently at what intervals the intervals can vary from of 2 weeks to several weeks 6 weeks or so like this one between the two propagations here so there are northward propagations of the cloud-bands which occur with genesis in the equatorial region.

And northward movement towards the monsoon zone that is towards 90 degrees 20 degrees north so this kind of serious northward propagation is part of the repaltyre of the monsoon year after year irrespective whether it is a drought like 74 weather drought and whether it is a good one like 1975 was a good monsoon year so year after a year what we see the series of northward propagation.

So, a major feature of the intra-seasonal variation that we discovered was the series of northward propagation of the cloud-bands from the equatorial Indian ocean onto the Indian region which occur year after year irrespective of whether it is a good monsoon or a drought. Now that spacing between the period between these propagation two successive propagation varies and as we saw sometimes in the onset phases.

You get very quick propagations in very quick succession so sometimes two or three propagations occur in the onset phase in quick succession later on their credit intervals of 2 to 6 weeks okay so in fact this is a basic feature then of the monsoon over the Indian region. Is this genesis of cloud-band over the equatorial region which move northward on to our monsoon zone

at intervals of anywhere between 2 to 6 weeks which occurs yet after the year irrespective of whether it is a good monsoon or a poor monsoon.

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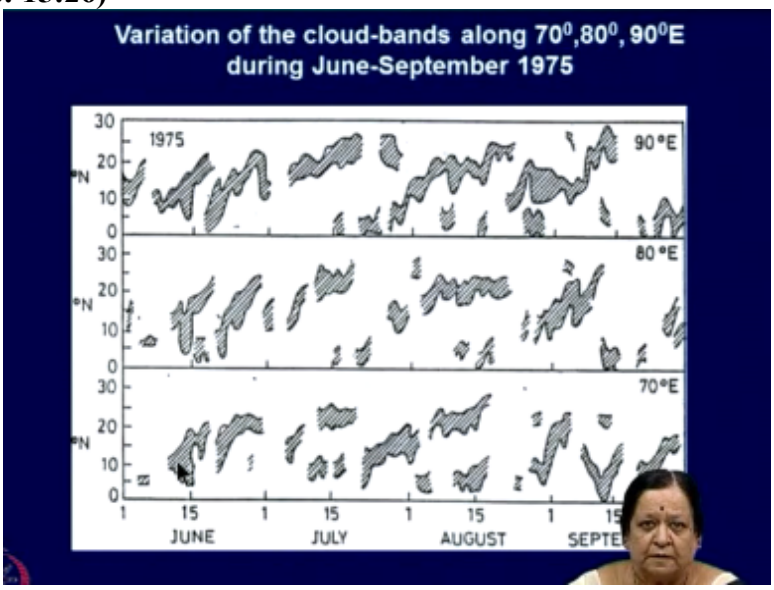

What you saw here was what happens in different years at 90 90 degrees east we sat on the central longitude of Bay of Bengal and saw now what you see here is what happens in the same year at different Indian longitude. So this is 70 degrees east this is 80 degrees east and this is our good one 90 degrees east which is saw earlier and what you see is that in fact the feature you saw at 90 is also seen at 80 and 70.

And there is a great deal of coherence when your northward band when you had northward movement of a band at 90 you see it also at 80 and you see it also at 70 so in fact this is northward propagation is as not of cloud-bands just around 90 rather they correspond to cloud-bands which are stretching all the way from 70 to 90 which are stretching across the Indian longitude and such a band is moving northward in fact we saw the image of such a band in the first picture.

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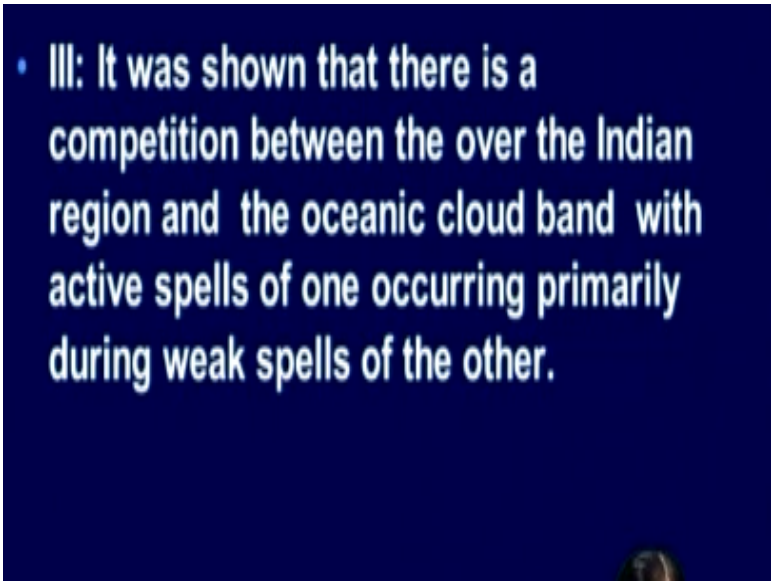

So okay so this is the second important feature the first important feature was that in fact there are two favorable locations for cloud-bands to occur one is over the heated continent in north around 20 norths and the other is an over the warm equatorial Indian ocean second was that every monsoon season we see a series of northward heard propagations of the cloud-band which is generated over the equatorial Indian ocean and moves northward.

Now the third feature that we we found was that in fact that appears to be a competition between the band over land and the band over the ocean such that active phases of this one band occurred during week phases of the other and I believe you can see that here you see in this picture for example this is an active phase of the northern band in which equatorial band did not appear it started appearing here.

And it actually was sustained for quite a while when there was no band in the north and then it move northward once it was in a phase that where it was active here it did not appear here as it became weaker it started appearing but then disappeared because this one will continued and then again appeared and moved northward when there was no band here so there is a seesaw of activity between the this and this so there is a competition between the last band on land and between the band over the ocean.

So, this is the third feature then that we saw.

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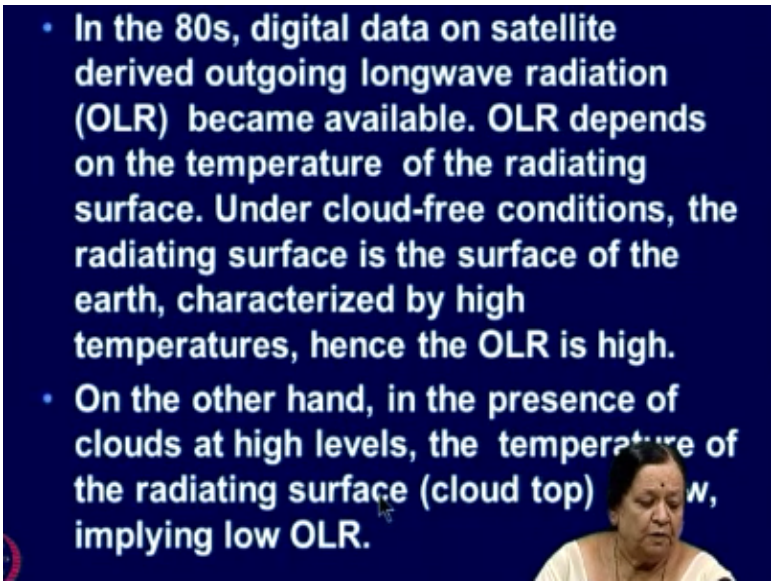

Now all this was done by looking at satellite pictures you know the kind of imagery that you saw earlier and from 80s we got digital data say otherwise it was a matter of assessment that this band is of bright cloud-bands which stretch over a large longitudinal range and so on but in the 80 s we started getting digital data and this makes a big difference because now the you can do analysis in a more objective manner.

