The Monsoon and Its Variability
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Lecture - 25
El Nino Southern Oscillation (ENSO) Part 2

So I will continue today with discussion of El Nino Southern Oscillation that is ENSO.

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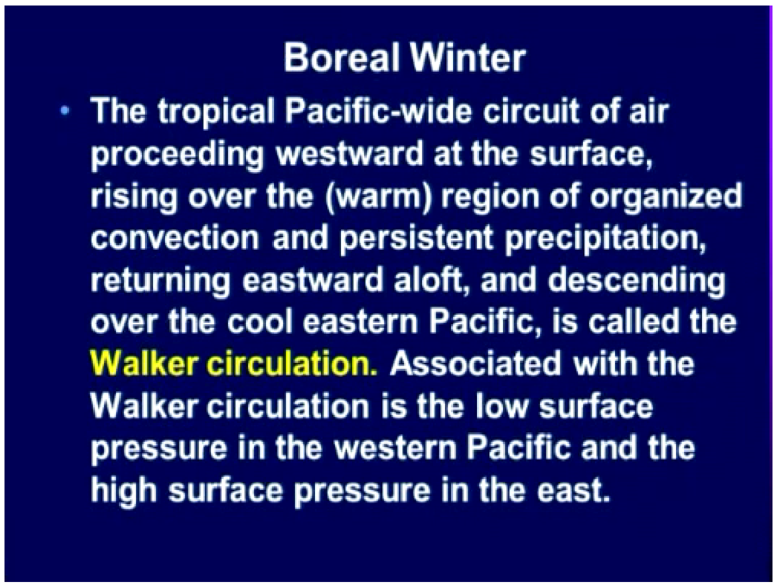

Now just to remind you we did look at the Boreal Winter that is to say December, January, February in the last lecture. And what we showed was that there is a tropical Pacific-wide circuit of air proceeding westward at the surface, rising over the warm region of organized convection and persistent precipitation, over the west pacific. Returning westward at higher levels and descending over the cool eastern pacific, and this is what is called the Walker circulation.

And associated with the Walker circulation is the low surface pressure in the western Pacific and the high surface pressure in the east. So this is what we saw.

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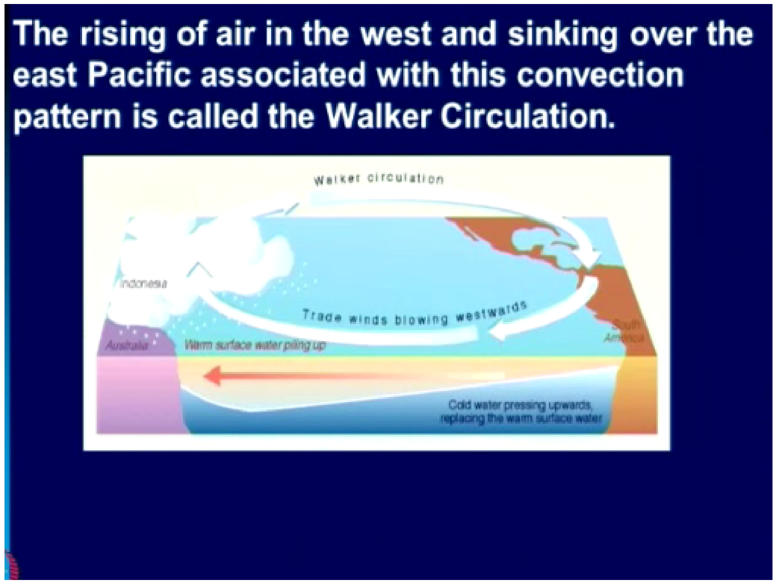

The Boreal winter circulation, boreal winder circulation that is December, January, February circulation, in fact involves rising of air over the west Pacific and sinking of air, over the east Pacific and this can viewed as a east-west circulation which is called the Walker circulation.

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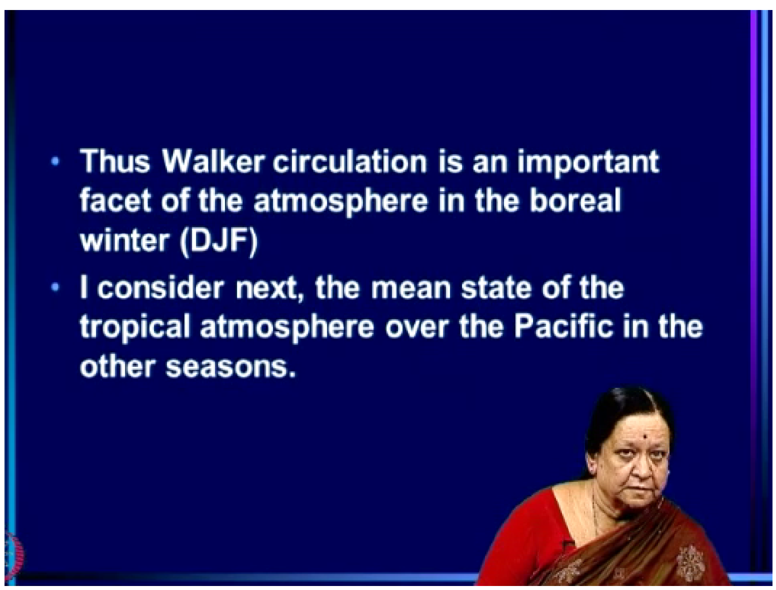

Now, so Walker circulation is an important facet of the atmosphere in the boreal winter. Now let us consider the mean state of the tropical atmosphere over the Pacific in the other seasons.

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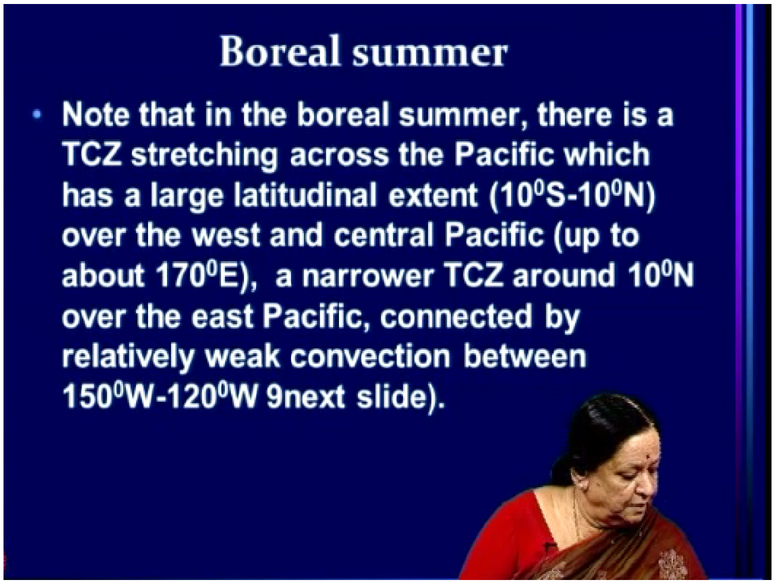

So consider Boreal summer which is June, July, August.

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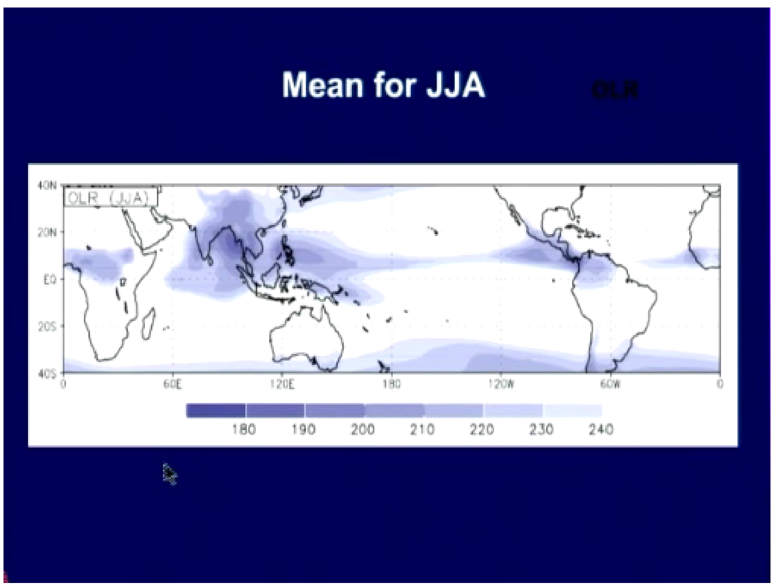

And if we look at the OLR pattern for June, July, August then what you see is that there is a TCZ stretching across the Pacific which has a large latitudinal extent over the West and Central Pacific up to about 170, a narrower TCZ around 10 north over east Pacific, connected by relatively weak convention between 150 west and 120 east. So if we look at mean June, July, August precipitation there is deep convection here.

And you can see that it is continuous the belt is continuous from the Indian region. And then there is also a zone of low OLR consider by lateral extent, latitudinal extent just off the coast of this Central America and in between here from about 150 West to 120 West is a much, much weaker and a thinner tropical conversion zone, but it is very much there, we do have OLR below 240 there.

So there is a bend of low OLR stretching across the Pacific all the way here but here the latitudinal extent is very large and here also it is substantive.

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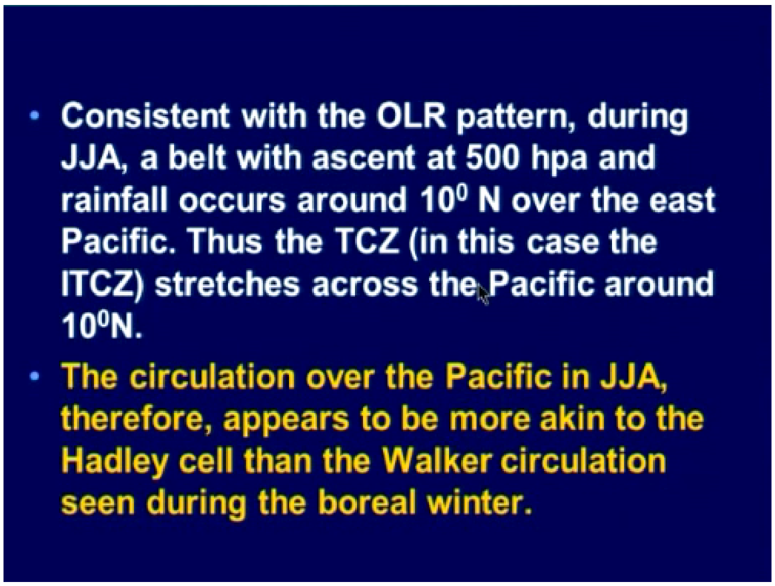

So consistent with the OLR patter during June, July, August a belt with ascent at 500 hpa and rainfall occurs around 10 degrees north over East-Pacific. Thus the TCZ in this case stretches across the Pacific at 10 north.

