The Monsoon and Its Variability

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Lecture - 09
Evolution of the Ideas about The Basic System Responsible for The Indian Monsoon - Part 1

In the last lecture, we have started talking about what is the basic system responsible for the monsoon. We already talked about the first hypothesis for the system namely that the monsoon is a gigantic land-sea breeze. Now in this lecture, we will talk about the evolution of the ideas about the basic system. You may recall that in the last lecture, we ended with comments by Simpson, which said that the land-sea breeze theory is not tenable.

Because we cannot understand the observed spatial and temporal variability of the monsoon on the basis of land-sea breeze theory. We cannot explain it by land-sea temperature contrast. So now let us look at how the ideas about the basic system have evolved.

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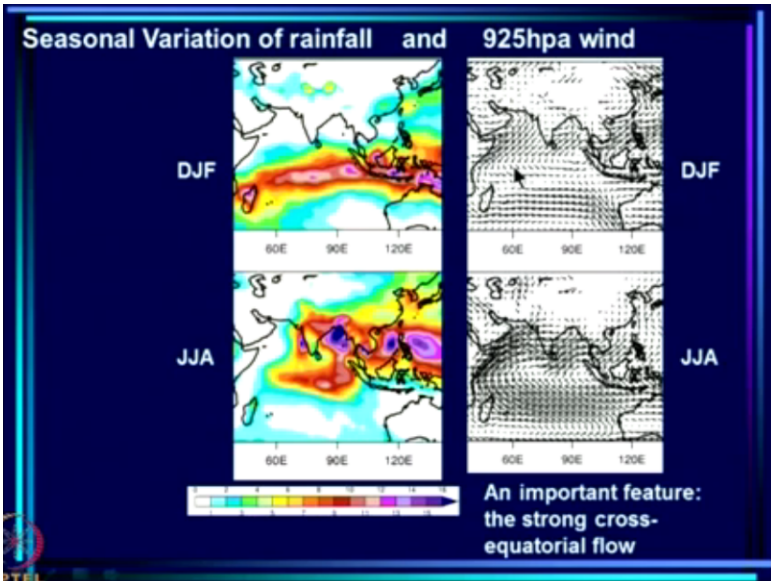

And that is what I propose to do here and before we do that let us remind ourselves what is it we are trying to understand? What is it we are trying to explain? And it is of course the seasonal variation of rainfall and wind. Now here I have the rainfall for December, January, February and it is over the equatorial region and June, July, August and the monsoon has come over land, there is a rain here.

Now the winds also change in direction as you see they are in December, January, February from the northeast and they change to southwest here. I want you to also note an important feature of the winds in June, July, August or summer monsoon season namely that there is a crossing that occurs. These are the southeast trades and they cross over. They cross over as southwest winds when they come to the Arabian Sea.

This cross-equatorial flow you will realize is very important and many theories have in fact talked in detail about that as well.

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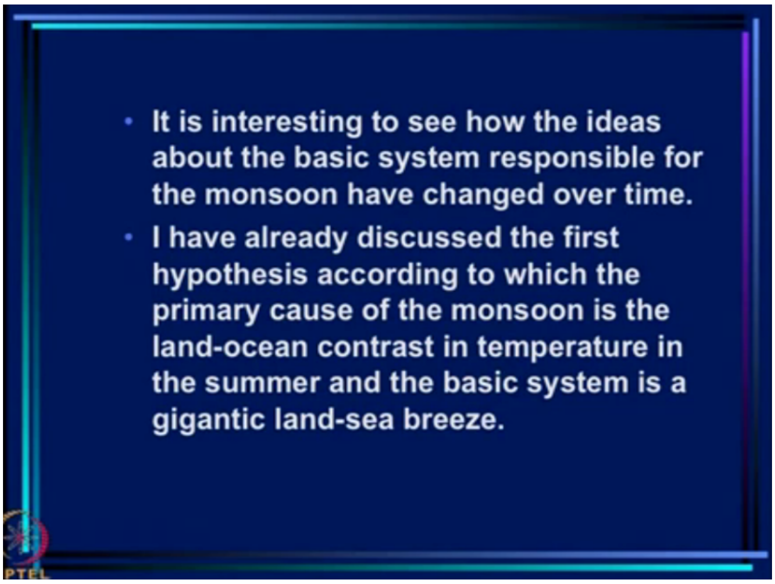

So what we are proposing to do in this lecture? Is to see how the ideas about the basic system responsible for the monsoon have changed over time. Now as I mentioned the first hypothesis is that the primary cause of the monsoon is the land-ocean contrast and in temperature in the summer and that the basic system is a gigantic land-sea breeze.

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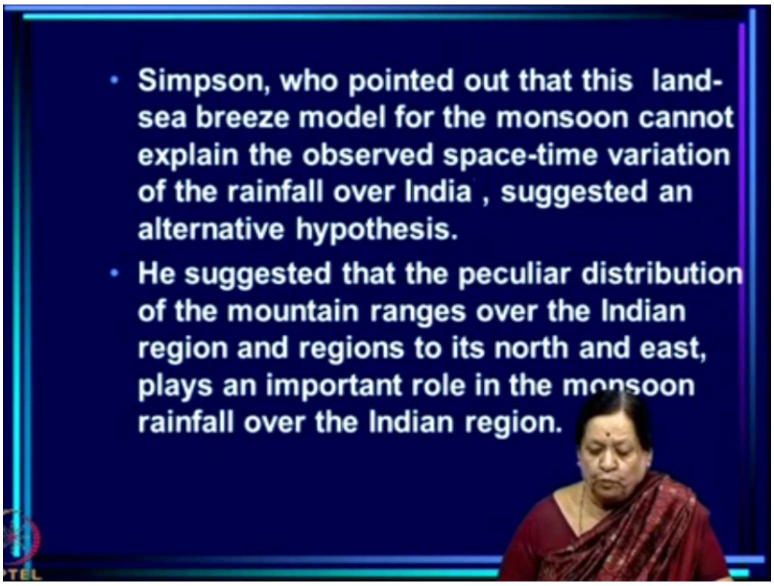

Now Simpson who actually pointed out that this land-sea breeze model for the monsoon cannot explain the observed variation of the rainfall over India suggested an alternative hypothesis, an alternative hypothesis to land-sea breeze. He suggested that the peculiar distribution of the mountain ranges over the Indian region and regions to its north and east plays an important role in the monsoon rainfall over the Indian region.

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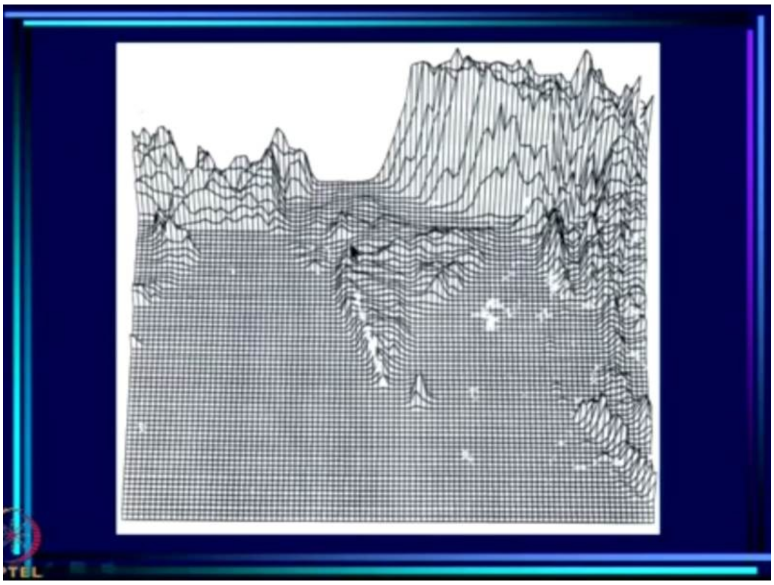

So this is the new theory and an important element of that theory is the peculiar topographic distribution. This is the mountains over India. This you see is the huge Tibetan Plateau to the north and these are the Western Ghats and there are of course hills in the northeast region as well.

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Here you see it as you see it in an atlas. So you have this Himalayas to the north and you have also high mountains on the Burmese Coast and there are the Western Ghats and Eastern Ghats and of course Vindhyas and Aravalis and so on and so forth. So this is the peculiar mountain distribution over the country.

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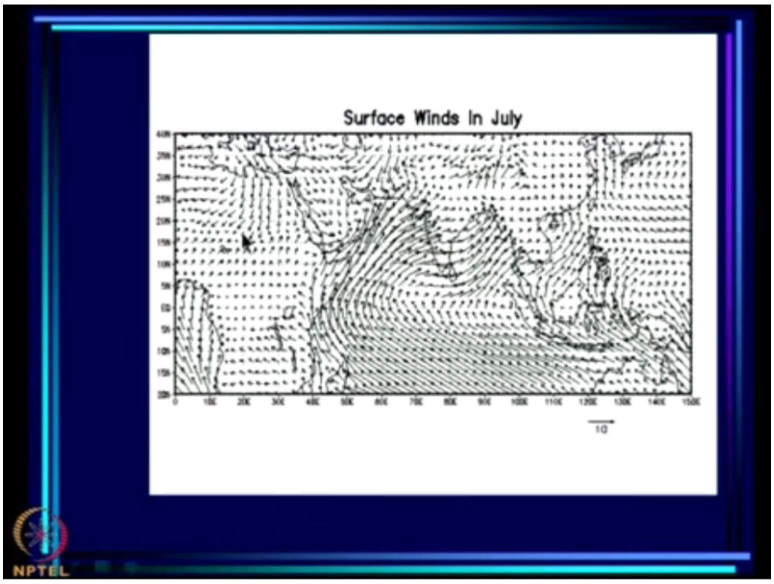

And these are the surface winds, which you have seen before. This is the cross-equatorial flow and now here you can see that the winds are coming almost at right angles to the Western Ghats.

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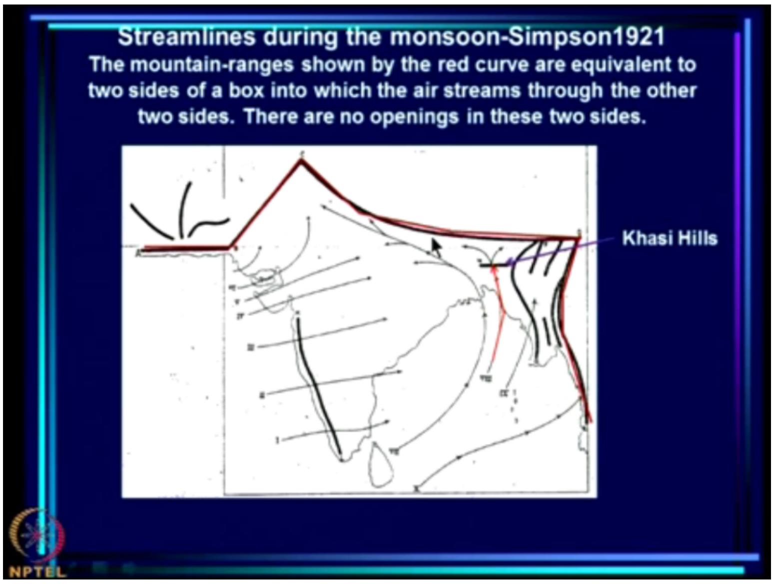

So what is Simpson's theory? Simpson has drawn these stream lines of the flow during the monsoon, they go this way and what he says is that these mountain ranges, he is talking about the mountain ranges, which I marked as red. These mountain ranges in fact are equivalent to 2 sides of a box. You can say on the north and on the east okay. There are mountain ranges so there are 2 sides of a box into which the air streams through the other 2 sides.

So these are the other 2 sides, the air is streaming through the other 2 sides, but the box is closed to the north as well as to the east okay. There are no openings in these 2 sides and the air is flowing from the other 2 sides.

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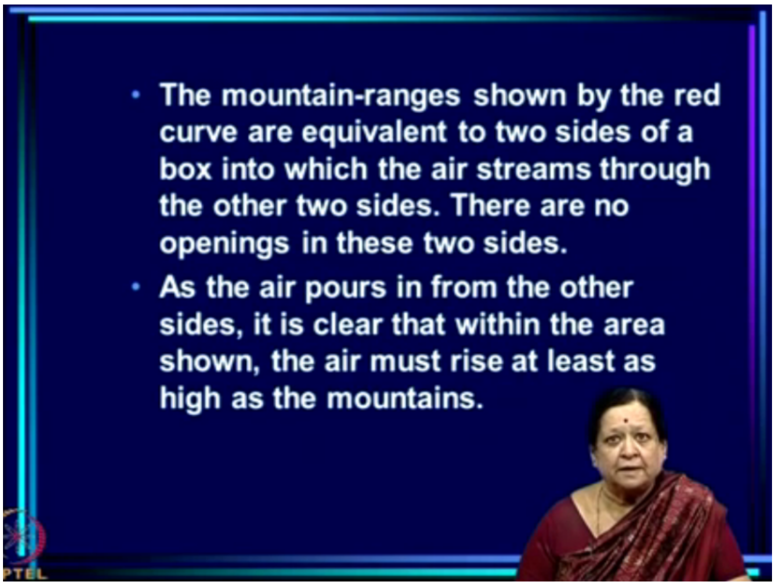

So what he is saying is that the mountain ranges, which I had colored red are equivalent to 2 sides of a box into which the air streams through the other 2 sides. Now there are no openings in these 2 sides. As the air pours in from the other sides, it is clear that within the area shown the air must rise at least as high as the mountains okay. This is his logic.

