The Monsoon and Its Variability
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Lecture – 07
The Indian Monsoon: is it a gigantic land-sea breeze?

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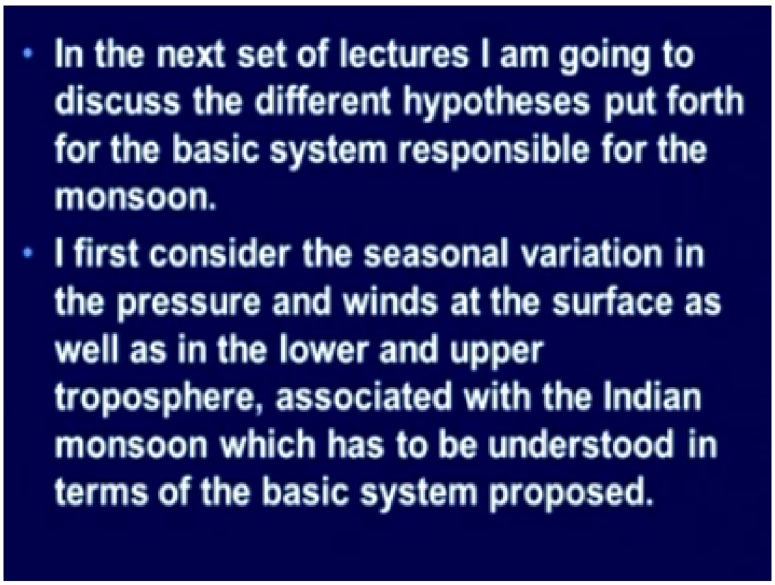

So, now in this set of lectures, I am going to discuss different hypothesis put forth for the basic system, responsible for the monsoon. So, this is what I am going to consider in the next set of lectures. So, I will first consider the seasonal variation in the pressure and the winds at the surface as well as in the lower and upper troposphere associated with the wind and Indian monsoon, which has to be understood in terms of the basic system proposed.

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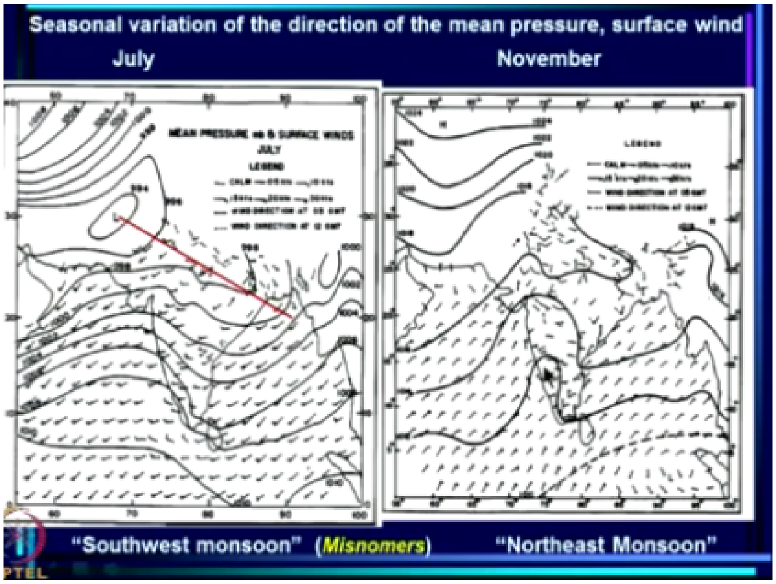

So, what is this; the system that we are trying to develop a hypothesis for that is what will look at first. Now, this is something we have seen before, this is the seasonal variation of the direction of mean pressures of this wind from July to November and this seasonal variation is what Arabs were concerned about and seasonal variation of the winds, you can see, this is from the Southwest in July and from the Northeast in November.

So, this was the southwest monsoon and these are the Northeast monsoon, which I will show at the end of this set of lectures to be Misnomers but this is the seasonal variation in the surface wind, please notice that there is also a variation in the surface pressure, that there is a low pressure belt in July here over what I call the monsoons zone and this low pressure belt shifts southward; equator ward in November, okay.

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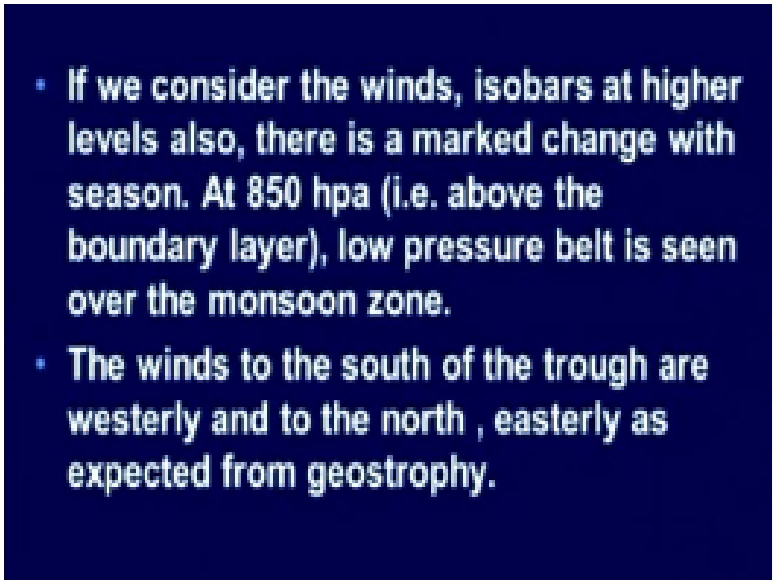

Now, if you consider the winds, isobars at higher; and isobars at higher levels also, there is a marked change with season, okay.

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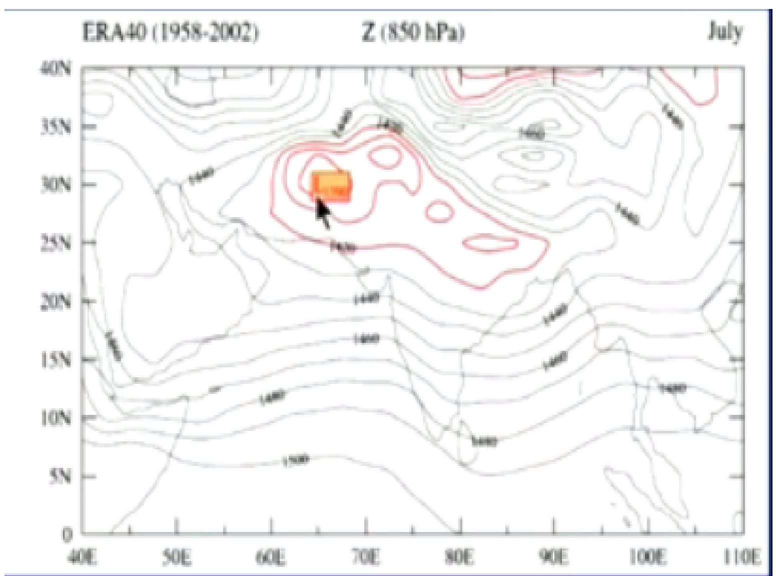

So, now these are the isobars that you see first, these are from the reanalysis where the Europeans centre, from that we; now generate with the computer the kind of charge which were; we choose to; we drawn earlier by hand, so now what you see here is the low pressure over the monsoon zone and this is at 850 hpa which is about 1.5 km above the ground, so this is at the pressure surface 850 hpa.

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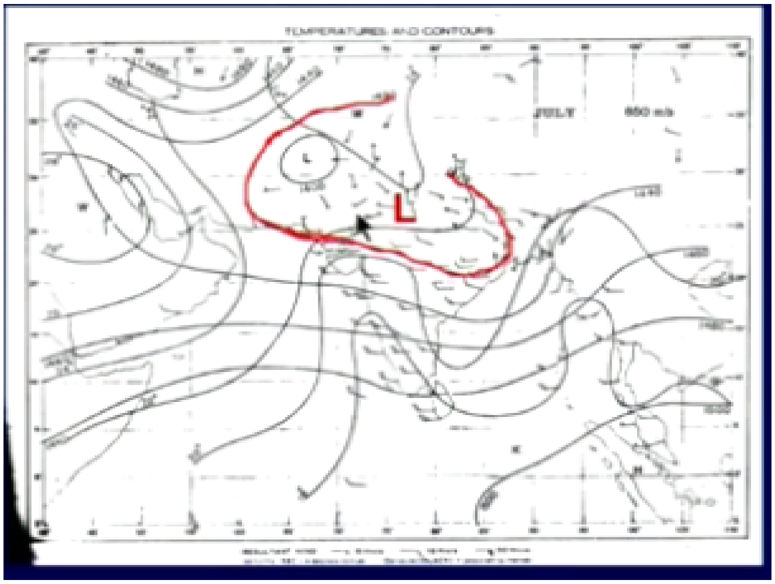

And what you see is pretty much over the surface trough, is the trough zone; low pressure zone of the surface field over the monsoons zone, okay. Now, what are the winds like? Now, this is from the IMD Atlas and again you see these as both winds and pressure and actually, also temperature but I am not going to much talk of temperature right now, so what you see here is again a low pressure belt over the monsoons zone.

And you can see that south of the low pressure belt are the westerlies and north of the low pressure; minimum pressure are easterlies. So, you have; if this is the line of monsoon trough, say minimum pressure, then south of it, you have westerlies and north of it, easterlies. As you know from geostrophy, this is what will logically happen. Remember now, we are above the planetary boundary layer, right.

So, there is the main component of wind is geostrophic that is along isobars and therefore you will have westerly winds, here and easterly winds here.

