The Monsoon and Its Variability
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Lecture - 15
Monsoonal regions of the world

So today we are going to discuss the monsoonal regions of the world. So far we have primarily focused on the Indian monsoon, but now we should know what are the other regions of the world, which also experience the monsoon. So that is what we will look at today.

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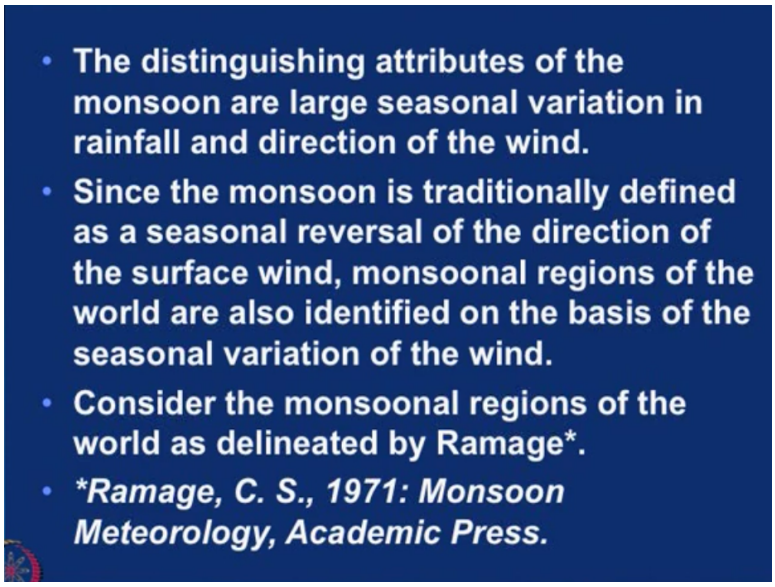

In fact, the distinguishing attributes of the monsoon are the large seasonal variation in rainfall and direction of the wind. Since the monsoon is traditionally defined as the seasonal reversal of the direction of the surface wind, you remember this definition came from the fact that it was Arab sailors who coined the word monsoon. So the traditional definition is in terms of seasonal reversal of direction of surface winds.

So monsoonal regions of the world are also identified on the basis of the seasonal variation of the wind. Consider the monsoonal regions of the world as delineated by Ramage.

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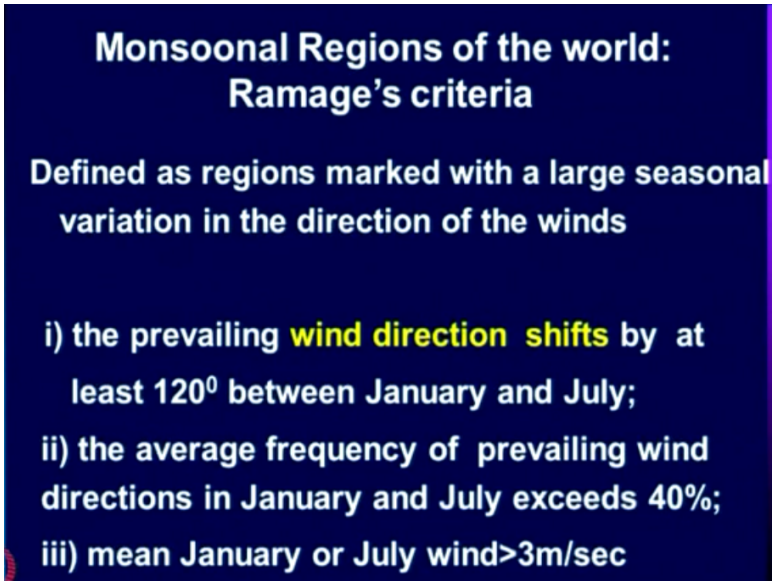

Now how did he delineate these regions? He defined monsoonal regions of the world as those regions which satisfy the following criteria in terms of the wind. So these are defined as regions marked with a large seasonal variation in the direction of winds. The prevailing wind direction shifts by at least 120 degrees between January and July. So seasonal reversal would mean 180.

So he is saying that at least there should be a difference of 120 degrees between the direction of wind in January and July. Then the average frequency of prevailing wind directions in January and July should exceed 40%. You know the wind direction should not be so variable that we cannot talk, that the mean wind is not representative of too many days. Therefore, he says when we talk of prevailing wind.

It should be wind that occurs on most of the days in those months. So he said the average frequency of prevailing wind direction should exceed 40% and there is one more condition he put in. Actually he is not implicit in the kind of definitions that people had used before him and that is that main January or July wind has to be > 3 m/s. This strikes me as being slightly arbitrary.

Although it is true that when we talk of changing of wind direction, the wind has travelled certain magnitude before we can talk of changing wind direction, but whether it should be 3 m/s or 2 m/s or 1 m/s is really subjective decision.

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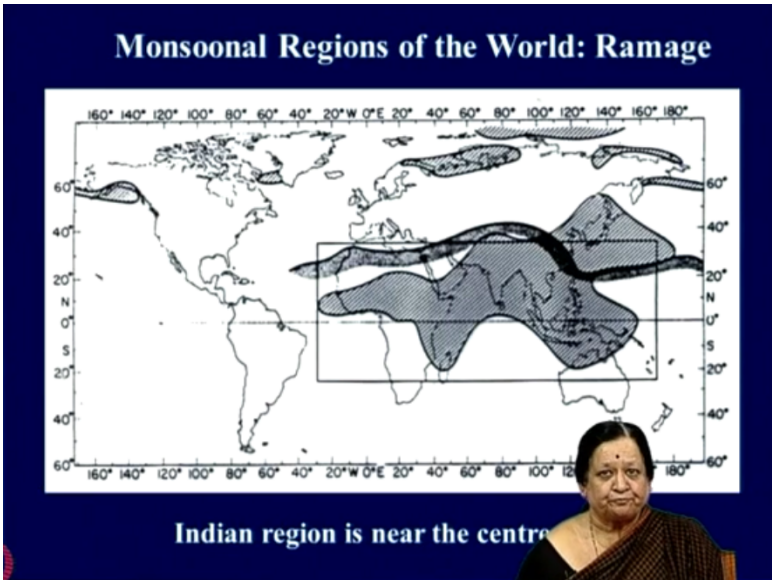

So these are the monsoonal regions of the world delineated by Ramage using these criteria and in fact they come somewhat complicated. So he then suggests that this is the box which in fact delimits the monsoonal regions of the world, notice that India is very much at the center of the monsoonal regions of the world, according to Ramage and according to him monsoonal regions comprise primarily of Africa and Asia and part of West Pacific.

That is what according to him they include. So these are the monsoonal regions of the world as delineated by Ramage on the basis of winds.

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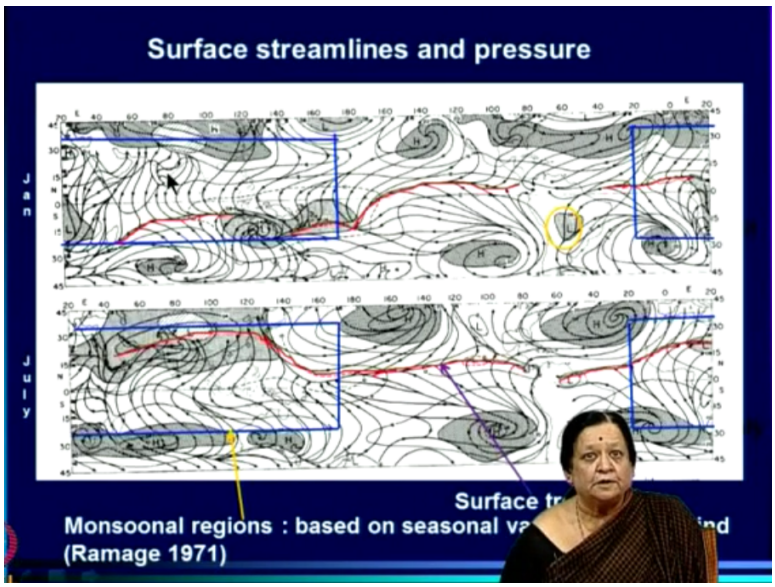

Now let us see, how they came about because what you see here is the surface streamline patterns in January and in July below and I am sorry about the longitudes and not what they were before and India is around here. And you see actually that in January the winds are from

the North East and they change completely to become from the South West here in July. So this is the major monsoonal change which you see in this box here.

Similarly, the winds also reverse here. Now he claims that the other regions are not monsoonal. The red line corresponds to the surface trough and only problem there is, that they had given a gap here, over South America. They do not continue the trough and in December-January-February actually there is a low created over South American region much the same way that we have a low created over the Indian region here.

And say over the Indian region here, the trough actually moves northward. It is south of the equator in January and it actually moves northward to lie over India in July. But they have not drawn the trough to lie over South Africa in the January case. And this again is a subjective decision I believe.

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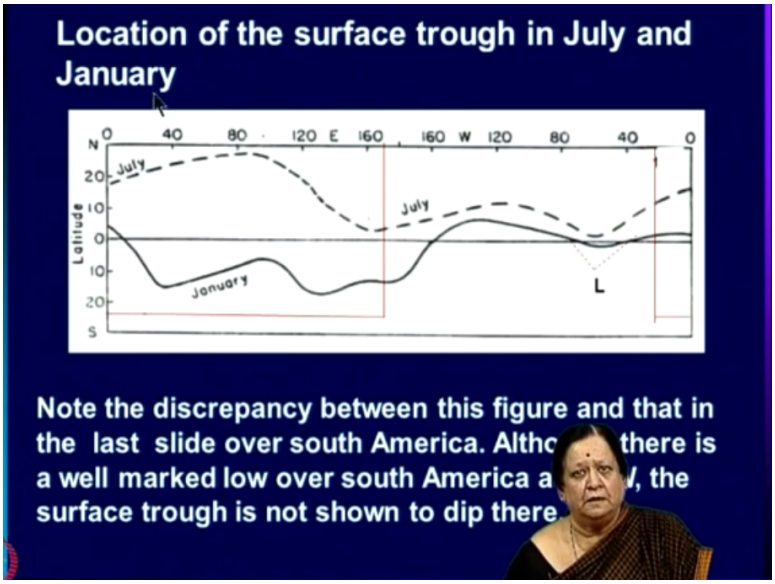

So when draws the location of the surface trough in July and January, what you will see is, this is again the picture we have seen before, this is the July and this the January and I have drawn in red boxes, indicated Ramage's regions over there. These are the monsoonal region of the world and you can see immediately that monsoonal regions are characterized by a very large migration of the trough, extending over 20 degrees in latitude.

So there is a big difference in the latitudinal location of the July trough and the January trough over monsoonal regions. If you look at the other regions which are not monsoonal according to Ramage, then in fact you see that over most of the regions there is hardly any

change < 10 degree change between the January location and the July location of the surface trough.

And what I have indicated here is that have they taken the South American low into account, then you would have had some kind of a substantive seasonal variation over South America as well. But they have not done so

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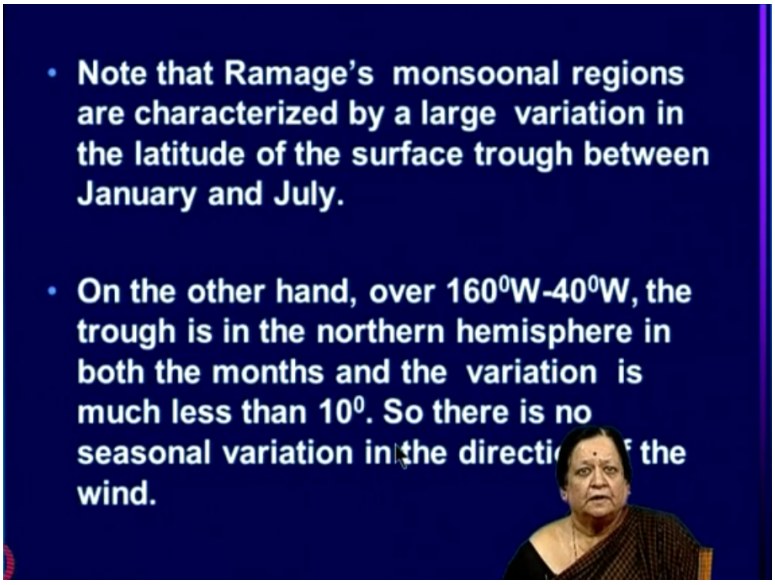

Now so we have seen, if we superpose monsoonal regions as determined by Ramage, on to the surface trough in January and July then monsoonal regions are characterized by a very large variation in the latitude of the surface trough between January and July. On the other hand, over 160 west to 40 west, that is to say over much of the specific ocean starting with 160 west.