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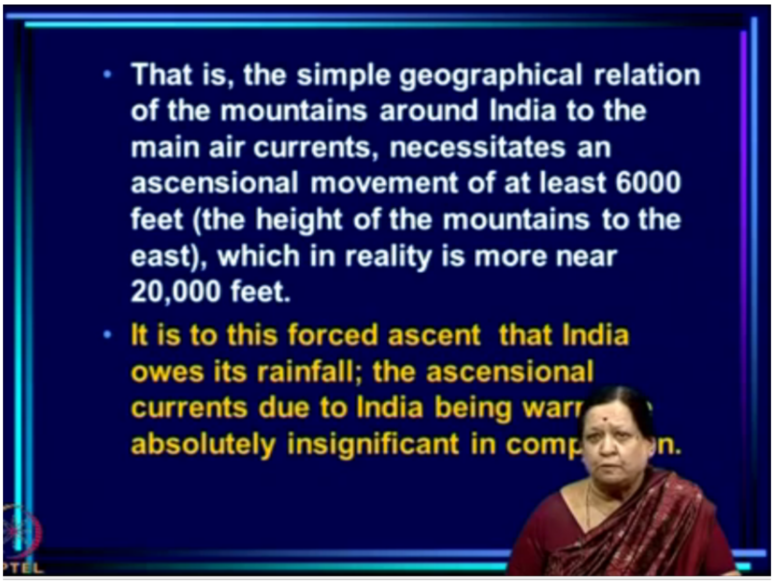

So he is saying that the simple geographical relation of the mountains around India to the main currents necessitates an ascensional movement of air at least up to 6000 feet that is the height of the mountains to the east, which in realities more near 20,000 feet. So actual ascent of air is up to very, very high level. He is aware of that and he is saying minimum ascent up to 6000 feet has to occur simply.

Because that is the height of the walls of that box on the Northern East okay. So he is saying because there are walls there is force ascent of air because air that is flowing in has to get out of the box and the only way it can do it by ascending. So it is to this force to ascend that India owes its rainfall. The ascensional currents due to India being warm are absolutely insignificant in comparison.

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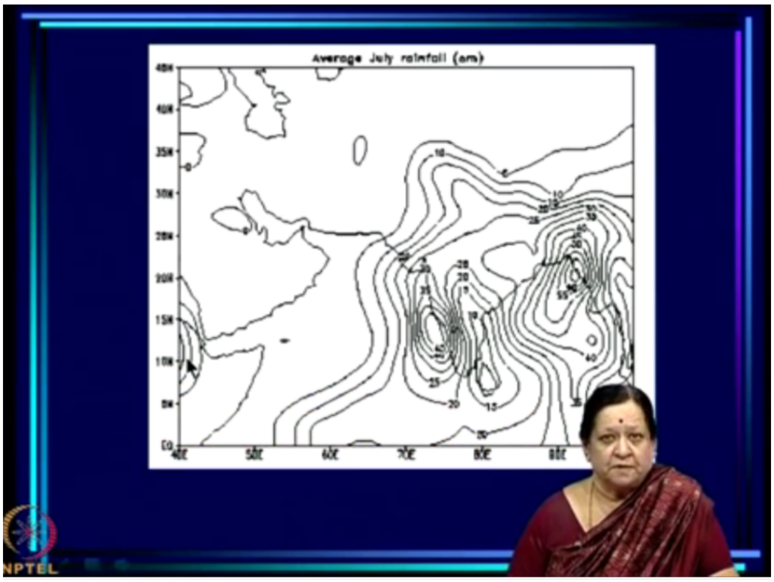

So he is saying the fact that land is warm compared to ocean. It will generate some winds and ascend, but what is more important is this force ascent due to the mountains okay. Now this is the mean average rainfall July rainfall over India and this is of course from the sea map, which is partly a satellite derived and partly based on land gages, but it has a coarse resolution compared to the rainfall maps that we see from India Met Department.

So this is the high rainfall on the west coast that you see very, very low rainfall here okay. This is Tamil Nadu coast. This is the south eastern coast of the peninsula. There we have very low rain, very high on the west coast then very high here in the northeast including Cherrapunji, which gets one of the highest rainfalls and then the rainfall decreases as we go this way.

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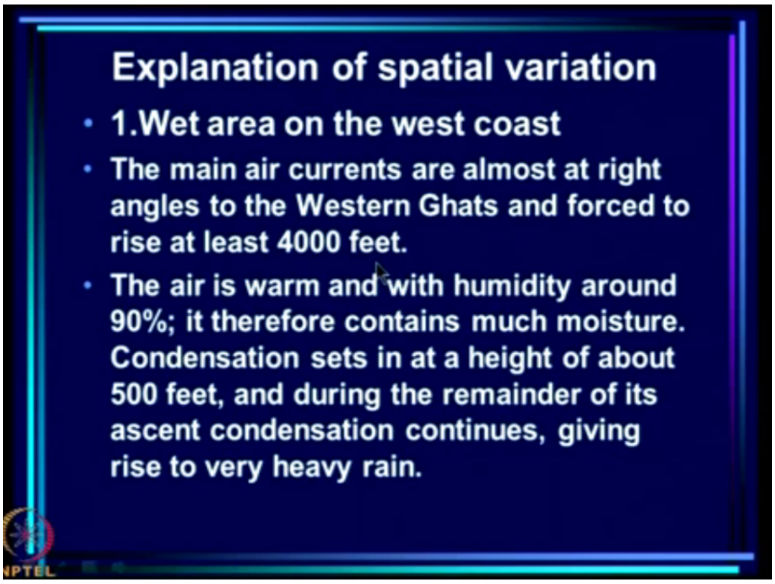

This is the main pattern okay. So now he actually gives us explanation for why it with space the way we have seen? So the first is the wet area on the west coast that we have seen. We have also seen that the main air currents are almost at right angles to the Western Ghats and forced to rise at least 4000 feet okay. Now this air is warm and with humidity around 90%. It therefore contains much moisture.

Condensation sets in at a height of about 500 feet and during the remainder of its ascent condensation continues giving rise to very heavy rain. See this is the process that we have seen earlier how forced ascent due to topography in this case Western Ghats can give rise to condensation clouds and rain.

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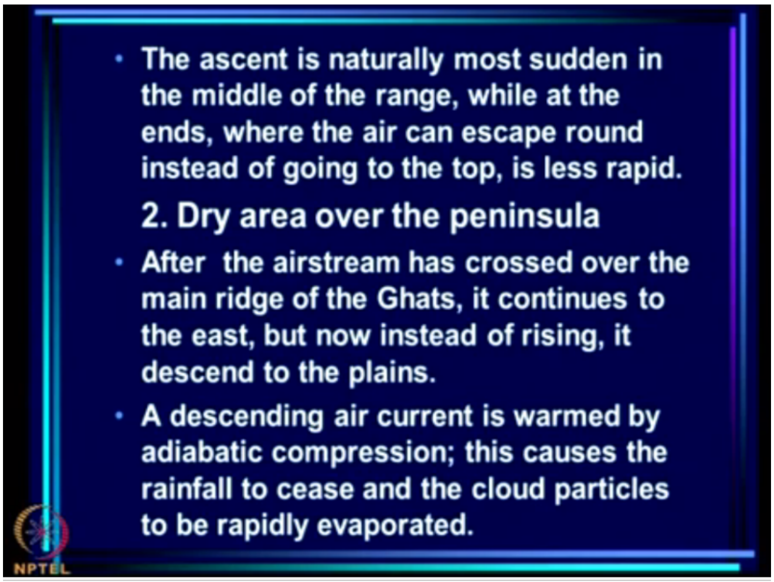

Now the ascent is naturally most sudden in the middle of the range while at the ends where the air can escape round instead of going to the top it is less rapid.

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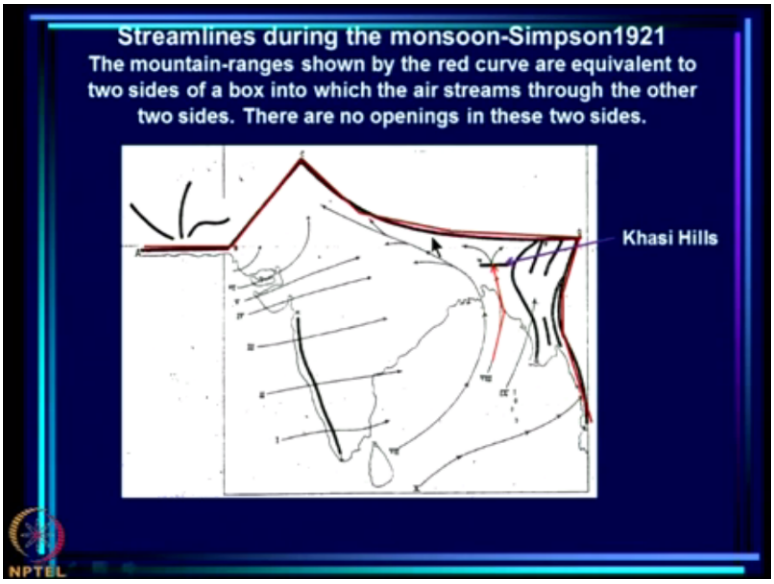

So what he is saying is if we look at the mountain ranges, then this is the mountain range of Western Ghats and right in the center it is difficult for the air to go around whereas towards the edges like here, the air can kind of skirt around the mountains and go in this manner. So he is saying that in fact the strongest ascent he calls it the ascent is naturally the more sudden in the middle of the range.

While at the ends where the air can escape around instead of going to the top, it is less rapid okay. So in fact right near the central part near Honavar you get highest rain on the west coast okay. So this is the explanation for the west coast rainfall and this is something we are all very familiar with. Then he asked for why is it dry over the rest of the peninsula? We have seen that as well.

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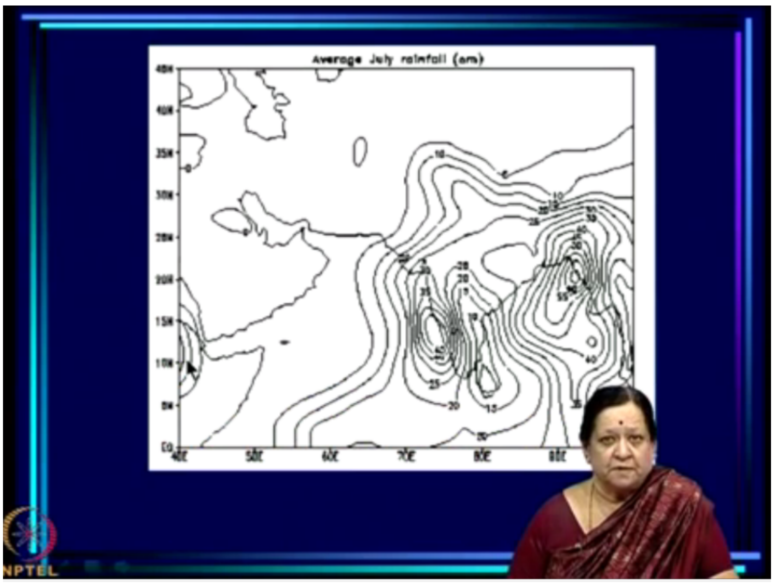

That compared to the rain here this is the west coast high rain here and compared to that you have a dry whole here. The rain is very less on the south eastern part of the peninsula. This you have seen. Now what is his explanation for that? He says after the air stream has crossed over the main ridge of the Ghats, it continues to the east, but now instead of rising it descends to the plains right.

It has already gone over the mountains and now it is descending to the plains. A descending air current is warmed by adiabatic compression. This causes the rainfall to cease and the cloud particles to be rapidly evaporated okay. So we have descending air current over the plains to the east of the Ghats and there the rainfall ceases because the cloud particles get rapidly evaporated okay.

So this is what you see here that you have high rain here and low rain here because the air is descending over this portion here after having ascended over the Western Ghats.

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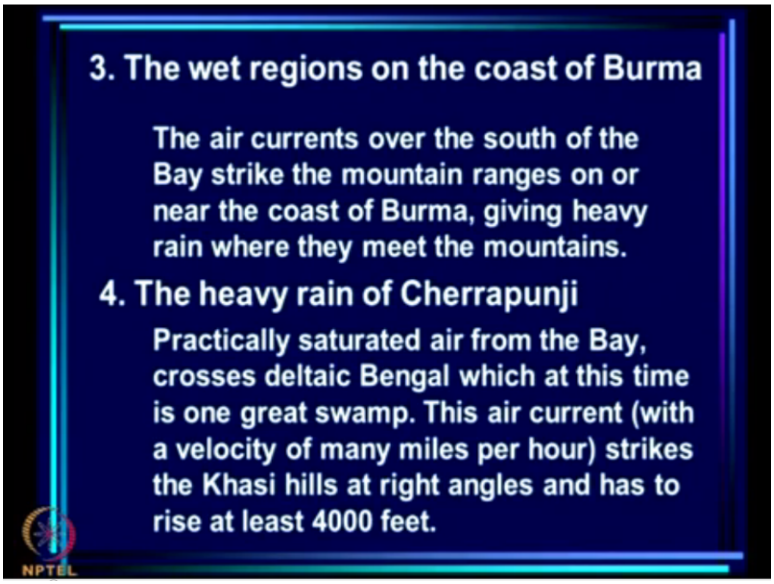

Now what about the wet regions on the coast of Burma? The air currents over the south of the Bay strike the mountain ranges on or near the coast of Burma giving heavy rain where they meet the mountains. We can see his idealized figure of mountains again and you will see here.

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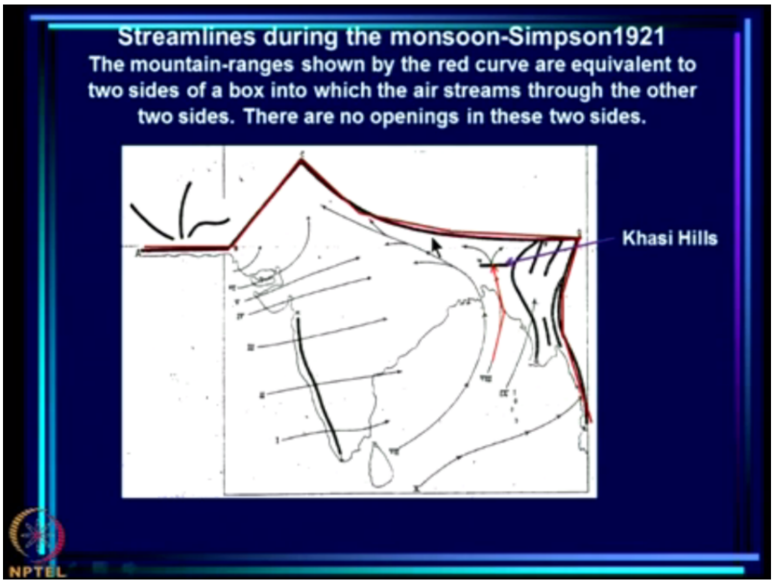

See these are the high mountain ranges on the coast of Burma and the air stream that goes at right angles to these will naturally have to ascent and that will give very high rainfall over the coast of Burma. So now we have an explanation for why it rains on the west coast? Why it is dry over the peninsula and why there is so much rain over the coast of Burma?