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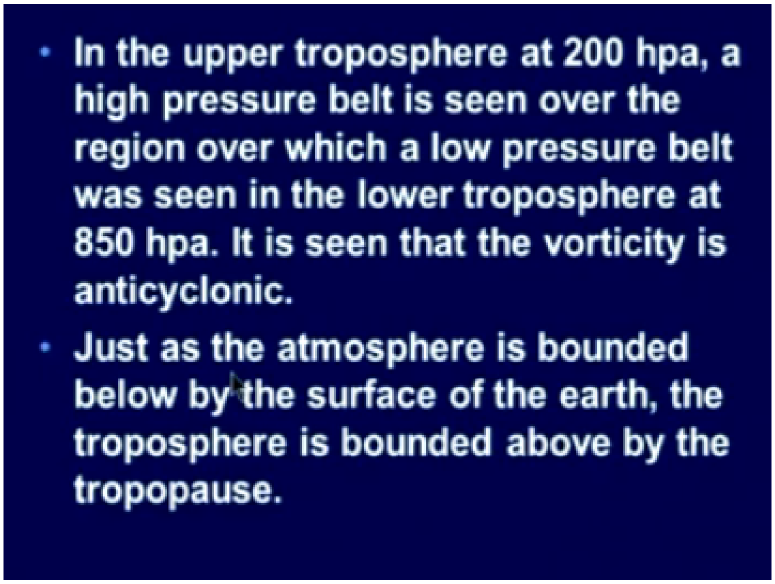

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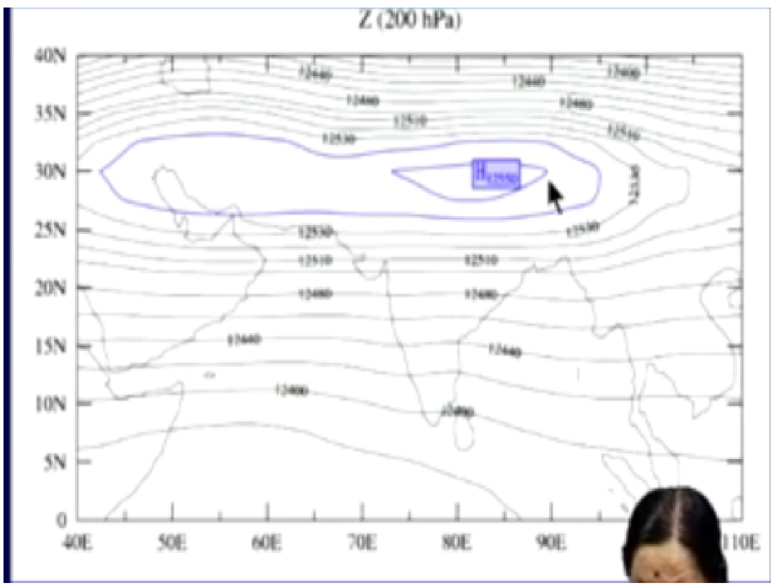

Because the high pressure is here, low pressure is here, geostrophic wind would be this way, so that the pressure gradient which would be this way from high to low balances the Coriolis force, so you have westerly winds here and easterly winds here as soon as you come above the boundary layer. Now, in the upper troposphere at 200 hpa, a high pressure belt is seen exactly more or less over the region where we had a low pressure.

So, if we go to 200 hpa, and these are levels of; in fact, these are the levels of the 200 hpa surface okay, so there are 2 ways in which you can show pressure contours either you can show the pressure at a fixed level of spheres at 10 km, 15 km or whatever or you can take a pressure surface such as 200 hpa and ask the question what is the height of that pressure surface above the see level.

And what you find here is that there is a high pressure here which is about; at which the height of 200 hpa is more than 12,000 metres, so this is about 12 km or so and so, there is a low pressure belt over lying the low pressure belt, okay, so if we were to go back, see what do we expect? See, this is the region of cyclonic vorticity, if we go to 850 millibar, this is the level above the boundary layer; this is the region of cyclonic vorticity.

So, you will expect that the bounding layer will have convergence in this region; region of the monsoons zone and air will ascend in this region, right but the air cannot go on ascending, it has to eventually descend and for that, the troposphere acts as a lead, so the air that ascends or the air that converges in a boundary layer and ascends has to stop ascending somewhere, diverge and then descend in the surrounding region, that happens in the upper troposphere.

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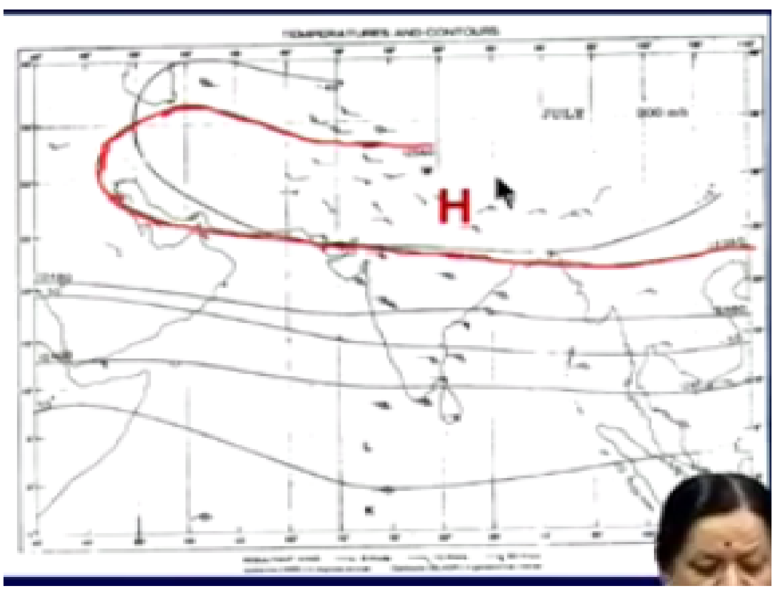

So, you have a cyclonic vorticity here which corresponds to ascend of moisture and when we go to the upper troposphere, you have a high pressure zone, so this high pressure zone is built up because of the ascending air and notice that here the vorticity is actually anti-cyclonic, see the wind is stronger here than here, so the sign of the vorticity is this way, so it is clockwise which means it is anti-cyclonic in the northern hemisphere.

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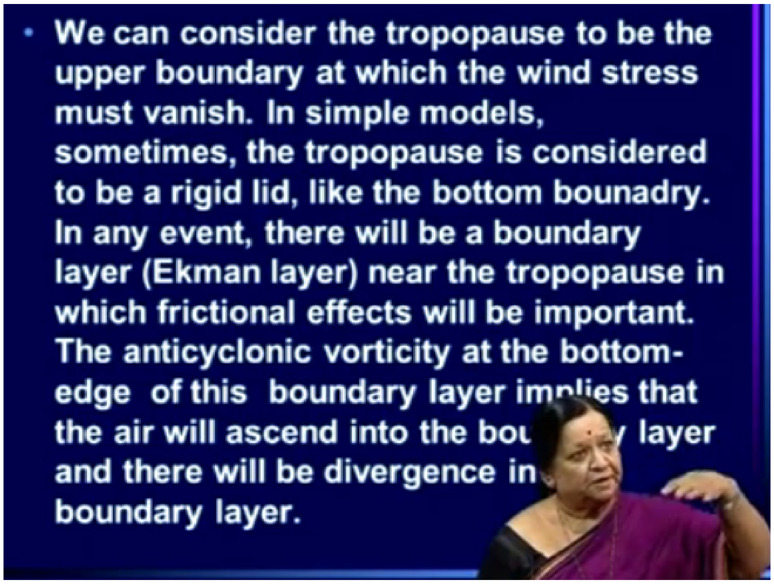

So, what we can see now is that, in in fact, so, what did we see hat at 850 hpa; I am sorry I keep using the word millibar, here at 850 hpa, we had cyclonic vorticity and low pressure belt, right and then when we went to 200 hpa, we had a high pressure belt over the region where there was a low pressure belt at lower levels and the vorticity here is anti-cyclonic okay, so what we can consider is the following.

We can consider tropopause to be the upper lead of the atmosphere because all the action that they we are interested in is in the troposphere, right, beyond the tropopause, you know that the temperature starts increasing in the troposphere, so we can consider the tropopause to be an upper boundary and there instead of having, it is not a solid wall like the surface of land, so there we could impose the condition of 0 wind stress, instead of 0 wind, which was the no slip condition.

And in simple model, sometimes, tropopause is also considered to be a rigid lead like the bottom boundary okay, but so in any event, we expect irrespective of whether you take it as a free boundary with stress free condition, mean stress going to 0 or a rigid boundary, there will be a boundary layer near the tropopause okay and where frictional effects will be important, so just like a boundary layer, near the surface of earth, you will have a boundary layer near the tropopause, right.

And now, you saw that at the edge of the boundary layer and since we are talking of boundary layer attached to the upper limit of the atmosphere or the tropopause, then the edge of the boundary layer means around 200 hpa or so, the vorticity is anti-cyclonic, right. Since the vorticity is anti-cyclonic, this boundary layer will be opposite of what we saw at the surface when the vorticity was cyclonic, it will be divergence in the boundary layer, okay.

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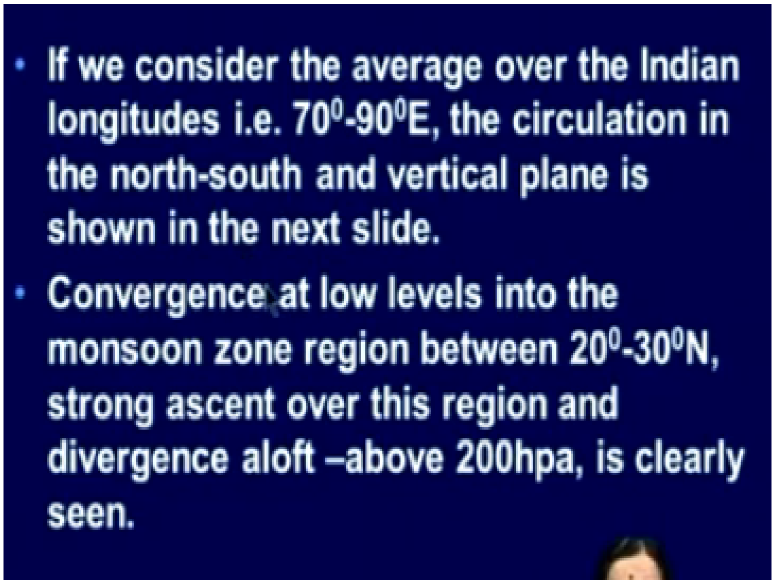

So, in fact we have cyclonic vorticity and above the boundary layer and convergence in the boundary layer. In the upper boundary layer, at the edge of the upper boundary, the vorticity is anti-cyclonic and you expect divergence to occur there and then when you have divergence in the upper level, the air that is diverging in the upper layer will descend in the surrounding region; region surrounding the region over which ascend is taking place okay.

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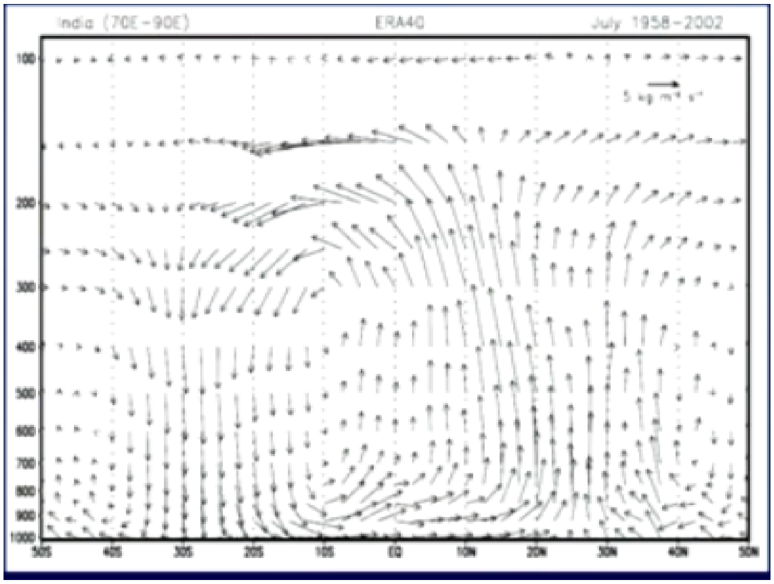

So, now suppose, we look at, what is the circulation like when we average over 70 to 90 degrees, so we are looking at the circulation is a North South vertical plane, right, we are averaging over an average longitudinal belt, 70 degrees to 90 degrees, which we can call Indian longitudes, remember, 90 degree is sort of the centre of the Bay of Bengal, it goes very near almost through Calcutta and 70 degree is just of the West Coast of the peninsula.