So east of 160 west over the entire ocean and including the South American continent, the trough is in the Northern Hemisphere in both the months and the variation is much < 10 degrees. So there is no seasonal variation in the direction of the wind. So this is how delineation of the monsoonal region can be reconciled with the classic picture drawn by, of how the surface trough changes. So the 2 are consistent.

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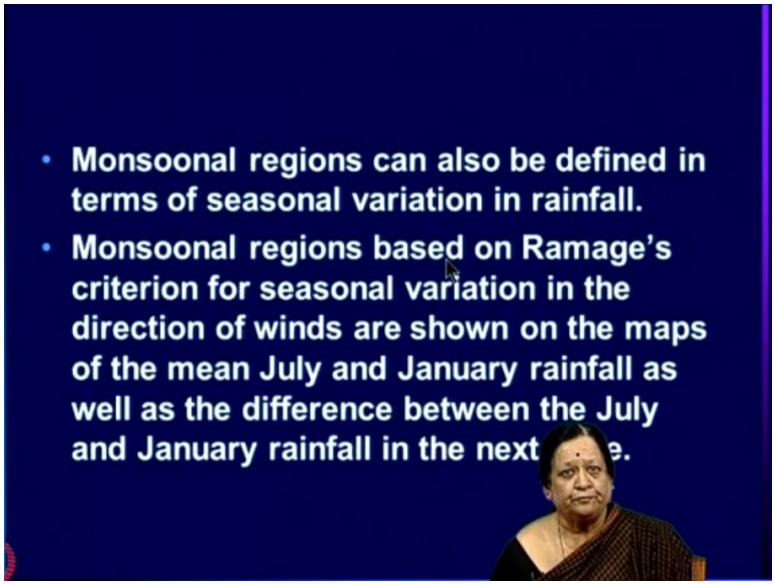

Now, as I pointed out before we who live in the monsoonal regions of the world really are concerned with the seasonal variation in the rainfall associated with the monsoon and over Indian region for example in common parlance, monsoon means rainy season and rainfall associated with the monsoon is also called monsoons or we talk of poor monsoon years in which rainfall is much below the average.

We talk of good monsoon years when it is above the average and so on. So to us, the monsoon is also synonymous (()) (08:03). Now we must see, how monsoonal regions based on Ramage's criteria for seasonal variations in the direction of winds, in fact how do they related to the variation of rainfall. See, that is the most important thing to see for us.

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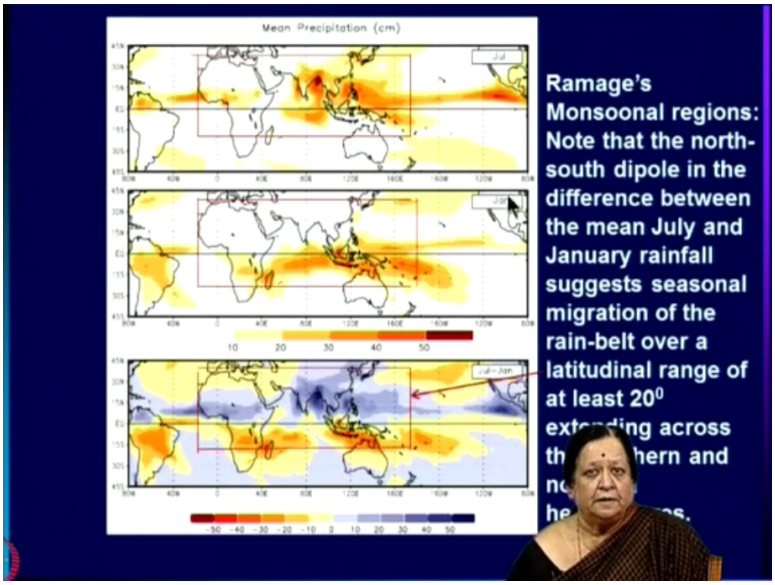

And here now we have, these are again Ramage's monsoon in the red box and now I have made India more to the center of the plot. And what you see here is the rainfall of July, rainfall of January and this is the difference between July minus January. So blue means, rainfall is much more in July in the northern part here then it is in January and this means rainfall is more in January, yellow (()) (08:56).

Rainfall is more in the southern hemisphere here that it is in July. So what we see here is, that monsoonal regions, you have a large shift of the rain-belt. And the fact that there is a shift of the rain-belt is reflected in this dipole here, right, because this is of one sign and this is of the other sign. This says that the rain is more in July here, they say the rain is more in January here, this suggests that the rain-belt moves from here to here between January and July.

This is very clear. So this is not so dipole that we see here is a manifestation of the seasonal migration and what therefore Ramage's monsoonal regions are associated with seasonal migration of this major rain-belt over a latitudinal range of at least 20 degrees or so. That is what it is.

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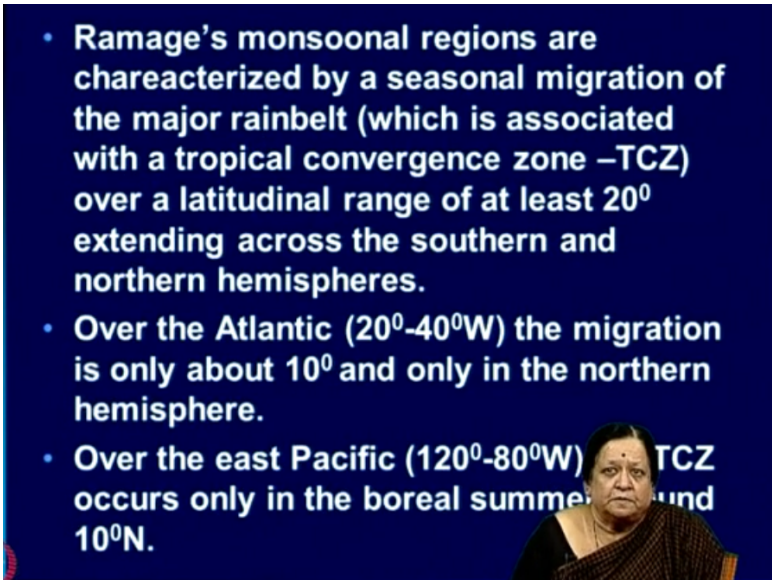

Now, so Ramage's monsoonal regions are characterized by a seasonal migration of the major rain-belt which we know, we have seen in the last lecture which is associated with a tropical conversion zone over a latitudinal range of at least 20 degrees extending across the southern and northern hemispheres.

So this is again can be considered as a distinguishing attribute of monsoonal region that there is a seasonal migration of the rain-belt associated with the TCZ over a latitudinal range of at least 20 degrees from one hemisphere to another. Now over the Atlantic the migration is only about 10 degrees and only in the northern hemisphere. So we see here that over the Atlantic which is here you can say that this is a bit of a migration.

It has come from near the equator slightly to the north and then it is migration and over the pacific really there is no migration but rather the systems stay in more or less there, but being much weaker in January and there is a strengthening in July and that is what you see here. Big blue here just means that there is a strengthening, in situ strengthening of the system over the east pacific.

So over the Atlantic the migration is only very small and only in the northern hemisphere over the east pacific a TCZ occurs only in the boreal summer around 10 degrees north.

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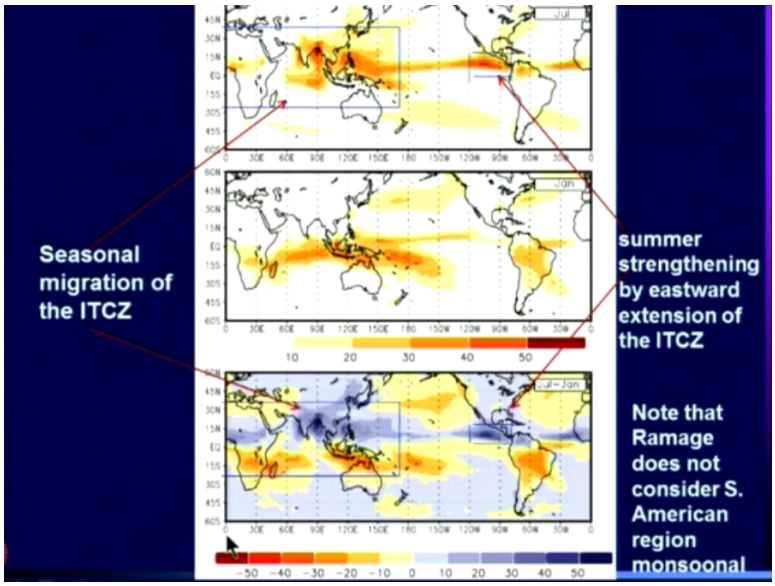

Okay. So what do we see then, that these regions again these are Ramage's regions here and these regions are characterized by seasonal migration of the ITCZ where as this region is specific is characterized by summer strengthening by eastward extension of the ITCZ. So there is summer strengthening and eastward extension. See the ITCZ immense here, even in the winter.

But it is strengthened in the summer and extends east ward, that is what is seen here, okay? Now note that Ramage's boxes never include South America. So although you see that over

the South America longitudes you do get a shift of the rain-belt which you can see also as a (()) (12:43) here, but Ramage does not consider that as a part of the monsoonal region.

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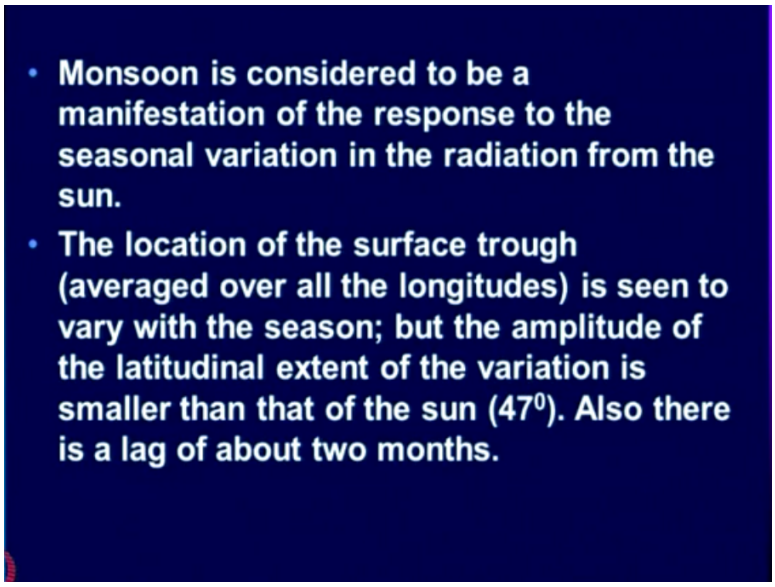

So monsoon is considered to be a manifestation of the response of the, to the seasonal variation in the radiation from the sun. See, the distinguishing attribute of monsoon is the seasonal variation. Where does that come from? That is a response to the seasonal variation in the radiation from the sun.

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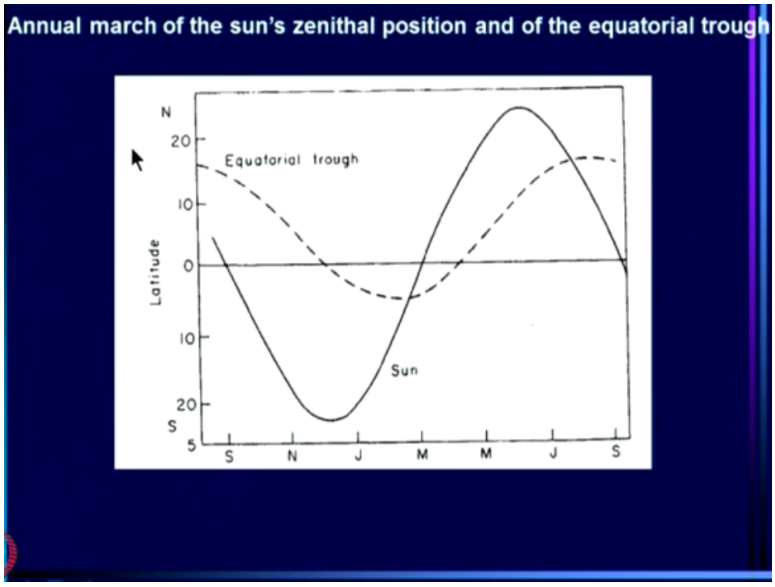

The location of the surface trough average overall longitudes in fact also varies and this is a picture from that. So if you talk about the equatorial trough and your average overall the longitudes then this is the latitude of the equatorial trough and this is the latitude of the sun.

And remember in September the sun crosses the equator, so it is at 0, then it goes to the southern hemisphere.

Then it crosses again in March and then it comes to the northern hemisphere. So this is a very simple oscillation of the latitudinal location of where the sun is overhead. And you can see that this is the Tropic of Capricorn and this is the Tropic of Cancer. So the sun is overhead at latitudes which vary from Tropic of Capricorn to Tropic of Cancer over the year and this is the way it varies in a very smooth manner.