Now heavy rain at Cherrapunji, practically saturated air from the Bay crosses the deltaic Bengal, which at this time is one great swamp because it has already rained a lot there. This air current with a velocity of many miles per hour strikes the Khasi hills at right angles.

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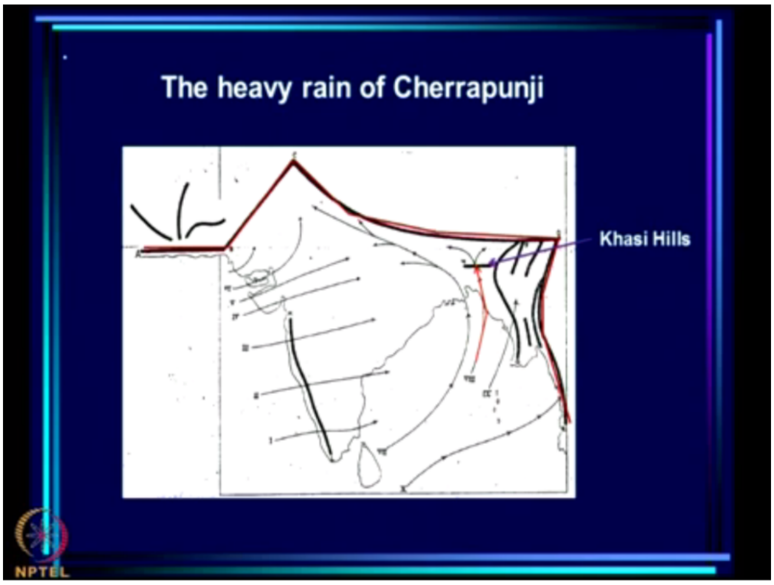

Now this is again Simpson's view of the topography simplified view and what you see here rather Khasi hills and so this air which is coming from the Bay of Bengal going over what was then called Bengal, this whole Bengal region which he claims is almost a swamp, now actually encounters Khasi hills at right angles to that air stream okay. So this air current with the sufficiently high velocity strikes the Khasi hills at right angles and has to rise at least 4000 feet.

So now you see the situation near Cherrapunji where again you have very moist air hitting the mountains at right angles and therefore rising. This is the Khasi hill thing so this is why you have very high rain at Cherrapunji.

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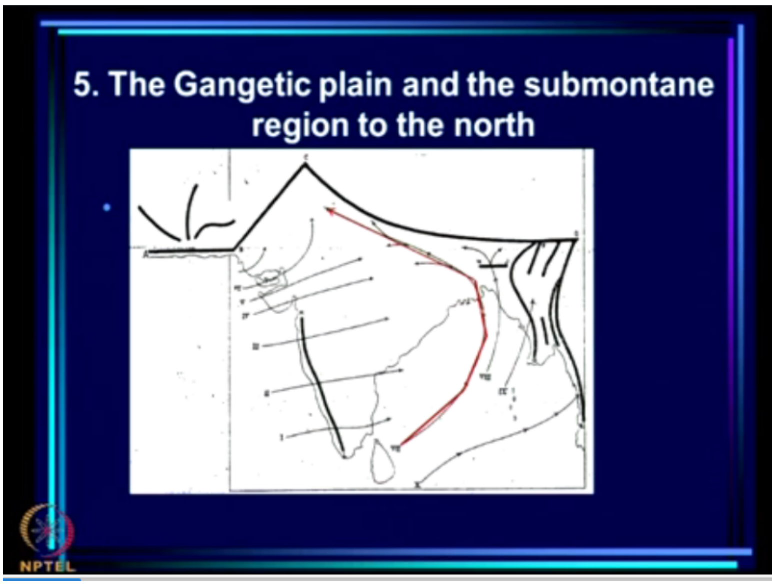

Now what happens over the Gangetic plain and the submontane region to the north?

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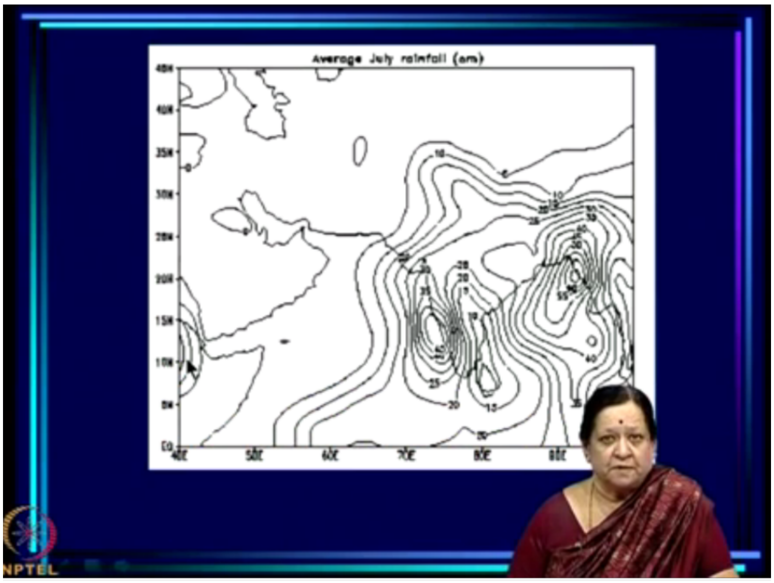

Now we have seen I think we should just see what the observations are on that side as we mentioned here the highest rainfall is here near the head Bay and as we go towards the North

West the rainfall is decreasing that is very clear here. You can see the contours here the heavier rain is here and as we go steadily towards the northwest the rainfall has decreased okay.

So this is what now he is trying to explain why does the rainfall decrease in the Gangetic plain from here to here, remember the mountains are here. So this is where we are trying to find out why the rainfall has decreased okay. So this is the Gangetic plain and this is the idealized picture of the stream line, which comes here. So its air that has come over the Bay of Bengal and now is easterly over this region okay.

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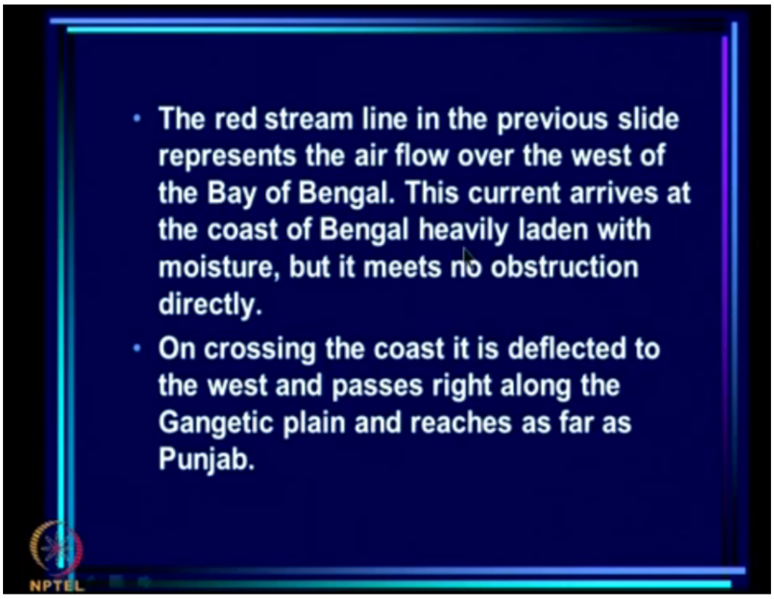

So this is the air current, so the red stream line which I just showed you represents the air flow over the west of the Bay of Bengal. This current arrives at the coast of Bengal heavily laden with moisture, but it meets no obstruction directly. So this is the case in which you see there is no obstruction here. All the obstructions are here. This air that comes across meets no obstruction, but it gradually proceeds towards the west okay.

So he says this current arrives at the coast of Bengal heavily laden with moisture, but it meets no obstruction directly. On crossing the coast, it is deflected to the west and passes right along the Gangetic plain and reaches as far as Punjab.

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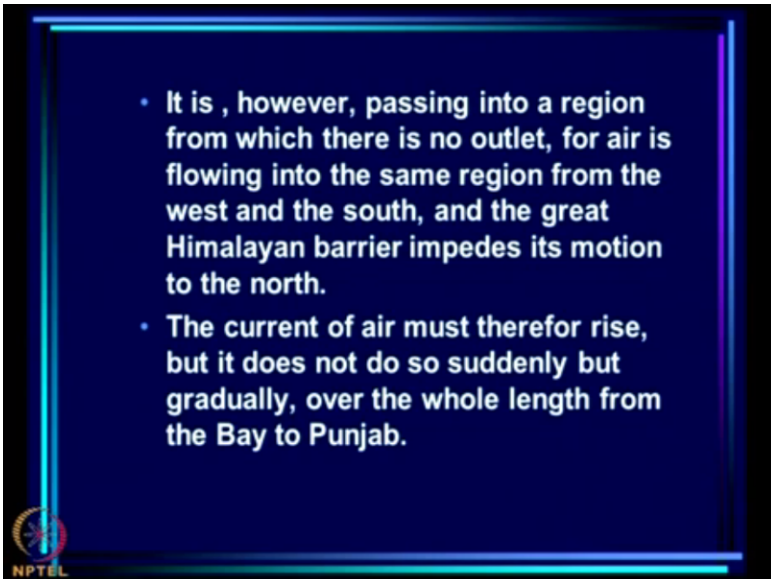

This we have seen. It is however passing into a region from which there is no outlet for air is flowing into the same region from the west and the south and the great Himalayan barrier impedes this motion to the north. So his picture is as follows.

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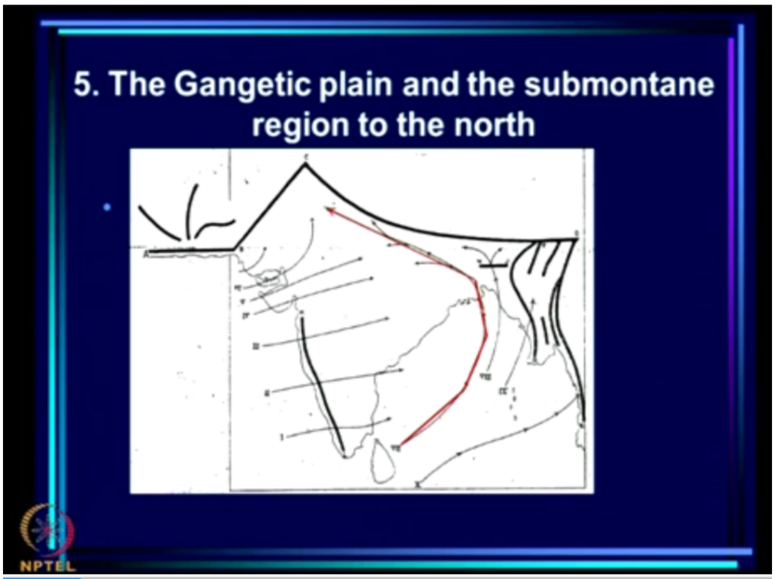

You can see that the air is flowing into this region from Arabian Sea as well. You see this is the air coming from the Arabian Sea, this is the air coming from the Bay of Bengal and so air is coming together here and it has nowhere to go because there is a wall here and there is a wall here. This is way he envisage the picture. So what we have here is that it is deflected to the west and continues going east.

It is however passing into a region from which there is no outlet as we have seen because the air is flowing into the same region from the Arabian Sea as westerly flow as well as from the

Bay of Bengal as easterly flow okay and there is the great Himalayan barrier to the north so it cannot go north. So this current of air must therefore rise, but it does not do so suddenly but gradually over the whole length from the Bay to Punjab.

So this is his picture then that over this region then the air ascents because there is lot of convergence of air but it does so gradually, it is not like you know coming to a mountain and suddenly there being a sharp increase and sharp ascent, it does so very gradually as it moves here and actually the ascent decrease as you go from Bengal to here. So this is why the rainfall decreases as you go from here to here.

This is what his claim is okay. So the current of air must therefore rise but does not do so suddenly, but it rises gradually over the entire region and that is really his explanation for the rainfall over the monsoon zone now.

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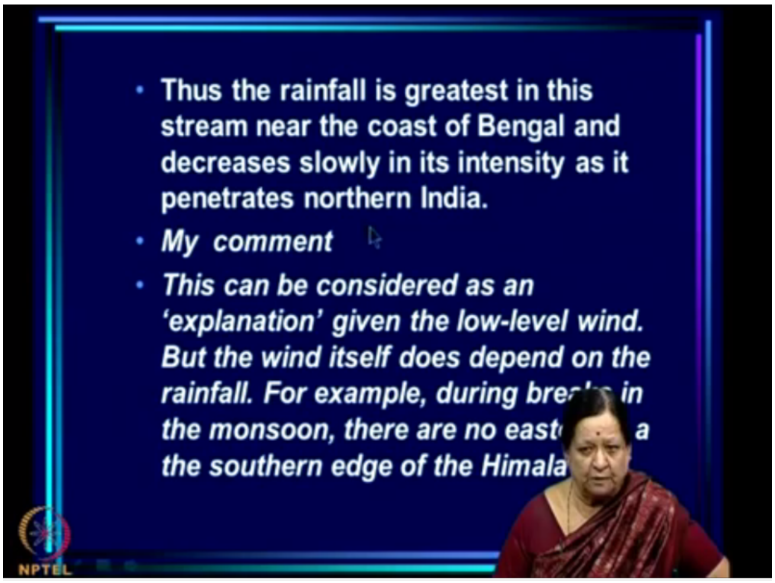

Remember it depends on there being a current from the Bay of Bengal air current that is to say winds from the Bay of Bengal, which go towards the northwest. So he says since it is now ascending and ascending right from the Bay of Bengal to the north western parts he says and the ascent is higher near the Bay and slowly decreases as you go towards the Northwest. He says rainfall is greatest in the stream near the coast of Bengal.