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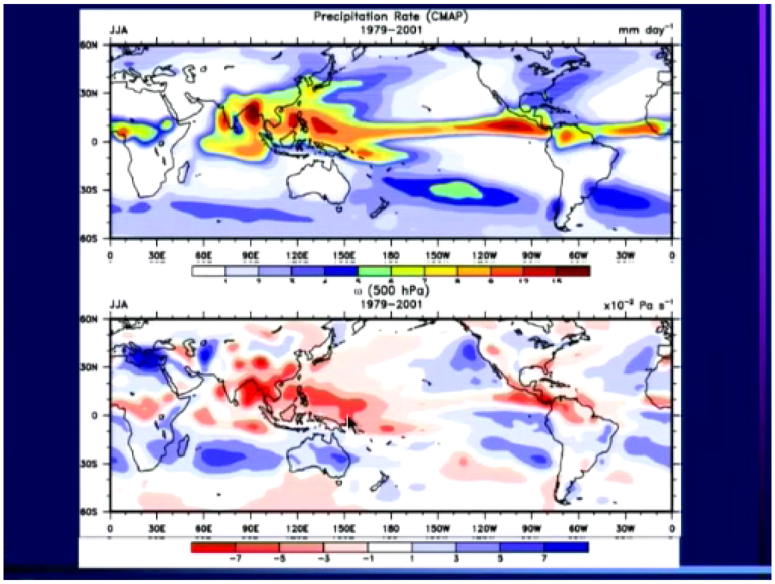

So now this is the precipitation rate for June, July, August and again you see heavy precipitation, this is our monsoon season, heavy precipitation over Indian region but now we are concerned more with the Pacific so there is very, very heavy precipitation over West-Pacific. There is reasonably heavy precipitation over this part of East-Pacific but in between it is somewhat less. This is over the reason where the OLR was also slightly higher but still below 240.

Now, in fact the precipitation date and the ascent velocity of ascent at 500 (()) (04:18) is very comparable as we expect and we see that there is very weak ascent over this intermediate region reasonably strong ascent over this region and very strong ascent over this part.

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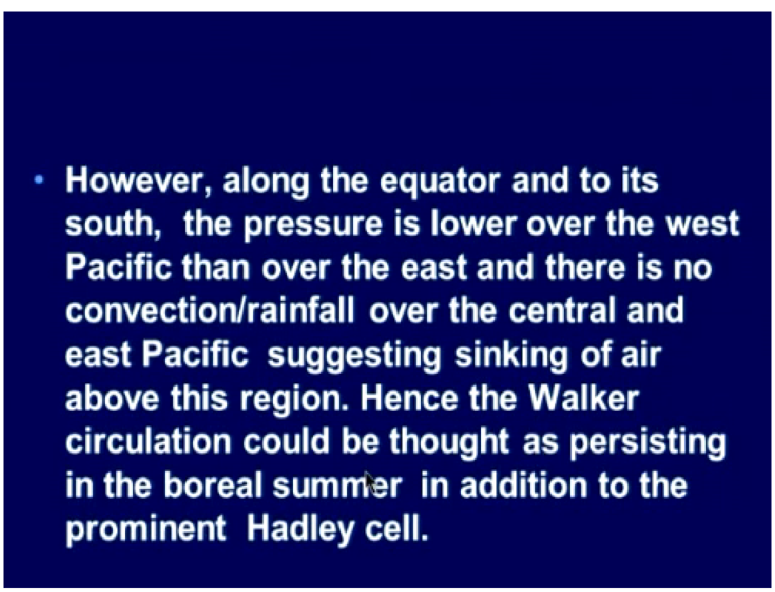

So however, along the equator and to its south, the pressure is lower over the West-Pacific than over the east and there is no convection or rainfall over the Central and East-Pacific suggesting sinking of air above this region.

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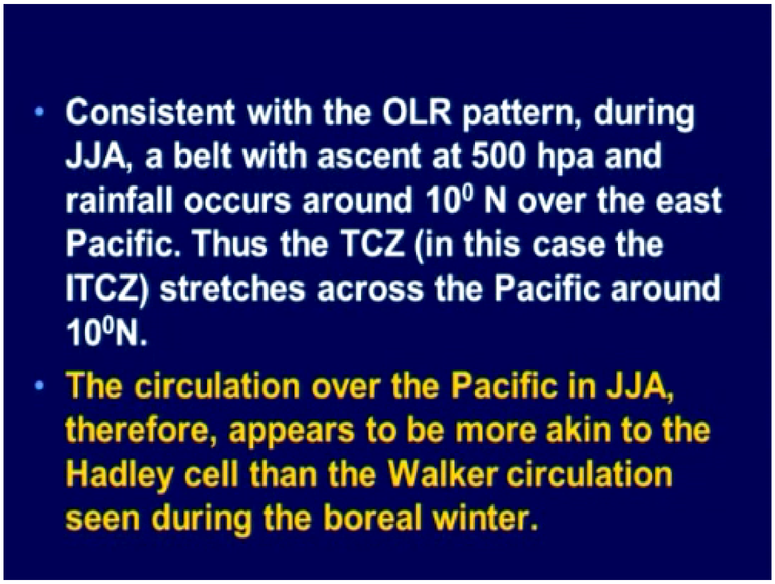

Okay. So consistent with the OLR pattern, during JJA, we have this belt around 10 degree north and the tropical convergence so in this case it stretching right across the Pacific. So when we look at the OLR or the precipitation so on, we would think that this is much more like the Hadley cell, so you have ascent at this latitude and decent everywhere else.

So this much more like the Hadley cell circulation we saw where within a small latitudinal belt you have strong ascent and convection in rain and over the rest of the region we have sinking and so there is no ascent and this is exactly what we see in the precipitation also. And you see it very clearly here that you have an ascending zone and it is surrounded by descending zone here and here. So this could be thought of as a north-south cell okay or what we called a Hadley cell.

So the circulation over the Pacific in JJA, therefore, appears to be more akin to the Hadley cell than the Walker circulation seen during the boreal winter. Because, of course you have ascent here and descent here, but if we look belt we have ascent here and decent in both these places. So it does look more like a Hadley cell. However, along the equator and its south—see if you look at along the equator and its south then indeed the west is convicting; west has rain.

And east does not have west has ascent east does not have, so one can think of having a Walker circulation also in addition to the Hadley cell. So along the equator and to its south, the pressure is lower over the west Pacific than over the east and there is no convection or rainfall over Central and East-Pacific suggesting sinking of air above this region which we have seen. See there is definitely sinking of air all around here. This whole region has sinking of air.

Hence, Walker circulation could be thought of as persisting in the boreal summer in addition to the Hadley cell. So we think of the Hadley cell in which ascent is occurring here and descent is occurring in the surrounding region and Walkers cell, in which we have strong ascent here and decent here. So it is a combination of both of them. But mostly in literature it is only the Walker circulation which is emphasized as far as Pacific is concerned.

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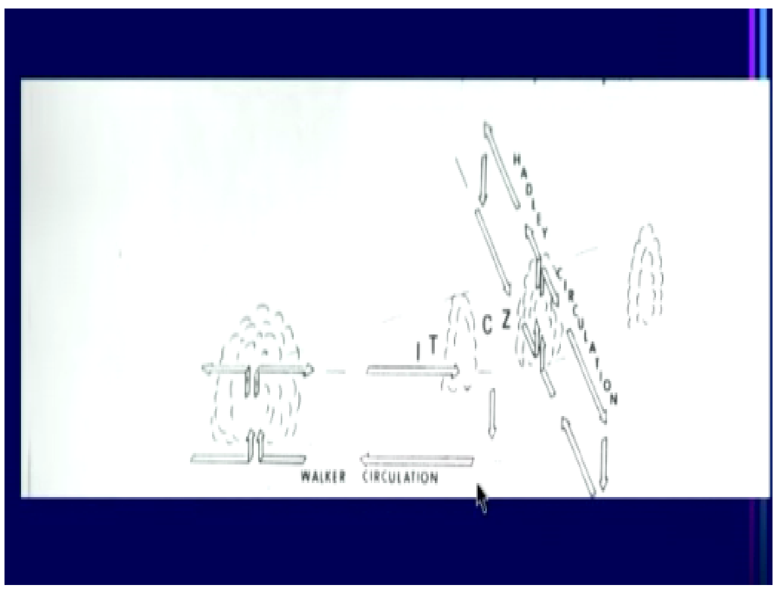

So what we have here is a picture like this. This is the ITCZ and on the one hand there is this East-West circulation which is the Walker circulation and on the other hand you have a Hadley circulation which is a North-South kind of cell and what it is, is a combination of both of them over the East-Pacific.

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Now let us consider the Seasonal Cycle, because we have so far looked at only what happens in the winter and summer of the northern hemisphere or the boreal winter and boreal summer. So let us see now how the seasonal evolution takes place and that we will do by looking at Monthly OLR pattern.

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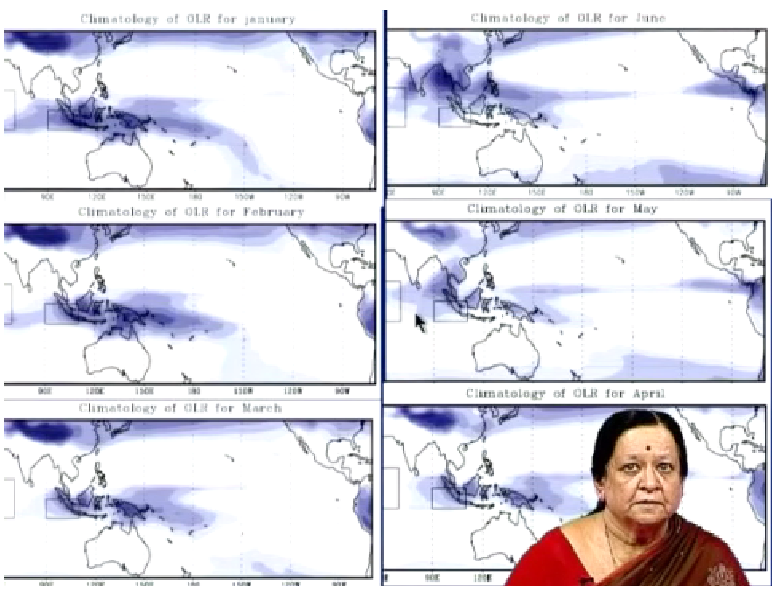

So this is a snapshot of 6 mean monthly OLR patterns goes from January here February, March and then April, May and June okay. Now one thing important to see is that around the West-Pacific the picture looks sort of similar in all the months, okay. There is variation of a certain kind which I will point out, but basically you have convection over the west Pacific. Now as far as January, February, March is concerned that is all there is to it.