And when you do all the averaging, the equatorial trough also varies in a smooth manner but notice that the amplitude of variation is much smaller than the variation of the sun because this amplitude is 47 degrees or so, whereas this amplitude is of the order of 20 degrees or so, from here to here. So the amplitude of variation is much less, also you notice that there is a lag.

Now this is where this sun is at the minimum or the most southern most latitude and that occurs as you know between in December, end of December, where as the minimum or the southernmost latitude of the equatorial trough occurs about 2 months later. Similarly, there is a line between the peaks as well of about 2 months. So the location of the surface trough average overall the longitudes is seen to vary with the season.

But the amplitude of the latitudinal extend of the variation is smaller than that of the sun and also there is a lag of 2 months as you have seen.

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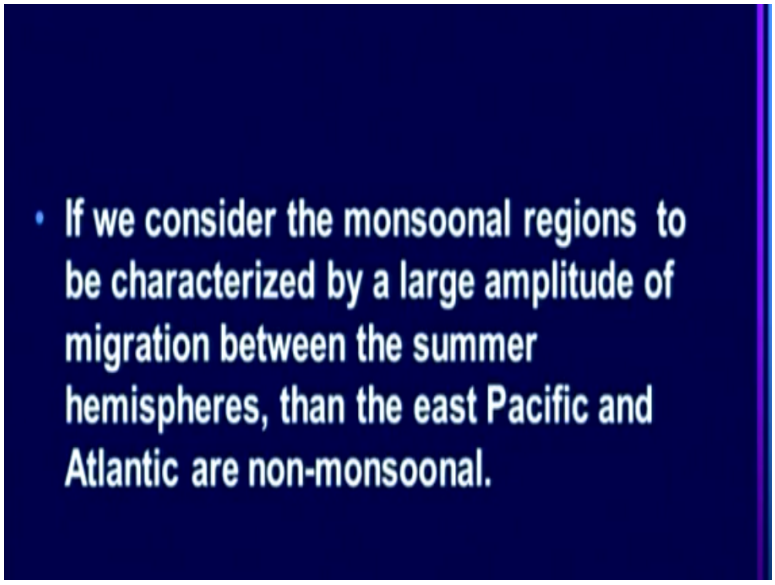

Now if you consider the monsoonal regions to be characterized by a large amplitude of the migration between the summer hemispheres then the east specific and Atlantic are obviously non-monsoonal because they do not even have the ITCG in the summer hemisphere during December-January-February.

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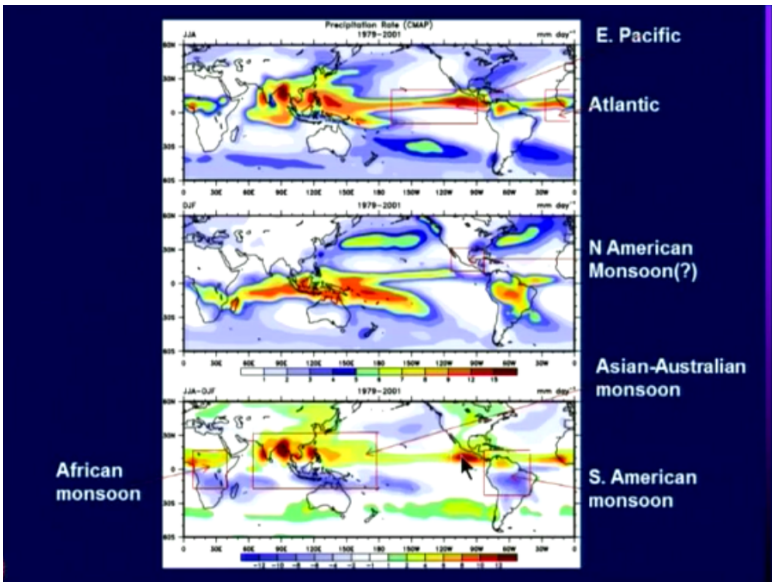

Okay, now again we see what are the different monsoonal regions of the world and you can see what are the different regions. So we have the east pacific here and the east Atlantic here both of which are not considered monsoonal at all. Then we have the Asian-Australian monsoon which we have seen before which is this huge region here. Asian-Australian monsoon is this huge region here.

Then we have the African monsoon which is this region here and you can see that both of these are very clear dipole kind of a thing when we look at the difference it is very clear that there is a seasonal migration of the rain-belts here. Whereas, here as we mentioned before there is an in situ strengthening. But you also see that there is a South American monsoon here where you have strengthening in the Southern summer and there is a dipole signal here.

And see, this is the South American monsoon flared up (()) (16:40) and you see that during JJA also toward the north there is a rain-belt here. so South American region also seems to have a seasonal migration, although the amplitude is not as large as the classification of Australian monsoon or the African monsoon. Now recently it has become very fashionable to say that even the monsoon, North America has a monsoon.

And (()) (17:07) claim is the North American monsoon region. And for some reason monsoon has become a very catch word and everybody would like to have a monsoon at their own door step. I think partly thing kind of reasoning has gone into defining this as a North American monsoon. We will get into that when we study the other monsoonal regions in greater detail, but as far as one can see, it really does not satisfy the criteria of seasonal migration or anything like that.

What seems to be happening is that in the summer there is some extension of these specific ITCZ to give some rain over Mexico and parts of United States Southern parts of United States and since that occurs in the summer they call it the North American monsoon. It is somewhat debatable, whether it is a monsoon in the sense that the other monsoonal regions of the world are.

Since they talk of the African monsoon, the Indian monsoon, the Asian monsoon, the Australian monsoon, Australia also you can see is part of this poll with shift in the rain-belt very clear.

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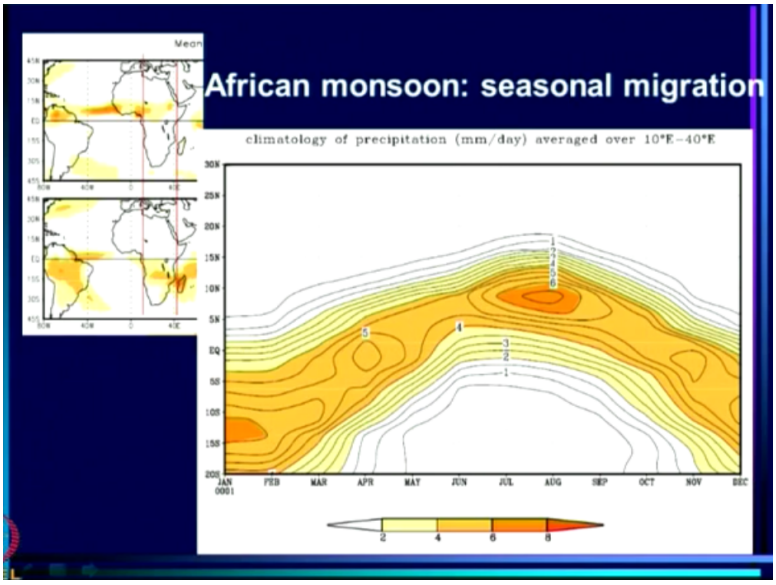

But North American, you do not quite see the same thing, but never the less, it has now come into work. Now let us look at how the migration actually occurs. So now we are looking at monthly pictures. At over a given longitudinal belt, so first we look at Africa and this is 10 degrees to 40 degrees east and what it looks like I have shown you here. This is between these 2 red lines we were looking at.

We are averaging over these longitudes and asking the question where is the rain-belt. So in January you see clearly the rain-belt is here, the equator is here as you can see, rain-belt is in the southern hemisphere and then it goes to the northern hemisphere. This is a very classical picture of seasonal migration of the kind we have seen before the Indian monsoon as well and we will see again.

So this is the African monsoon, how it goes from the southern hemisphere to the northern hemisphere. But we should also see, I had asserted that this rain-belt is associated with a tropical conversion zone. Now this assertion requires proof and that is what we are going to look at now. This from the European center, reanalysis and what we have here is the vertical circulation. So it is the circulation in the plane, not so towards us vertical plane.

And what you see here is, this is for 2 months, this is January and this the average of a several years and this is July, okay? And what you see here is this (()) (20:13) ascent here. This is where the rain occurs and you can say that the ascent is throughout the troposphere here. So it is very much like the tropical conversion zone or (()) (20:13) CEF1, the dominant mode of diversion of mission.

So that is what is responsible for the rainfall of the African monsoon and you see that this is the July pattern, again very similar ascent through the troposphere, so that we can say that there is TCZs in both the hemispheres, the northern hemisphere during the northern hemispheric summer, southern hemisphere during the southern hemispheric summer and there is a season migration between the 2.

So this is a classic case of the monsoon in which the TCZs move from one hemisphere to the other in response to the movement of the sun.

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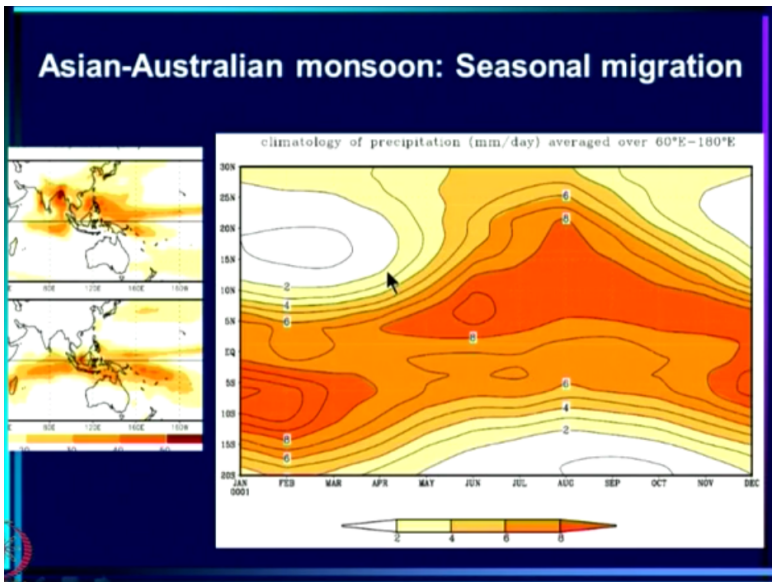

Okay. Now, we look at the Asian-Australian monsoon and we are going to look at a very large region, average over a very large region. It is 60 degrees east to 180 degrees east. And when we do that again we see very nice migration here. Of course, notice that the rainfall is so much higher in the Asian-Australian monsoon then it is in the African monsoon. See the same shades are used.

But you see this is much less and you have 6 and 8 here and here you see much higher than occurs in the Asian-Australian monsoon. Again you see very nice seasonal migration of the belt.

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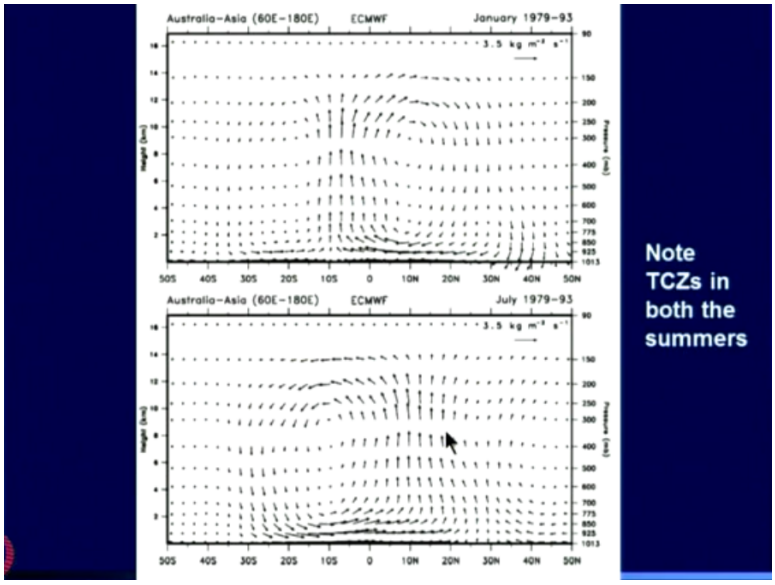

Okay, now question is there TCZs in both the hemispheres? Yes, even when we average over such a large region, 60 to 180, it is very clear that you have over the, in January over the southern hemisphere very nice and clear ascent, right, up to the upper troposphere and you see the same in the northern hemisphere in July. So there are TCZs in both the hemispheres.