And decreases slowly in its intensity as it penetrates over northern India. Now this all sounds like good theory, it sounds reasonable, but the catch is that it depends on the winds or what Simpson calls air currents being the way they are okay, but you know we know very well there are breaks in the monsoon in July when actually there are no easterlies at all. So it is that we cannot assume a given pattern for the low level wind and then figure out the rainfall.

See the wind itself depends on the rainfall so during breaks in fact there are no easterlies and this explanation cannot hold. So rather than saying this explanation does not hold, this explanation sort of does not take into account the interaction between rainfall and wind. It assumes that the wind pattern is what it is, just like it assumes the mountains to be what they are, but while the mountains remain steady, the wind does not okay.

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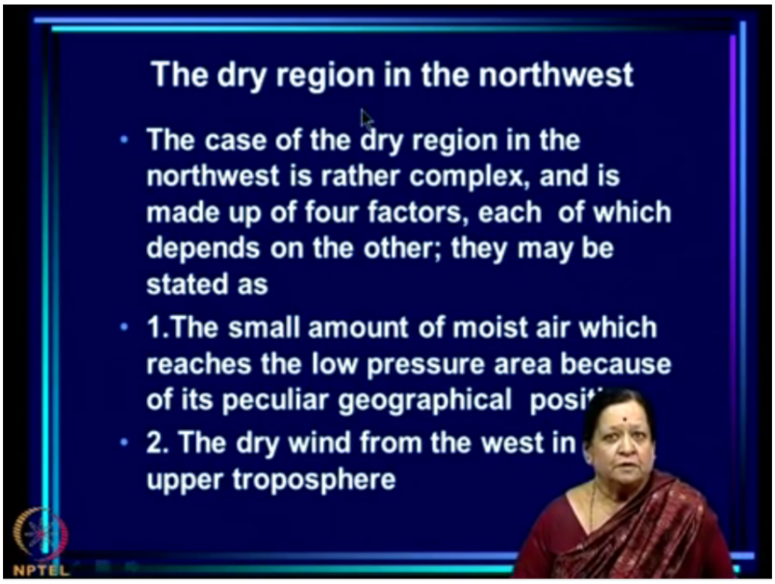

Then comes the very interesting question of the dry region in the northwest okay. So the case of the dry region in the northwest is rather complex and is made up of 4 factors he says each of which depends on the other and they may be stated as the following. First and foremost, the small amount of moist air, which reaches the low pressure area because of its peculiar geographical position.

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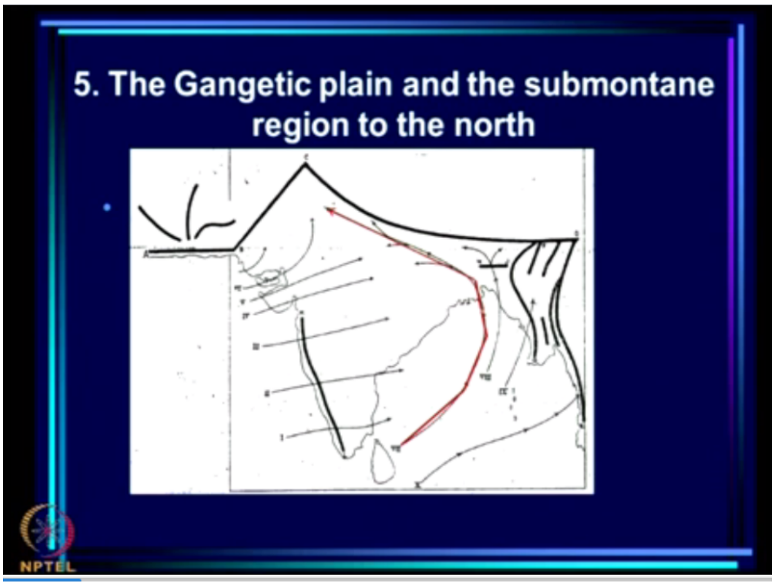

So we have seen earlier now we are talking of the northwest region here. So he is saying relatively small amount of this moist air is reaching here this is one of the reasons because of its geographical location. He says the small amount of moisture, which reaches the low pressure area because of its peculiar geographical position is one reason.

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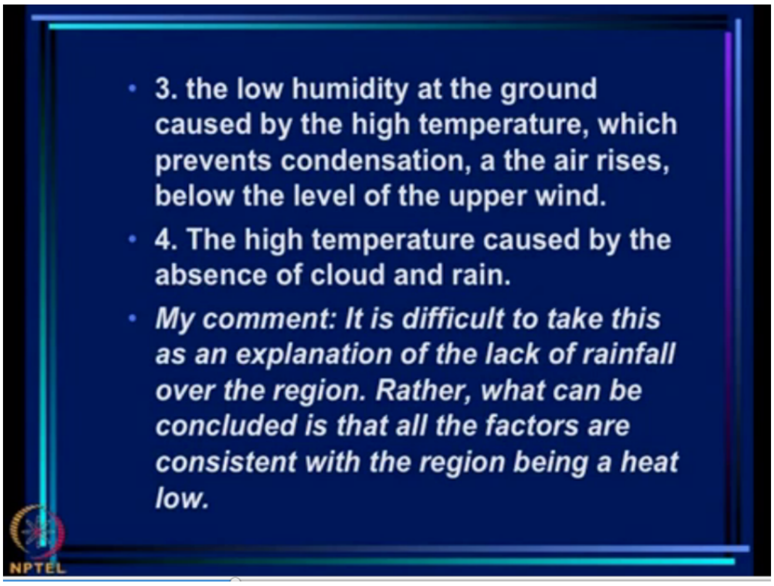

The dry wind from the west in the upper troposphere now low humidity at the ground caused by high temperature, which prevents condensation and as the air rises below the level of the upper wind. So there is no condensation, there are no deep clouds okay and because of this the temperature of land is high and because of that there is low humidity at the ground okay. So this is how all these factors are interconnected.

And the high temperature caused by the absence of cloud and rain is what he lists as the fourth important thing okay. This is my comment on Simpson's explanation, it is difficult to take what he has given as an explanation of the lack of rainfall over the north western part rather all the factors are consistent with the region being what is called the heat low and I will be talking about these heat lows.

These are low pressure regions, which have no rainfall. I will be talking about these dynamical systems a little later in the lecture as well. So again this is the matter of things being consistent that there is no cloud and rain, the temperature is high okay so the humidity is low and so on and so forth and there is a lot of dry air coming into the region.

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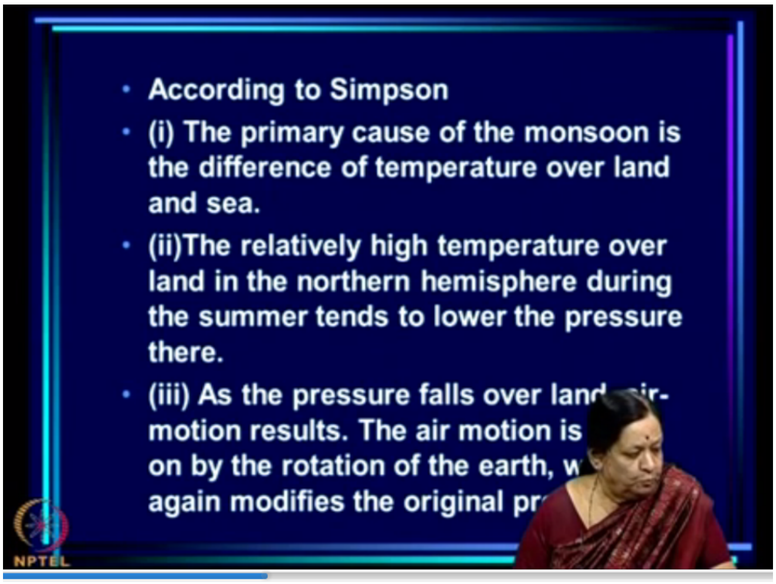

So now according to Simpson, what is the basic system responsible for the monsoon? What is the primary cause of the monsoon? So although here short down the land-sea breeze theory of the monsoon, he still says that the primary cause of the monsoon is the difference of temperature over land and sea okay. So that he still maintains is the important thing.

The relatively high temperature over land in the northern hemisphere during the summer tends to lower the pressure there as the pressure falls over land air motion results and the air-motion is acted on by rotation of the earth, which again modifies the original pressure.

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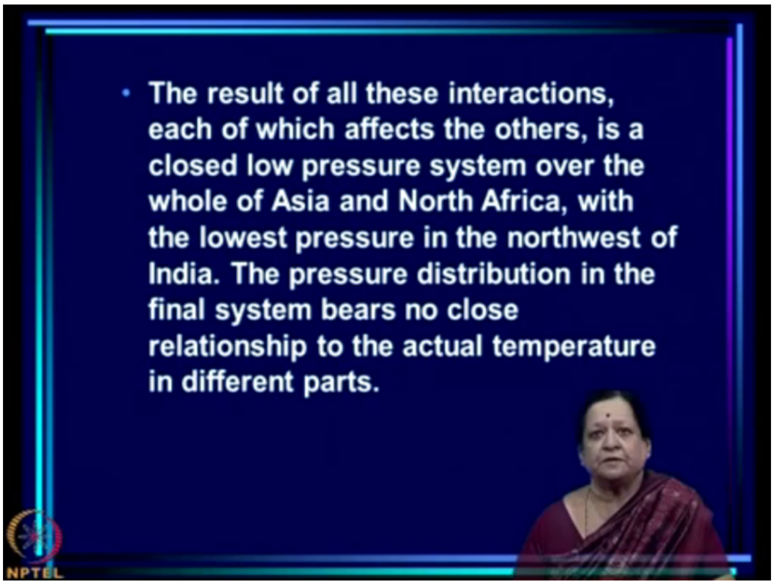

So he is being in a lot of interactions here and the result of all these interactions each of which affects the others is a close low pressure system over the whole of Asia and North Africa with the lowest pressure in the northwest of India. The pressure distribution in the final system there is no relationship to the actual temperature in the different parts.

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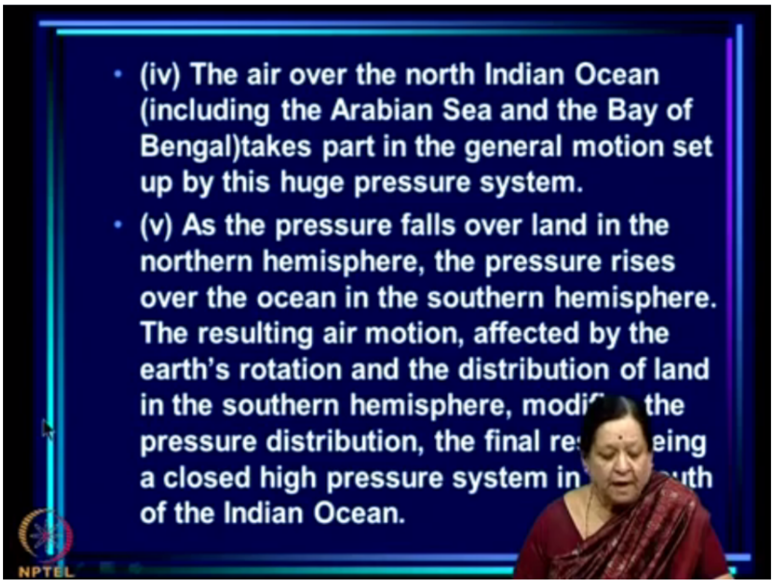

This is an important point to recognize that the finally pressure and temperature patterns are not by any means identical. Then he goes on to say the air over the North Indian ocean including the Arabian Sea and the Bay of Bengal takes part in the general motion set up by this huge pressure system, which involves low pressure extending right from Africa to India and high pressure in the southern hemisphere.

And this huge pressure gradient, this huge pressure system sets up the air currents or the winds okay. So the air takes part in this general motion set up by this pressure gradient as the pressure falls over land in the northern hemisphere the pressure rises over the ocean in the southern hemisphere. So we have high pressure in the southern hemisphere, a huge low pressure belt in the northern hemisphere.

The resulting air motion affected by the earth's rotation and the distribution of land in the southern hemisphere modifies the pressure distribution. The final result being a closed high pressure system in the south of the Indian Ocean.

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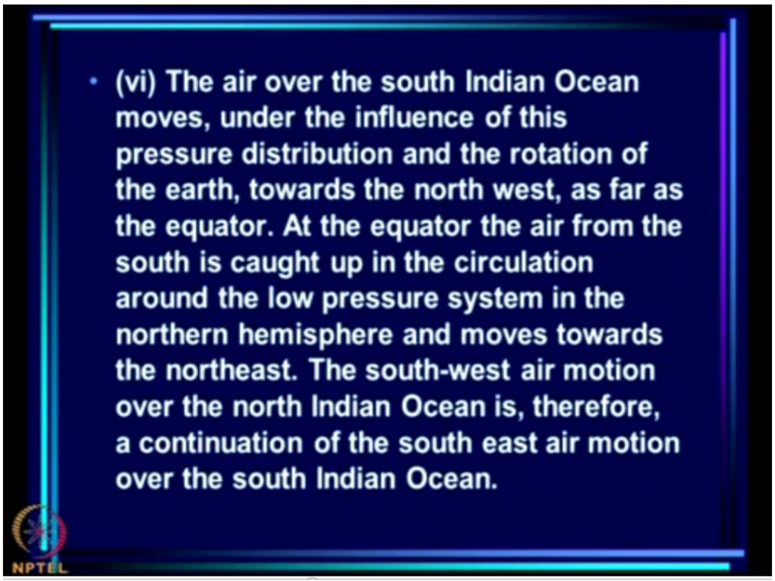

So he is again talking of how the pressure gradient is set up, the air over south Indian Ocean moves under the influence of this pressure distribution and the rotation of the earth towards the northwest as far as the equator. So these are the south easterly trades okay going from the high pressure region to the south of the equator to the equator okay.