Now what was this data on this data was an outgoing longwave radiation when I talk about the background I will talk about this but let me just mention at this point that the source of atmosphere energy for atmospheric circulation is the sun so it is the solar energy that drives atmospheric circulation so we get radiation from the sun and this radiation is shot wave radiation because the sun is very hot.

In turn the other atmosphere system emits radiation back to space that is how the balance is maintained if it was not emitting back then we would earth atmosphere system would get hotter and hotter but that does not happen so the balance is maintained and so we have the earth atmosphere system radiating back to space now the earth atmosphere system is much colder than the sun so the radiation that the earth atmosphere system emits is in the long wave.

Okay and what satellites can measure very efficiently is the outgoing longer variation, so this is the outgoing longer variation from the earth atmosphere system so now there are measurements daily measurements grid point measurements of what we call OLR or outgoing long wave radiation from the earth atmosphere system now with these digital measurements of OLR and we can reduce the regions where there are clouds.

How is that because outgoing long wave radiation depends on the temperature of the radiating surface right and so under cloud-free conditions what the surface that emits the radiation is the land or the sea which is rather hot but when there are clouds the emitting surface is the cloud top so when the cloud top is at a very high level in the atmosphere then the OLR or the outgoing long wave radiation will be much less because the temperature is much lower.

Okay so when OLR is high we do not see it we deduce that there are not any clouds but when the OLR is low we can certainly say that there is a cloud top at a very high height okay at a very high level in the atmosphere which is emitting the radiation.

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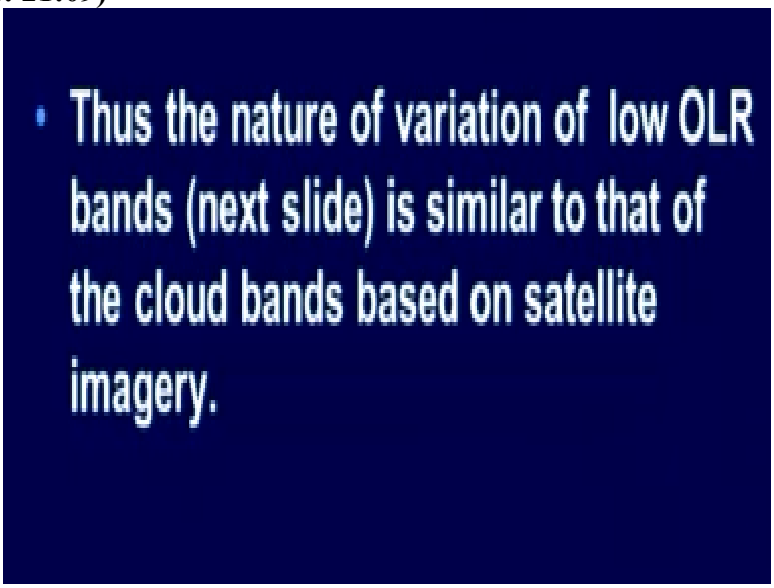

So the nature of variation of low OLR bands that is where is the outgoing long wave radiation low that is where the cloud tops are very high remember so if we now trace using the digital OLR data we can actually look at regions of low OLR and that corresponds to what we saw with the eye or in the images as cloud-bands so the regions of OLR are the regions with clouds which have tops at a very high level in the atmosphere.

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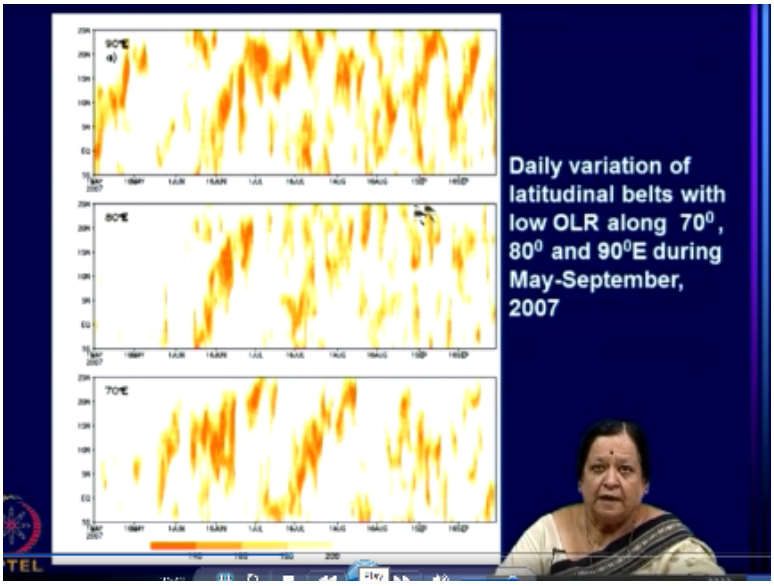

And if we analyze that data that kind of picture we get is rather similar to what we got from analysts of satellite images so this is not a surprise because after all a feature that we saw in the imagery has to be reflected also in the digital data and what you see here is for another year May to September of 2007 and what we have plotted as color is regions of low OLR again the plot is very similar we have latitude here and day here.

Okay so if this tells you that on this day the band extends from about 3 degrees north to about 10 degrees north of course now with this satellite data we are able to also go to the southern hemisphere and look at the entire equatorial belt with the imagery that we analyzed it used to be either northern hemispheric or southern hemispheric so we were restricted to the northern hemispheric imagery as soon as we got OLR data.

We could in fact include the entire equatorial region 10 north to 10 south that is what you see here and again what you see is very market feature that is the propagation the northward movement of the cloud-band of course it is a complicated feature there are other things happening but again you see here this is the onset phase use of one propagation here another here and then the third propagation here.

This is the phase when it got established then again, the equatorial oceanic band got flared up again this flared up and then another northward movement and you see again like we saw before that these northward movements are coherent across the Indian longitude that is to say what we are seeing is a band which stretches right across the Indian longitude and moves northward.