In the tropics, the convection is by enlarge redistricted to west of the dateline. There is no convection in the equatorial or tropical regions at all on the eastern side. So this is true for January, February and March. The low OLR region is restricted to this part of the tropical Pacific over this part of the tropical Pacific, what we could call West and Central Pacific. And there is absolutely no region of low OLR over this part here.

So this is a very important future and this is what was described if the circulation associated with this kind of convection was described as Walker circulation with rising here and sinking here. But see what happens from April onwards. From April onwards, you begin to see a nice zonal band and East-West band of low OLR right here. It is there in April and note that in between here it is slightly weaker than at the other to extremes.

Of course in April it kinds of ends here but by may it has (()) (10:08) of the coast of the America's, so you have 2 relatively strong convection parts join if you wish by a relatively weak convicting part but this is a single band on this monthly scale stretching right across the Pacific, it is a TCZ or an ITCZ in this case because the convergences which is associated with this is indeed in the tropical. So we have an ITCZ here.

Notice also in addition to that, we have a what we call SPCZ- South Pacific Conversion Zone which is an additional conversion zone which we see right from January, in fact it is very strong in January, February, March it begins to become weaker from April and actually then May and June, it actually become much less weak much more weak compare to.

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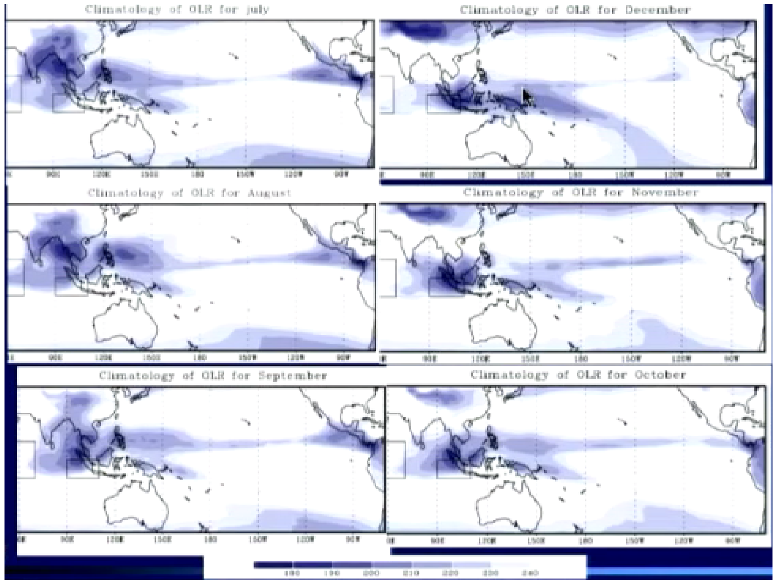

Okay so now we have we have seen here what happens up to May and in May already use see onset is occurred over part of the bay and this region is getting the cloud band here is moving to the north here and here we see a well developed ITCZ. Now what happens in June, we have this is June, this is July, August and September and July, August and September mean monsoon months.

And what you see here is actually the tropical conversion zone very, very prominent and West-Pacific is also very intense, this part is also reasonably intense, SPCZ is weaker. And you see of course a lot of convection, this is our monsoon. So the west has moved all the way to go over the Indian region here by July, August. But this one remains pretty much in the same place and September also.

Then October still its persisting but now its weaker and our Indian region now things have come to the south November now this is a bit like April where the band does not quite reach America's and by December this is beginning to evaporate; this is beginning to go away; by January this whole convection will disappear.

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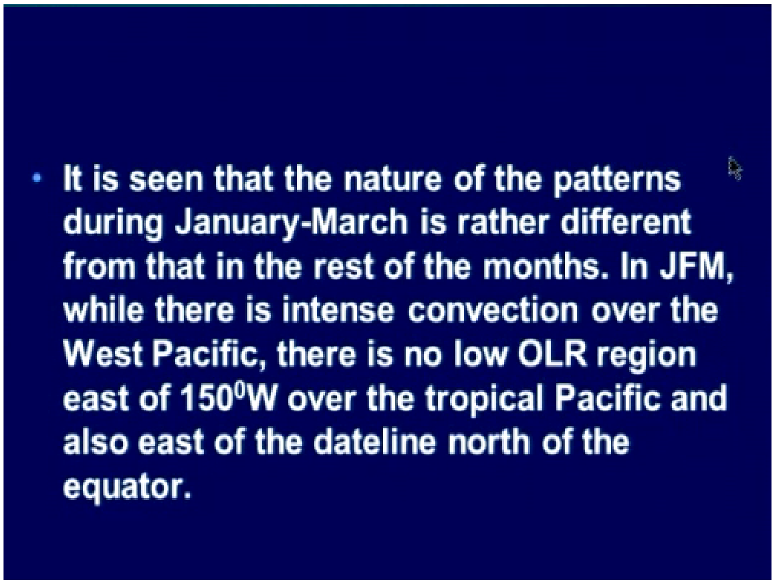

So in the nature of the pattern during January to March is rather different from that in the rest of the month. In January, February, March while there is intense convection over the West-Pacific there is no low OLR region east of 150 west over the tropical specific, this is what we saw here that there is absolutely no convection east of 150, east of this region. There is no convection in the tropical belt at all in January, February, March.

And also east of the dateline north of the equator, so the convection is not there over the eastern part.

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Thus for JFM, the prominent feature is the East-West asymmetry in convection and the Walker circulation is a large part of the story. So you can see here that for January, February, March large part of the story is that air is rising here, and air is sinking here. And we could conceive as a cell east west cell which is ascent here and there s decent here. So for the boreal winter which is January, February, March the east west is asymmetry in convection and Walker circulation is a large part of the story.

However, in the other months, the prominent feature of the OLR over the region east of the dateline is the zonal band of low OLR stretching across the Pacific around 5 degrees north associated with the ITCZ. Thus, in these months, the east west asymmetry is restricted to the equator and south tropical Pacific and this is what we have seen here that in these months, see if you look at this one then we can say that the air is rising here.

But really it is sinking only over this part and over this part particularly when we go to the pick monsoon month, July and August you see that the air is rising over this entire band and this looks like it is a north south circulation. This is an important point which is often not emphasized in the literature. Okay. So in other months, the prominent feature of OLR over the region east of the dateline is the zonal band of low OLR stretching across the Pacific around 5 degrees north associated with the ITCZ.

Thus, in these months, the east west asymmetry is restricted to the equator and southern tropical Pacific is the way you could put it. Now of course it is important when you say we want to understand the seasonal variation of tropical convection over the Pacific, what we would like to know is why is there no convection over this part in January, February, March, how does it appear there in April, what decides on this kind of seasonal variation across the from month to month. So this is what we would like to understand. Now how do we understand this?

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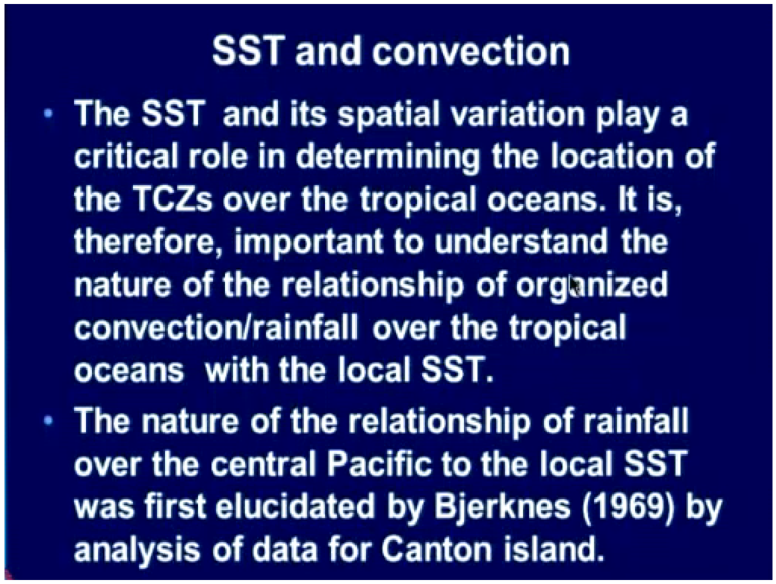

See we will begin to understand it by looking at the sea surface temperature patterns, why is that? Because, the SST and its spatial variation play a critical role in determining the location of the TCZ over the tropical oceans. Okay. See the key factor which determines where the convection where the low OLR region will be, the key factor is SST is spatial variation. Now it is therefore important to understand the nature of the relationship of organized convection or rainfall over the tropical oceans with the local assistance.

And we have touched on this problem before but I would like to mention here that in fact this the nature of the relationship of rainfall over the Central Pacific to the local SST was first elucidated by Bjerknes in 69' by analysis of data for Canton Island. This paper of Bjerknes one or 2 papers he wrote which have turned out to have enormous impact on our understanding of so and so. It is interesting that in this paper he addressed the question of the relationship of rainfall over Canton Island to the sea surface temperature.

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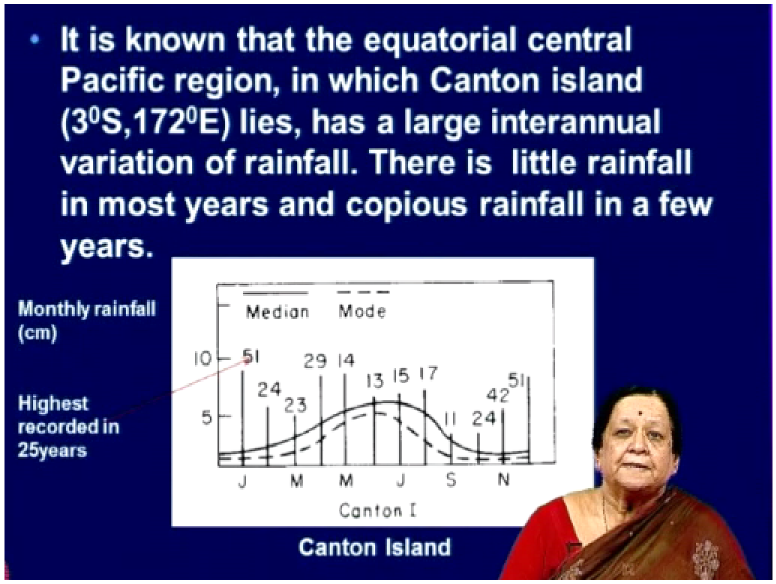

Now the Central Pacific region to which Canton Island belongs, it is also considered part of the line islands there are about 6 or 7-line Island and line Island precipitation data is also available and has been analyzed. So Canton Island is one of those Island in the Central Pacific, you can see its at 172 east and 3 degrees south very close to the equator and these places these stations Island stations have enormous amount of interannual variation.