At the equator, the air from the southeast caught up in the circulation around the low pressure system in the northern hemisphere and moves towards the northeast. Now this is because the Coriolis force changes sign as the air crosses the equator instead of pushing any wind to its left in the southern hemisphere now it is pushing it to its right. So this is why we get south westerly flow.

And the southwest air motion over the north Indian Ocean is therefore a continuation of the southeast air motion over the south Indian Ocean. This is why I pointed out to you this important cross-equatorial flow, which contributes moist air to the monsoon. So this has been again emphasized and it has been shown that in fact the air that is crossing as the southwest monsoon over the Arabian Sea.

And next from the southern hemisphere as southeast trades this is what Simpson has pointed out.

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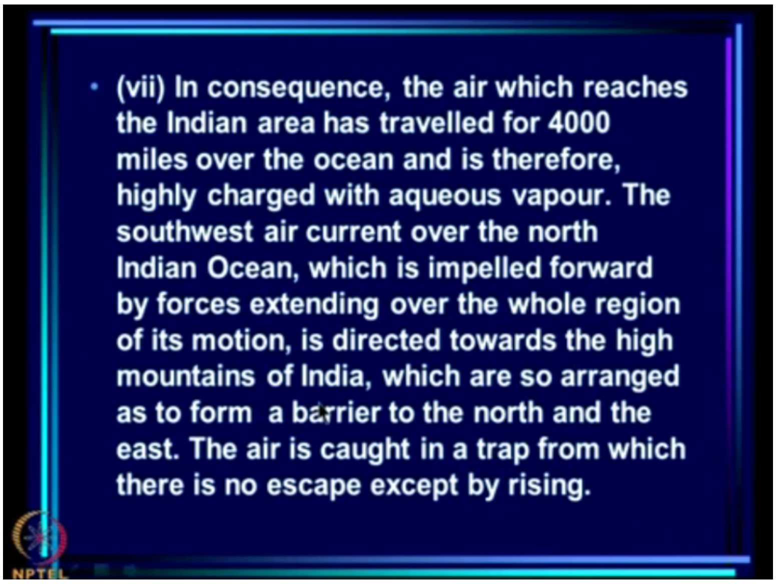

So in consequence, the air which reaches the Indian area has travelled for 4000 miles over the ocean and is therefore highly charged with aqueous vapour. The southwest air current over the north Indian Ocean, which is impelled forward by forces extending over the whole region of its motion is directed towards the high mountains of India, which are so arranged as to form a barrier to the north and the east.

So now you have the scenario that Simpson has built up that you have a pressure gradient set up with high in the southern hemisphere, low in the African Asian belt in the northern hemisphere, air motion results from this pressure gradient and there is rotation of the earth and in consequence of all this you get south westerly flow and the air is finally directed into this box as Simpson envisaged it with a northern wall in the east.

So in consequence the air actually which crosses the north Indian Ocean in fact comes into the box, which is formed by the mountains there. So the air is caught in a trap from which there is no escape, but for rising okay.

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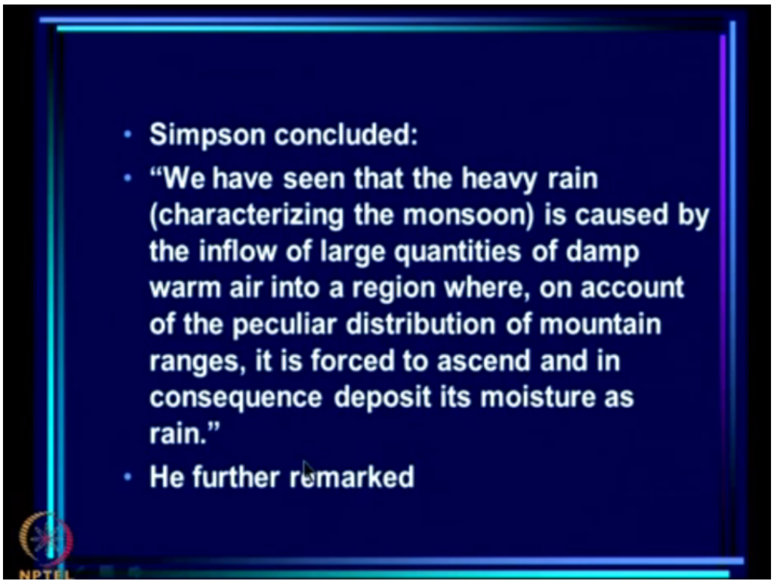

This is Simpson's thing. So Simpson concludes that we have seen that the heavy rain characterizing the monsoon is caused by the inflow of large quantities of damped warm air into the region on account of the peculiar distribution of mountain ranges, it is forced to ascend an inconsequence deposits its moisture as rain okay.

So he is saying that mountain ranges are primarily responsible, are a major element in making it possible for the large rainfall over India which we call the monsoon.

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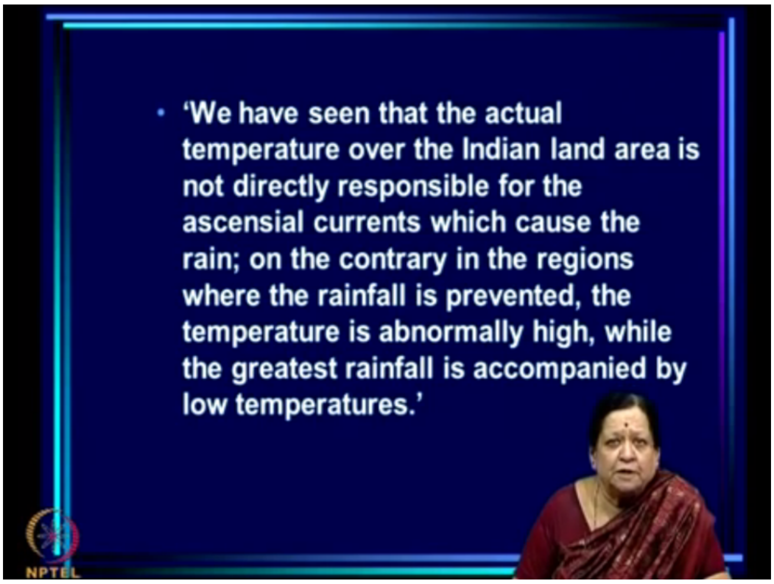

But he further remarked that we have seen that the actual temperature over the Indian land area is not directly responsible for the ascensial currents, which cause the rain okay. He is saying the actual temperature is not responsible for the rain is not responsible for the ascending currents, which are related to the rain; on the contrary in the regions where the rainfall is prevented the temperature is abnormally high.

That is in the north western part of India while the greatest rainfall is accompanied by low temperature. So this is Simpson's theory of the monsoon.

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So although Simpson argued against considering the monsoon as a gigantic land-sea breeze, the basic system that he proposed is also special to the monsoonal region. He claims that it is because of the special configuration of the mountain ranges that we get ascent of air here and therefore rainfall. So it is a system which is special to the monsoonal region resulting from an interaction of the air motion set up by land-ocean contrast with the special topography of the region.

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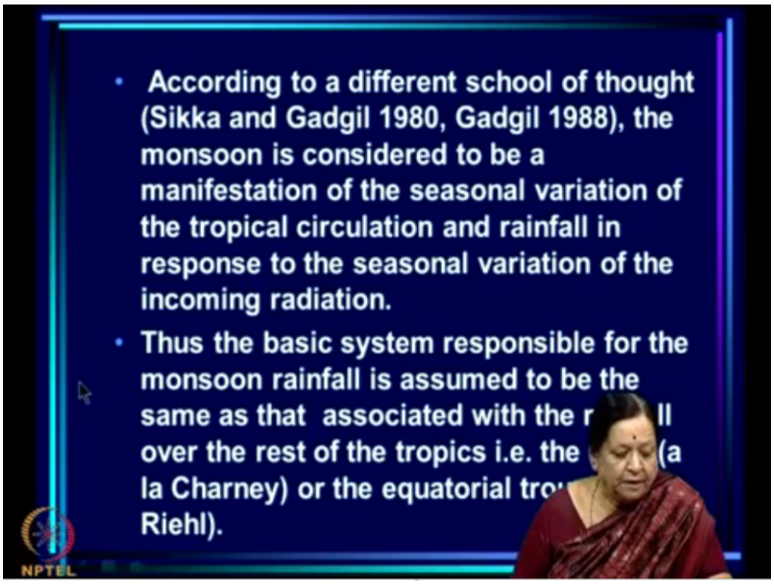

So this is what Simpson has argued for. Now so all along the thinking so far has been that the basic system responsible for the monsoon is the special system, which occurs over the monsoonal region whereas however been a different school of thought okay in which the monsoon is considered to be the manifestation of the seasonal variation of the tropical circulation and rainfall in response to the seasonal variation of the incoming radiation okay.

So thus the basic system responsible for the monsoon rainfall is assumed to be the same as that associated with the rainfall over the rest of the tropics that is ITCZ a la Charney or the equatorial trough a la Riehl.

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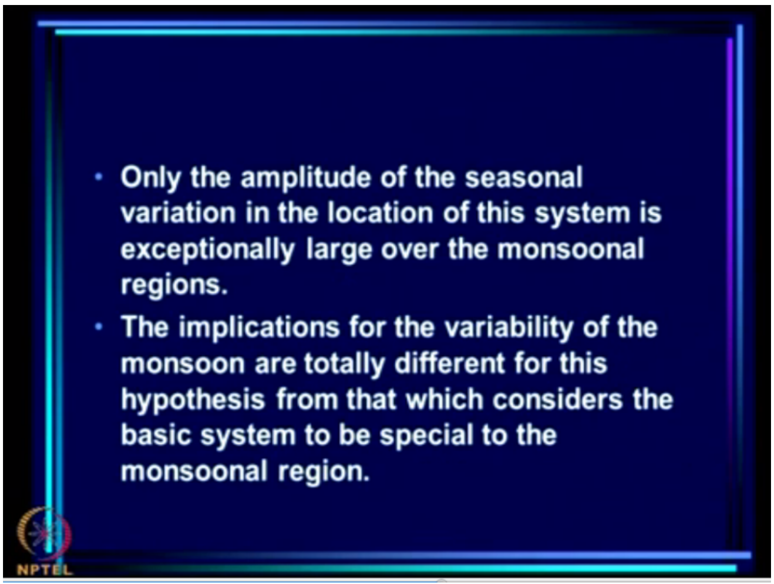

So this second school of thought says the basic system that gives us rainfall over monsoonal region is not different from the ITCZ, which gives rainfall over the tropical Pacific okay, but the amplitude of the seasonal variation in the location of the system is exceptionally large over monsoonal region. Now the implications for the variability of the monsoon from these 2 kinds of schools of thought if you wish are entirely different okay.

Because if the second hypothesis is 2 if the system is the same then some of the feedbacks which lead to the variability of the ITCZ over the Pacific should also operate over the monsoonal region whereas if it is a special system one has to work out what leads to the variability by looking at the special system itself okay.

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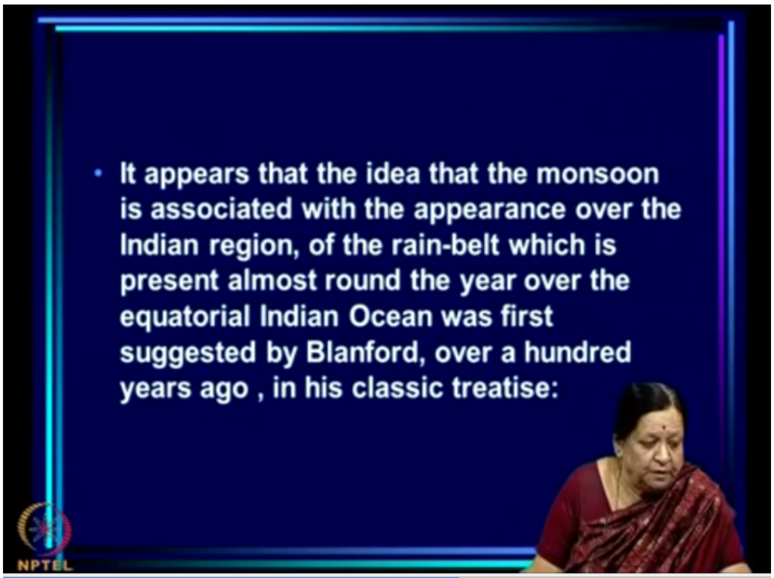

It appears very interestingly now in fact several years I would say almost 40 years before Simpson, the idea that the monsoon is associated with the appearance over the Indian region of the rain-belt, which is present round the year over the equatorial Indian Ocean was first suggested by Blanford in his classic treatise. It is amazing how many of the so called new ideas that we think have come only in the modern era can be traced to this genius Blanford.

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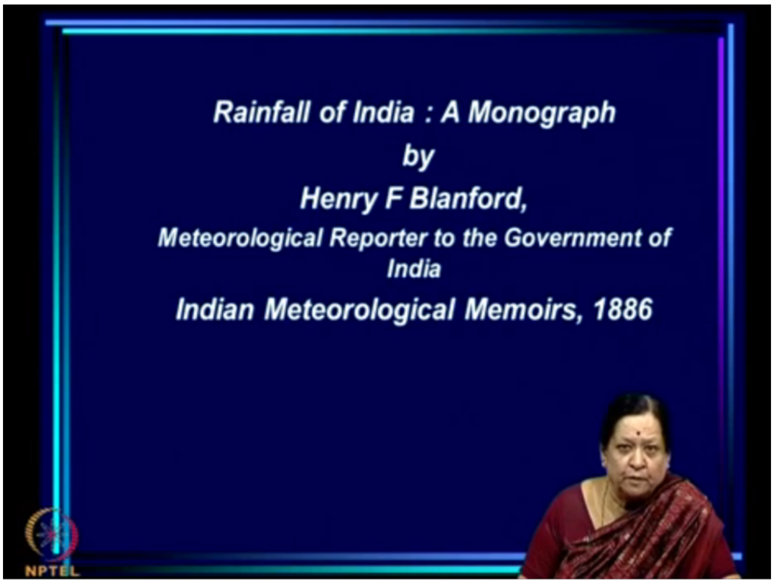

And which he has in fact expounded on in his very classic treatise, this is Rainfall of India, A Monograph by Henry F Blanford who was the Meteorological Reporter to the Government of India and this is published as an Indian Meteorological Memoirs, 1886.