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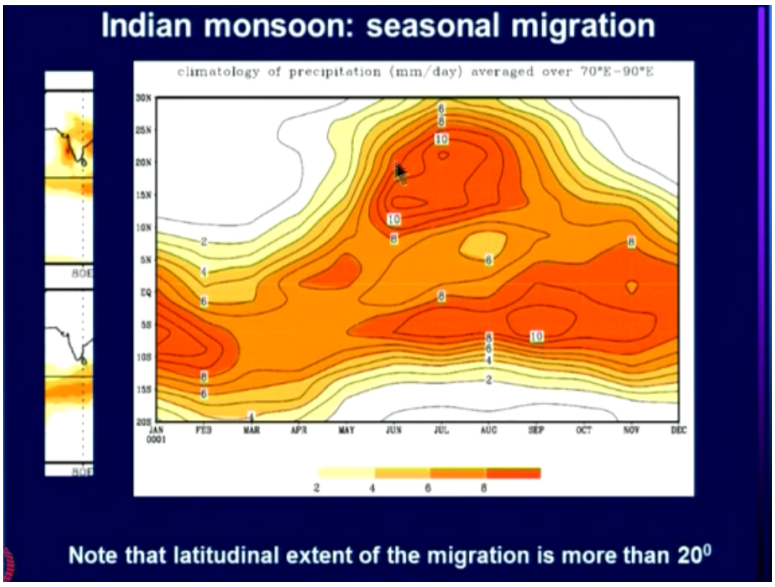

Now if you look at the Indian monsoon and now we are looking at a relatively small part of the Asian-Australian monsoon, we are looking from 70 to 90 east only. It is shown here and what you see is, in fact there is a seasonal migration, but you also see that there is an equatorial band persisting here and this is something we have seen and the latitudinal extent of the migration is more than 20 degrees.

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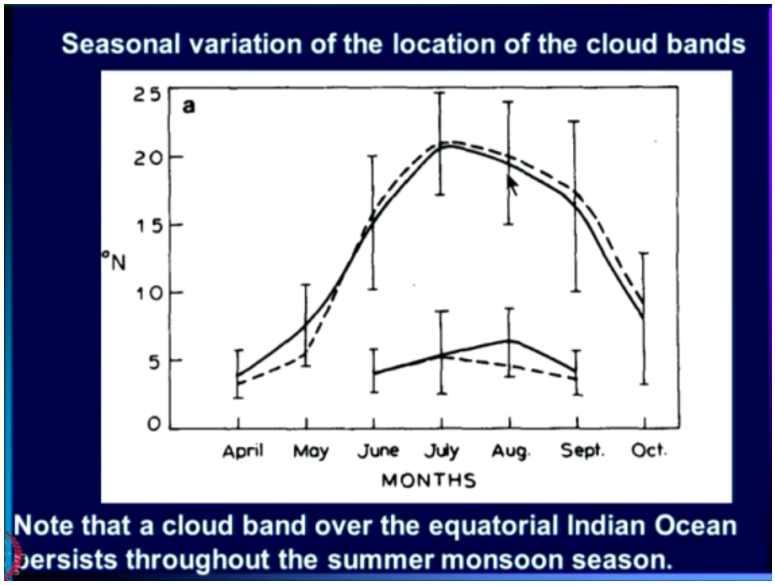

And we know very well that actually we have the primary band which moves north and you can see that the latitudinal movement here, remember the data for the southern hemisphere was not available, otherwise it starts from around 0 or 5 south and so on and you have a very large variation in latitude and this is the seasonal migration of the primary bank which is the TCZ, but there is also another equatorial band which persists through the season.

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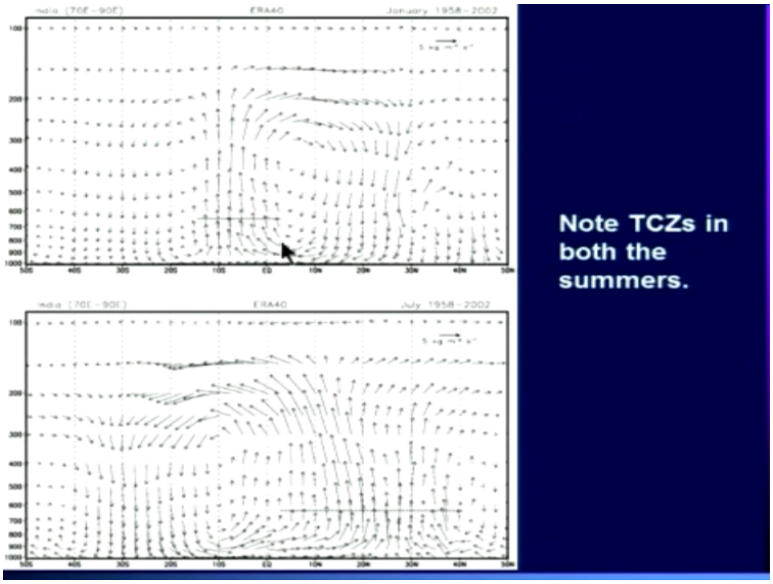

Now even when we average over 70 to 90, again we see that the rain-belt is associated with ascent throughout the troposphere and this you can see that there is a TCZ here in January and there is also an ascent throughout the troposphere in July, but notice that the region over which it is ascending in July is much wider than the one in January.

Now this is because if you look at the main picture, then you get ascent due to the equatorial band as well as the primary band. You see everything appears here and that is why there is a huge region over which ascent is occurring.

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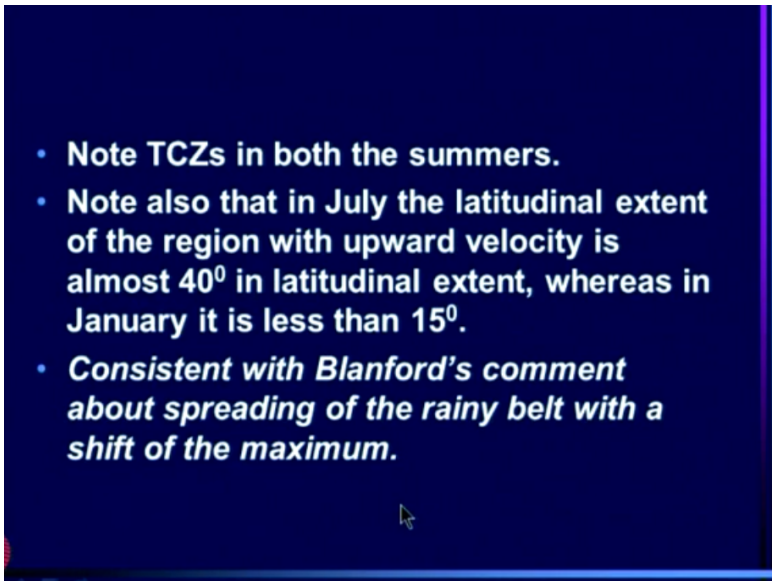

So we note, as far as the Indian region is concerned, there is TCZs in both the summers and that in July the latitudinal extent of the region with upward velocity is almost 40 degrees in latitudinal extent, you can see this is almost 40 degrees in latitudinal extent where as this is only about 15 degrees of so, each of these is 10 degrees. So you can see very clearly this is about 40 degrees in extent. Whereas January it is 15 degrees.

Now if we look at these monthly pictures, what we see is actually consistent with Blanford's comment about spreading of the rainy belt with the shift of the maximum.

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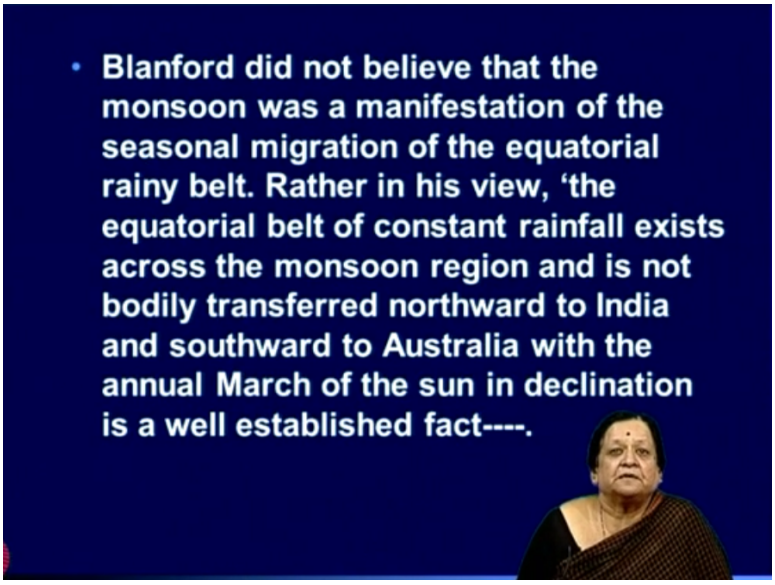

You may recall that in the last century in 1886, Blanford with the little data available have made very perceptive comments on the nature of the system that gives us the rain, the Indian monsoon and he did not believe that the monsoon was a manifestation of seasonal migration of the equatorial rainy belt. Remember he was aware that there was a rainy belt in the equatorial region, but he did not think that it is a seasonal migration.

Rather in his view, the equatorial belt of constant rainfall exists across the monsoon region and is not bodily transferred northward to India and southward to Australia with the annual March of the sun in declination is a well established fact he says in 1886.

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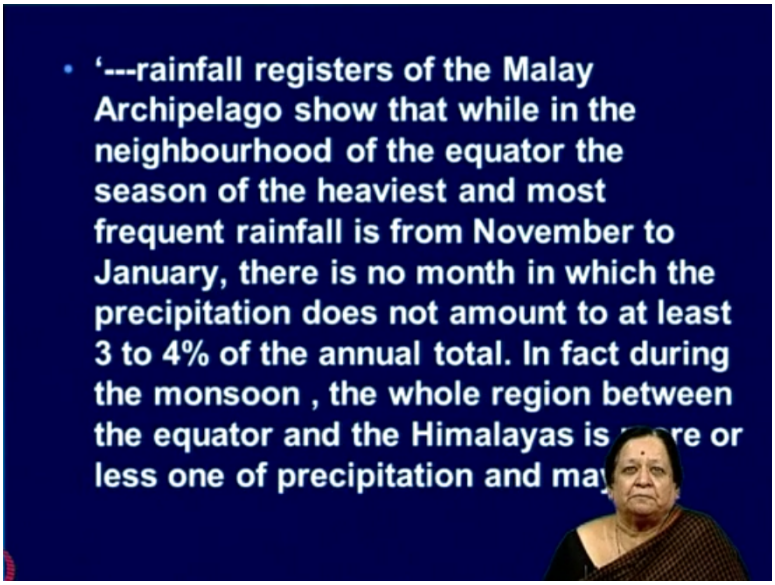

That is not a matter of marching with the sun. He continues saying rainfall registers of the Malay Archipelago show that while in the neighborhood of the equator the season of the

heaviest and most frequent rainfall is from November to January. There is no month in which the precipitation does not amount to at least 3%-4% of the annual total. So it is raining all the time in the equatorial belt which is a true statement.

In fact, during the monsoon the whole region between the equator and the Himalayas is more or less one of precipitation.

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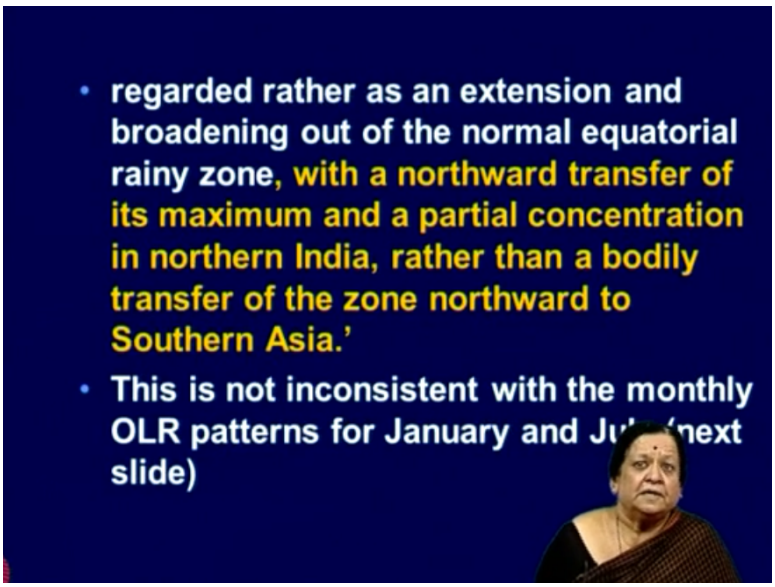

And maybe regarding rather as an extension and broadening out of the normal equatorial rainy zone which is an interesting concept. So he says it is not as if the equatorial belt moves away, it becomes broader in latitude, okay it becomes extended northward and furthermore, he says with a northward transfer of its maximum, so whereas in the winter November till January the maximum rain was in the equatorial region.

Now the maximum rain occurs to the north. Now, with a normal northward transfer of the maximum and a partial concentration in northern India rather than a bodily transfer of the zone, northward to southern Asia. So this is a very interesting and perceptive remark and in fact, the monthly pattern that we saw with ascent over 40 degrees of latitude and so on and so forth is consistent with this and it is also consistent with the monthly OLR pictures that we used to see.