That is in most of the years there is very little rainfall and then suddenly in a few years there is copious rainfall. You can see that by looking at what is the mean, see this is the median, and this is the mode this is January, February, March and this is all rainfall in centimeters. Now, so the mean January, rainfall is < 5 centimeter, you can see that here and or median is < 5 centimeter, mode is also this. But there is this extreme highest recorded in 25 years is 51 centimeters.

So it is many, many times the mean and the same is true for all these months. You have huge amount of rain occurring there towards the end of the year December, January and even in other year-- other months of the year the rainfall can be substantive but most of it is in the, in the months of at least the highest rainfall seems to be from November to about January. So this rainfall distribution is very skewed, most of the time you have hardly any rain and then some years you get a lot of rain.

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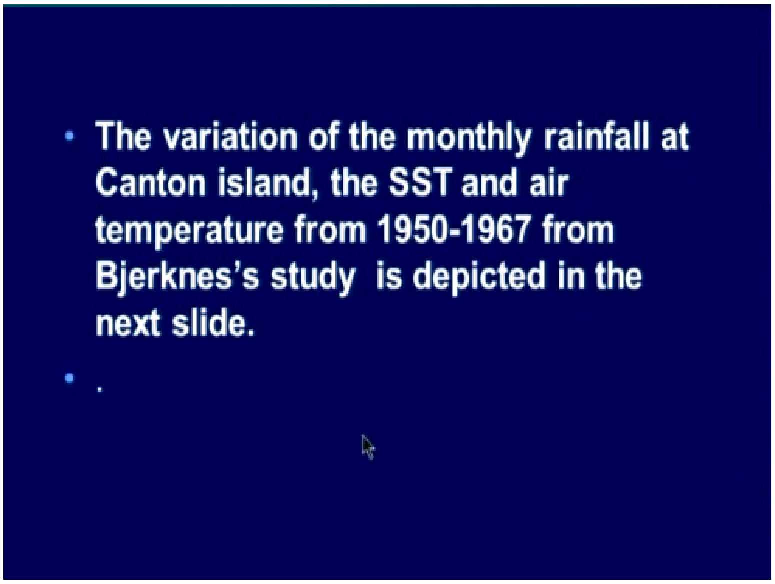

So variation of the monthly rainfall at Canton Island the SST and the air temperature from ‘50 to ‘67 from Bjerknes’s study is given here.

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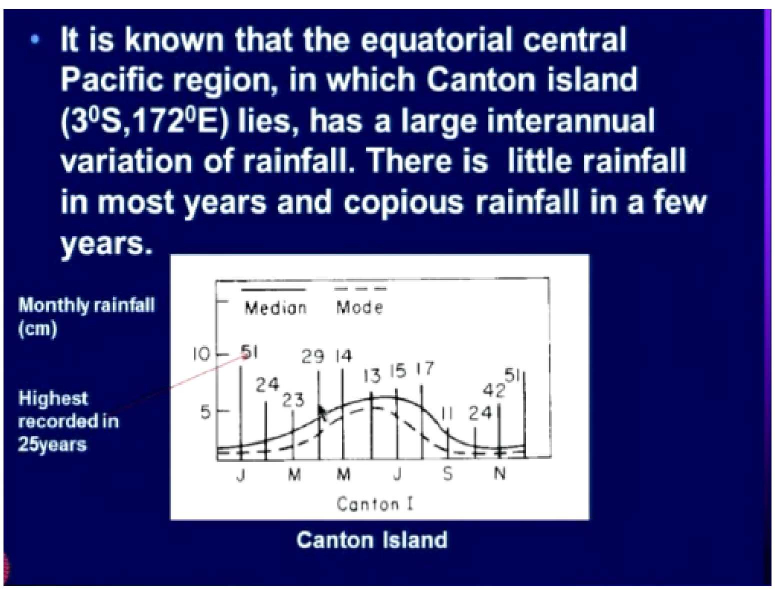

And what you see here is rainfall SST solid and air temperature dashed we will not worry too much about air temperature right now. SST is solid and I have marked here what corresponds to about to 28 degrees here. So this is about 28 and this is the rainfall recorded at Canton Island. So by enlarge you see the rainfall is very, very small you see the little, little bars here okay. This is the 10 centimeter line.

So the rainfall is rather small over most months but suddenly it rains a lot and you see what has happened. This is where SST is < 28 but suddenly when it is well above 28 you get this enormous amount of rain. Similarly, again here SST is lower and there is no rain at all, but if you go here again SST is high and you get enormous amount of rain and moreover it is sustained for several months, you see that, it is sustain for several months during this.

And again now you see SST becoming cold and rain has been sparest generally below 10 centimeters. So generally the monthly rainfall is < 10 centimeter, however, there were periods in which monthly rainfall was sustain at a high level well over 10 centimeter for several months and this occurred when SST was about 28. So this, I think although he did not call it a threshold and he did not actually discuss this in too much of detail in the paper.

He was only concerned with the impact of SST on rainfall, which is very clearly brought out here. But actually the concept which came to be known as presence of an SST threshold was first discovered by Bjerknes in this study.

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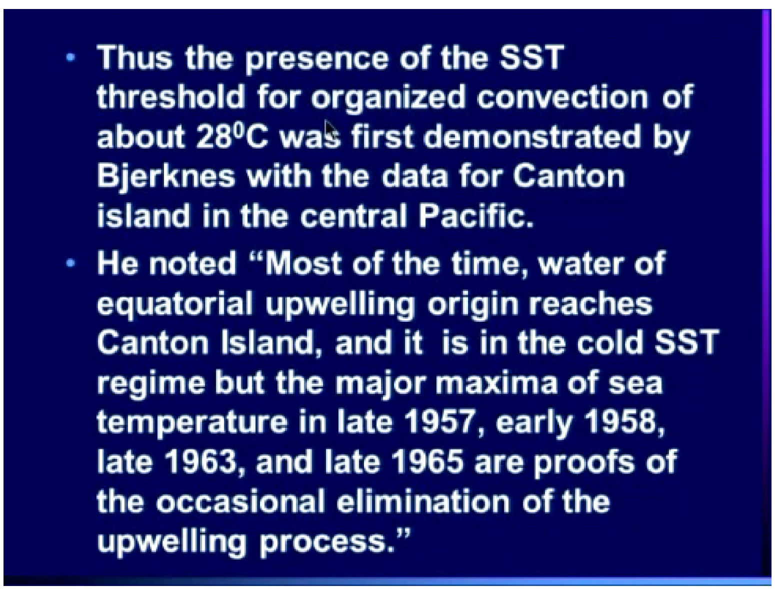

So presence of, the SST threshold for organized convection of about 28 degree centigrade about which I have discussed that length in another earlier lecture was first demonstrated by Bjerknes with the data from Canton Island in the central specific. And the way he quoted was, he said, most of the time water of equatorial upwelling origin, now you remember from the last lecture that there was a tongue of cold water on the equator.

And towards that kind of limit of that is around on the Central Pacific. So most of the time this water of cold equatorial upwelling origin reaches Canton Island and it is in the cold SST regime okay that is well below 28. But the major maximum of SST in late '57, early '58 late '63 and late '65 are proofs of the occasional elimination of the upwelling process, this is what he says.

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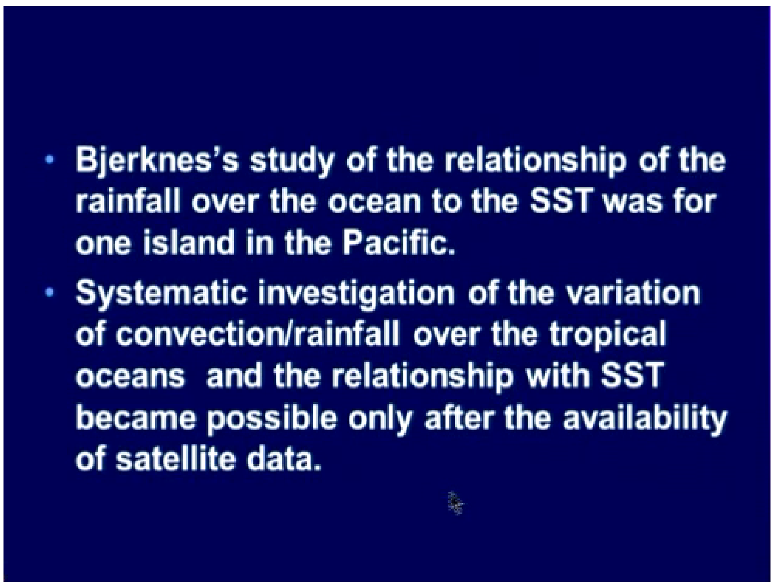

And it is during this that rainfall increases very much when SST becomes high. So Bjerknes study of the relationship of the rainfall over the ocean to the SST was very illuminating but it was after all relationship at one point, relationship of the rainfall over one island to the SST of the region surrounding the island. Now, before the satellite era we did not have any objective measurement or synoptic measurement of the clouds over the ocean.

They become available only in the satellite era and later on even direct measurements of tropical rainfall become possible with satellites. So systematic investigation of the variation of convection or rainfall over the tropical ocean and the relationship of this convection or rainfall with the local SST or sea surface temperature of the ocean above which this convection is occurring became possible only after the availability of satellite data.