It goes across the Arabian Sea and then through Gujarat and Rajasthan and so on, so 70 to 90, we can consider our Indian longitude, suppose we take an average over those okay and then asked the question, how is the air moving in this plane, mediate diurnal vertical plane or north south vertical plane that is what you see here okay, so this is the equator, this is North okay and what you see is that around a monsoons zone is around here; 20, 25 or something like that.

And what you see is convergence of air in the monsoon zone at the lower level ascends and at upper levels, you see divergence and the air that is diverging is descending primarily in the winter hemisphere, in our summer, the winter hemisphere is the southern hemisphere, so what you see is a very nice circulation here okay, so you have the monsoon zone here and ascent of air, the air that is ascending more southward to the southern hemisphere and descends here.

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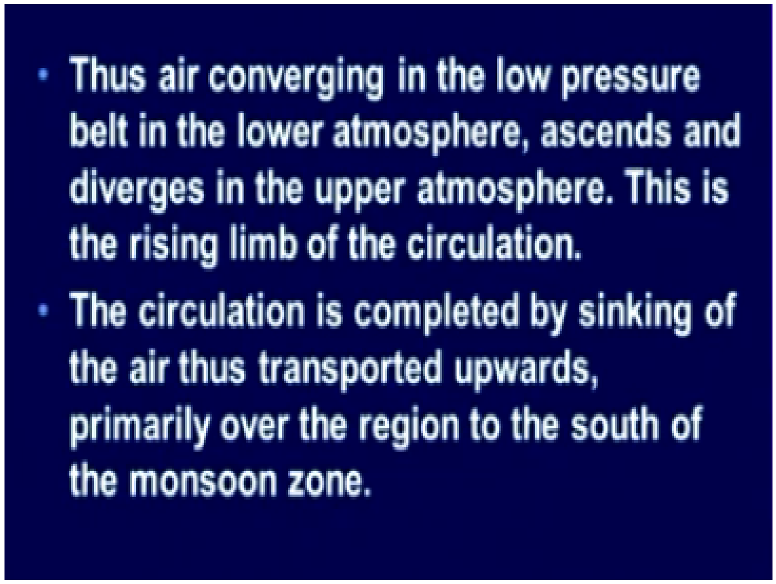

But note that the ascent is over a rather broad region okay which was almost from 10 south to about 25, 30 north okay, so this is the vertical circulation associated with the monsoon. So, air converging in the low pressure belt in the low troposphere ascends and divergence in the upper troposphere, this is rising limb of the circulation. The circulation is completed by the sinking of the air transported upwards primarily over the region, south of the monsoons zone.

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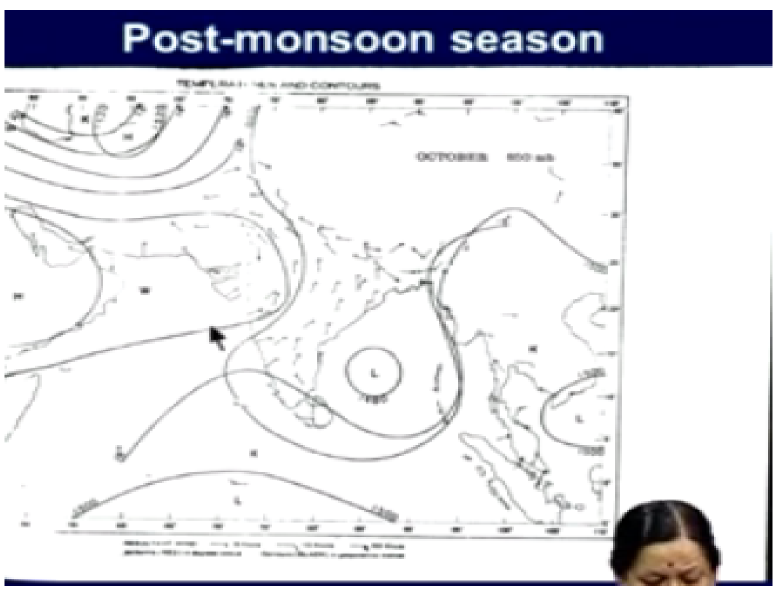

So, this is the nature of the bees, this is what we are trying to understand the theories of. Now, when we talk of seasonal variation, it is also important to look at post monsoon season, so if we look at post monsoon season, we saw this, what happens at the sea level in fuse lights earlier, this is at 850hpa, so this is above the boundary layer, remember earlier in the summer monsoon July, the monsoon trough was here and the low pressure belt was on the monsoon zone.

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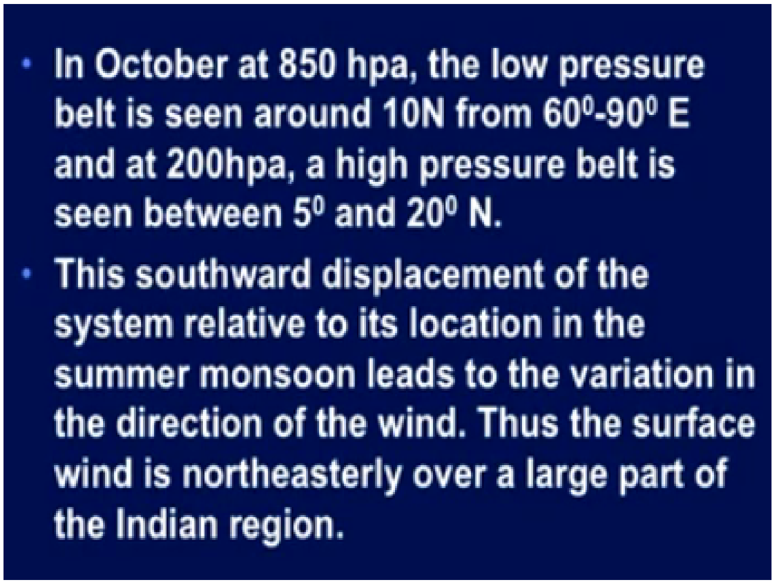

Now, you see the lowest pressure is here over the Bay and we are getting a Southward shift at the low pressure zone for October, it is more or less around 10 degrees North, the monsoon trough has moved to 10 or 12 degrees North or so, so the seasonality is seen in the seasonal variation in the location of the low pressure belt, this is for October. So, in October at 850 hpa, remember that 1.5 km above that ground, so it is above the boundary layer.

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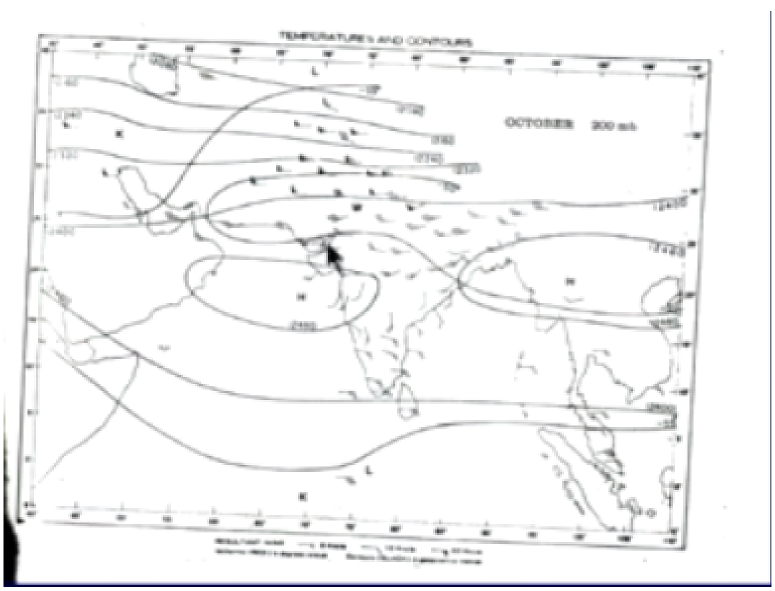

The low pressure belt is seen around 10 North from 60 to 90s and at 200 hpa, high pressure belt is seen, so again let us just see the 200 hpa in October and what we see is that over the region where there was the low pressure belt, now a high pressure belt is seen here okay and what you see is the associated winds now. So, the system which used to be here has now moved southward with the season.

So, now, so in October at 850 hpa, the low pressure belt is seen around 10 degrees North from 60 to 90 and at 200 hpa, high pressure belt is between 5 and 20, so again, you know it is absolutely essential that you have a high pressure region in the upper troposphere overlying a low pressure region, so as to ensure that the air that is ascending throughout the troposphere can actually diverge and then descend okay.

So, if the vertical cell, actually extends through the troposphere, you have high pressure in the upper troposphere overlying the low pressure exactly like we saw in July except now the entire system is moved southward, so it is around 10 North or so is the centre is being around 22 or 24 North as it was in July, so this southward displacement of the system relative to its location in the summer monsoon leads to the variation in the direction of the wind does; now you can see the winds here.

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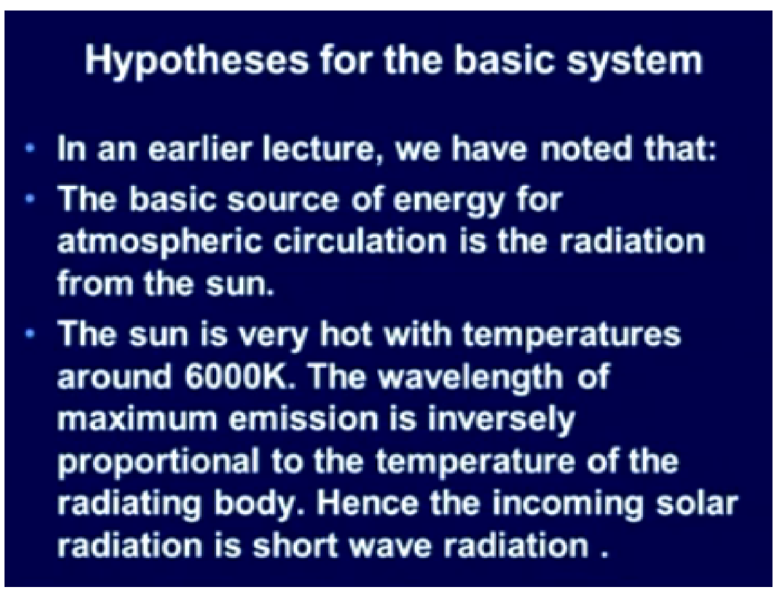

This is the; okay, these are the winds that you see here and now you can see that the winds are largely from the North or there north easterly here and here the winds are westerly over this region okay, so associated with the shift of the low pressure belt, we have a shift in the winds as well okay. Now, what are the hypotheses which can explain the seasonal variation that we have seen in all these, plus the more important thing, the seasonal variation in rainfall as well, okay?