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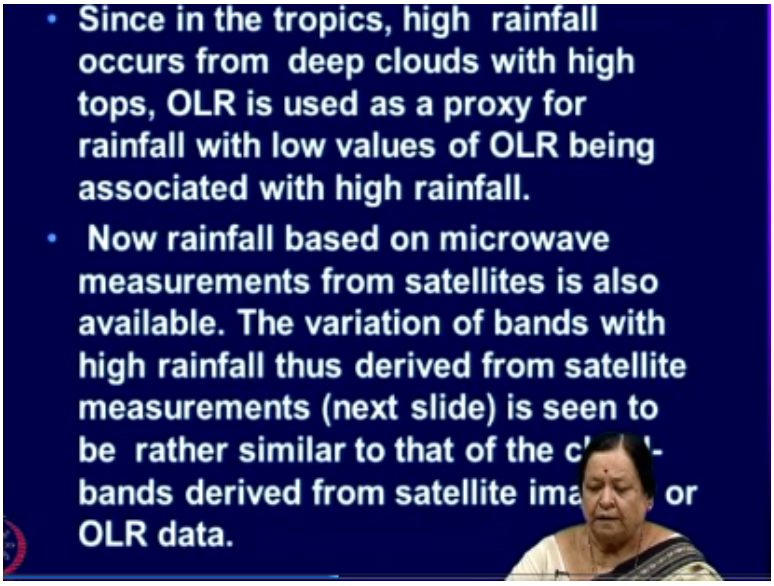

Now since in the tropics high rainfall across when deep cloud tops with high clouds with high tops OLR is used also as a proxy for rainfall in the tropics and low values of OLR are being associated with high rainfall now with the new satellites there are also direct measurements of rainfall possible these are based on microwave measurements from satellites.

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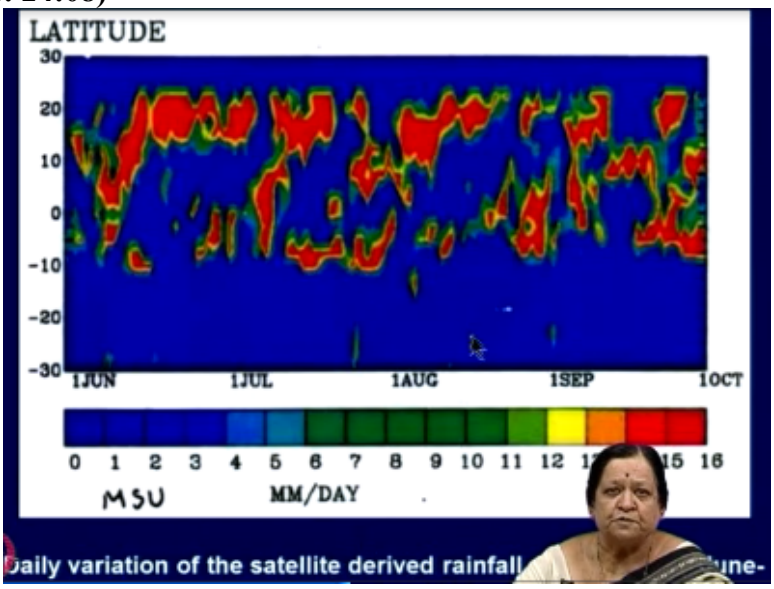

And this is actually a figure derived this is the rainfall as seen from satellites what you see instead of shading regions of low OLR now we are shading regions of high rain so rain above say 14 millimeters a day or something like that or maybe 1 centimeter a day is what is appearing as bright red there and what you see here from data of this microwave founder MSU data is very beautiful northward propagation and again the presence of too low you know oceanic band and a band to the north and very nice northward propagation are seen with rainfall data.

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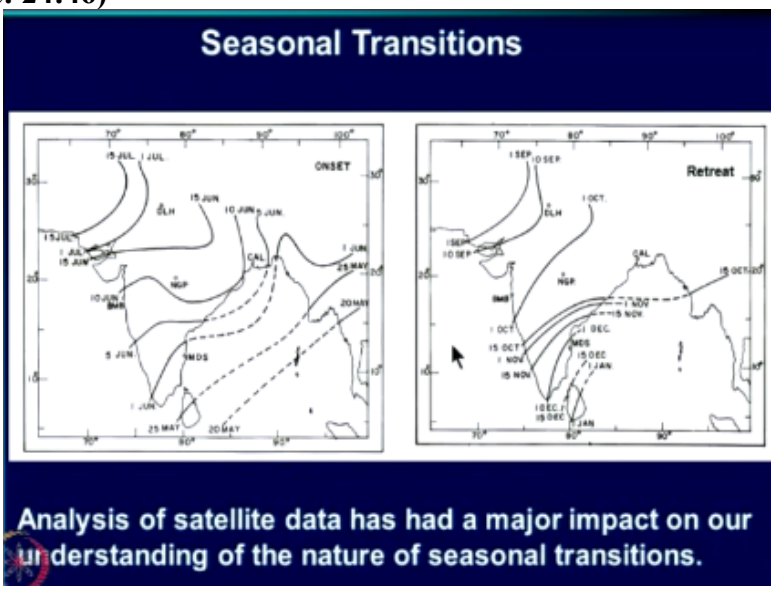

Okay so we learnt a new thing by looking at satellites that throughout the season there are these northward propagations of the cloud-band occurring right from April to October now you may recall that we had looked in the last lecture at what are what are the dates of onset of the monsoon and we have seen monsoon onset over Kerala occurs around first June and afterwards there is a northward propagation of the monsoon.

Or the advance of monsoon in the onset phase there is also an eastward progression but this is northward progression eventually leads to the establishment of the monsoon in the monsoon zone so this is the onset phase in the retreat you remember was the steps were reversed and the retreat appeared to be a southward movement that is to say the rain gets more and more restricted to the southern parts the edge of the monsoon comes southward this is the retreat of the monsoon.

Now so one would think just by looking at these maps that the system that the rain system moves northward in this case and moves southward in this case but what satellites told us was something different.

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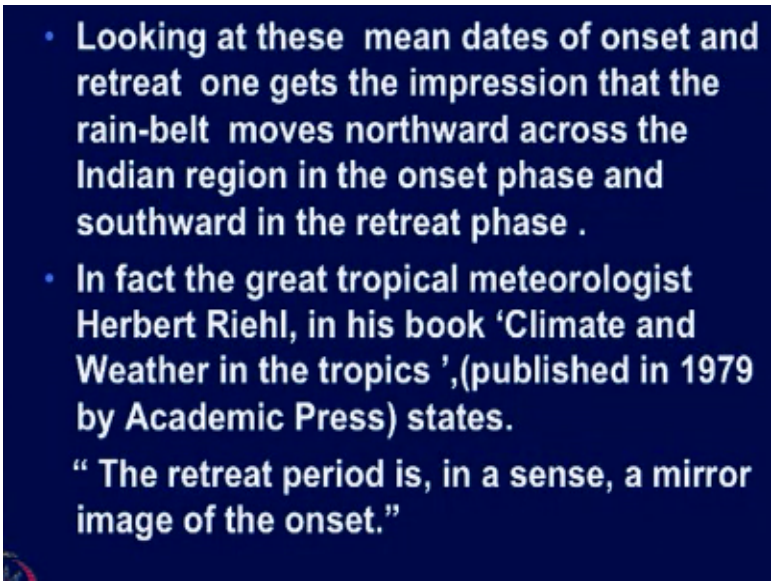

See looking at the mean dates someone said, and it did one gets the impression that that rain-belt moves northward across the Indian region in the onset phase and southward during the retreat phase in fact before people started looking at satellite pictures people thought retreat was the reverse of onset in a set and that is a book by our great tropical meteorologist by Herbert Riehl on climate and weather in the tropics.