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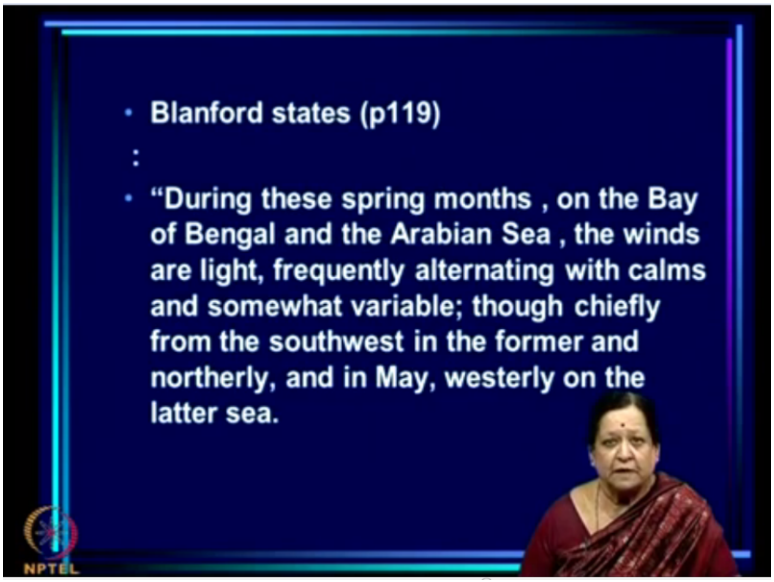

So this is a very classic memoir and in that how does he talk about the basic system responsible for the monsoon? So he begins with the spring months. He says during this spring months, on the Bay of Bengal and the Arabian Sea, the winds are light, frequently alternating with calms and somewhat variable though chiefly from the southwest in the former and northerly and in May westerly on the latter sea.

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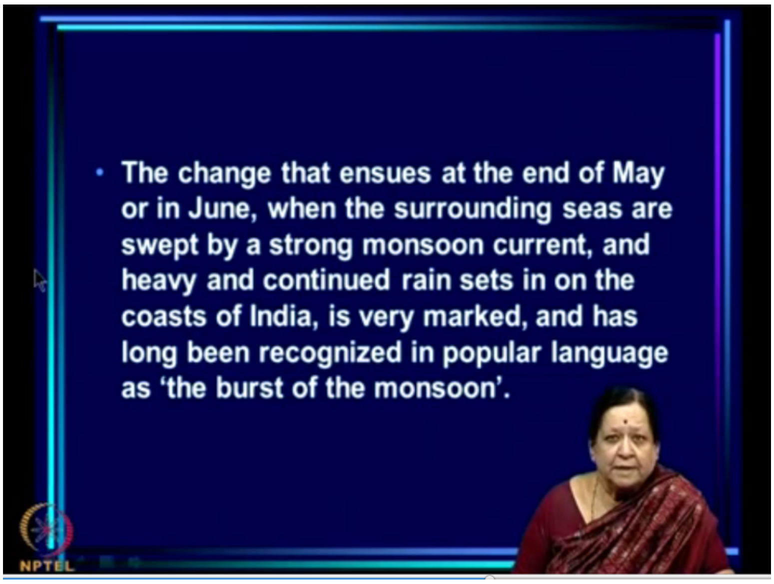

So he is saying during spring months, the winds are weak and variable. The change that ensures at the end of May or in June, remember that is when the onset of monsoon over Kerala occurs. This is what he is talking about. The change that ensures at the end of May or in June when the surroundings seas are swept by a strong monsoon current and heavy continued rain sets in on the coast of India is very marked.

And has long been recognized in popular language as the burst of the monsoon. So this is the onset over Kerala, which has been popularly called burst of the monsoon for well over a century now.

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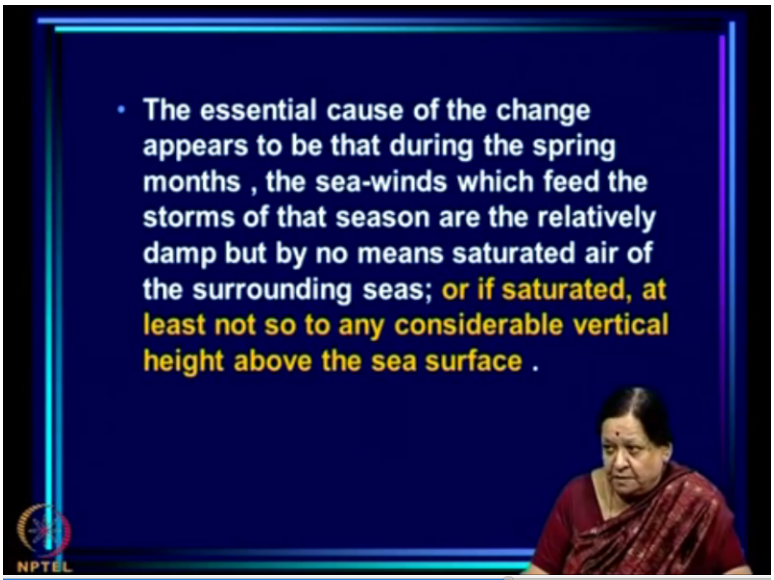

Then he talks of what is the essential cause? The essential cause of the change from the spring conditions okay where you have light and variable winds and hardly any rain over

India to what happens during the burst of the monsoon? The essential cause of the change appears to be that during the spring months the sea winds, which feed the storms of that season are the relatively damp, but by no means saturated air of the surrounding seas.

So during the spring he says the air that generates the storms around India is actually simply the sea wind, which feed the damp by no means saturated air of the surrounding seas. So this is the local air sea interaction kind of thing. So these are local winds that generate the storms or if saturated at least not so to any considerable vertical height above the sea.

So what he is saying is that the water vapour in the air is constraint to the lower layers of the air in the spring.

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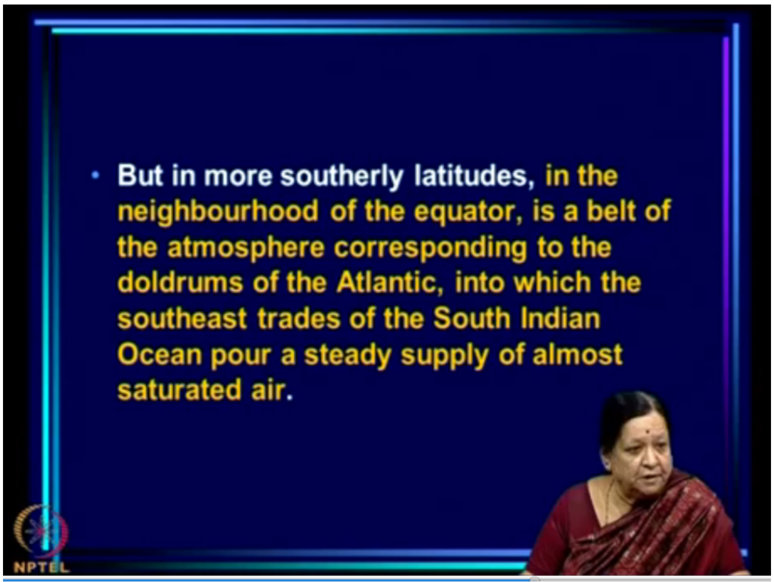

But in more southerly latitude that is to say in our spring itself over the equatorial region in the neighborhood of the equator is a belt of the atmosphere corresponding to the doldrums of the Atlantic into which the southeast trades of the south Indian Ocean pour a steady supply of almost saturated air.

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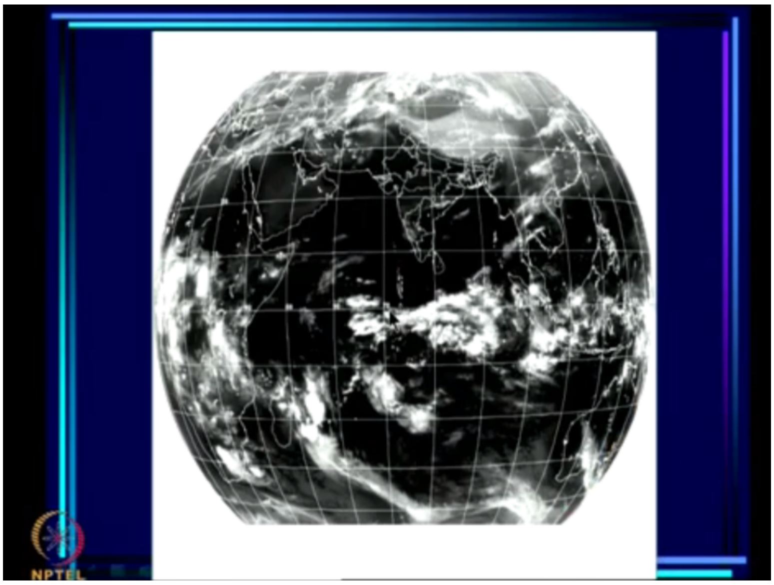

So he is saying in spring itself, there is a rainy belt and I believe this is the picture. This is the satellite picture in spring and what you see is that there is an equatorial band here and this is the band, which is what Blanford refers to is a rainy belt and into this moisture laden air is flowing from the southeast, here these are the southeast trades, this is what he is talking about.

So he says that in the more southerly latitudes, there is a band which corresponds to doldrums in the Atlantic which is very similar to the ITCZ what we call now the ITCZ over the Atlantic into which southeast trades of the south Indian Ocean pour a steady supply of almost saturated air.

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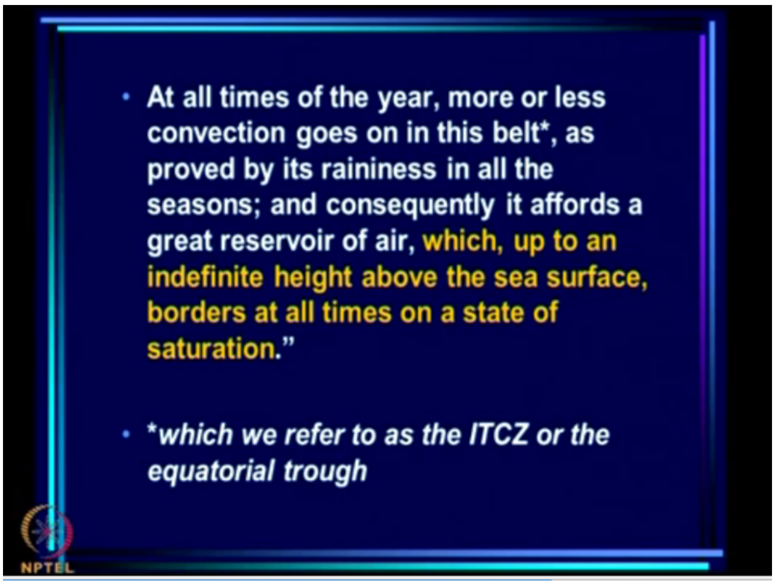

So at all times of the year more or less convection goes on in this belt okay. So this is what we refer to as the ITCZ or the equatorial trough. So the ITCZ or the equatorial trough is located over the equator in our spring that is April, May and he says that in fact at all times of the year some convection goes on here, there is always some rain here as proved by its raininess in all the seasons.

And consequently it affords a great reservoir of air, which up to an indefinite height above the sea surface, borders at all times on a state of saturation. Now remember he is talking in 1886 where we did not have upper air measurements and so he says that there is moisture up to an indefinite height above the sea surface. Now we know up to what height it is there, but it is up to so he is talking of a very, very deep moist layer.

So what he is describing is an ITCZ over the equatorial region and the critical characteristics of the ITCZ in terms of the moist air being water vapour layer extending to very, very high levels that is what he is referring to.

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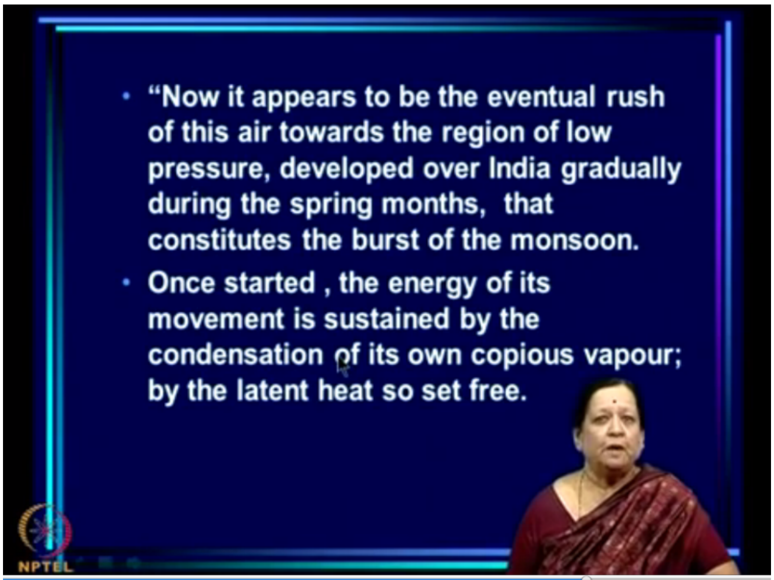

So now it appears to be he continues this is Blanford again talking. He has described what is happening over the equatorial region in the spring and then he says now it appears to be the eventual rush of this air towards the region of low pressure developed over India gradually during the spring months that constitutes the burst of the monsoon.

So he has a very clear notion that the burst of the monsoon involves this movement of this moist air in the ITCZ over this region okay. So he is saying the coming of the TCZ over our region constitutes the burst of the monsoon once started and this is the very important point he makes once started the energy of its movement is sustained by the condensation of its own copious water vapour by the latent heat so set free.