Now, we have; so to understand those hypotheses again to revise the little bit of the fundamentals we learned in an earlier lecture, that the basic source of energy for the atmospheric circulation is the radiation from the sun, the sun is very hot with temperatures around 6000 K and the wavelength of maximum emission is inversely proportional to the temperature of the radiating body, so the incoming solar radiation is short wave radiation okay.

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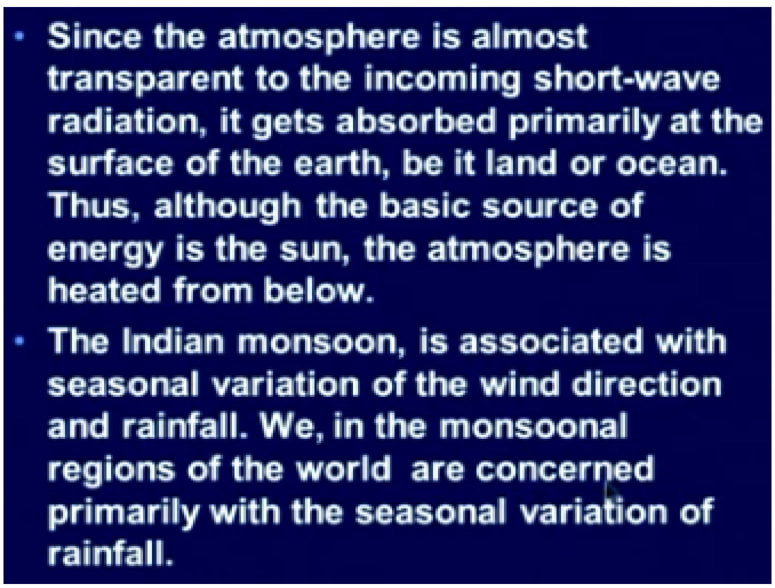

And since the atmosphere is almost transparent to the incoming shot wave radiation, it gets absorbed primarily at the surface of the earth, be it land or ocean. Thus, although the basic source of energy is the sun, the atmosphere is actually heated from below okay, whether it is by land or ocean. The Indian monsoon is associated with seasonal variation of the wind direction and rainfall; this is how the Indian monsoon was defined by seasonal variation of wind direction originally.

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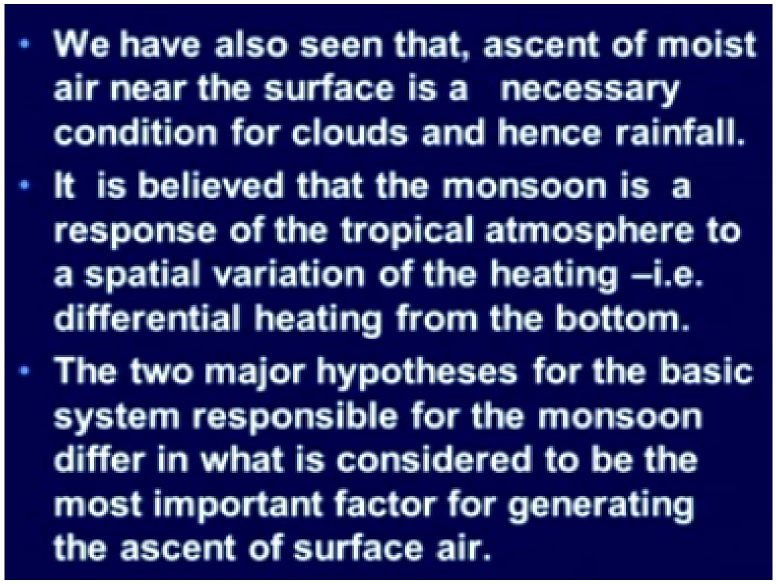

And of course, to us it means seasonal radiation of rainfall much more so than the variation of wind. We, in the monsoonal regions of the world are concerned primarily with the seasonal variation of rainfall. So, now to understand what leads to the seasonal radiation of rainfall, we have to remind ourselves that ascent of moisture near the surface is the necessary condition for clouds and hence rainfall.

Now, it is believed that the monsoon is a response of the tropical atmosphere to a spatial variation of the heating that is to say atmosphere is heated from below, so at the bottom boundary, if the heating is not uniform but rather varies in space, this is what we call differential heating from the bottom and monsoon is believe to be a response of the atmosphere to differential heating that is heating which is not uniform at the bottom boundary but rather varies in space okay.

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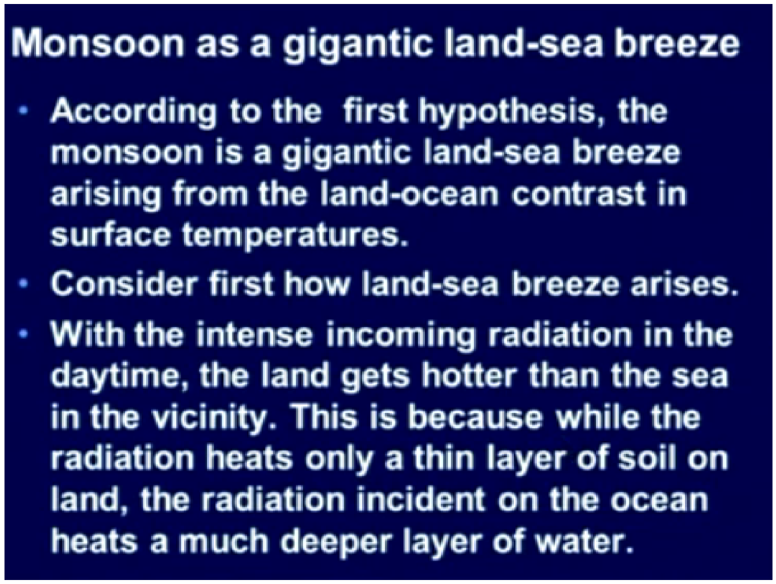

Now, the 2 major hypotheses for the basic system responsible for the monsoon differ in what is considered to be the most important factor for generating the ascent of surface air, okay, so the 2 major hypotheses differ in what is the differential heating, this kind of monsoonal circulation okay. The first theory which in fact even today is found in textbooks, we use the monsoon is a gigantic land-sea breeze, okay.

This is what we were taught in schools as well, that according to the first hypotheses, the monsoon is a gigantic land-sea breeze arising from land, ocean contrast in surface temperatures okay. Now, let us consider first, how a canonical land-sea breeze arises okay, before we consider the monsoon as a gigantic land-sea breeze okay. How do we get land-sea breeze? Now, land-sea breeze is what we all experienced, when we go near to the coast.

Why do we get land breeze? Because with the intense, incoming radiation in the daytime, the land gets hotter than the sea in the vicinity and why is that? Given the same amount of radiation, land gets hotter than sea because the specific heat capacity of land is different from that of the ocean, so, while the heat that is incident on the land goes to heat up only a thin layer of the soil. For the ocean, it heats up a much deeper layer of the water, okay.

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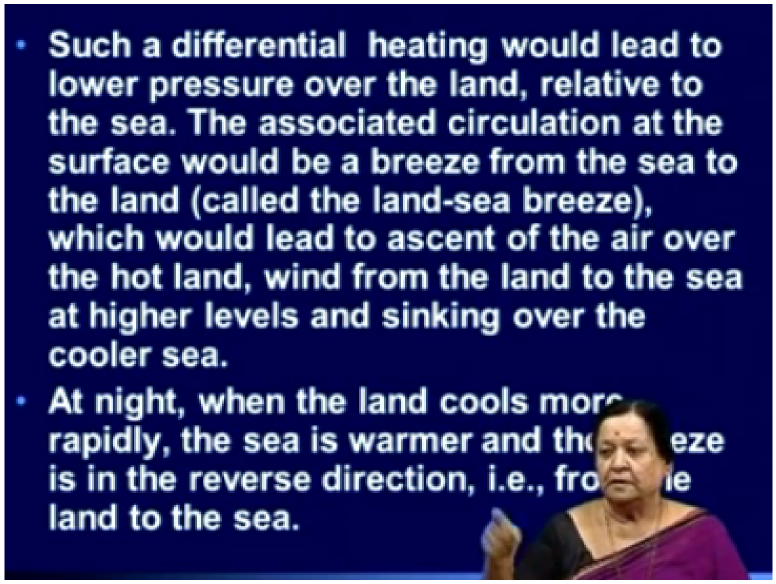

So, this means that given the same kind of radiation incident, which is at daytime, we will have hotter; the land becomes hotter than the ocean around the place okay, relative to the sea, the land becomes hotter. Now, the associated circulation at the surface would be a breeze from the sea to the land called the land breeze, why? Because the land is hotter than the sea, so there will be low pressure created on land, relative to the sea and the air will move towards the low pressure and that is the land-sea breeze.

Because that is the air moving from sea to land because the pressure decreases from sea to land okay, this is the standard land-sea breeze. Now, what happens at night? At night, land cools very fast okay, so wind goes from the land to the sea at night because the sea is warmer and low pressure would be there, so it is in the reverse direction. Now in a standard land-sea breeze, what happens to the air that goes to land in the daytime?

It rises over land; over the hot land and then the circulation is completed by the divergence of this air and sinking over the cooler sea okay, so the associated circulation at the surface in the daytime is a breeze from sea to the land which would lead to the ascent of air over the hot land, wind from that land to the sea at higher levels and sinking over the cooler sea, so you get a circulation completed in that, at night it reverses.

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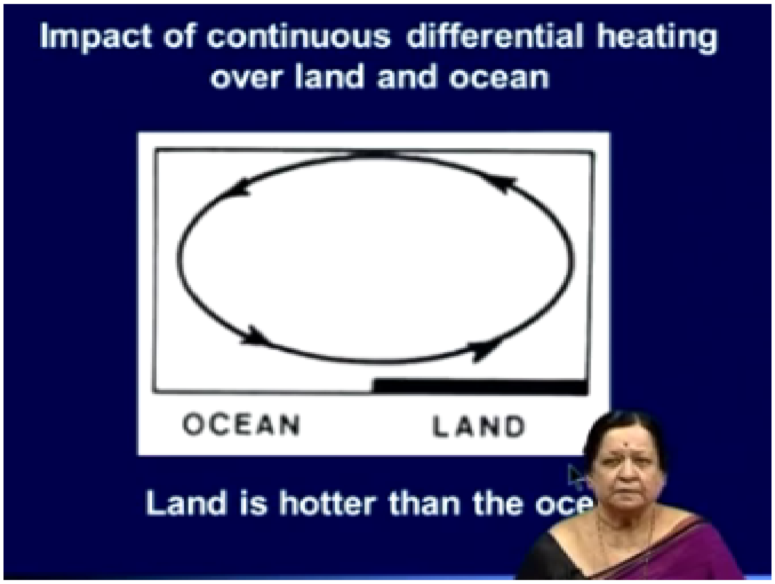

So, this is the kind of thing that we get, that in the daytime, we have; at lower level circulation from the sea to the land because the land is hotter and the pressure is lower and ascent of air over land, then it diverges and because ocean is cooler, I am sorry ocean is cooler than land, it descends over there. So, if land is maintained hotter than ocean, this is what we get and this is called the land-sea breeze.