This was in 1969, I believe all the references will be provided to you in fact what Riehl says it the retreat period is in a sense a mirror image of the onset, so they expected that the reverse of retreat will occur during onset but when we see what happens with satellite imagery.

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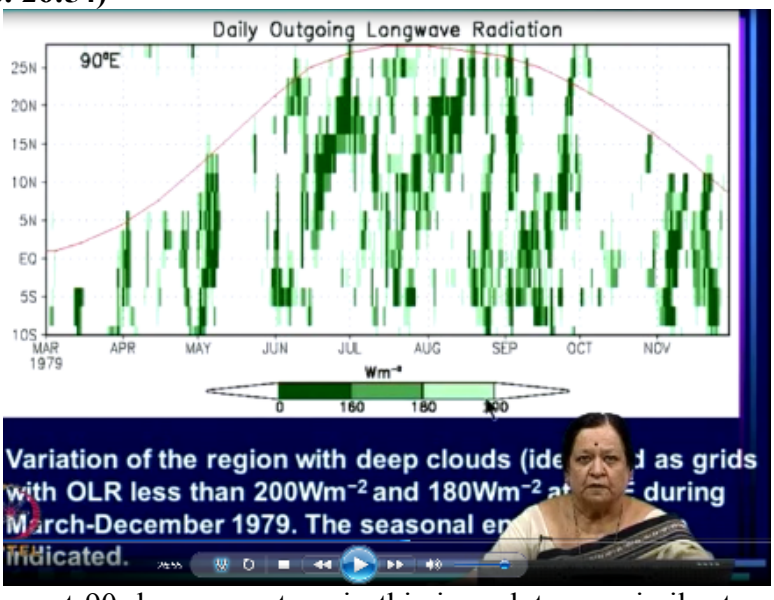

In fact, April to June at 90 degrees east again this is a plot very similar to what we have seen before shaded regions of low OLR are the regions of clouds and this goes all the way from

March to end of November and because you know last period is covered is northward propagations looks very fast but what you see and this is in fact that red line is the envelop of the propagation.

So that is where they tend to go so if you look at the envelop it goes northward and it comes southward okay but if you look at the actual cloud-bands that is a surprise certainly in the onset phase as we expected we get northward propagation and what is happening is that you have successive genesis of clouds in the equatorial region which move northward but they move further and further northward in the onset phase.

So initially it would only up to 5 north then it moved up 10 north up to Bangalore Mangalore latitude then the next northward propagation mode much further up to 20 north of Mumbai and so on and so forth, so onset phase then comprises northward propagations each successive northward propagation taking the cloud-band further and further north okay now if you thought that retreat was the mirror image of onset phase.

You would think that in during the retreat phase you would get southward propagation but that is not at all what you see in the retreat phase what you see is when the envelop is going southward the bands are not going southward again the bands are cloud-bands are being created over the equatorial Indian ocean and they are moving northward but this time they are moving to a lower and lower latitude.

That is to say the destination of the northward movement becomes more and more southward but retreat also comprises northward movement just like onset does so this was the surprising result from study of satellite imagery which we would not have anticipated.

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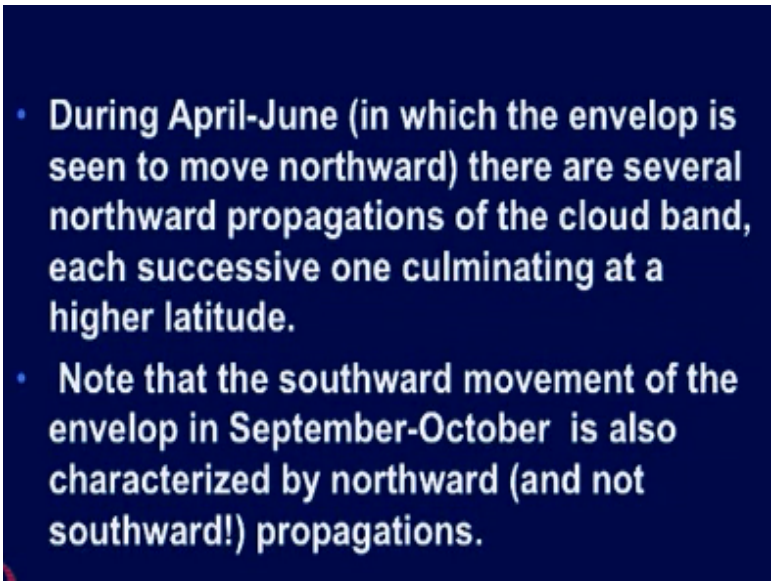

So, we said not the southward movement of the envelop in September, October is also characterized by northward and not southward propagation, so the cloud-bands have this tendency to go on propagating northward now if it is in the onset phase they will go further and further northward if it is in the retreat phase they will start going less and less northward with every successive propagation.

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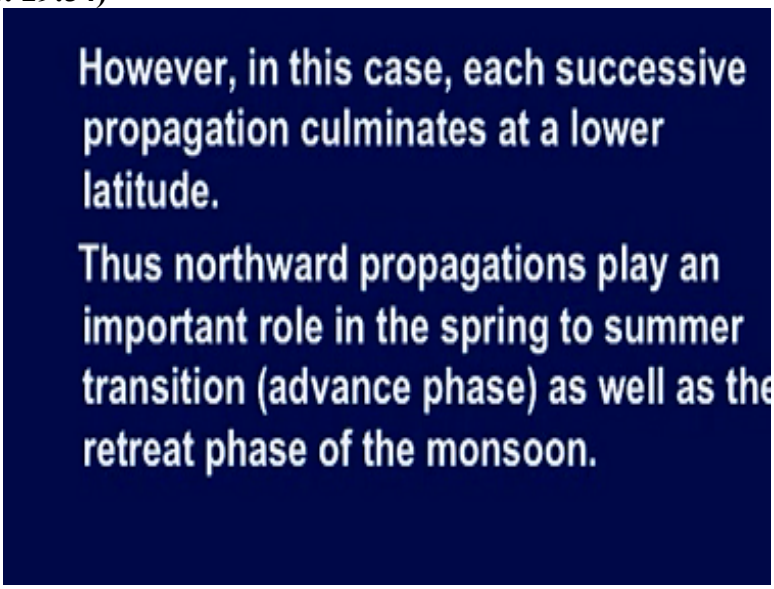

Okay so northward propagation plays an important role in both the transition in the onset phase as well as the retreat of the monsoon.

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Now let us see what else we learnt from satellites we have already been introduced to active spells and breaks which were defined on the basis of conventional observation rainfall okay now let us see what is the signature of these active and weak spells what is the structure of active and weak spells look like the rainfall pattern is the structure we saw with conventional data now what does the structure look like in a from the satellite data.