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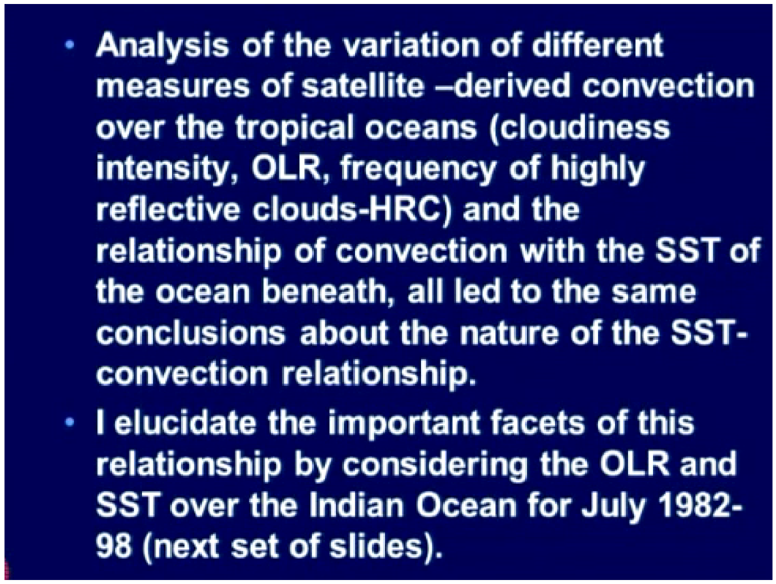

I am not going to go into details here about the different studies but just summarize what was learnt. So analysis of the variation of different measures of satellite derived convection it all began with subjectively derived satellite measure of cloudiness intensity, (()) (23:35) then came the OLR which we have used very often, Outgoing Longwave Radiation. There was also data all frequency of highly reflective clouds.

Because albedo for cloud depends on how high the cloud top is and how deep the cloud is. So highly reflective clouds are a data set that was complied and that also was analyzed by Walliser and others. What is very nice is that the result that was originally derived in cloudiness intensity turned out to be so robust that similar kind of nature was relieved for all these different measures of convection which become more and more fancy.

In fact, in the discussion there we have even shown the results of the latest measurement with cloud set which is a higher resolution cloud measuring satellite. So the relationship of convection and SST of the ocean beneath all lead to the same conclusion about the nature of convection or SST rainfall relationship and what are the important facets of this relationship. We have to remember this because we are going to apply what we have learned to understanding the seasonal variation.

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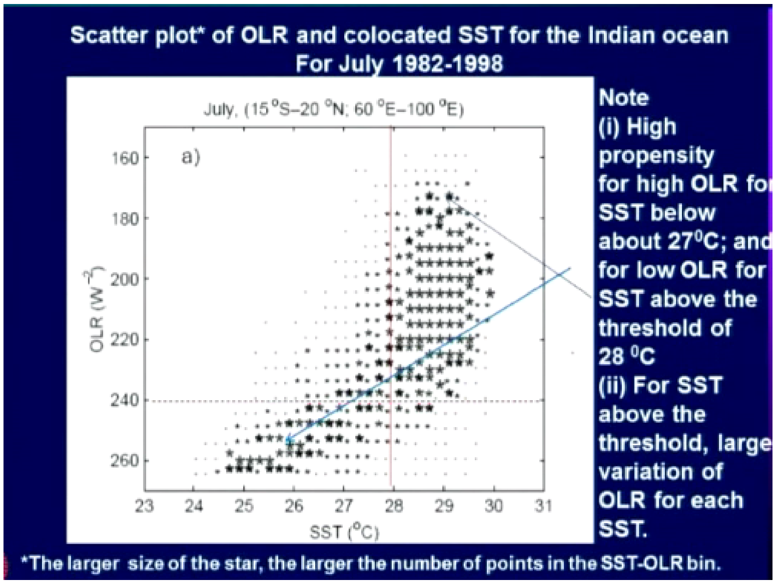

Now Scatter plot was generated by-- for various indices. What I show here is a scatter plot for the Indian Ocean region of the OLR outgoing long variation and collocated SST for July only of ’82 to ’98, so several years are here. Now notice that the OLR is actually plotted in a reverse direction so it increases downward which means that as you go up convection increases OLR decreases, okay. The radiating surface is going higher and higher in the troposphere.

Now what has the major-- by the way the size of this star indicates how many points are in this particular bin. So for example this corresponds to a bin with 29 degree centigrade SST and this is 180 OLR. So the points here are much larger for example then the points and here there are 0 points, here there is few points and here there are more points. So size of the star tells you, gives you an idea of the number of points in this bins.

And it is-- these kind of caterpillars will give you an insight into the relationship between the 2. So what do we see then? This is 240 which is a reasonable threshold for identifying organized convection deep convection in the tropic; this is 240Watt per meter square, so above this line we can say there is considerable convection. Now, and this is the threshold of 28 degree centigrade for SST and what do we find? See, there is a whole lot of points here.

So below 28, the points tend to have high OLR higher than 240. So there is propensity for high OLR for SST below about 27 or so. So this is this part here below about 27-- see there is there are very few points with SST with OLR lower than 240 so all of these is below 240 below the line of 240 which means OLR is higher than 240 so these are all relatively non-convective system and if one is below 27 there is a very high likelihood high propensity for high OLR.

Whereas if you go above 28 then there is a very high chance that OLR will be < 240 so very high propensities for occurrence of deep convection or occurrence of low OLR for SST above 28. And you see a market change in the distribution across the SST threshold of 28 here. It is also important to remember that once this threshold is crossed once the ocean is warmer than 28 then it does not mean that you will have always have a lot of convection you still have points here.

There is a whole range for any given SST which is higher than the threshold, OLR varies over large range from close to 240 to very, very low values where which implies very deep convection over large region. So there is a very large variation for a given SST once the threshold is crossed and this is why we said, SST being above the threshold is a necessary condition for deep convection but it is not sufficient.

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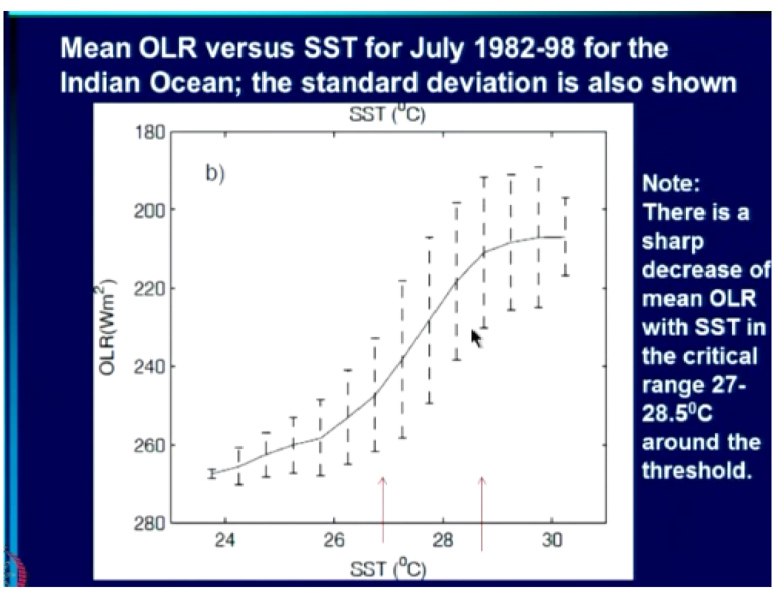

Okay. Now this is the mean OLR versus SST again for the same data. And what you see is that the mean is increasing somewhat gently here and I mean when I say mean is increasing I mean convection is increasing, OLR is actually decreasing. Very sharp increase in convection or decrease in OLR occurs across the threshold of 28 from below 27 below 28 to above 28 this part has very sharp increase in the mean.

And then you say that above about 28.5 it flattens out, this is where you know what the mean OLR or the mean convection has no relationship with SST. So there is a sharp decrease of mean OLR with SST in the range about 27 to 28.5 around the threshold.

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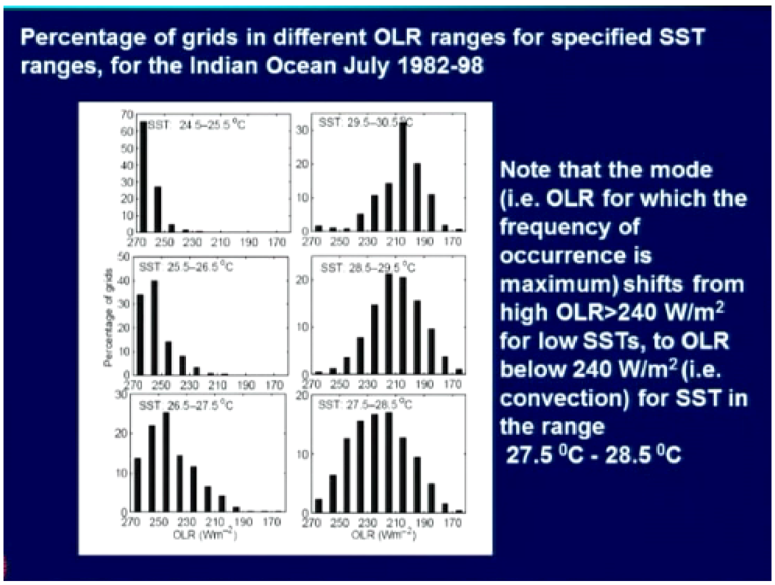

Now, if we look at the frequency distribution, first specified SST ranges, that is to say for pixels, these are all 5 degree/5 degree regions, and remember that there are lot of pixels for every July and there are several July, so all these are added together in this analysis. And what we find is for example when the ocean is-- for pixels which correspond to cold SST, this is 24.5 to 25.5, vast majority of the pixels have very, very large OLR.

Now actually the OLR starts to decrease as the SST increases but what is remarkable is the change in the distribution across here because the mode has always been < 240 rather larger than 240 for OL; for SST below 27.5 suddenly it shifts to values which are which indicate deep convection or OLR of the order of 240 or so. So here the mode is at 250, here the mode is at 260, here the mode is at 270 watts per meter square.

So 270, 260, 250 so still the mode implies that most of those pixels are not convicting, but across the threshold when we suddenly go to the 27.5 to 28.5 then we find the mode has shifted to this is 220 and this is 230. So 230 and 220, and this is 210. So it has suddenly shifted to convective thing and it in fact shift further towards lower OLR a little bit and then remain more or less same. Of course, when you go way beyond 29.5 there are that many pixels itself so one has to take this with the (()) (31:35). Okay.