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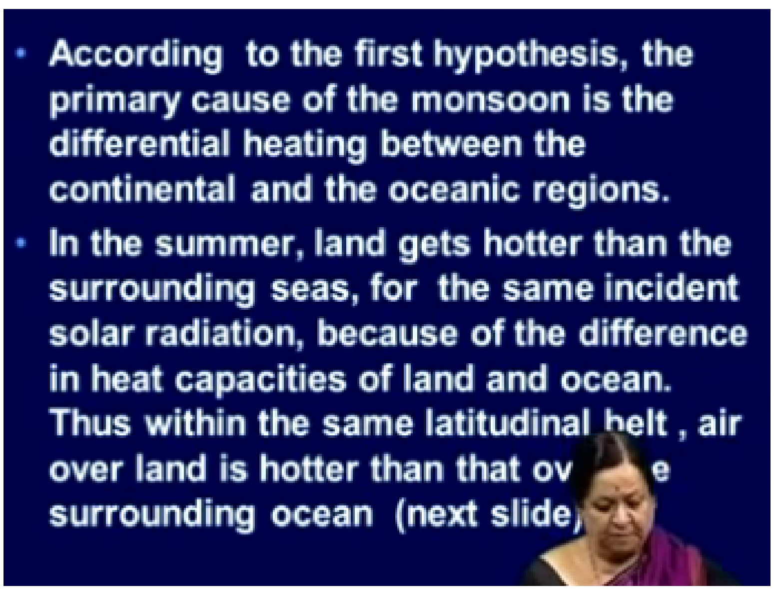

In the daytime, it is from sea to land an exactly, opposite happens at night which is from land to sea okay. So, the impact of continuous differential heating over land and ocean would be this. Now, according to the first hypotheses, the primary cause of the monsoon is the differential heating between the continental and oceanic regions. Now, in the summer land gets hotter than the surrounding seas, for the same incident solar radiation.

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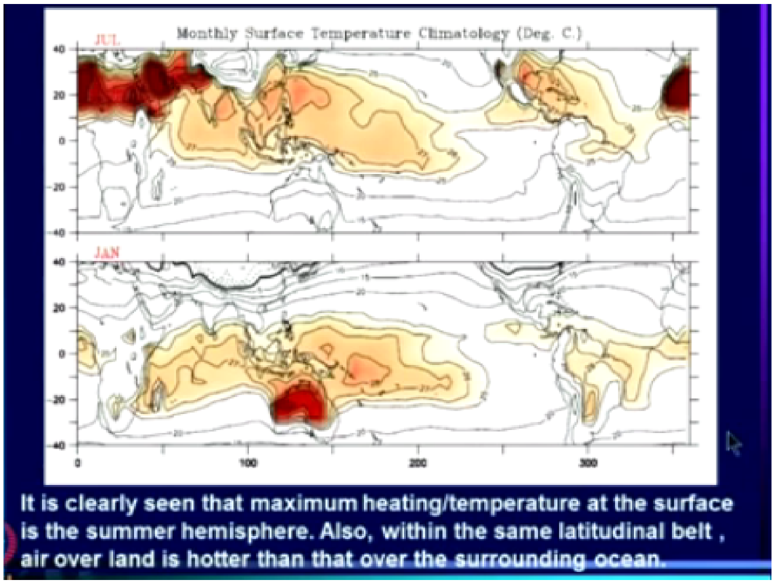

Because of the difference in heat capacities of land and ocean, thus within the same latitudinal belt, air over land is much hotter than that over the ocean and you can see that here, this is the surface; monthly surface temperature climatology, this is for July and this is for January. So, July means that the sun is overhead in the northern hemisphere and you see the land brighter shades are higher temperatures.

You can see that the land is much hotter than the ocean and this is southern hemispheric summer in January, where you can see that the Australian continent is much hotter than the surrounding ocean. So, it is clearly seen that maximum heating or temperature at the surface is in the summer hemisphere, so first of all note that highest temperature occur in the summer hemisphere, which is the northern hemisphere in July and the southern hemisphere in January.

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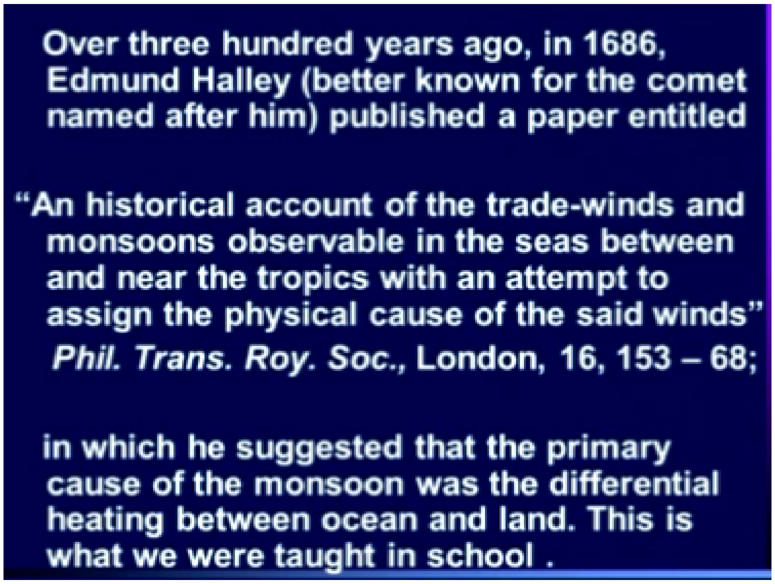

And within the same latitudinal belt, land gets much hotter than the ocean okay, so, this is the famous land-ocean contrast which is supposed to be responsible for the monsoon according to the first hypotheses and it is amazing that we have a very long history of theorizing about the monsoon over more one than 300 years ago, Edmund Halley, who is better known for the Halley comet.

In fact, published a paper entitled an historical account of trade winds and monsoons observable in the seas between and near the tropics with an attempt to assign the physical cause of the said winds. This is very interesting, we are discussing in these lectures, physical cause of the monsoon and this is exactly the problem that was addressed by Halley way back in 1686. This was published in the philosophical transactions of the Royal Society of London.

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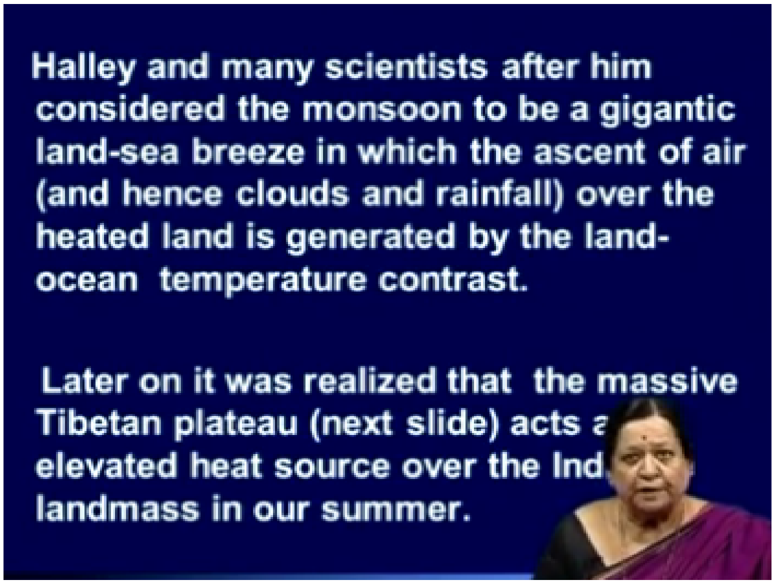

Now, what did he suggest in this? He suggested that the primary cause of the monsoon was the differential heating between ocean and land; this is what we were taught in school. Now, Halley and many scientists after him considered the monsoon to be a gigantic land-sea breeze in which ascent of air and hence clouds and rainfall over the heated land is generated by the land-ocean temperature contrast.

So, we remember we have talked about how ascent of surface air in the moist; surface moist; moist surface air in a tropical atmosphere can lead to clouds and rainfall, so what leads to the ascent was suggested by Halley as the land-ocean contrast, so the contrast between land and ocean in the temperatures or in the heating of the atmosphere from below leads to a gigantic air sea breeze; sea air breeze; land-sea breeze, in which there is ascent of air over land.

Because now we are not thinking of day and night but rather with season, so in the summer, in our summer, land is much hotter than the sea around it and therefore we get a land-sea breeze but which is the gigantic because the contrast is also on the scale of continents and oceans okay, so over the heated land, we get ascent of air which will give clouds and rainfall was the assumption and so, the land-ocean temperature contrast was supposed to be the primary driving force of the monsoon, okay.

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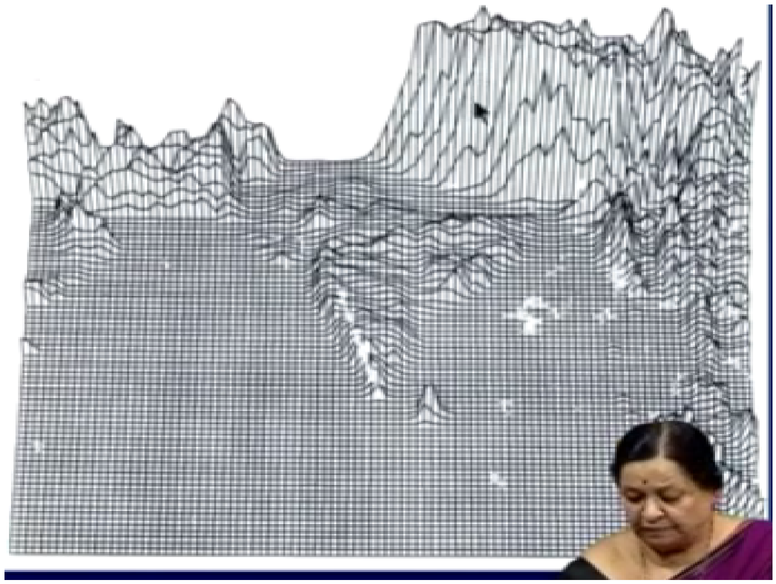

Now, in Halley's time, people were not aware of the impact of rotation of the earth, Coriolis came later and Coriolis force was included in this discussion, so this is a continent we are looking at and this is the land-ocean contrast but we should also mention that we have a very unusual topographic scenario in our country, we had Tibetan plateau to the North, which extends to half the troposphere.