So this is the very important point he is making that once you have a tropical convergence ongoing then it is sustained by the latent heat of condensation within its own region.

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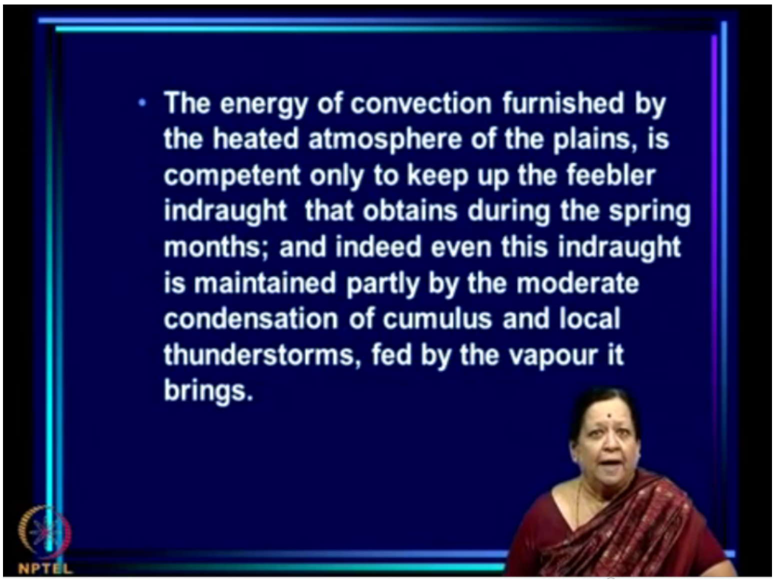

And the energy of convection furnished by the heated atmosphere of the plains. So he is talking of you know the land-ocean contrast that has been often emphasized. So the energy of convection furnished by this kind of gradient of temperature between land and ocean furnished by the heated atmosphere over the plains he says as compared to that over the ocean is compete and only to keep up the feebler indraught that obtains during the spring months.

So actually as Simpson had pointed out in May, India is much hotter than in July. So actually this land-ocean contrast is very, very high in May so there is considerable energy of convection furnished by this land-ocean contrast, but all it can do is to generate a feeble indraught that obtains during the spring months.

And indeed even this indraught is maintained partly by the moderate condensation of cumulus and local thunderstorm fed by the vapour it brings okay. So even this energy is not the total energy for that feeble indraught, part of the energy also comes from our pre-monsoon thunder showers, this is what Branford is saying.

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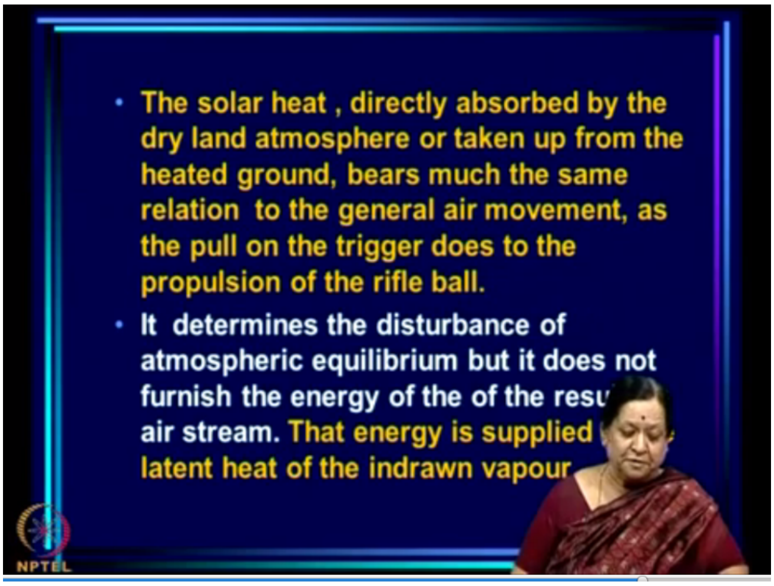

So then he actually puts it very beautifully I think the solar heat directly absorbed by the dry land atmosphere or taken up from the heated ground, there is much the same relation to the general air movement, as the pull on the trigger does to the propulsion of the rifle ball. I think this is an extremely important similar analogy because he has expressed very beautifully I think.

What is the role played by the land-sea contrast? He says solar heat directly absorbed by the dry land atmosphere or taken up from the heated ground there is much the same relation to the air movement that is the strong monsoon winds as the pull on the trigger does to the propulsion of the rifle ball okay. It determines the disturbance of atmospheric equilibrium, but it does not furnish the energy of the resulting air stream.

So just like the energy is provided by what is in the bullet itself or the rifle ball itself. The trigger does not provide the energy. What the trigger does is to provide the perturbation so similarly he says the land-sea contrast provides the perturbation or a disturbance to the atmospheric equilibrium, but actually it does not furnish the energy of the resulting air stream that energy comes from the latent heat release.

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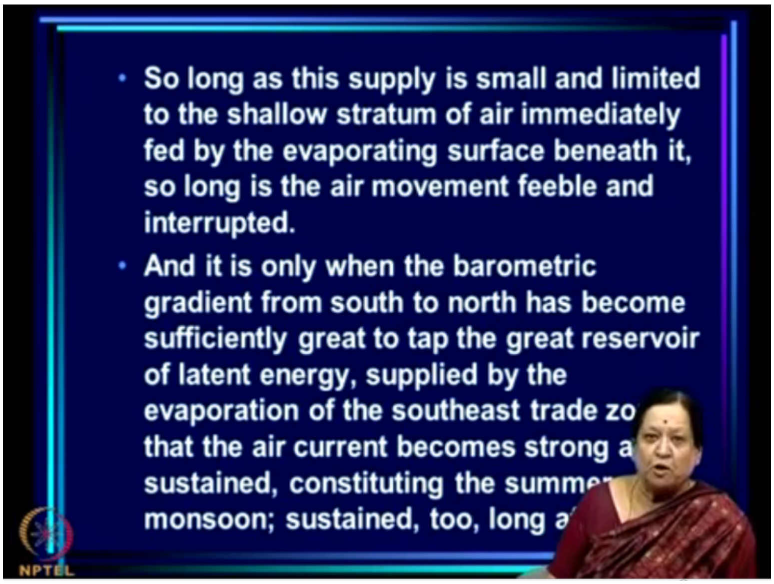

This is what Blanford has said and he says so long as this supply is small and limited to the shallow stratum of the air immediately fed by the evaporating surface beneath it, so long is the air movement feeble and interrupted. So he is now talking of the spring situation. He is saying so that the supply of moisture is limited to the shallow layer above the sea and is fed directly by the local evaporation over the sea itself.

Then the air movement is feeble and interrupted. It is only when the barometric gradient from south to north has become sufficiently great to tap the great reservoir of latent energy supplied by the evaporation of the southeast trade zone that the air current becomes strong and sustained constituting the summer monsoon. So this is again a very, very important point that only when the barometric gradient from south to north.

This is something Simpson also talked about has become sufficiently great to tap the great reservoir of latent energy. So he is saying that pressure gradient has to be great, but once that has become great then is the latent heat tapping by the winds that lead to the monsoon. This is what he is saying.

Sufficiently great to tap the great reservoir of latent energy supplied by the evaporation of the southeast trade zone that the air current becomes strong and sustained constituting the summer monsoon. So strong and sustained wind can occur only when this great reservoir of latent energy is tapped.

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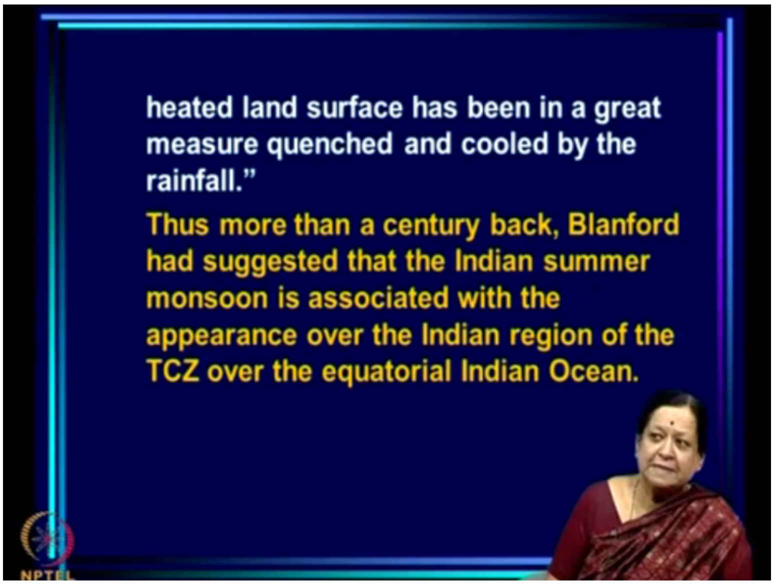

And he says sustained to long after the heated land surface has been in a great measure quenched and cooled by the rainfall. So he is now talking of in a sense before Simpson pointed out the same thing again that this monsoon is sustained even when the land surface cools because of the rainfall okay. So it is amazing that more than a century back Blanford has suggested that the Indian summer monsoon is associated with the appearance over the Indian region of the TCZ over the equatorial Indian Ocean.

He called it by another name but the physical system he described was in fact the intertropical convergence zone as Charney has conceived it. So this is a very, very interesting thing that this kind of an understanding of the basic system geniuses like Blanford had long before in fact more than 1 century back.

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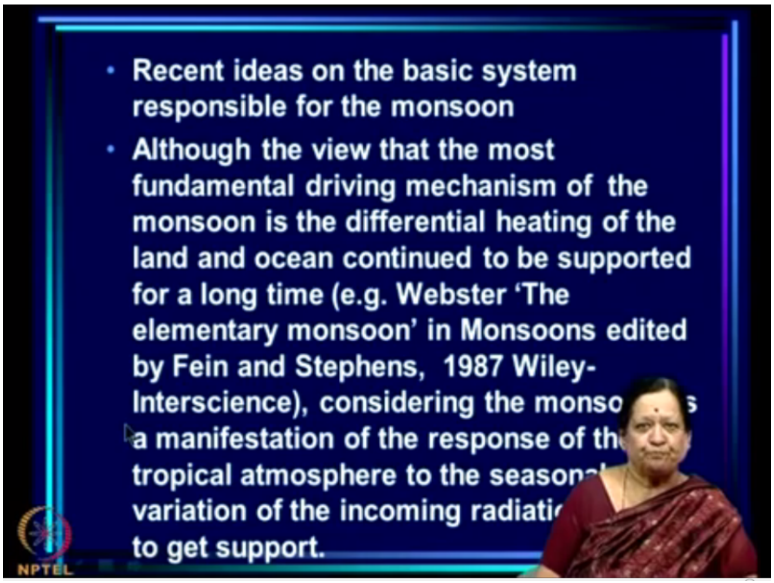

And now recent ideas, how has the monsoon been talked about in recent literature? Okay so unfortunately what has happened is that although the view that the most fundamental driving mechanism of the monsoon is the differential heating of land and ocean continued to be supported for a long time. So the thing that was originally proposed by Hailey actually continued to be supported for a long, long time.

Namely if you look at important chapter, the elementary monsoon in a book entitled the Monsoons that came out in 87 where Peter Webster has tried to explain how monsoon arises. What he talks about also is a gigantic land-sea breeze of course with modifications in the sense he puts in how the deep clouds arise over land and so on and so forth, but the basic idea remains that is the gigantic land-sea breeze.

And the primary cause is the land-sea temperature contrast. So this idea has continued to be in literature for a long time considering the monsoon as a manifestation of the tropical atmosphere to the seasonal variation of the incoming radiation began to get support in the 70s I would say, in the late 60s and early 70s. So this monsoon has a gigantic land-sea breeze, land-sea temperature contrast being the primary cause of the monsoon and so on.

Or monsoon being attributed to a very special system over the monsoonal regions has continued to holds way in textbooks as well as in monographs and you know specialized books on the subject even to this day I must say, but an alternative school of thought namely considering the monsoon as a manifestation of the response of the tropical atmosphere to the seasonal variation of the incoming radiation began to get support.

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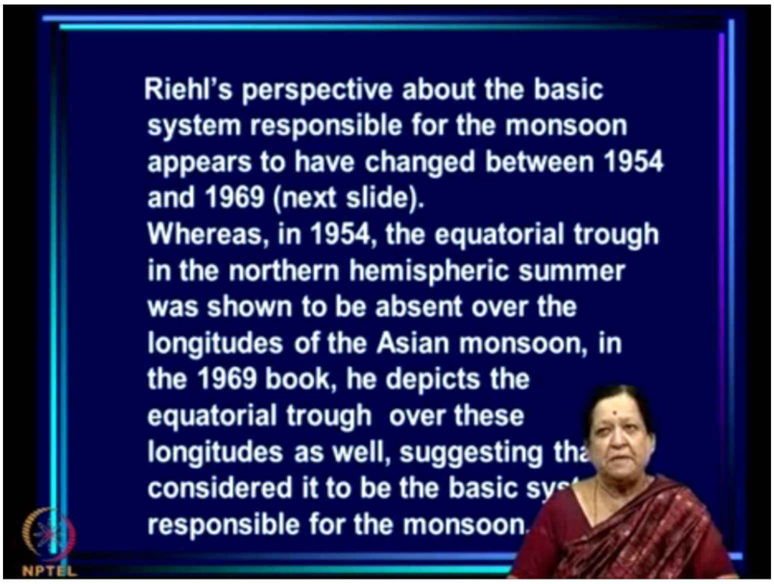

Now this was with Riehl who was again another giant in the field of tropical meteorology. He is the one who formulated the concept of equatorial trough, but even his perspective of the basic system responsible for the monsoon appears to have changed between 54 and 69.