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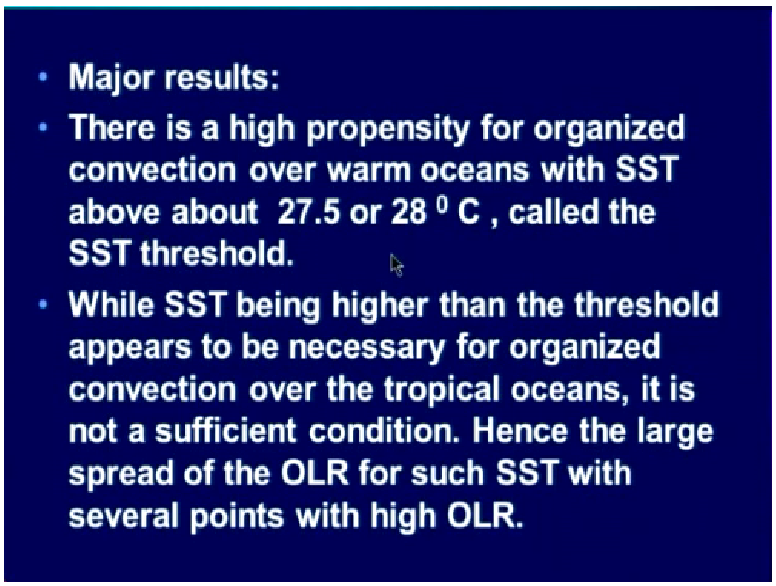

So what are the major results that there is a high propensity for organized convection over warm oceans with SST above about 27.5 or 28, called the SST threshold. Now while SST being higher than the threshold appears to be necessary for organized convection over the tropical oceans, it is not a sufficient condition. We saw this and that is where there is such a large spread of the OLR for such SST with several points having high OLR as well as several points having low OLR.

So there is a high propensity for organized convection once the threshold is crossed but if the threshold is cross there is no guarantee that you will have organized convection, you may have no convection at all.

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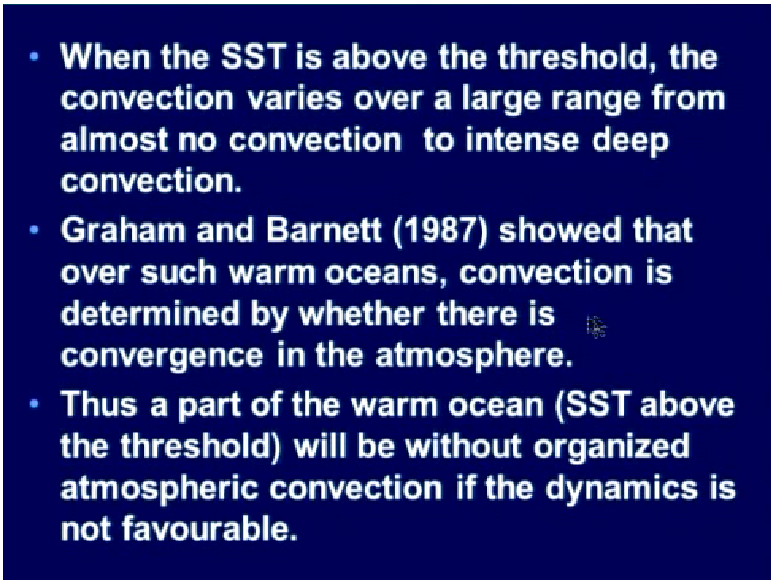

So you have a variation between no convection to intense deep convection. And Graham and Barnett showed that over such warm oceans, convection is determined by whether there is convergence in the atmosphere or not. In other words, SST has to be above the threshold but one it is above the threshold also unless there is convergence in the atmosphere which leads to ascent of air from near the surface of the ocean there will not be any clouds.

So dynamics, favorable dynamics is very important and therefore if this is absent then a part of the ocean warm ocean where SST is above the threshold will be without organized atmospheric convection if the dynamics is not favourable. So unless there is convection you will not get unless there is convergences there is no convection.

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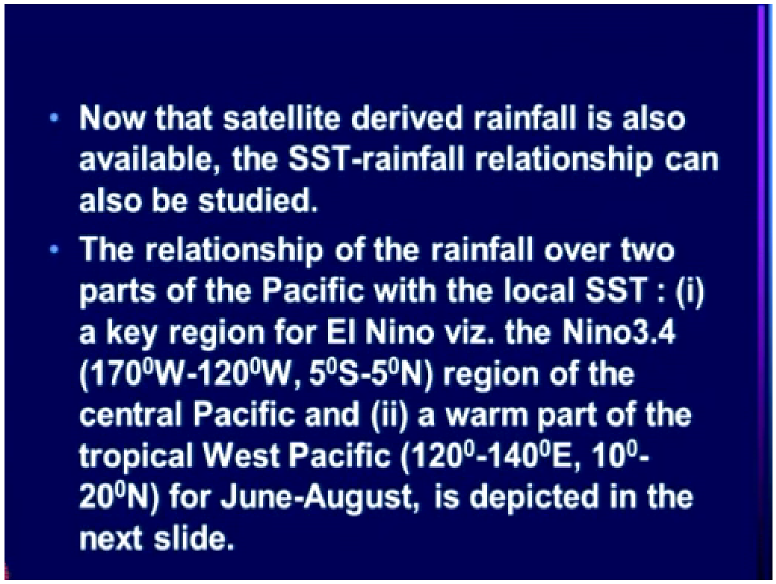

Now so far we have been talking of satellite derived measures based on clouds but now satellite derived rainfall is also available, and the SST-rainfall relationship can also be studied. Now, I am now going to focus a little bit on the Pacific Ocean which we are discussing right now, because that is where and so occurs. And-- so let us consider the relationship of the rainfall over the 2 part of the Pacific with local SST.

Now first is the key region for El Nino, this is the so called Nino 3.4 region which is 170 West to 120 West and 5 south to 5 north. This is the region of the Central Pacific, you remember, Canton Island is very much in this region it was 170 West, and 3 South I think. And warm part of the tropical west Pacific which is 120 to 140 and 10 to 20 for June to August.

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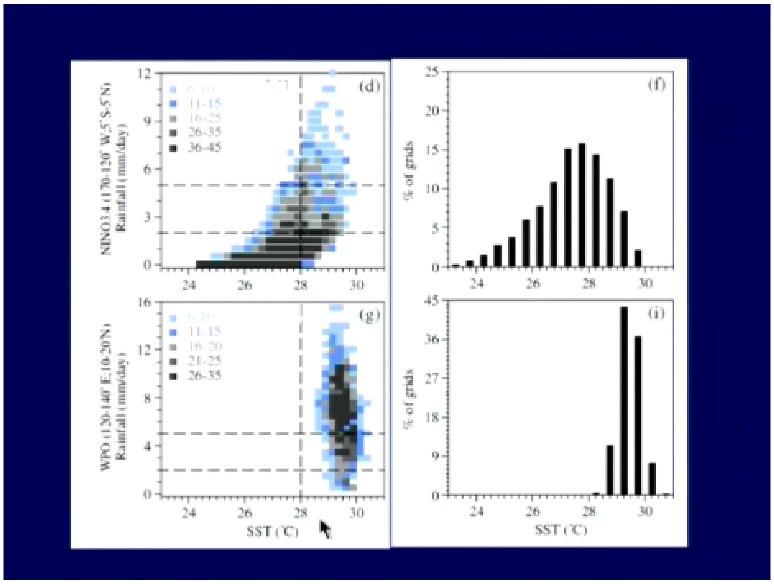

So this is the Nino3.4 region Central Pacific. And again what you see here is the scatter plot only thing is the number of points is now indicated by colors, the black and the gray corresponds to many points and the blue is somewhat less number of points. So this is done for June, July, August for several years and it is all pull together and what you see is what you saw before there is a threshold of above 28.

Before that by enlarge most of the rainfall is < 3 millimeters per day, it is only above that, that things change a bit and above 28 you get very long tails here with very heavy rainfall amounting to 12 millimeters per day or even more. So now let us look at this Nino 3.4 region. This is the frequency distribution of the SST and what we find is that a large number of points here are just around the threshold.

See this is 28 and a large the mode is just around the threshold here. On the other hand, if you look at the west Pacific all the points are above the threshold of 28 and we see no relationship between rainfall and SST, it is just a huge blur like this, it is indicating there is no relationship between SST and rainfall whereas here if we plotted the mean and so on we would get a relationship because once the threshold is crossed you see this minimum also leaps up.

So one the threshold is crossed then you always get some rain, you always get some rain once the threshold is crossed that is very clearly seen here.

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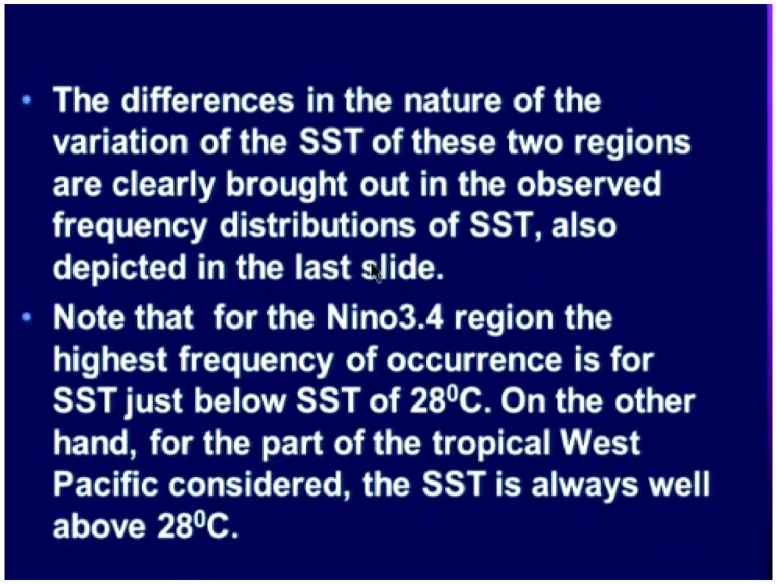

So the differences in the nature of the variation of the SST of these 2 regions are clearly brought out in the observed frequency distributions of SST which are also depicted there. Note that for the Nino 3.4 region the highest frequency of occurrence is for SST just below 28 degree centigrade. So this is what we saw here, in fact this is 28 here, so the mode is for SST just below 28 and this is just above 28.

So between 27 and 28 we have a large number of points here of the order of 30% of the point are between 27 and 28 and you have substantive number just above 28 also about 15% of the point. So, highest frequency of occurrence for this Nino 3.4 region it just below SST of 28. On the other hand, for the part of the tropical west Pacific SST is always well above 28 and that we have seen, this is 28 and there is not a single point where this region is below 28.

So SST is well above 28 for the entire region.