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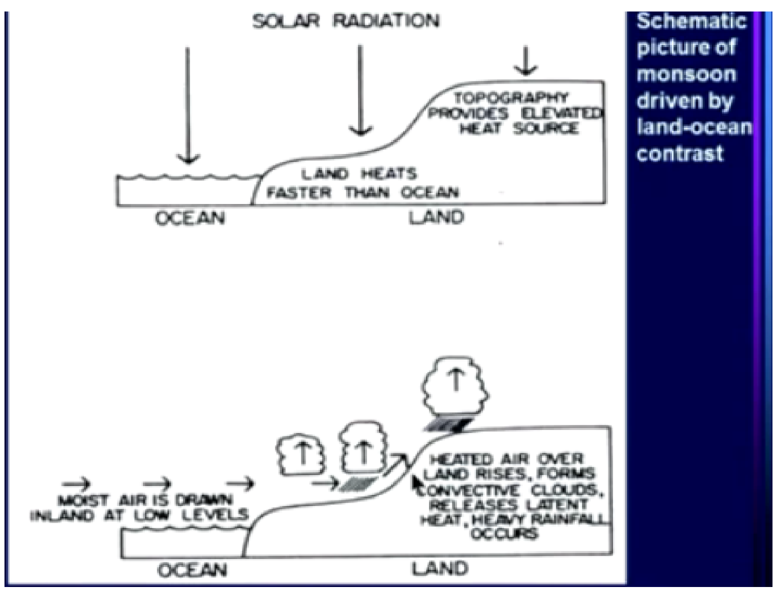

So, not only do we have heating of the subcontinent relative to the ocean around but we also have and; what people call an elevated heats source because this mountain is raising through the half the troposphere, so it is a very very strong heating that is generated, so people realised that

Tibetan plateau would also have an impact and so the kind of schematic of the monsoon driven by land-ocean contrast is what you see here, that land heats faster than ocean.

This is land, this is the same solar radiation but land heats faster than ocean. Then, there is the topography, this in the Tibetan topography which provides an elevated heat source and so land heating faster than ocean means lower pressure gets created here and that leads to this is the gigantic land-sea breeze, so that leads to moist air from the ocean being sucked towards the land and that leading to clouds and rain okay.

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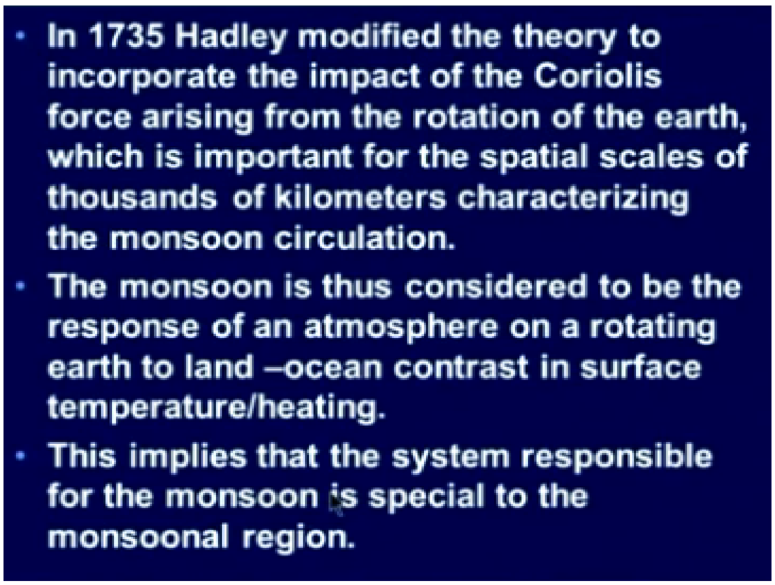

Heated over the over the land rises forms convective clouds releases latent heat and you get copious rainfall over land and this is supposed to be the monsoon. This is the first model of the monsoon. So, as I mentioned before, now this gigantic land-sea breeze theory was modified a bit by Hadley, who took into account what Coriolis force would do, so what would happen is rather than simply the wind going from high pressure to low pressure, a Coriolis force would make an impact on this wind.

And because that is important for spatial scales of thousands of kilometres characterizing the monsoon, so finally from this first hypotheses, monsoon is considered to be the response of an atmosphere on a rotating earth to land-ocean contrast in surface temperature or heating okay and this implies that the system responsible for the monsoon is special to the monsoonal region, right because it is a system that gets generated during the summer over land okay.

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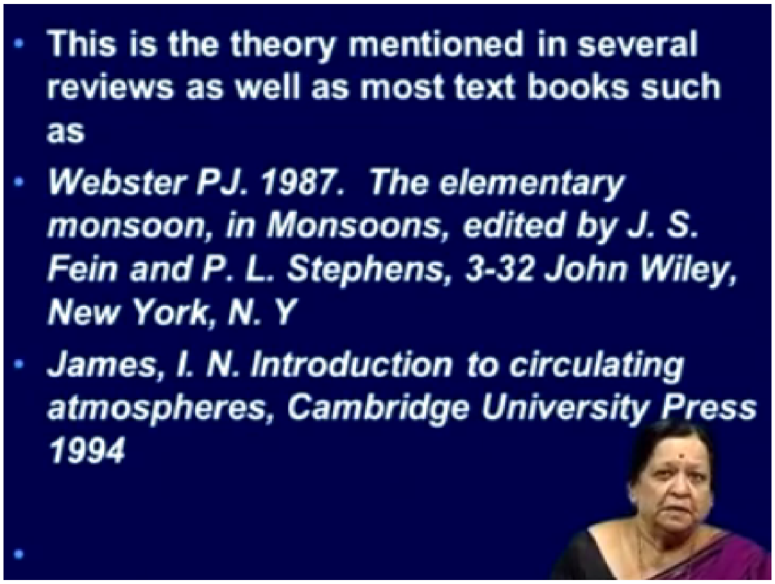

And it reverses during a winter, it disappears, there is no rainfall in a winter, so this is; if we believed that land-ocean contrast is the primary force of the monsoon then, the system responsible for the monsoon is very special to the monsoon region, okay. Now, as I said this theory is even today mentioned in many, many textbooks and in important reviews like 2 have quoted, this is a paper by Webster on Elementary monsoon in a book edited by Fien and Stephens in 87.

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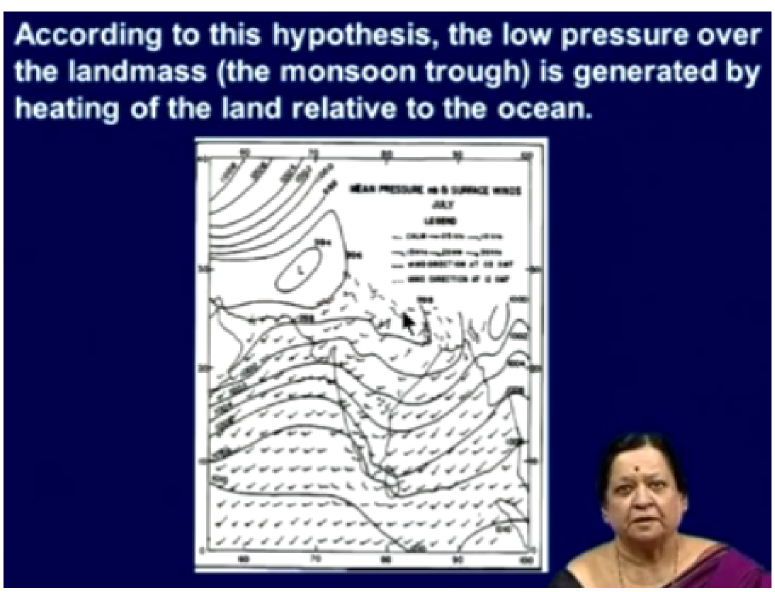

And many books of which I give just one example, which gives introduction to circulating atmosphere in which are something about the monsoon, refer to the monsoon as being generated by land-ocean contrast in temperature okay. So, what is the hypothesis then? According to this hypotheses, the lower pressure over the land mass over; of the monsoon trough which is this low pressure here, remember this is the low pressure belt here, okay.

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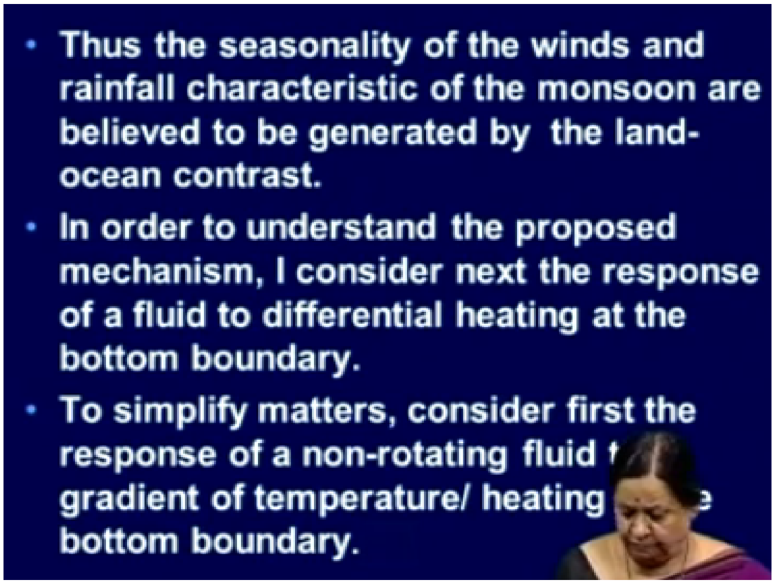

It generated by the heating of the land relative to the ocean, so heating of the subcontinent and of course, the Tibetan plateau here leads to the low pressure over here, this is what; so, the seasonality of the winds and the rainfall characteristic of the monsoon are believed to be generated by the land-ocean contrast. In order to understand the proposed mechanism, we first; let us consider a simple case of a fluid subject to differential heating at the bottom boundary, okay.

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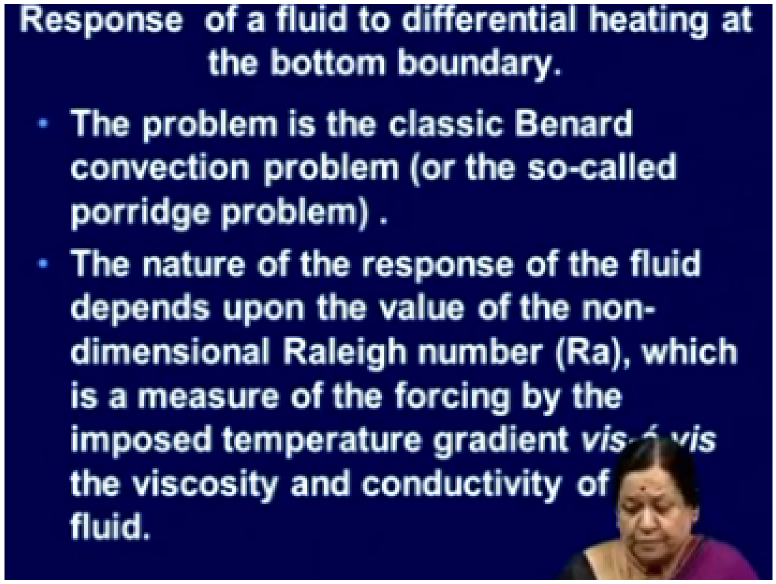

So, to just understand what happens when you have; say atmosphere heated from below, just considered the simplest possible scenario in which we forget about the rotation of the earth okay and we consider what happens to a fluid which is heated from below. Now this is a classic problem, this is the response of a fluid to differential heating at the bottom boundary, so you have response of heating; the fluid heated from below and this is called the classic Benard convection problem or the so-called porridge problem,

Why is it called the porridge problem or in India you could call it the sambar problem, is that if the heat is too much, the porridge or the sambar will get burned, unless it is stirred okay, so this is why it is called the porridge problem and now I will go on to say what does one mean by heat being too much okay. The nature of the response to the fluid depends on the value of the non-dimensional Raleigh number okay, which is a measure or the forcing by the imposed temperature gradient vis-s-vis the viscosity and conductivity of the fluid.