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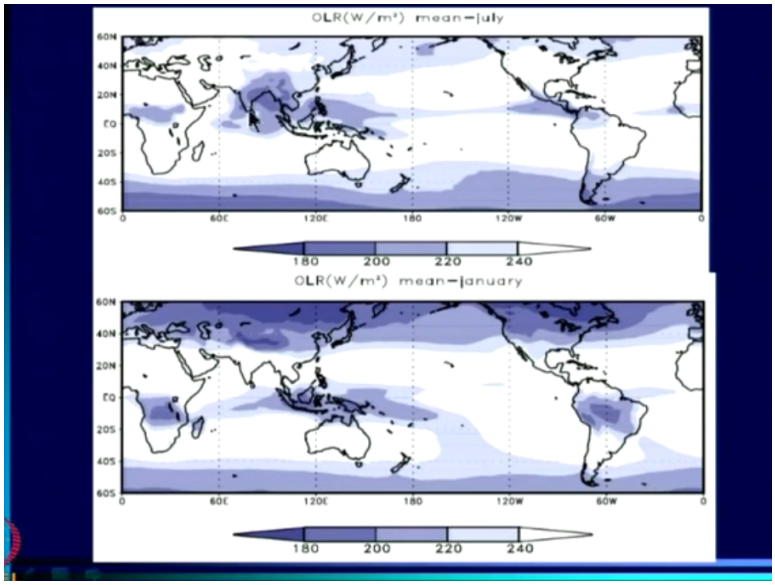

Where we see, in fact the lower inner region is a broad region with a minimum OLR around here, true, but it is not as if this one has given a (()) (27:36) to also have a low OLR region.

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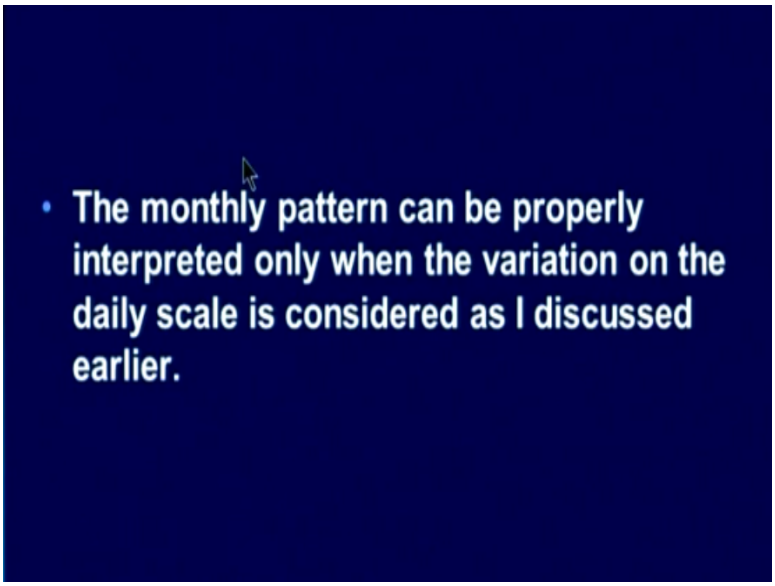

So this again is very consistent. So it is clear that the monthly pattern can be properly interpreted. Only when the variation and the daily scale is considered as I discussed earlier. So earlier we had shown that only on the daily scale we saw that this monthly pattern arouses because of the presence of 2 ITZx or tropical conversion zone and the propagation between the 2 equatorial region and the monsoon region.

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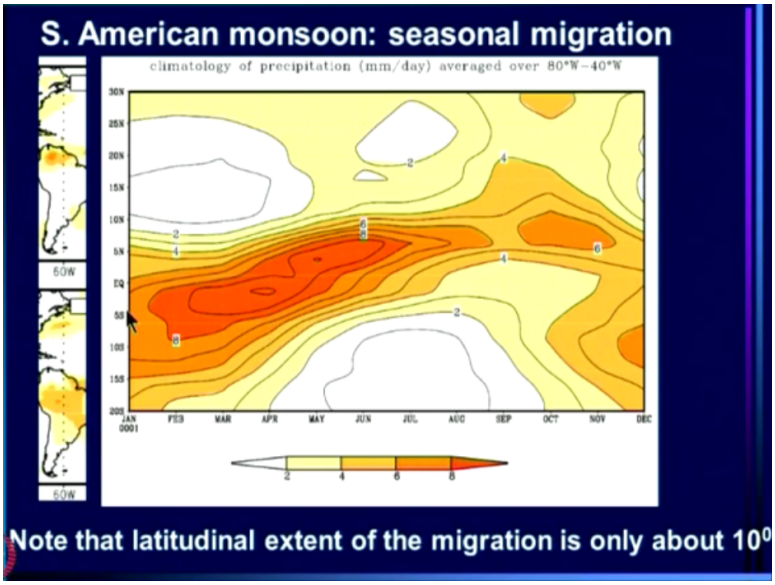

Now we consider the South American monsoon which according to Ramage is not monsoon at all. So we look at this region, this is South American and again this is July and this is January and you can say that there is a shift of the rain-belt. And if we take the average over this belt, what we see is in fact a migration.

Now the question is, say we are not so much bothered about wind, we would be happy to call this a monsoon if in fact we see that the rainy season is again to a TCZs and indeed it is.

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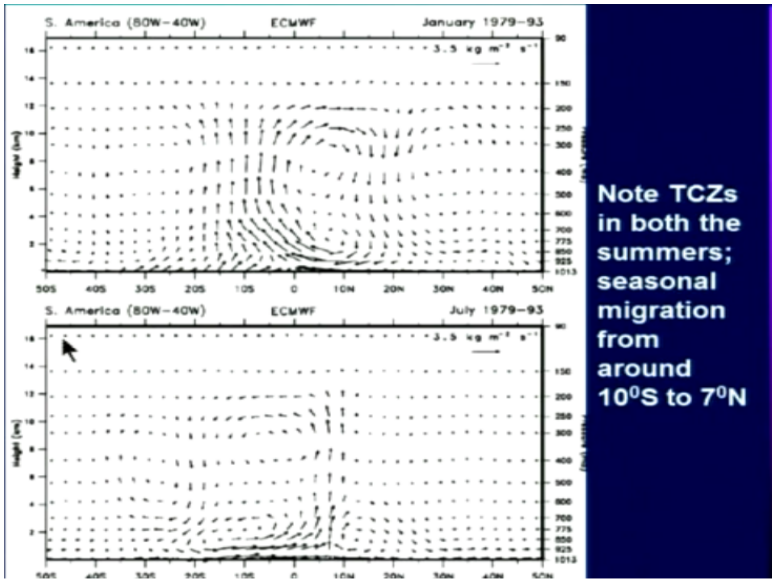

So we have for January you see a broad band of rising, again rising up to the upper troposphere. So this is again the canonical tropical conversion zone that we see here and in the northern summer we see a somewhat narrower but the same story, that the ascent is

throughout the troposphere, so we have again TCZs in both the hemispheres and a seasonal migration between them.

And the only thing is with the latitudinal extent of the seasonal migration is only from about 10% south to 7% north. So it is a little < 20 degrees. It is not as large as what we see over the Asian region or over the African region. But otherwise it seems to have the characteristics of a monsoonal region.

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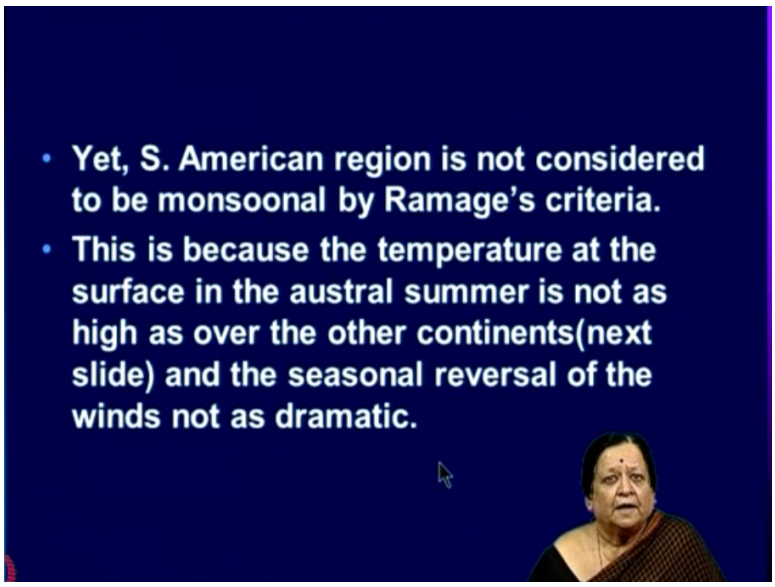

Now in spite of this, South American region is not considered to be monsoonal by Ramage's criteria. This is because the temperature at the surface in the austral summer is not as high as the other continents and the seasonal reversal of wind is not as dramatic.

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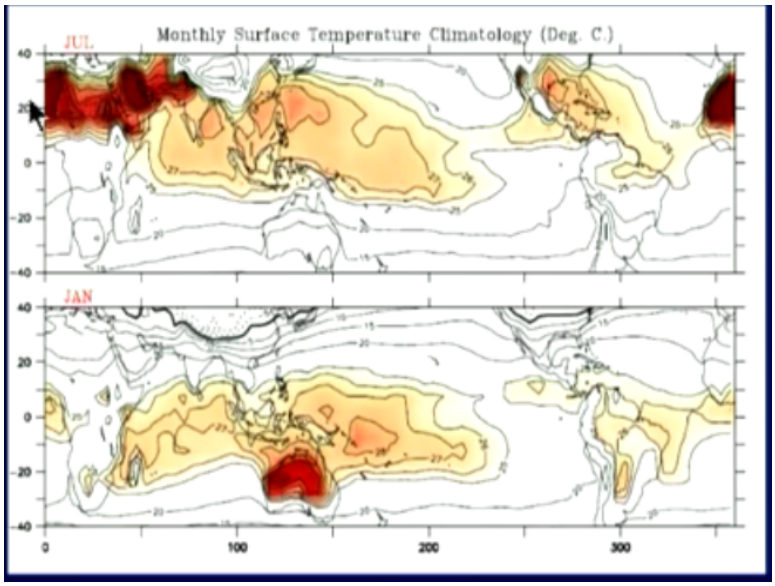

See, this is what I meant when I said that the third criteria of Ramage which said that the winds have to be > 3 m/s wind speed, may have been the one that killed the possibility of having a monsoon over the South American part. Now you see, this is the surface air temperature and you can say reds are very hot. And you can say how hot it is here in the northern summer.

And this is the Sahara and our Thar Desert and this is the Australian desert in the southern summer, but compared to that the temperature contrast is not much over South American and for that matter well Africa also. Africa also there is not that higher temperature but the Ramage has no problem in calling this monsoonal region.

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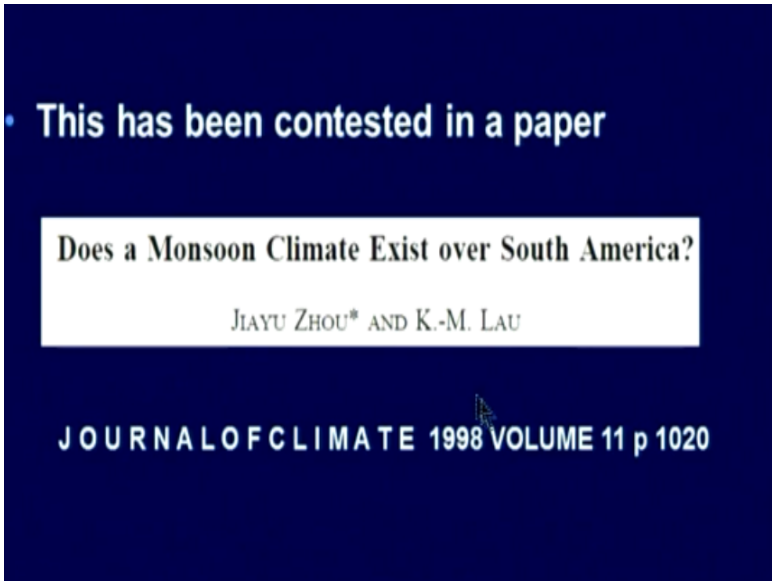

But I believe there is some problem in calling this, as far as Ramage is concerned, but then this has been contested in a nice paper called does a monsoon climate exist over South America by Zhou and Lau and this came out in 1998.