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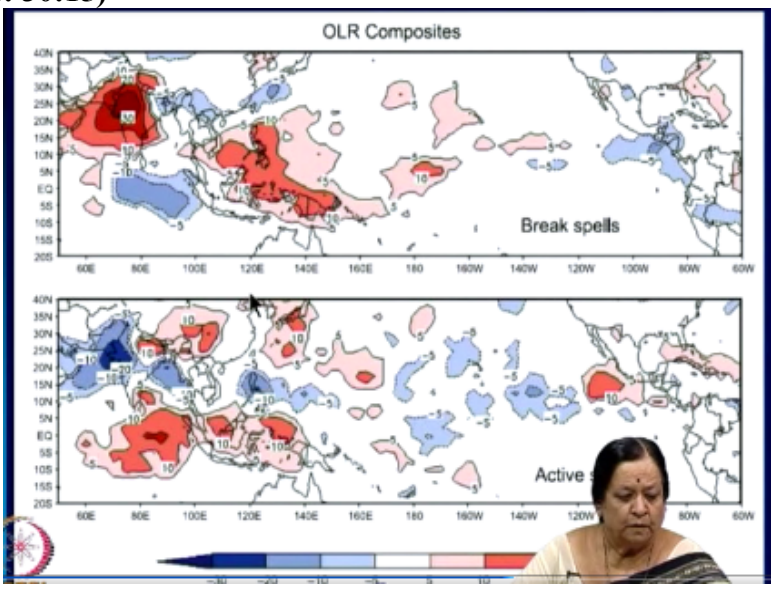

And what we see here is when we define breaks or active spells on the basis of rainfall over monsoon zone we know the dates on which they occur then what we do is take the average OLR for those days and these are the this is the composite of break spells but note what we have plotted is not the actual OLR but what we call the OLR anomaly that is to say how I OLR differs from the average.

So here for example the blues represent negative anomaly this means less than the average this means that is clouding there or rain there right negative OLR anomalies mean more rain positive OLR and anomalies mean less rain so during the break obviously you will have less rain over the Indian region that is very clear but now this satellite data allows us to see the signature of these break spells over that other parts particularly now over the equatorial Indian Ocean.

We saw that the equatorial Indian ocean played a very important role did in onset and retreat phase because that is where the cloud-bands were generated you saw cloud-bands being generated over equatorial Indian ocean moving northward now what is the equatorial Indian ocean doing during our breaks but let me turns out that the eastern part of the equatorial Indian ocean is very active lots of clouds in our break spells.

Okay and exactly the opposite occurs in our active spells, so this is the average picture OLR anomaly for break spells and this is the average picture for an active spells and what you see here is that naturally in the break spells convection that is to say clouding is suppressed over the Indian region at that time convection flares up over the eastern equatorial Indian ocean and that means there is more rainfall.

Than average over the eastern equatorial Indian ocean during the break phases you also see a signature here of the break phase and this is also been popularly called a quadrupole we will come to that when we discuss breaks in detail but you see that this part of the West Pacific also has a break that is to say suppression of convection of rainfall and to the north is a region where there is more rainfall and more clouding.

So this is the signature of breaks over the Indian region you will also see some signature over the East Pacific now you see exactly the opposite happening in active spells but in active spells you see that the active spell is rather coherent and stretching across right from the Indian region to the West Pacific so you have an active spell which is stretching across here and in a way you can say break spell is stretching across here too.

So, the signature of active and break spells from satellite data tells us that perhaps this Eastern Equatorial Indian ocean is playing some role in the variation of rainfall we observe over the Indian region during the monsoon between active and weak spells.

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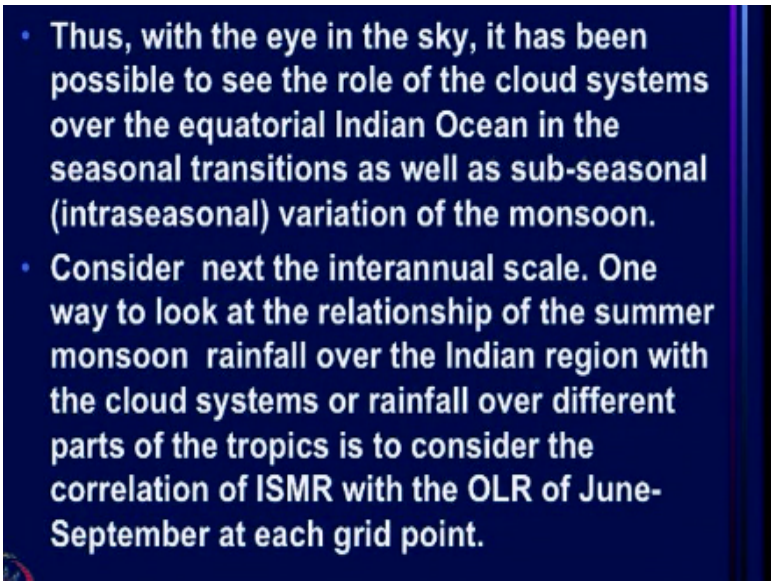

So, with the eye in the sky what have we found we have found that the cloud systems over the equatorial Indian ocean play a very important role in seasonal transition as well as the intra-seasonal variation that is the variation between active spells and weak spells and also a new feature of intra-seasonal variation has been found by looking at the satellite imagery series of northward propagations that occur throughout the monsoon season.

Now can we get any hint of what is the signature of droughts and excess monsoon season on this and this from the satellite data can we get any hint of what is the signature over the rest of the tropics of a monsoon drought or a monsoon excess rainfall season so there is so far we have been looking at composites we looked at the OLR or OLR at anomaly corresponding to a break this was average over all break days.

Similarly, we looked at OLR anomaly corresponding to an active spell this is the OLR anomaly average over all the active days.

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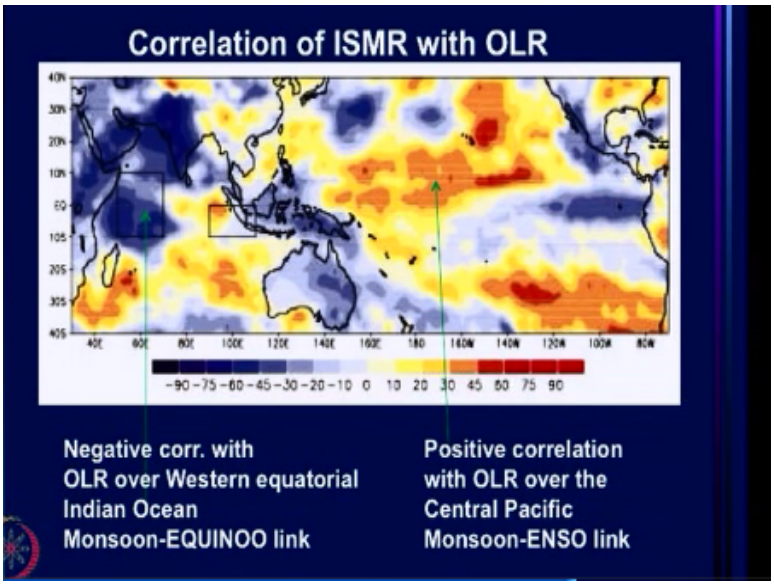

There is another way to look at the signature of a relationship and that is to compute the correlation of the quantity you are interested in with the OLR over the entire region let me explain you remember we looked at all-India monsoon rainfall India summer monsoon rainfall we called it as ISMR that is the one from which we detected droughts of the Indian monsoon and excess monsoon rainfall season.