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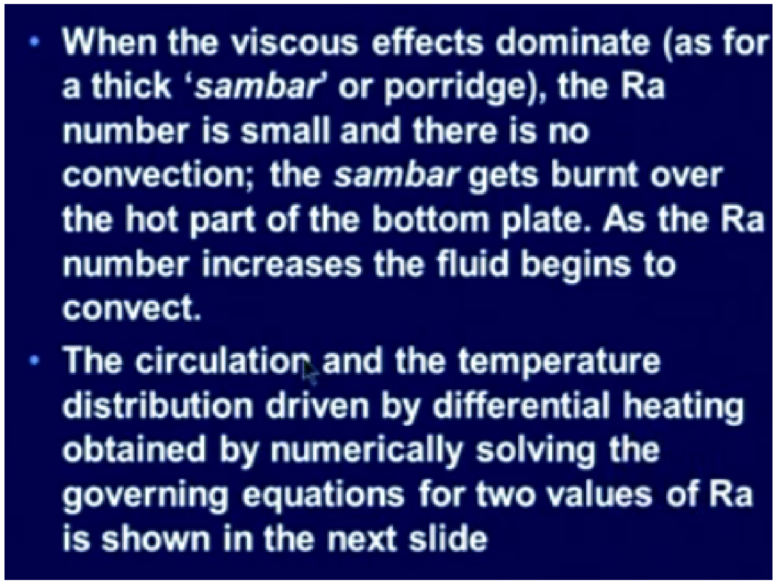

We know very well that water when heated from below does not really get burned because it just convects, whereas, porridge or the thick sambar heated from below can get burned, so it has to do with the viscosity of the fluid as well and Raleigh number is a non-dimensional number which determines how large is the heating vis-a-vis the viscosity and connectivity of the fluid, so when viscous effects dominate as for the thick sambar or porridge, the Raleigh number is small.

And there is no convection, that is to say, there is no convection of the fluid, the fluid is sitting in the bottom as it is and burning because there is too much heat there okay. So, the sambar gets burned over the hot part of the bottom plate. As the Raleigh number increases, the fluid begins to convect and the classic example is that if you heat water, then the hot water at the bottom rises to the top and there is regular convection maintaining the fluid and there is no burning and so on.

So, what; how the fluid reacts depends on the Raleigh number? Now, this actually the equations of this can be readily solved, at this point I am not going to bother you with the questions but show you just the solution. So, the circulation and the temperature distribution given by differential heating, obtained by numerically solving the governing equation for 2 values of Raleigh number, as shown in the next slide.

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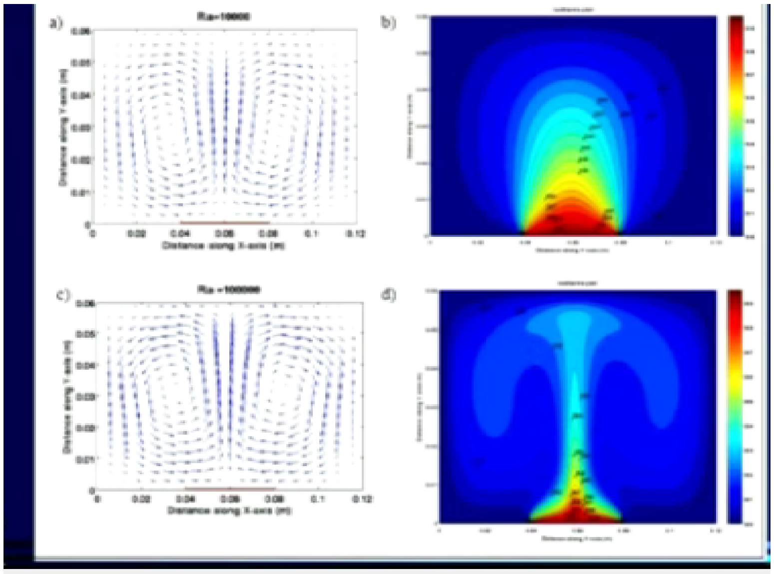

And what you see here is the temperature in colours and blue to red means hotter and hotter and the fluid is heated from below and it is heated only over this part of the plate okay, it is heated only over the red part of the plate and this is a numerical solution to what happens in a steady state, it is in fact being cooled on all sides here, on the sides here, so that on the whole, the fluid does not get heated up okay, there is equilibrium possible.

So, we have heating from here and what this leads to is, ascent of air or whatever fluid it is, okay so low level you get a; lower low pressure region created here, fluid moves towards the low pressure region. Imagine, if you like that this is land and this is sea, so the fluid in moving, air is moving towards the land rising diverging and in this case, descending in the surrounding air where this bottom temperature is colder, okay.

So, we have the kind of circulation that we described qualitatively as land-sea breeze here. Now, what happens as Raleigh number increases? Then the ascending limb becomes narrower and the descending limb becomes broader okay, so as the heating increases vis-a-vis the viscous effects and we know that the atmosphere we seen in the earlier lectures that atmosphere is not very viscous and viscous effects are mainly in the boundary-less.

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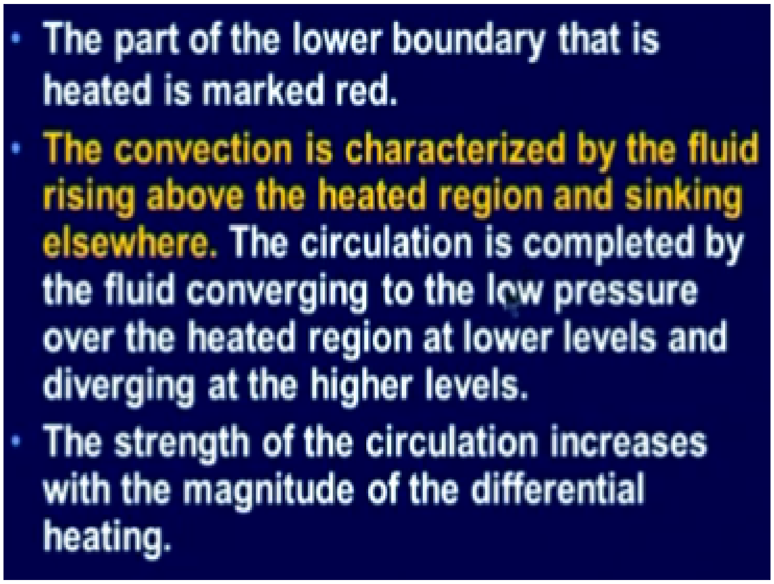

So, as we go towards the inviscid limit, then we see that we get a very, very narrow ascending region and a relatively broad descending region, so this is; now the basic response of a fluid heated from below. Remember we are not worried here about the rotation of the fluid okay. So, as I mentioned that convection is characterized by rising above the heated region and sinking elsewhere.

And circulation is completed by fluid converging to the low pressure over the heated region at low levels and diverging at the higher levels, so the strength of the circulation increases with the magnitude of differential heating, so keeping the viscosity same if we increase the differential heating which water implies that Raleigh daily number is higher, the strength of the circulation is higher; stronger ascent here.

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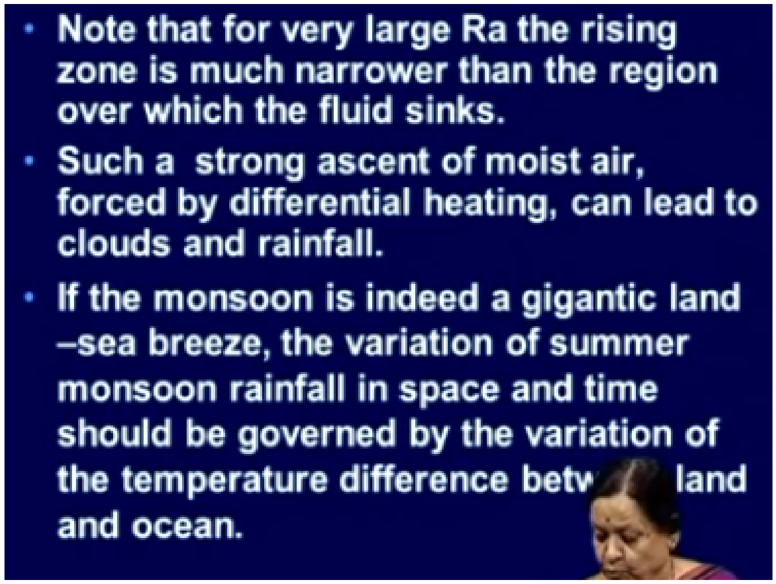

And you see, this is the circulation that is driven that you have convergence at low levels, air ascending divergence at high levels and air descending in the surrounding region, okay and so, this is the way the circulation is completed and the strength of the circulation increases with the magnitude of the differential heating. So, for very large Raleigh number, the rising zone is much narrower than the region over which it sinks okay.

Now, so let us go back to the atmosphere, we expect that such a strong ascent of moisture force by differential heating can lead to clouds and rainfall, right because once we have strong ascent driven by these differential heating and if the ascent is above the lifting condensation level, we can get clouds and rainfall, okay. So, if the monsoon is indeed a gigantic land-sea breeze, the variation of the summer monsoon rainfall in space and time should be governed by the variation of the temperature difference between land and ocean okay.

So, the first hypotheses which is the one we were taught and which is the one which is quoted extensively in many, many textbooks namely that the monsoon is driven by land-ocean contrasting temperatures, this is the way, this is the fluid mechanics of that, ascent driven by differential heating and the stronger the differential heating, the narrower the ascent and narrowing the ascending region and stronger the ascent and more clouds and rainfall.