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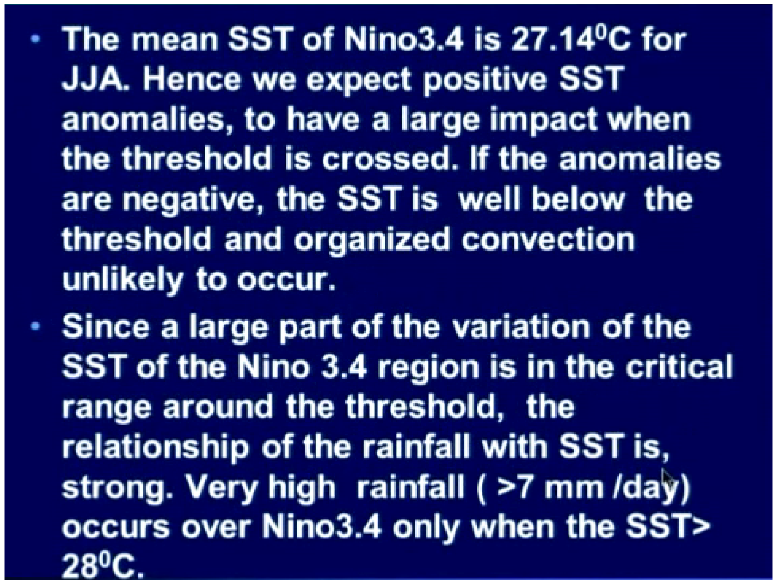

Now the mean SST for Nino3.4 is 27.14 for June, July, August. Hence, we expect positive SST anomaly to have a large impact when the threshold is crossed, right. And typically we have seen the SST anomalies of the El Nino we have seen those before in the introductory lecture to El Nino and thereof the order of 1 degree or even more. So with such anomalies you will get this threshold to be cross.

In fact, we saw that the threshold was actually threshold of 28 was actually crossed for the El Nino that Bjerknes looked at in his figure for Canton Island. Okay. So for, if we have positive anomalies we can have a large impact and the rainfall will increase. If the anomalies are negative on the other hand, then the rainfall remain sparest. So this is the asymmetry and I will come to this later.

But this is the problem if one looks at only anomalies and not at the actual SST one can be mislead because the response is not asymmetric. We are saying that the warm anomaly or the positive anomaly will enhance rainfall. But negative anomaly does not in rainfall. Rainfall is anywhere very small one it is below the threshold. So there is no depression with negative anomaly.

So the response is not in any way anti-asymmetric in terms of actual rainfall because what matters is the actual SST and not the SST anomaly which is a creation of our own thinking, we subtract the mean from the SST and then go on looking at anomalies to see how things are different from average. Now that can lead some give some insight but it can be misleading if we try and look at SST rainfall relationship.

Okay. Now since a large part of the variation of the SST of the Nino 3.4 region is in the critical range around the threshold, the relationship of all the rainfall for SST and very high rainfall say > 7 millimeters per day occurs only when SST is above 28 degree centigrade. So as I mentioned before, when we look at Nino3.4 then very, very high rainfalls, say 7 or so which is here will occur only above the threshold.

See this cap this peak of the distribution is entirely above the threshold also above the threshold you will always have non-zero rainfall that is another thing which is important. Okay, this occurs only when it is above the threshold.

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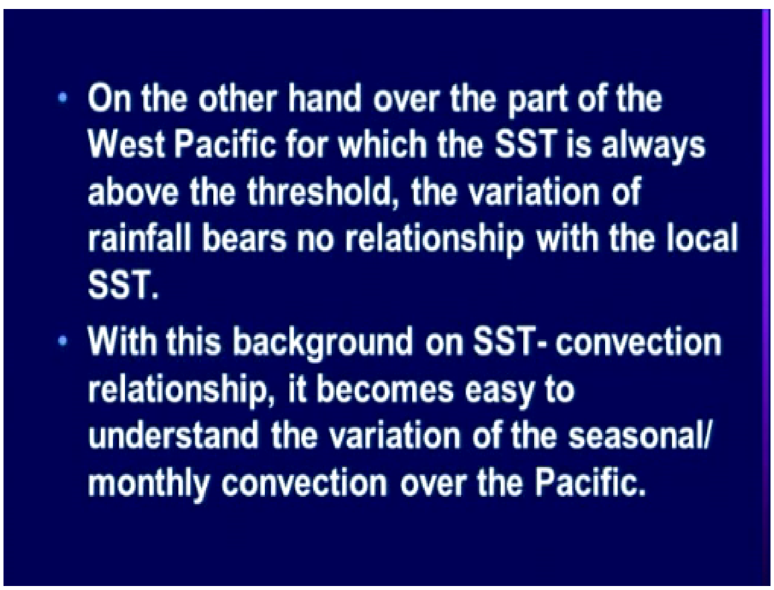

On the other hand, over part of the West Pacific for which the SST is always above the threshold, the variation of rainfall bears no relationship with local SST. This is also important to remember. So SST variations can have a very large impact of on convection rainfall of the atmosphere if the SST variation is around the threshold. If it is always above the threshold, then we cannot say very much on the basis of SST because dynamics will then determine whether you have convection or rainfall.

On the other hand, if it is very much below the threshold then whether you have positive or negative anomalies of SST you will get no rain at all and therefore there is no relationship between SST and rainfall. It is only in the intermediate range when SST varies across the threshold that we see very strong relationship of the rainfall in the atmosphere with the SST over the ocean, SST of the ocean over which it is raining.

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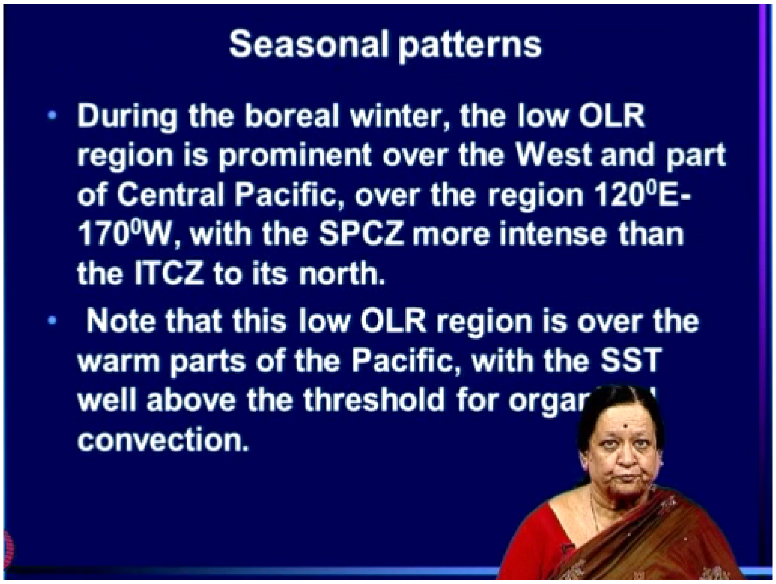

Okay. Now this is necessary to revise this background and the relationship of convection or precipitation with SST in order to understand and interpret the seasonal patterns as well as the monthly patterns. So let us begin with the simpler ones, the seasonal pattern. So during the boreal winter, the low OLR region is prominent over the West and part of the Central Pacific. And over the region 120 east to 170 west with the SPCZ more intense than the ITCZ to the north. Note that this OLR region, no sorry.

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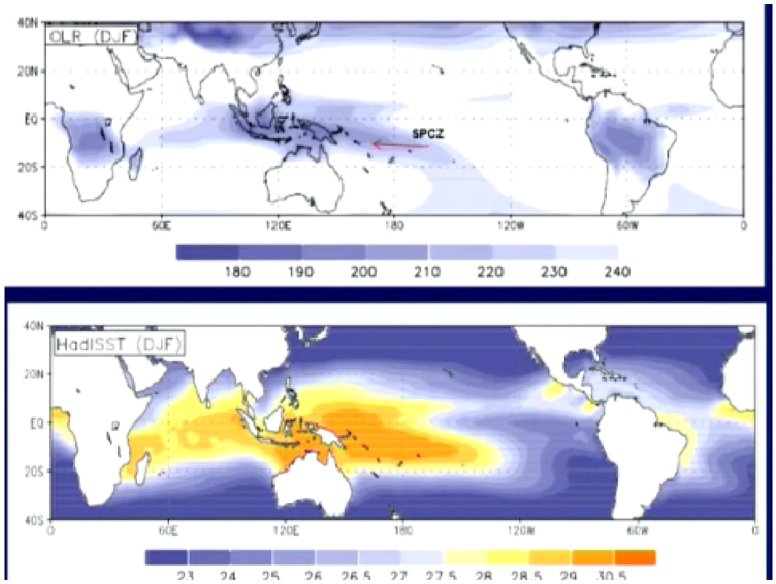

Okay. So this is t he boreal winter, so you have convection going here, this is the ITCZ and this is the SPCZ okay. And so, the low OLR region is prominent over west part western part of the Central Pacific and there is also SPCZ so within the low OLR region see this is part of west specific this is the dateline, so it comes right up to Central Pacific and in addition there is this SPCZ which is sort of going this way.

And just notice how close the pattern is to the warm SST. Remember the yellow is at 27.5 and here we see very close correspondence that the low OLR region is always within the warm ocean, it always over the warm oceans, you never see low OLR over cold oceans that is very clear. But you can have warm oceans then there are small bits here over which there is no convection and that you can see partly here as well.

So in the Indian Ocean as well the Pacific what you see is that the low OLR region over the warm parts of the Pacific with the SST well above the threshold for organized convection. See this is where these dark regions here are where SST is well above the threshold and that is where the low OLR region of the Pacific is. So the threshold does in fact determine the spatial patterns of OLR.

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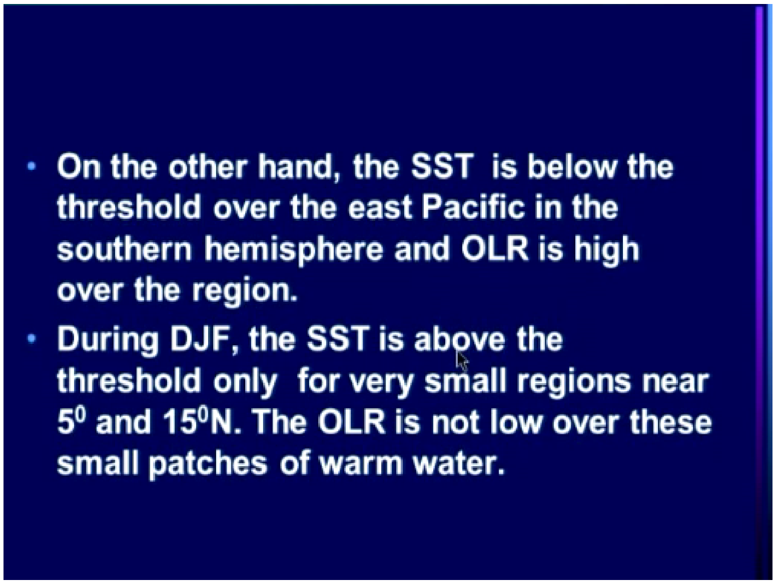

On the other hand, the SST is below the threshold over east Pacific and in the southern hemisphere and OLR is high over the region. So you can see here OLR is well above 240 and you can see that SST is below the threshold in this equatorial tong as well as east Pacific south of the equator. So here it is well below the threshold and there is no convection at all.