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- They showed that although the seasonal reversal of the winds is not as spectacular as in the Indian or African monsoon, the major features i.e. seasonal migration of the rainbelt (which we see as being associated with the TCZ) and cross equatorial flow (next slide) are present.
- I believe that S. America is a monsoonal region since there is a clear seasonal migration of the TCZ , but the monsoon is weaker than the Asian-Australian or African monsoon.

And what is showed was that although the seasonal reversal of the winds is not as spectacular as in the Indian or African monsoon, the major features that is seasonal migration of the rain-belt which we see as being associated with the TCZ, remember we just saw that and cross equatorial flow which is the next slide are present.

Now you have to remember that say cross equator inflow is another important facet of the monsoon and this is the low level flow during the thing and you can see that the air is actually coming from the other hemisphere.

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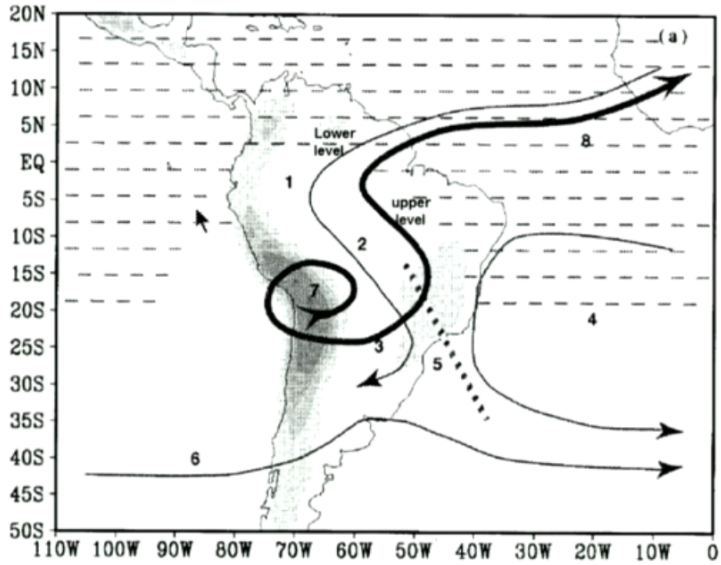

Now you will remember that when the monsoon trough gets established over the Indian region we have a very large cross equatorial flow which is particular large near the coast of Africa and that cross equatorial flow we had seen when we looked at the Indian monsoon.

Now that occurs on when you have a well developed trough in the summer hemisphere. So in that case it sucks in air from the other hemisphere that is precisely what is happening here.

You have air coming in from the northern hemisphere into the southern hemisphere and returning to the northern hemisphere that is the heavy line there. So this is what they showed that they have a cross equatorial flow is there and in fact we do see TCZs is in both the season. So I personally believe that South America is a monsoonal region since there is a clear seasonal migration of the TCZ, but the monsoon is weaker than the Asian Australian or African monsoon because the temperature gradients are not so spectacular.

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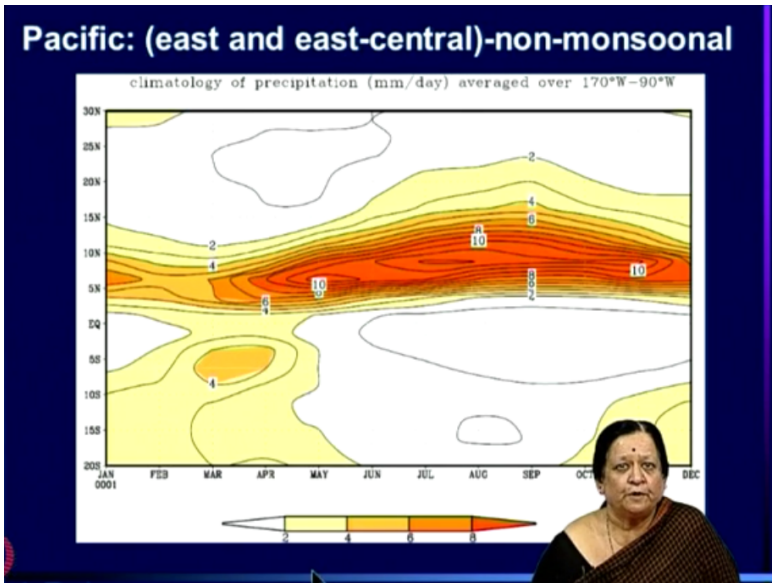

Okay. Now just to complete the stories, this we look at a non-monsoonal region. This is the pacific, east and east central, okay? So this is 170 west over up to 90 west and what you see is in fact a persistent system which strengthens in July-August and weakens afterwards, but it just hangs around the same place. There is no migration and we call it monsoonal. Now as I mentioned it weakens and we saw that and that is seen here.

Now this is January-February-March, when the system is very weak and it is comparable to the canonical ITZs or the ITZs over the west pacific only in this part. Only over our northern hemispheric summer. Here it is very weak rain. And let us see now what vertical circulation looks likes.

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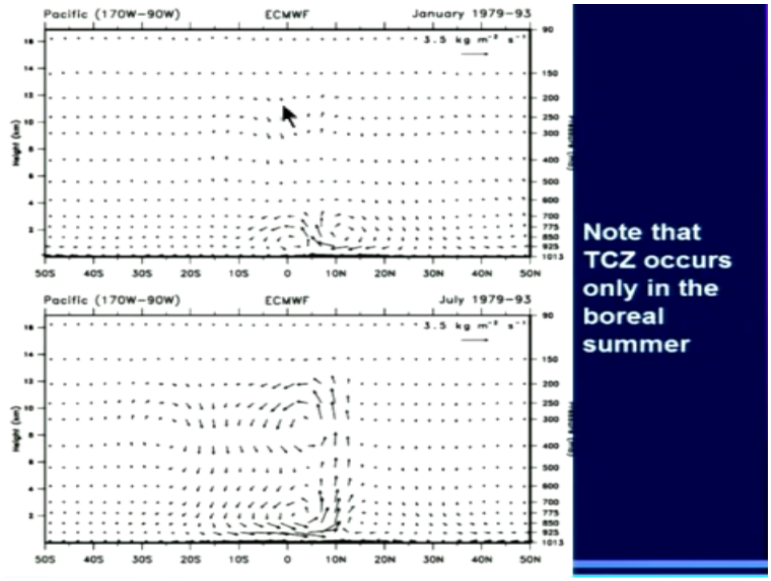

And that is very interesting. When we look at 170 west to 90 west, when we look at the summer, there is no problem. There is ascent through the troposphere here and descent here, but when we look at Vintage January case then what you see is a (()) (34:21) kind of a circulation. You say that there is ascent only up to here, okay. And there is no ascent throughout the troposphere,

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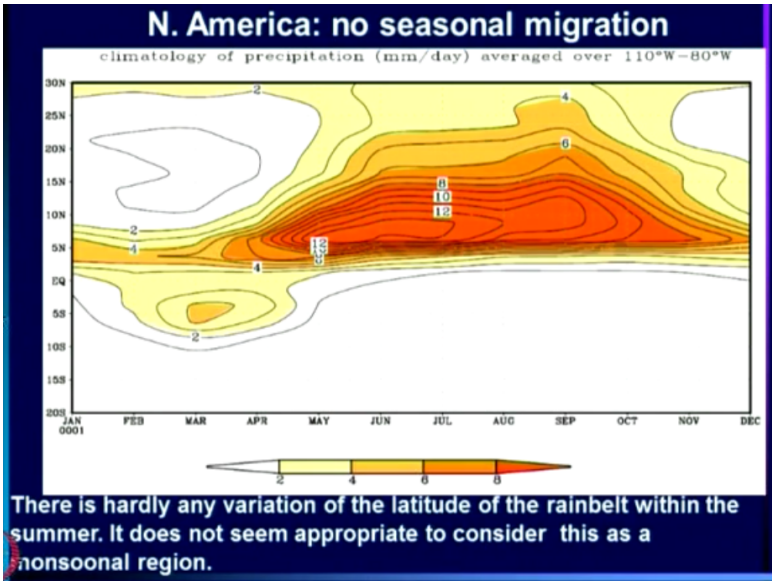

So that what we are seeing is January-February, this little rain that we are seeing here is actually associated not with the TCZ, but with the (()) (34:48) kind of circulation and there must be a SST maximum there even in January. This is the one. This is the pacific one.

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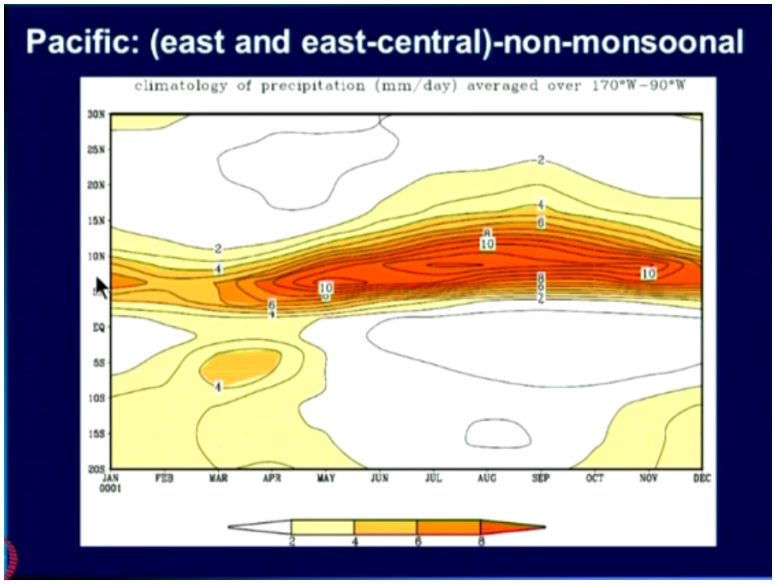

And so there must be even in January there is rain, but that rain cannot be attributed to a TCZ that is very clear, the TCZ occurs only in this part, only in the northern summer and that is what this diagram is telling you about the pacific. Now let us see about North American monsoon. And this is the so called North American monsoon region which is 100 west to 80 west and what you see here is in fact, there is considerable rain in the summer and very little rain in our summer, northern hemispheric summer and very little rain outside.

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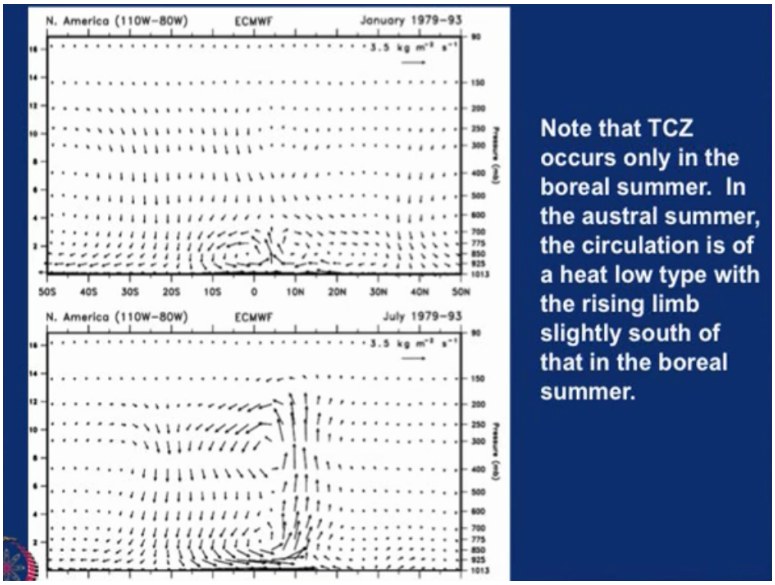

And this is the picture which in fact to what you saw in the East Pacific, adjoining East Pacific because here again you see ascent throughout only in July. And what you see in January is a heat low kind of circulation. So what you are getting is not a migration of the TCZ at all. It is the occurrence of a TCZ, only in the northern hemispheric summer.

So it is still associated with summer rains, no doubt and so are monsoonal region associated with summer rain. But the point is that we believe that monsoonal regions are characterized by seasonal migration of the rain-belt from the other hemisphere. That does not occur for the North American monsoon. So given this constant if people would like to call it a monsoon, what is in a name.

But there are major problems and major difference between this and the canonical monsoonal regions of the world.