Now this ISMR is s time series right we had the values right from 1876 to the present and in the earliest in the first lecture I have shown you how this Indian monsoon rainfall varies from year to year so ISMR varies from year to year and you may remember that the standard deviation is only 10% of the mean and when the magnitude of the ISMR anomaly is larger than the standard deviation.

We have the extremes which are it is a deficit then it is a drought and if it is a positive anomaly then it is an excess monsoon season so we have a whole time series of ISMR and we want to ask the question how is the variation of ISMR under monsoon rainfall related to events over different regions okay events such as the mean rainfall over the equatorial Indian ocean so on and so forth so the way to do it is that you have one-time series which is the rainfall ISMR.

With that you co relate the time series of each and every grid for which you have from satellite now we have OLR data which is daily from which we can get June to September average OLR for each year so what do we have we have a time series for every grid point of variation of June to September average OLR we also have a times series of June to September Ireland all-India rainfall which is ISMR.

Now given those two times series we can correlate them and derive the correlation coefficient now when the correlation coefficient is positive that means the series tend to go together when I say anomalies positive this and anomaly will also tend to be positive and so on then it is negative that means the series is at an opposite phase and we have to make sure every time that the correlation coefficient that you get is not really a figment of your imagination.

But it is statistically significant that also we will look at another way we look at signatures of events we are interested in are links between variation of quantity such as ISMR and the convection and rainfall over that tropics is by completing the correlation and what you see now is a map of the correlation blue regions are regions where correlation of ISMR amount of OLR is negative why negative because when OLR is negative that is when you get rain okay.

So, if you are calculating the rainfall you would see the blues as positive in other words then rainfall over the Indian region seems to be positively correlated to rainfall over the western equatorial Indian ocean see when this is blue this is blue okay it is negatively correlated to the rainfall over the eastern Indian ocean.

So, you have correlation between ice in my saying rainfall over India is positively correlated with rainfall over western equatorial ocean that is negatively correlated with the OLR over this region right because the OLR and rainfall are themselves negatively correlated right negative OLR anomaly corresponds to positive rainfall anomaly. So, we have a link between the western equatorial Indian ocean rainfall and the Indian rainfall ISMR.

Such that this is above normal this is tending this will also tend to be above normal when this is below normal this will tend to be below normal so this is what same sign of correlation with OLR reflects now if you go to this side you see that signature is opposite that is to say if you get rainfall here it is not it is heavy rainfall here is associated with below normal rainfall here and heavy rainfall here is associated with heavy rainfall here so you get a positive correlation between rainfall over western equatorial Indian ocean and over the Indian region.

And negative correlation between rainfall over central pacific and Indian region this is actually a region where it has been studied extensively this is a site of one of the most energetic phenomena in the tropics the El Nino and southern oscillation okay this is something about which we will talk in fact there will be at least two lectures on this event this is the most active phenomena in

the tropics and it also happens to be the best understood phenomena in the tropics.

The physics of which is now has been elucidated and which models are able to also predict and simulate so this is the El Nino southern oscillation and what you see here is the link between El Nino southern oscillation and the monsoon these are opposite in phase rain here and rain there are opposite in phase whereas rain here and rain here are in phase so that this is the link with what is happening over equatorial Indian ocean.

Now this mode this seesaw between the east and west when it rains more yet it rains less here when it rains more over the east it rains less over the west when it rains more over the west it rains less over the east there would be this seesaw between then over the equatorial in Indian ocean is called EQUINOO and these two modes ENSO and EQUINOO actually play a very important role in the inter annual variation or year to year variation of Indian summer monsoon rainfall.

So, with satellites then we are also able to see what we call tele connections that is to save connection with far of events connection of the monsoon within so connection of the monsoon with event over the equatorial Indian ocean which is nearer of course and these tele connections become evident when we look at satellite data.

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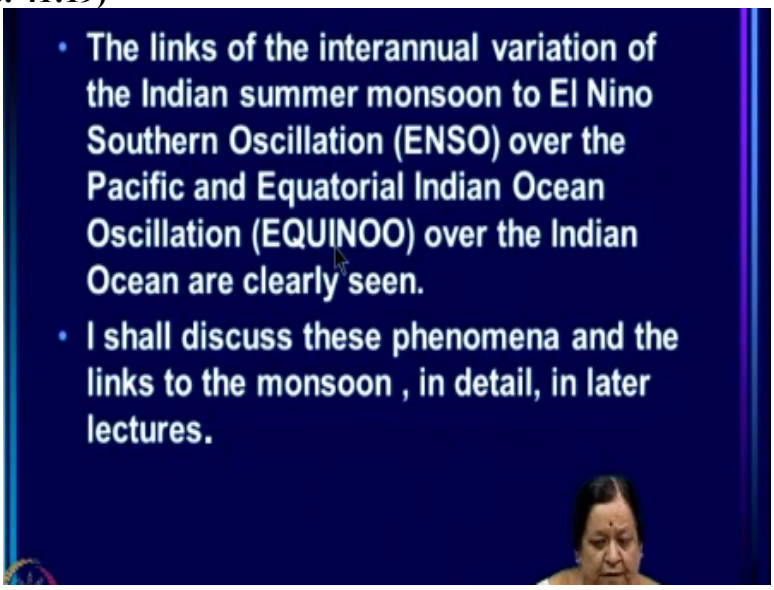

So, the links of the inter annual variation of the summer monsoon to ENSO over the Pacific and it is EQUINOO over the Indian ocean are clearly seen now in fact as I said these phenomena will be discussed in detail in later lectures and because there are very important events very important

phenomena in the tropics.

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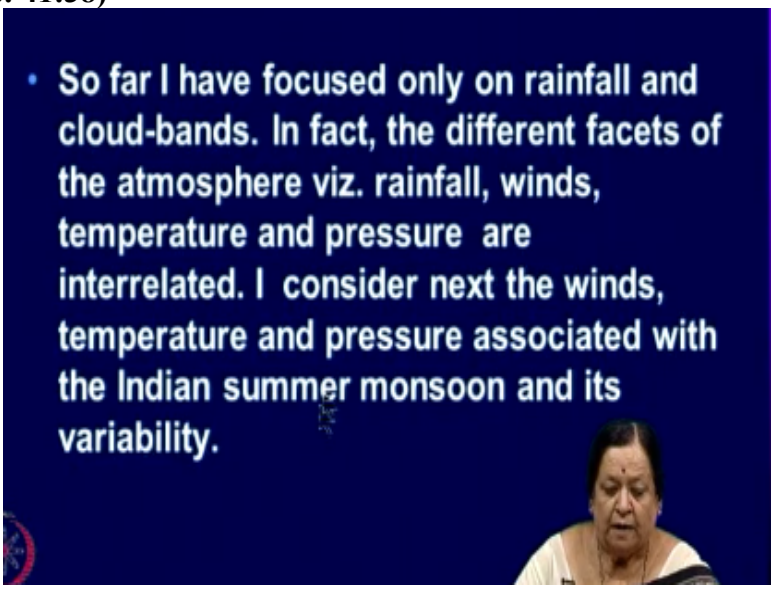

Now so far, I have focused only on rainfall and cloud-bands right and why did I do that because I said to people like us who are living in the monsoonal regions of the world what really concerns us is the seasonality of rainfall and not so much seasonality of winds which was the basis for the Arabs definition of monsoon or monsoonal regions of the world so that is why I first focused on rainfall.