So during DJF, the SST is above the threshold only for very small regions near 5 and 15 and the OLR is not low over these small patches of warm water this is what we saw here. These are these little patches of warm water. And low OLR does not occur there, there perhaps 2 small organized convections. Okay. Now we come to the-- this was the boreal winter, now we come to the boreal or northern hemispheric summer.

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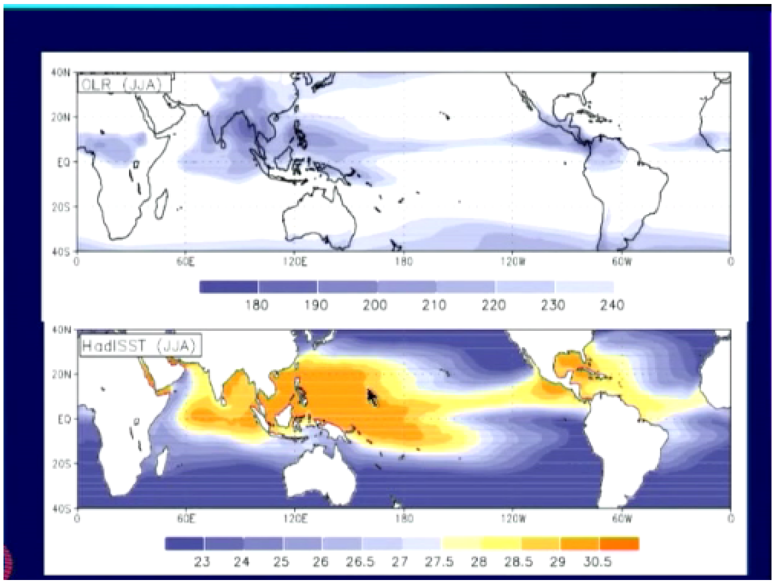

And here we see that for June, July, August again now you see sea stuff temperature is very warm over this whole patch and a large part of that is covered with low OLR region or convection. Now you also see that sea surface temperature is warm also over this part here, this is east of about 120 west and there again you see fairly you see a low OLR region latitudinal extent here.

Now in between you see this is a relatively thin strip of warm SST and on that part of that is actually a thin strip of low OLR here. So again here also we see a rather good correspondence—

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--that organized convection over the Pacific and also Indian ocean in the boreal summer is just like in the boreal winter is entirely confined to warm oceans with SST above the threshold. The low OLR region is prominent over the west and part of the Central Pacific. I mentioned also Indian Ocean, you can see here. Here also the Indian Ocean is warm in this patch and you can see this is the low OLR region almost over patch identical.

So the shapes are determined to a large extent by the SST itself.

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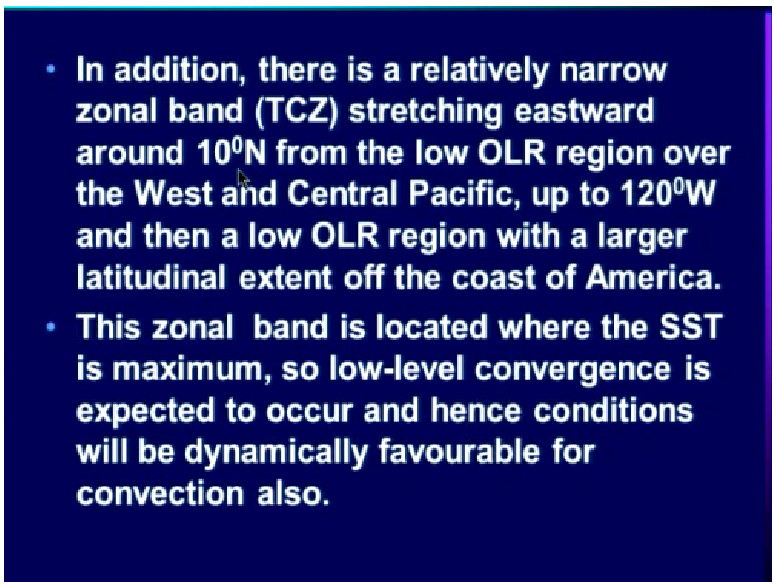

So in addition to the West Pacific low OLR region we already saw there is a relatively narrow band zonal band stretching eastward around 10 north from the low OLR region over the West and Central Pacific, up to 120 West and then a low OLR region with a larger latitudinal extent over the coastline of America, so we have this huge region huge blur of low OLR with intense convection then a thin TCZ and somewhat larger latitudinal extent characterizing the convection over this region.

Okay. This Zonal band is located where the SST is maximum, so low-level convergence is expected to and hence conditions will be dynamically favorable also. Now that is clearly seen here, you can see here that the SST is maximum in this zonal band, if you go north and south then SST is colder.

So if you have warm SST here and cold SST here because of the gradient right, warm air being lighter you will have lower pressure here relative to her and this will lead to convergence here from the north and south and that should lead to convection since SST is already above the threshold. So the dynamics is determined by the location of the maximum SST. And dynamics is also favorable here and the threshold is crossed so we have in fact this zonal band here.

This is important to remember. The low OLR region is prominent over this and--okay. So the zonal band is located where the SST is maximum and so there is low level convergence is expected to occur there and conditions will be dynamically favorable also for convection.

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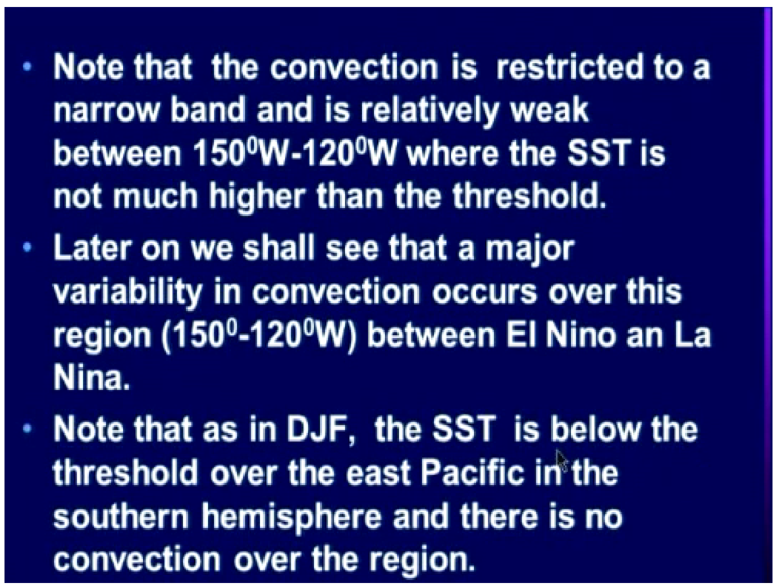

Now note that the convection is restricted to a narrow band and is relatively weak where the SST is not much higher than the threshold; this is the region 150 west to 120 west. In fact, later on we will see, see this region here, this is 180 this is the dateline and this is 120, so in between see this region between, where OLR is just below 240 and where you can see there is only a thin line above 28.

It is this in fact it turns out that the major difference in the OLR patterns associated with El Nino an La Nina are present or absent of convection in this region here 150 to 120. We will see that later so far we are looking only at the mean patterns So later on we will shall that a major variability in convection occurs over this region between El Nino and La Nina. Now we note that as in DJF, SST is below the threshold over the east Pacific in the southern hemisphere and there is no convection over the region.

So this is something we notice see how lower the SST is here over this region and there is no question of convection it is all white there, so this is something that we saw in the other season as well.

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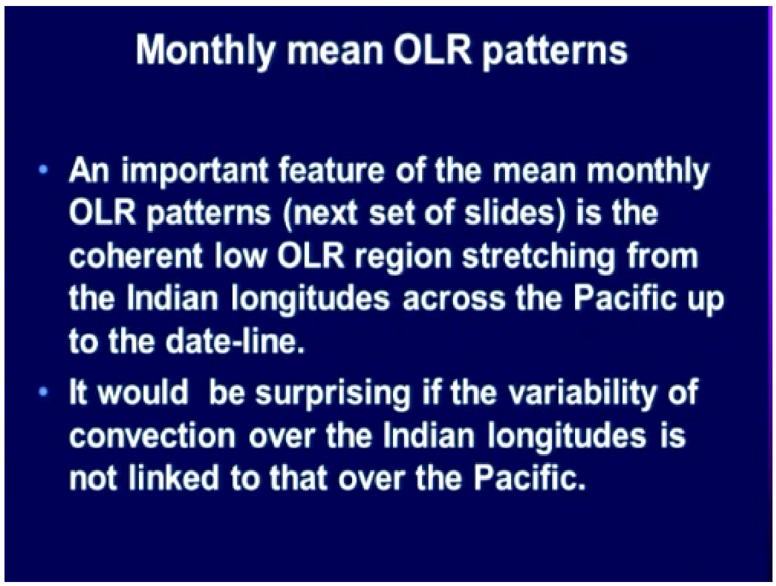

Okay, now we will look at-- so far what we have done now is shown that the pattern of OLR regions which are the regions there is organized convection can be understood in terms of the SSTs. In other words, SST patterns of where SST is above the threshold appear to determine to a large extent where the convection is going to occur, okay. So this is a very strong relationship and the fact that SST has to be above the threshold seems to be a very rigid constraint on where organized convection can occur.

So this is very clear from the seasonal patterns we have seen. Now we will go to Monthly mean pattern and see how the evolution occurs as far as the mean climate is concerned from the boreal winter through boreal spring to boreal summer and then austral spring and austral summer or autumn and our winter. Now it is interesting that we see that but it is important, now we I did mention that one thing to notice in this seasonal patterns is this is the JJA.

You see this low OLR region is a coherent zone, now here it is a for enormously large latitudinal extent but you see there is no gap between the 2, it is coherent between the Indian longitude and then stretching across the entire Pacific and in DJF of course the story is somewhat different, but in June, July, August we see it very much as that way then we will see what happens on the monthly scale.

But as far as June, July, August is concerned then we see that the low OLR region is certainly coherent between Indian longitude and the Pacific and it would be surprising if the variability of OLR or rainfall over the region is not link to variation of convection or rainfall over the Pacific. So it seems to me that we are looking at a part of (()) (52:15) system, we are looking at one part and obviously other parts of the system are going to have any impact in terms of the variability of the monsoon. So this is something we expect.

Now next we will look at Monthly mean OLR patterns how they are and then go on to see the characteristics of El Nino and La Nina. Thank you.