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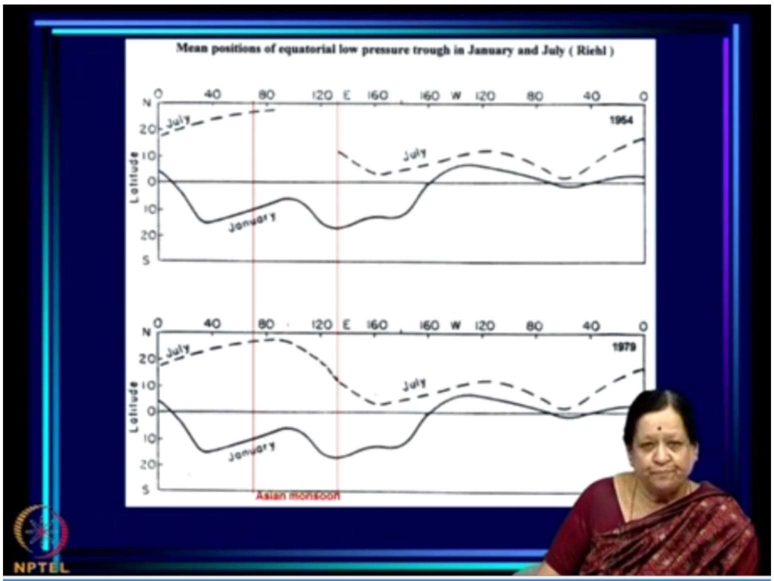

So let me just say, Riehl wrote 2 books, both of them are very important, 1 in 54 called tropical meteorology and 1 in 79 called climate and weather in the tropics, both are very good books and described in great detail the systems in the tropics in terms of what is absorbed and what is the physics and so on. Now what you see here is what appeared in Riehl's 54 book and this is the location of the equatorial trough now okay in January in solid.

And dashed in July okay and what you see is that the equatorial trough in fact is mostly in the southern hemisphere in this part in January, but here this is over the Atlantic and so on is straddles the equator as even north of the equator in January. In July, it shifts only a little bit over this region remains in the northern hemisphere. In this part of the world, this is the African region you know 0 to 40, he claims that the equatorial trough actually shifts in July, but over the Asian monsoon region, these are the Asian monsoon longitude in fact he puts a blank there.

He does not show any equatorial trough such as thing that perhaps something else is happening over the Asian monsoon region. This was in 54 okay, but a lot more information came after the mid 60s with the advent of meteorological satellites and lot of papers were written, Charney and Eliassen's theory came out and so on and so forth and with that Riehl appears to have changed his perspective.

And in the 79 book in fact he draws equatorial tough as a continuous line across the Asian monsoon suggesting that he now believes that the monsoon can also be contributed to the equatorial trough coming on to that region. So this is the very interesting thing as I mentioned. So Riehl's perspective about the basic system responsible for the monsoon appears to have changed between 54 and 69.

Whereas in 54, the equatorial trough in the northern hemisphere summer was shown to be absent over the longitudes of the Asian monsoon. In 69 book, he depicts the equatorial trough over these longitudes as well suggesting that he consider it to be the basic system responsible for the monsoon.

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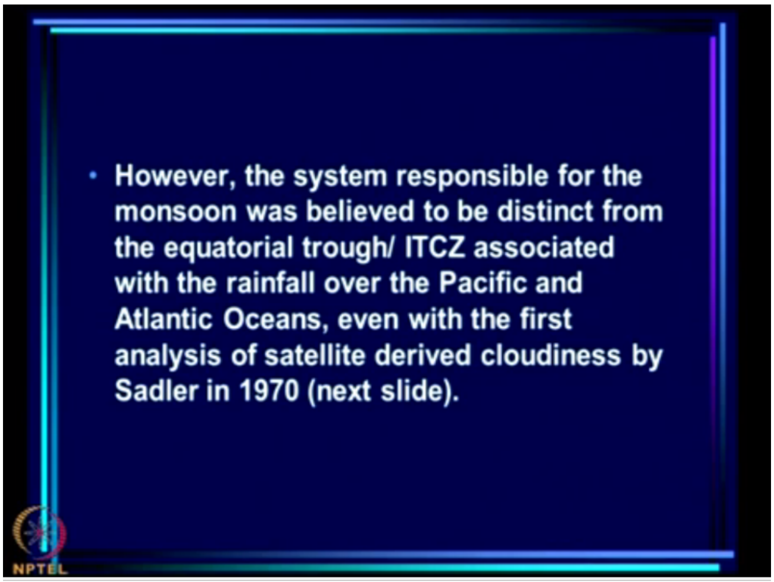

Although, even in that book he did not state it in that way okay; however, the system responsible for the monsoon was believed to be distinct from the equatorial trough or ITCZ associated with the rainfall over the Pacific and the Atlantic Oceans even with the first analysis of satellite derived cloudiness by Sadler.

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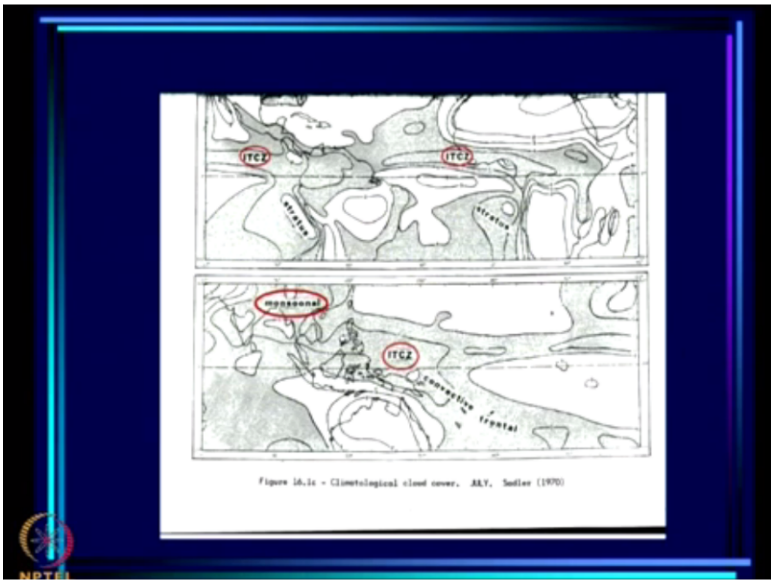

So this is Sadler's depiction, this is in fact climatological cloud cover this is entirely derived by analysis of satellite imagery, which came with the first meteorological satellites and what you see here is the situation for July and this is India here. So this is the eastern hemisphere and this is the western hemisphere if you wish and this is what he calls monsoonal region here and he calls the ITCZ over the Pacific here and here is the Atlantic.

And east Pacific and over both those regions, he attributes the high cloudiness to ITCZ. So Sadler also clearly hinting that you know this is the monsoonal system right here, this is centered about here, this is India and this is our monsoon rainfall decreasing as we go here, which is reflected in the cloud. So this is the heart of the Asian monsoon system and that is depicted not as ITCZ, but monsoonal even by Sadler.

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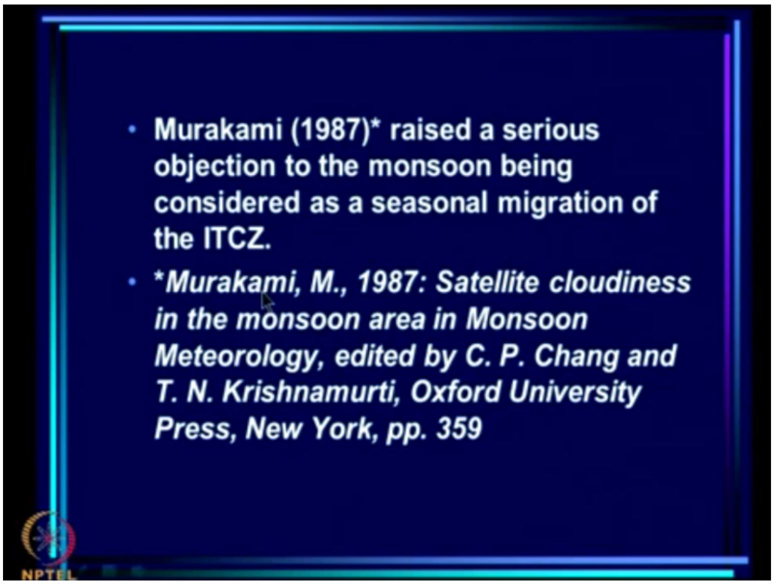

So actually while there was a suggestion though nobody had put it in so many words that monsoon could be considered as a manifestation of the seasonal migration of the ITCZ. There were objections raised to his concept by Murakami again in 87 same year that Webster published his elementary monsoon.

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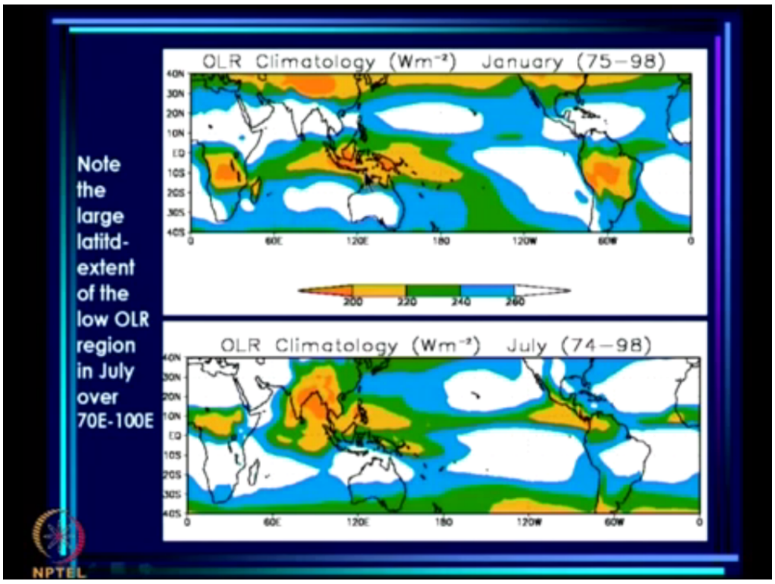

And what he said was the following, he is looking at OLR climatology and these are the low OLR regions here in January and this is for July. Now what you see is that in January, the latitudinal extent of this low OLR region is say about 10, 15 or so but if you go to July over the same longitudes you see the latitudinal extent of the cloud band is huge, it is more like 30, 40 degrees in latitude here.

So what he is saying is somehow the low OLR band flares up over this region, it occupies the huge region. In comparison, we say this is the ITCZ over the pacific. So in comparison with the ITCZ over the Pacific or the ITCZ over the Atlantic both of which you see here have typical latitudinal extent of 10 degrees, there is a huge thing here. So how can this be the same?

How can the system responsible for this with the same as the system which is responsible for this?

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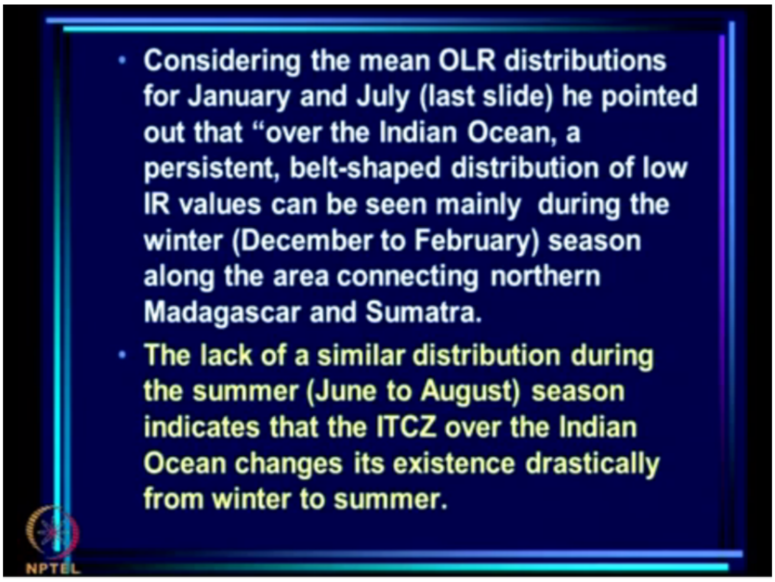

So he says considering the mean OLR distributions for January and July, he says over the Indian Ocean a persistent belt-shaped distribution of low OLR values can be seen mainly during the December to February season along the area connecting the northern Madagascar and Sumatra. The lack of similar distribution during the summer indicates that the ITCZ over the Indian Ocean has changed its existence drastically from winter to summer.

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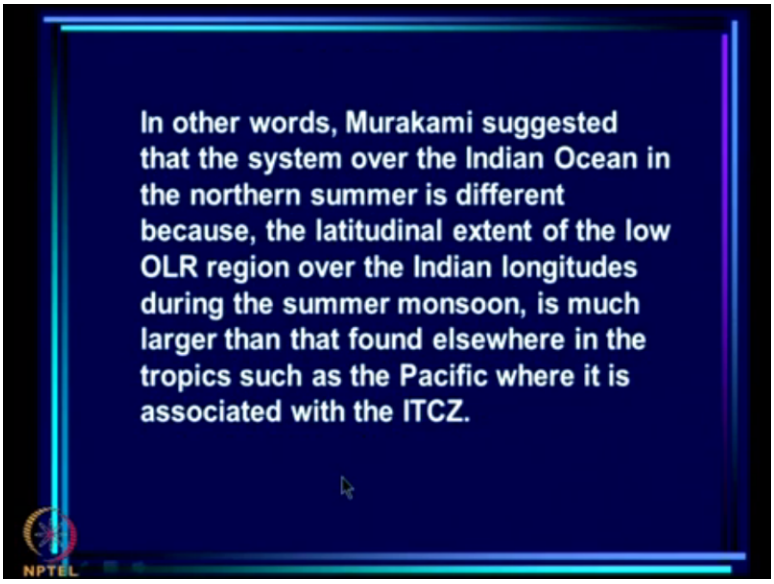

In other words, Murakami suggested that the system over the Indian Ocean in the northern summer is different because the latitudinal extent of the low OLR region over the Indian longitudes during the summer monsoon is much larger than that found elsewhere in the tropic such as the Pacific where it is associated with the ITCZ.

I am going to stop at this point because now as far as we are concerned the question is still open as to whether the migration of the ICTZ is what leads to the monsoon over the Asian region. So we will have to look at that and that is what we will look at in the next lecture.