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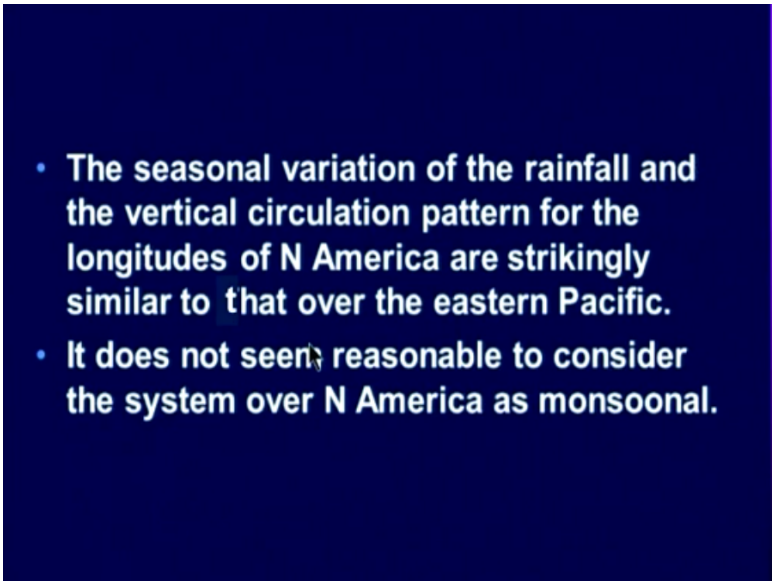

So the seasonal variation of the rainfall and the vertical circulation pattern, for the longitudes of North American are strikingly similar to that over the eastern pacific. It does not seem reasonable to consider the system over North America as, monsoonal. That is my personal view.

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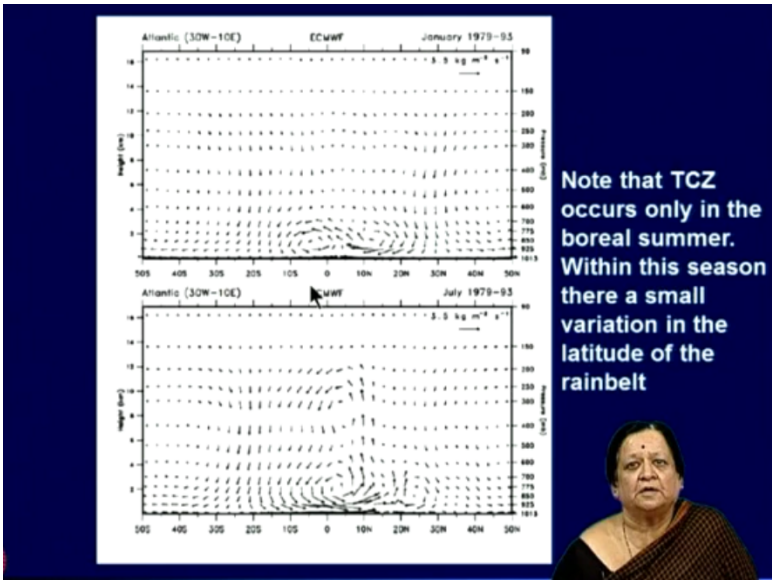

Now, this is another non-monsoonal thing which is Atlantic and there again we are seeing very similar pattern. Only in one season we are getting a TCZ kind of circulation. In January there is none.

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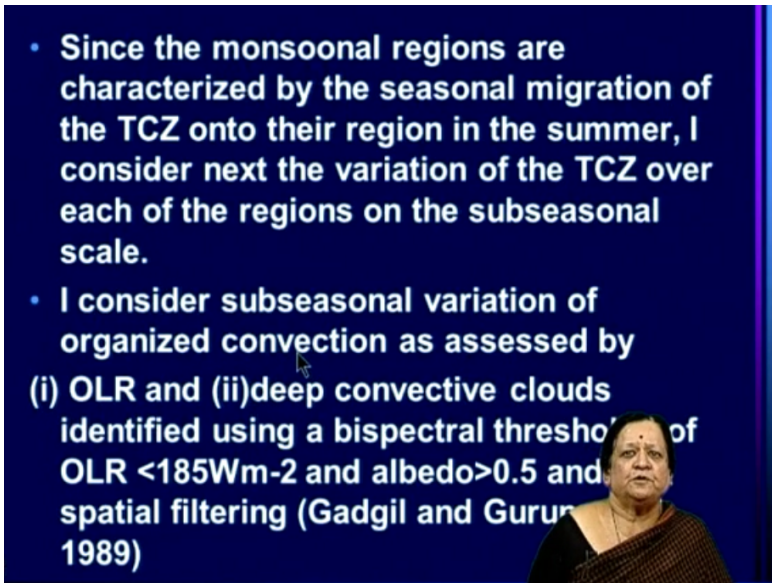

Since the monsoonal region are characterized by the seasonal migration of TCZ on their region in the summer, we will consider next the variation of the TCZ over each of the regions on the sub seasonal scale. Now why do we do that because we found that for the Indian monsoon, you have to understand the monthly scale, we had to go to the subs seasonal scale variation.

It is only when we looked at daily satellite imagery and saw that there 2 tropical conversion zone. One over the warm equatorial Indian ocean and another over the heated sub continent

to the north and there were fluctuations of these TCZs with an outward propagation of equatorial band on to the heated content. It is only when we realized all this could we understand what the monthly pattern look like.

So it is of interest to see. Are these features actually common to all the monsoonal regions that we have seen or are they special to the Indian region. So to do that we have to again look on the daily scale and I have done it by 2 ways. Now we have developed, because we saw that most of the secret of the tropics was in the tropical conversion zone. We have developed a bi-spectral algorithm to identify deep convective clouds.

You may remember when I mentioned (()) (38:38) HRC dataset, highly reflective cloud dataset. That also was bi-spectral. What he had done was first select. The clouds which were reflecting a lot albedo was high and then from them filter our clouds which were lower middle, high using intrared.

Now intrared we have a measure which in OLR, which is the standard one most people use and it is not bad because most of the time it is associated with deep conviction but we have also developed an algorithm in which we had used to threshold OLR of 185 watts per meter square and albedo> 0.5 and then use special filtering. And this was to objectively identify organized convection comprising deep convective clouds.

So both these were available and using this algorithm, there is a paper by Gadgil and Srinivasan in which we had looked at sub seasonal variation of clouds over the entire global tropics. So I am going to just show you what these 2 things say.

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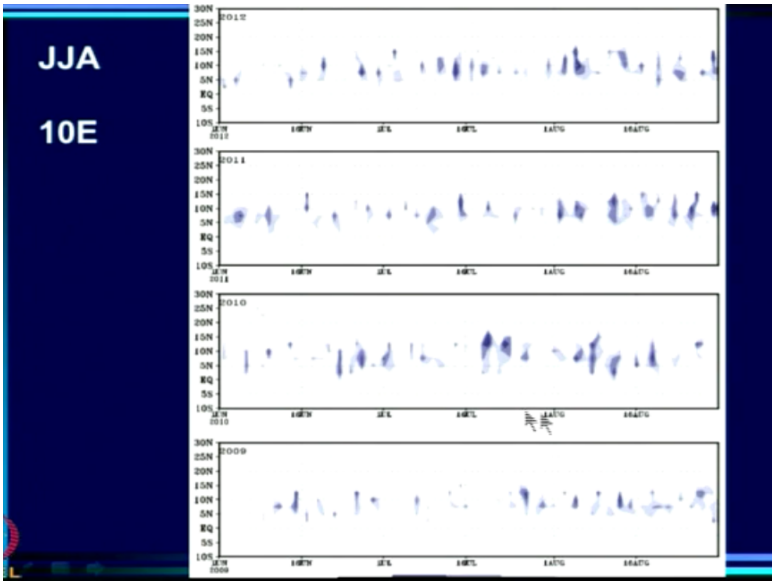

So first of all we start from Africa. You may remember that 10 degrees east is Africa and June-Jul-August. Perhaps I should quickly remind you what that is. Okay. There we are, alright. So this is 10 degrees east. This is the African rain-belt that we are looking at and so first of all we are going to see what is the variation in June-July-August of this rain-belt and that is what we will see now.

Okay, this is what we have, so that is over 10 degrees east and what we have market here is actually, sorry you are not able to see it but what we have here is again this is < 200 is the lightest, 200 to 180, what is 180 to 160 and below 160, darkest shade is below 160. And what you see here is that you know it is a highly intermittent phenomenon. These deep clouds occur on a regular basis, in a certain latitudinal band, no doubt.

And this we have done for 4 years now. This is 2009, 2010, 2011 and 2012. This is the last year. And what you see is it does not last for more than maybe 1 or 2 or 3 or 4 days, okay? Very short active space and it keeps generating and there are sometimes long spells in which it is absent and this frequency of these long spells is more in some years like you see here than in others 212 it was an active year.

And very much more in 2009. In 2009 you will see hardly any action going on here and this is for June-July and August, 3 months only. So what you see is, there are no propagation. The ITZs hangs around in this region and fluctuates in intensity. It dies it revives, it dies it revives. This is the general pattern which is very different from what we saw over the monsoonal region.

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The first one was OLR and this is from the bi-spectral algorithm that I showed you and this is of course for earlier years 75-76-82 and 83 and what you see is something very similar here. It appears and disappears, not much propagation, sometimes it is around for several days, most of the times the active spends are very sharp. So this is the nature of the African monsoon.

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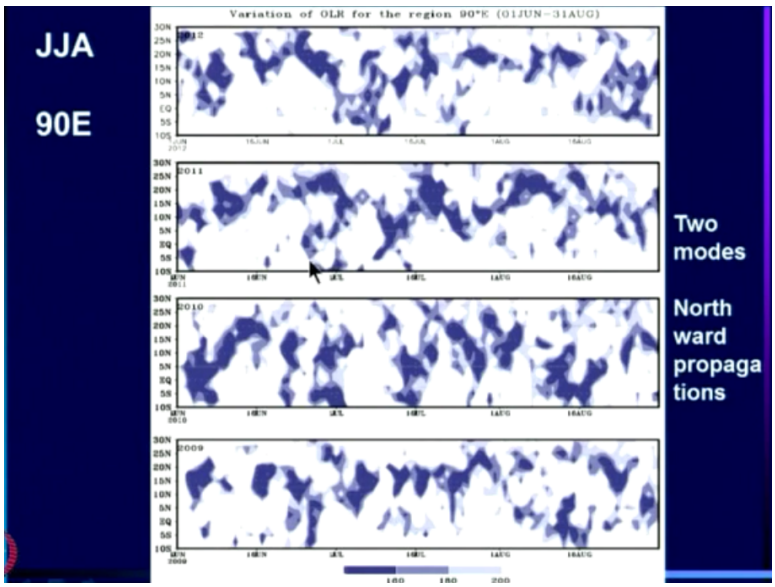

You seen in contrast using the very same criteria, some shares that we have done for the African one, this is 90 degrees east, which passes through Kolkata, more or less through the head Bay of Bengal. This is the center of the Asian-Australian monsoon. This is for June-July-August and you can see here all the things that we saw that there are 2 places where it can form either in the south or in the north and there is this very clean northward propagation.

Northward movement that you see, this is latitude and this is time and very prominent northward propagation that you see, I was mentioned here, this is 2012, normally we have a northward propagation towards last week of July and that you have seen in all these 3 years, very clearly. But this year we had as part of a national climate programs we had 2 ships in the bay trying to study how the northward propagation occurs, once in the head bay near here and one around here.

And unfortunately the ships were here exactly in this period and not a single northward propagation occurred, they came back around here, then another propagation occurred. See this is the height of variability we get from year to year. So even studying it in real life possess its own problem. See, in other years there are so many frequent northward propagations that we see.

So anyway, so this is an old story, we have seen that 90 degrees is the Indian monsoon there are 2 more and there is northward propagation.

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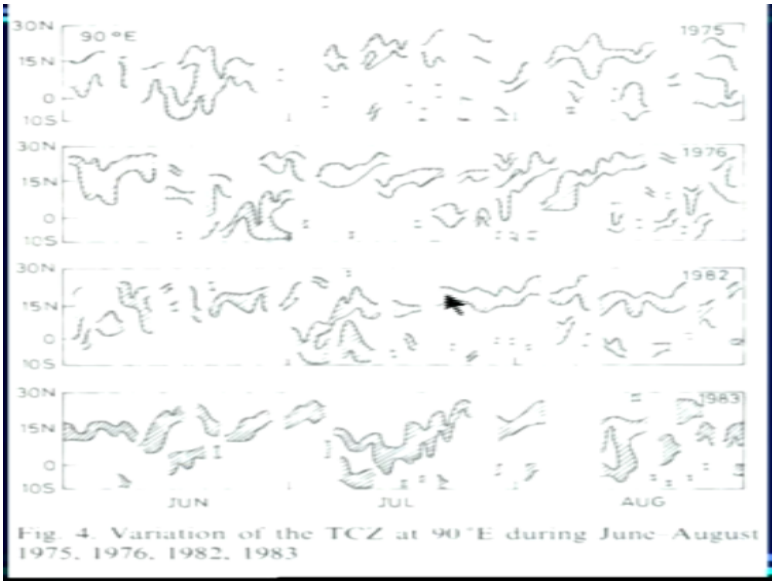

Fig. 4. Variation of the TCZ at 90°E during June–August 1975, 1976, 1982, 1983

And you will see that also with the bi-spectral algorithm again very nice north propagation that you see here and then hanging around another northward and so many northward propagations here. And the fact that there are 2 places where they get generated, here and sometimes here as well. So the 2 mores are also very clearly seen.