And we looked at what is the mean rainfall like and how does that involve vary with season and we also looked at different patterns of variability how does a how do the transitions occur the onset phase the retreat phase and fluctuations within the season now all this we looked at on the basis of rainfall because that is where the emphasis has to be in understanding and prediction but you know rainfall is one facet of the atmosphere.

The other important limit elements are temperature pressure winds and there are interlinked so one cannot say that I am interested only in rainfall therefore I will only look at rainfall if you want to understand the system you have to look at the entire atmospheric system and only then you can understand the physics and model it so we have to also look at winds temperature pressure.

How do they vary and what are the linkages between rainfall and winds rainfall of temperature pressure and so on so this is what we will consider next?

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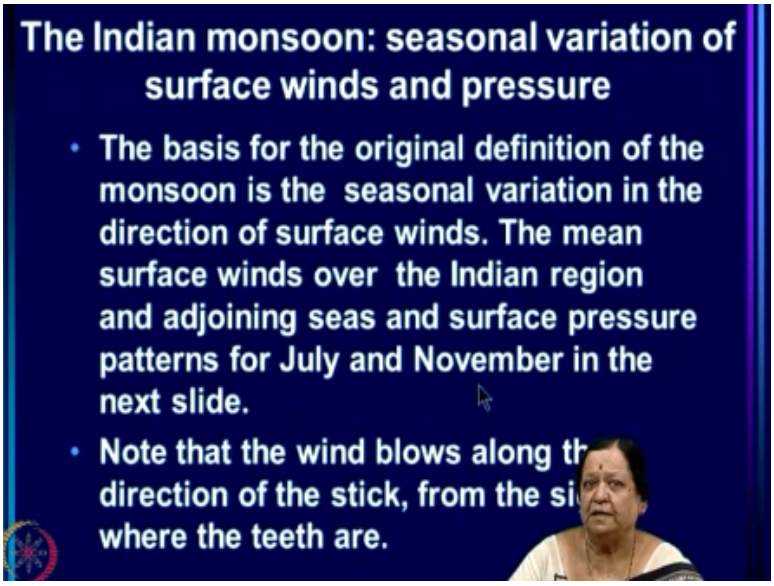

And so, let us now look at the Indian monsoon which is the seasonal variation of surface winds and pressure because see the basis for the original definition of the monsoon is the seasonal variation in the direction of surface winds that is how monsoonal regions of the world were defined initially now the mean surface winds over the Indian region and the adjoining seas.

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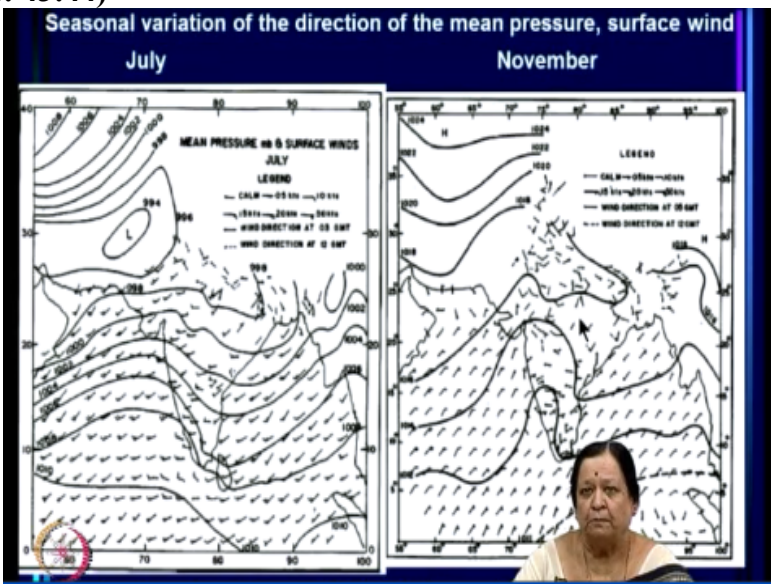

For July and November, we have seen here now this is a typical weather map they say but this is not a weather map this is a mean picture but this is the way meteorologist produce maps and it is a good idea to know what this map is representing in fact these arrows indicate the direction in which the wind is blowing so here you can see the wind is blowing from the southwest to the northeast.

Okay so the arrows indicate the direction of the wind and the number of teeth on the arrows I

must also mention that imagine if you wish when you see an arrow like this that you are holding an umbrella here and this is the tip of the umbrella so the wind blows from the handle to the tip and how strong the wind is determined by how many teeth are drawn on the handle okay so for example these are very very weak winds.

And we will see pictures later on of much stronger winds as well so what you see here basically is that the direction of the wind reverses now here it is blowing from southwest here it is blowing from north east and this you see this is the seasonal reversal of winds that our Arab sailors were concerned about this seasonal reversal of winds is it really the basis of the definition of monsoon the original traditional definition of monsoon.

And it is because these rains are from the southwest during our summer monsoon which is July July represents our summer monsoon because the winds are from the southwest in our summer monsoon this is called the southwest monsoon season not is that in the not in the November in the month of November, October, November, December is what we call the post-monsoon season November is representative of that you see that the winds have completely reversed direction.

It is now blowing from northeast to southwest initially it was blowing from southwest to north east now it is blowing from northeast to southwest, so this is a seasonal reversal in the direction of wind which was considered to be a very important feature of the monsoon now as I said we have been taught in school and these are words still unfortunately this terminology is still used even by meteorologists.

They call the summer monsoon June to September as southwest monsoon because the winds are from the southwest they call October, November, December as northeast monsoon so and because the winds are from the northeast.

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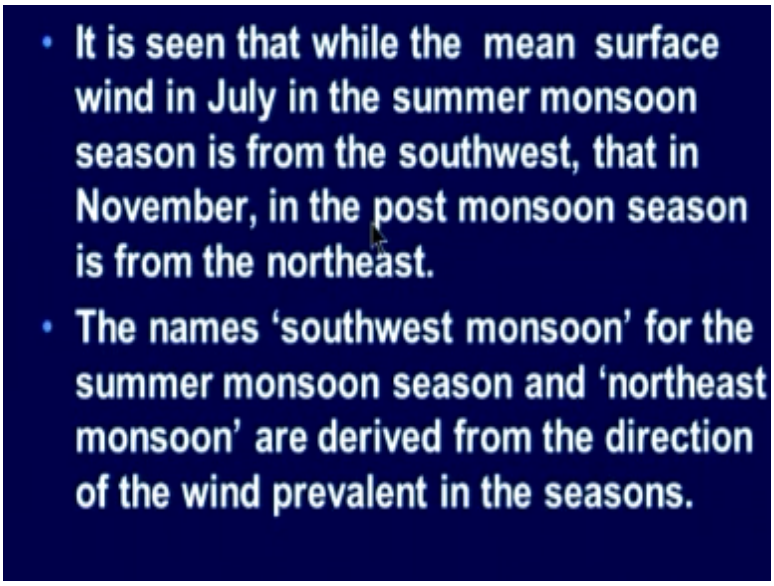

Now as we so you know while the mean summer rain in July in the summer monsoon season is from the south west the mean surface wind in November which is represented in post-monsoon season is from the northeast and the name southwest monsoon for the summer monsoon season and north east monsoon for the what we call the post-intra-monsoon season are derived from the direction of the wind prevalent in the seasons.