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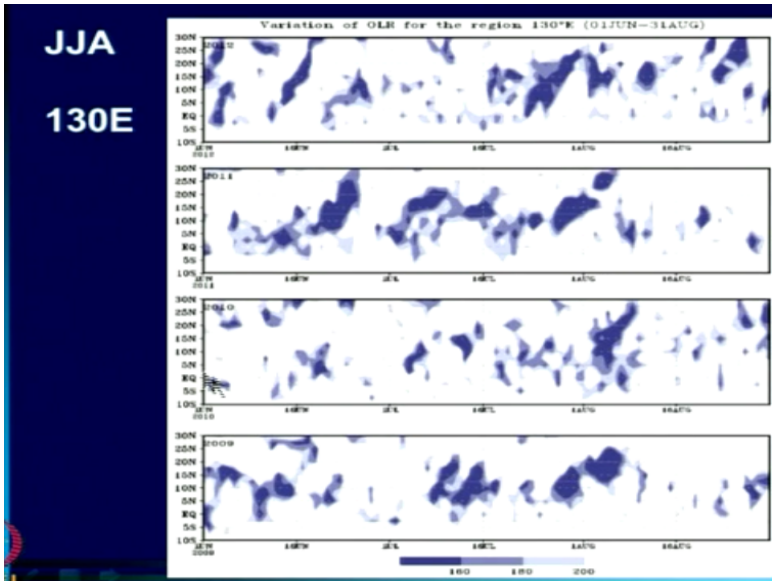

Now this is 130 East, this is just towards the west pacific. And there also you can see some nice northward propagations somewhat similar to the Indian region.

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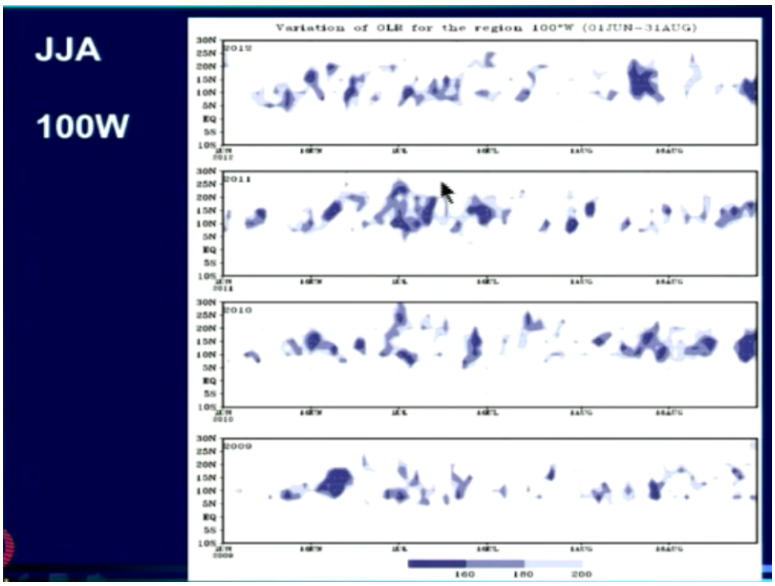

And this is 100 west now. 100 west is east specific and what you will see here again this is JJA, you will see that it is always around 10 north, okay, this is the non-monsoonal specific region and it occurs and disappears, it appears and disappears. It is simply fluctuation in situ. There is some propagation, but no clear cut dominance of northward propagation or anything like that you can say that there are cases when which it is highly intense and cases in which it is not there at all.

So you get these intense blocks here and here and here when it is very active. So no propagations at a single location in which it oscillates, a band in which it oscillates. That is the non-monsoonal one.

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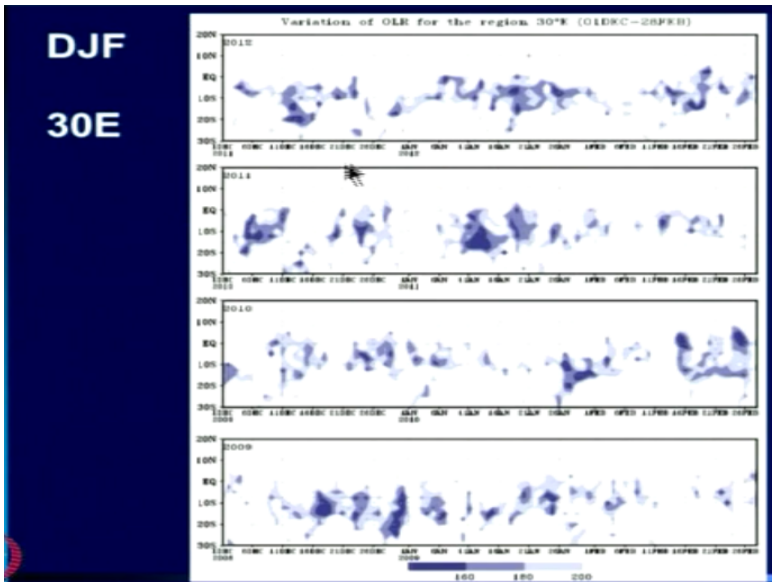

Now we go to DJF 30 degrees east. This is over Africa and over Africa sometimes you do see some forward propagation, sometimes you see like in our case, bimodal distribution with a lot of things arising around the equatorial region. But they do not occur year after year, unlike our region.

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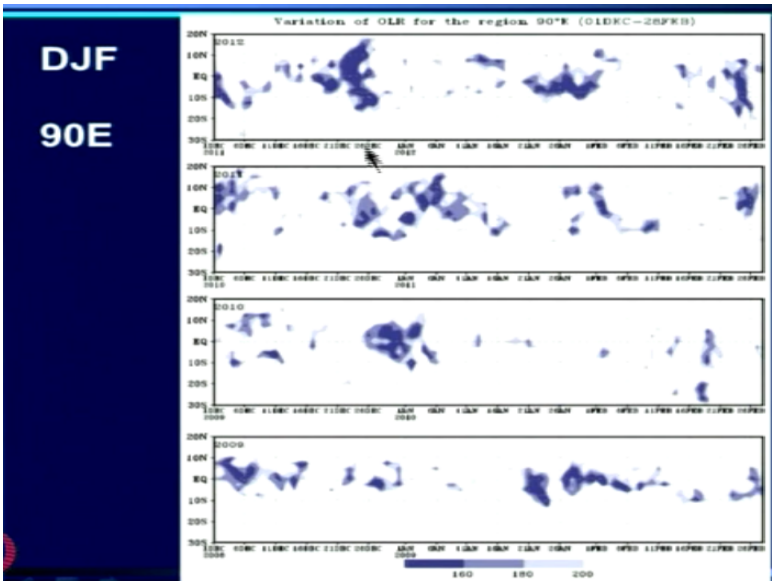

And this is the DJF 90 degrees where you are seeing some southwards propagations very cleanly but again only in some years. And this is DJF 130, so now we are getting to the Australian monsoon kind of thing, there again there are some cases in which you see, very

clean poleward propagation, but you do not see it every year, it is very different from the Indian region.

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This is again 130 east from our wise bi-spectral algorithm. There again you see, there seem to be 2 modes here. One in the equator and something coming in the north and you see that here as well. But you know both are fluctuating. There is no clear cut propagation except you see one year. Nice propagation which is poleward.

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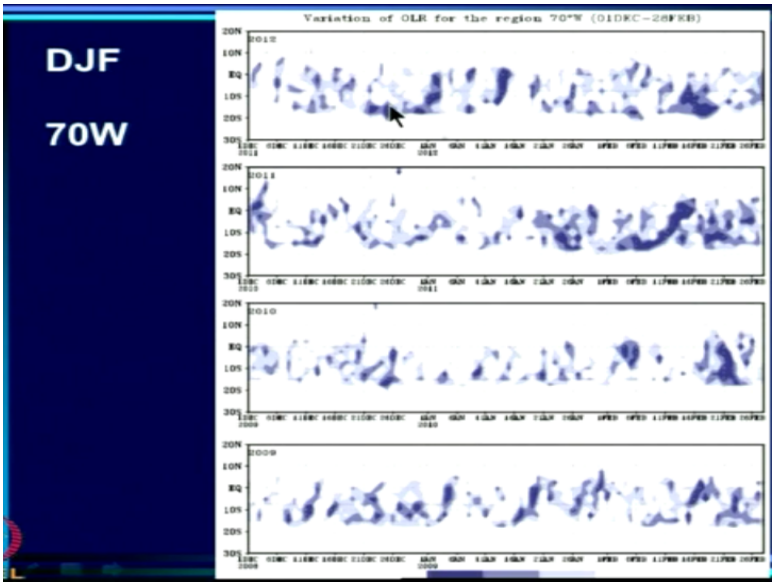

Okay, and this is 70 west, so this is South America, now South American again you see sometimes very nice poleward propagations but there are also equatorward propagations. So it is just fluctuating in space, as well as in time, unlike the African one it fluctuates over a

much larger latitudinal belt, the South American monsoon thing. But there is no clear cut biases towards propagation in one direction.

See for example, here it seems to be propagating towards the equator and here also it is propagating through the equator and here it is propagating towards the pole. So there are differences here.

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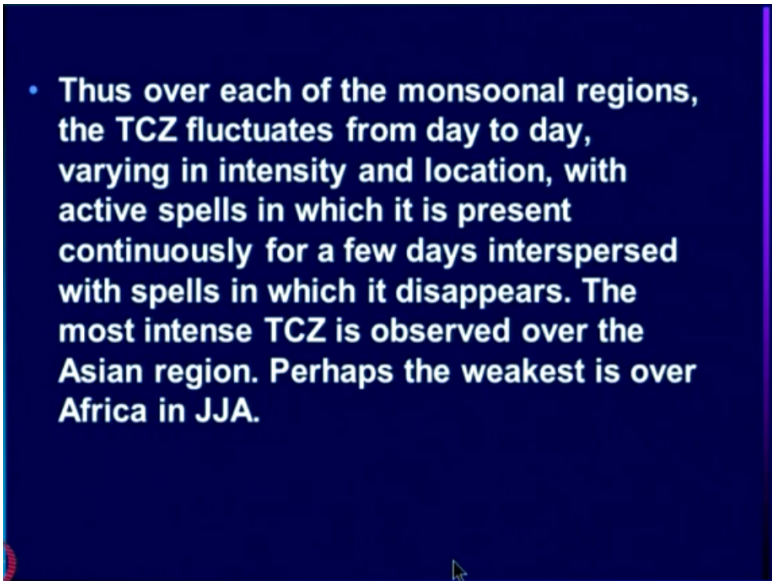

And the same story when you look at the bi-spectral. So over each of the monsoonal region, the TCZ fluctuates from day today, varying in intensity and location with active spend s in which it is present continuously for a few days, interspersed which spells in which it disappears.

The most intense this is observed over the Asian region and perhaps the weakest is over Africa in June-July-August where it appears to be just an extension if you wish of the TCZ over the eastern Atlantic region.

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Now poleward propagations are seen, over the Indian monsoon region every year during the summer monsoon. They are seen in some years over the Asian region and 70 west during the winter DJF. In later lectures we shall see that the variation of the monsoon rainfall and subseasonal scales is a manifestation of this subseasonal variation of the TCZ. It also has impact on interannual variation. So now we have a picture of how we get rain over monsoonal regions of the world.

It is primarily associated with the tropical conversion zone. What is the typical pattern of variation of this tropic conversion zones over different regions from day today on the subseasonal scale and of course we can also get variation on the interannual scale. Now the important thing about identifying the system is a tropical conversion zone is that to understand the fluctuation of this disease.

There are 2 kind of hypothesis that we have to test, one is factors that will be important for the oceanic TCZ as well. These are things like cloud variation feedback, so on and so forth which can lead to fluctuation of our oceanic TCZ. In addition, because the monsoonal regions are continental there will be feedbacks that are special to continental TCZs which in fact involves things like land surface processes so on and so forth.

So it is the sum of all these factors that lead to the fluctuations of the monsoonal regions. In addition to that of course there is a general factor that TCZ tends to compete with one another. We have seen that for the Indian monsoon region, the CTCZ competes with the oceanic TCZ as well as TCZ over the west specific and so on. So there are these tele-

connections between the different TCZs which will also play a role in determining the variability of the TCZ.

And therefore the variability of rainfall. So there has been, in some sense unification of the theories, understanding that the monsoon from one place should not be that different from another. The basic system is similar. Of course difference is there, topography differences in land surface, in the shape and size of continents and so on will have an impact not only on the mean monsoon pattern.

But variability and it is only when we understand all this will we be able to predict variability of the monsoon using dynamical models. Thank you.