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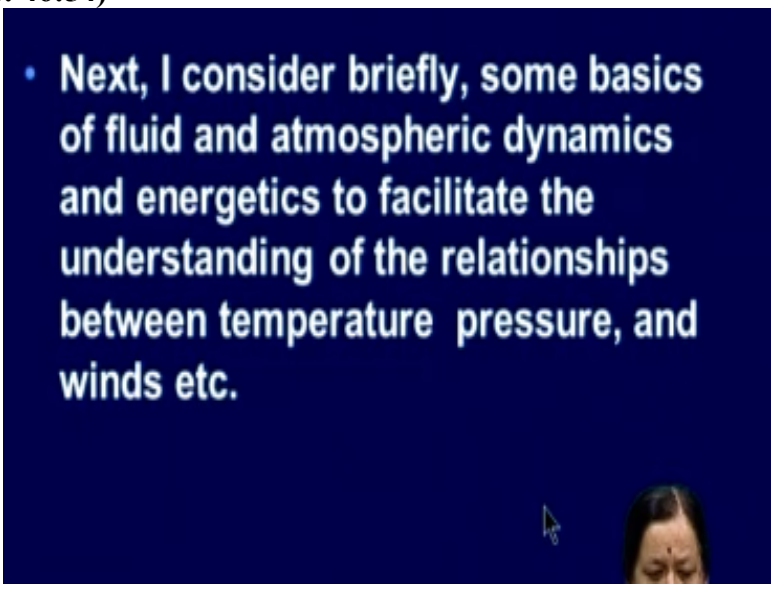

Now and when I talk to you about the basic system which is responsible for the monsoon and then you will realize that these are in fact misnomers.

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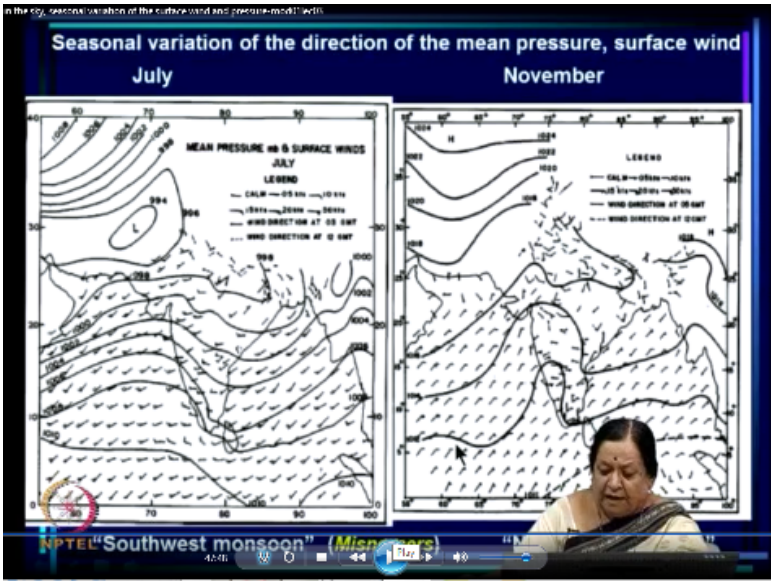

And they are also they are highly misleading because to a layperson when you call this the southwest monsoon and you see that the wind is coming from the south west they imagine that this means that the clouds that give us rain all comes from the southwest in this season. And they all come from the northeast in this season this is not something that it explicitly taught but this is an impression people have because of the names we use for the season.

Southwest and northeast okay but it turns out that is a highly misleading and are in fact misnomers and therefore we should actually formally abandon them but right now I do not think I will expound on why and where for that explanation will come only. When I explain what is the basic system see somehow when you say the system comes from here in the system comes from here the idea maybe that actually the basic system responsible may also be different.

And it may here it may be originated in the north and here it may originate from the south and so on now it turns out that that is another misunderstanding that it generated only because we insist on names which were originally generated by sailors. Because sailors what they care about is that actually the direction of the winds, so this is why I think we should stop using these words and actually now consider what is the monsoon system like.

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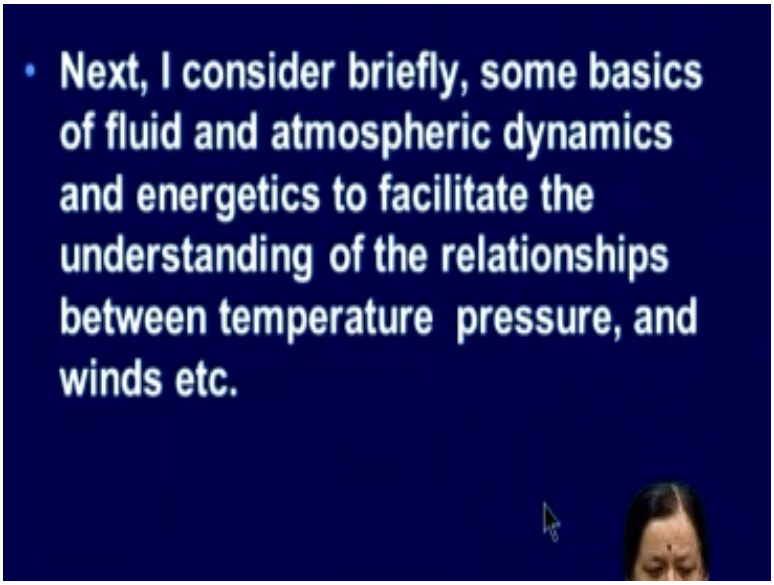

We have seen already what is the monsoon system is like in terms of rainfall now we have also seen that monsoon system another important characteristic is seasonal reversal of the direction of surface winds now we have to see that for the atmosphere over India as a whole what are the characteristics of the monsoon system so we have to look at the temperature pressure winds and so on only then be they will be able to unravel the dynamics of the system.

That gives us our monsoon rainfall so in the next lecture then what they will do is actually build up the background necessary for us to understand you know how the winds temperature pressure and so on are inter related and there by then I can talk about what is the basic system that gives us rainfall in the tropics as a whole and what is the basic system that gives us rainfall during our monsoon season.

What is the system that visits us which we call the monsoon? So that is what, I will start with in my next lecture. Thank you.