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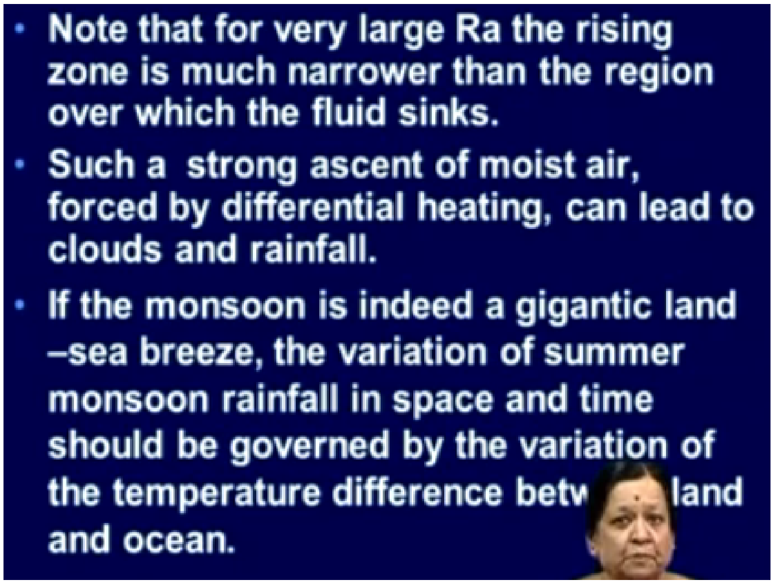

So, monsoon is then why said as a gigantic land-sea breeze, which is a response to continents being much, much hotter than the oceans okay. Now, one thing we have to realize is that if we believe that we have understood, what is the physical system responsible for the monsoon? We should be able to understand and explain the variability of the monsoon in space and time; you remember in the second lecture, we talked about how rainfall varies in space and time.

We saw how rainfall varies within a season from dry spells to wet spells and how it varies in space also, for example in the monsoon zone, you get much more higher rain over the Bay of Bengal and as we go North westwards towards Rajasthan, the rainfall decreases, right. So, we should be able to explain the space time variation of monsoon and particularly rainfall from the understanding of the basic physics system.

Physics of the monsoon or the basic system responsible for the monsoon, right, this is an absolute requirement. Now, what happens is, with this first hypothesis, which actually gives primacy to land-ocean temperature contrast, observations of the space time variations of the monsoon over the Indian region are not consistent with this expectation, right. What was the expectation?

That if the monsoon is indeed a gigantic land-sea breeze, variation in monsoon rainfall will be governed by variation in temperature difference between land and ocean, right. For example, if that temperature difference decreases, what happens? If the temperature difference decreases, we go to a case, which we have seen earlier whether heating becomes less intense, right. Then, we expect to get less rain because ascent is weaker; this is some simple minded fluid mechanical theory, right.

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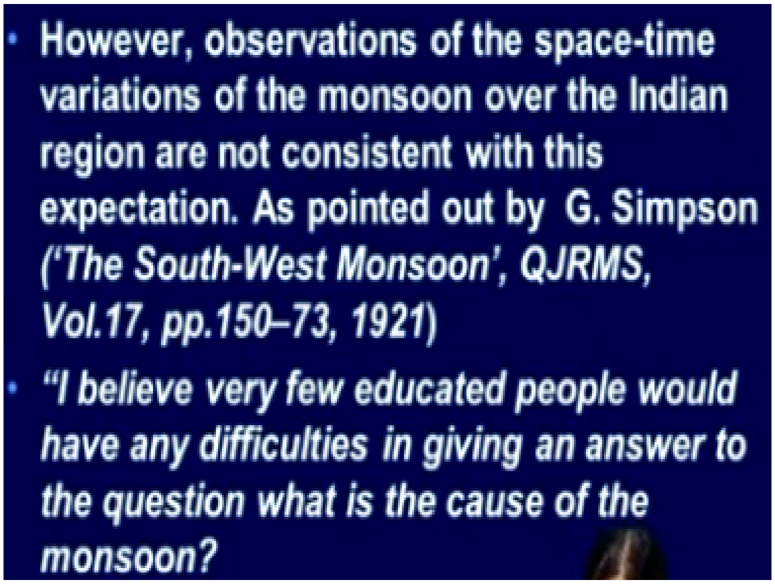

So, then we expect the variability to be determined by the land temperature contrast, okay. But, in fact, the observations are inconsistent with this expectation okay and this was first pointed out very eloquently by Simpson in the quarterly Journal of Royal Meteorological society as early as in 1921 okay, in a major review paper called the South-West Monsoon, he says, I believe very few educated people would have any difficulties in giving an answer to the question, what is the cause of the monsoon, okay.

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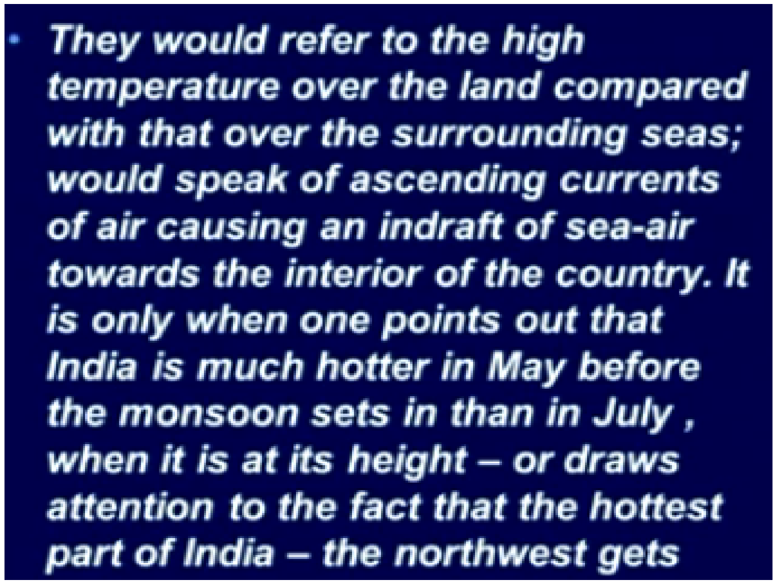

They would refer to the high temperature over the land compared with that over the surrounding seas, so this is the main land-sea contrast of temperatures, would speak of ascending currents of air, causing an in draft of sea air towards the interior of the country, right because the land is hotter, the air would ascent which equals ascending currents of air and this of course, is possible because the moist sea air at low levels is coming towards the land in the land-sea breeze.

And in that air, that is ascending so they would speak of ascending currents of air causing an in draft of sea air towards the interior of the country, it is only when one points out that India is much hotter in May before the monsoon sets in, it is only when one points out that India is much hotter in May before the monsoon sets in than in July when it is at its height, right, so what is now saying is in May, if the temperature contrast is much higher which it is.

Because the temperatures of land are very, very high in May, they are of the order of 40 degrees in many places, whereas in July, the land is much cooler, right. So, one would expect that there should be more rain in May than in July, right, so it is only when one points out that India is much hotter in May before for monsoon sets in, before the rainfall begins than in July, when it is at its height, right.

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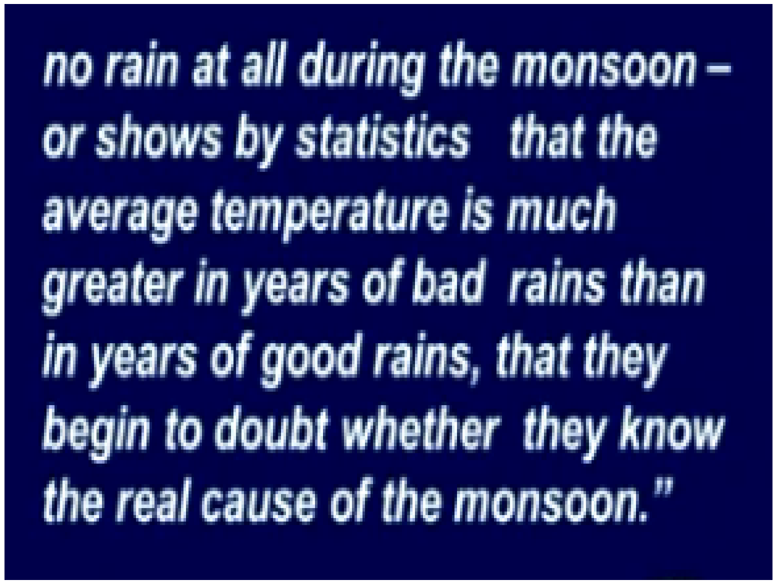

So, when you look at temporal variation, you have less land-ocean contrasting temperature, when you have rainfall or draws attention to the fact that the hottest part of India; the Northwest which is part of Rajasthan gets no rain at all during the monsoon, so if you look at the special variation, then temperatures is highest over Rajasthan in the Northwest as you call them as monsoon trough towards the Bay of Bengal, the temperature decreases.

So, the temperature contrast with ocean is maximum vis-a-vis Rajasthan or the North western part whereas it is minimum over the region to the eastern part; eastern part of the monsoon trough, but there is no rain at all over the Rajasthan and plenty of rain near the Bay of Bengal, you know whether eastern part; Orissa, Bengal and so on and so forth, so this again is contrary to an expectation that the variability in space will be determined by the variability of land-sea temperature contrast.

And then he makes a further point or shows by statistics that the average temperature is much greater in years of bad rains than in years of good rains that they begin to doubt whether they know the real cause of the monsoon. Now, this fact that the average temperature is much greater in years of bad rains than in years of good rains was something that was stated by Simpson but he did not actually show data for it.

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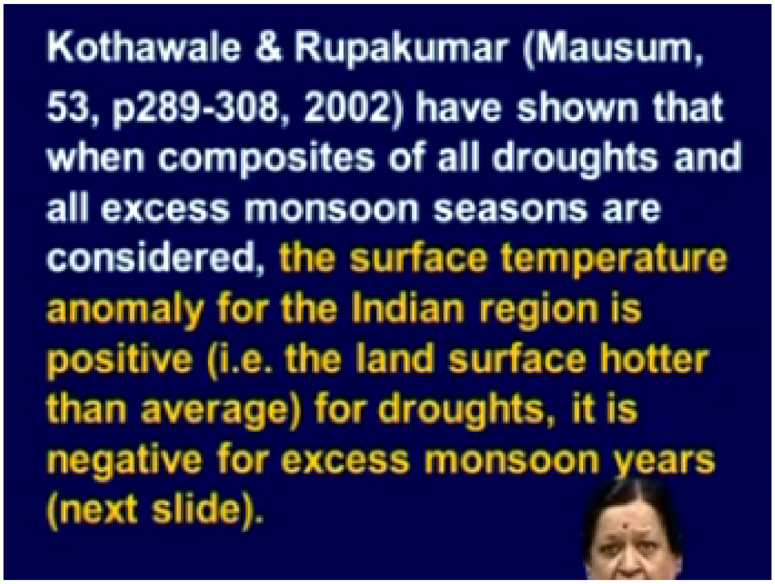

But I will show you some data, this was done by Kothawale and Rupakumar and what they did was, they made averages or composites of all droughts and all excess monsoon season okay, and they looked at surface temperature anomaly, remember anomaly just the temperature minus the average for the Indian region and did it for surface as well as at higher levels okay and what do they find?

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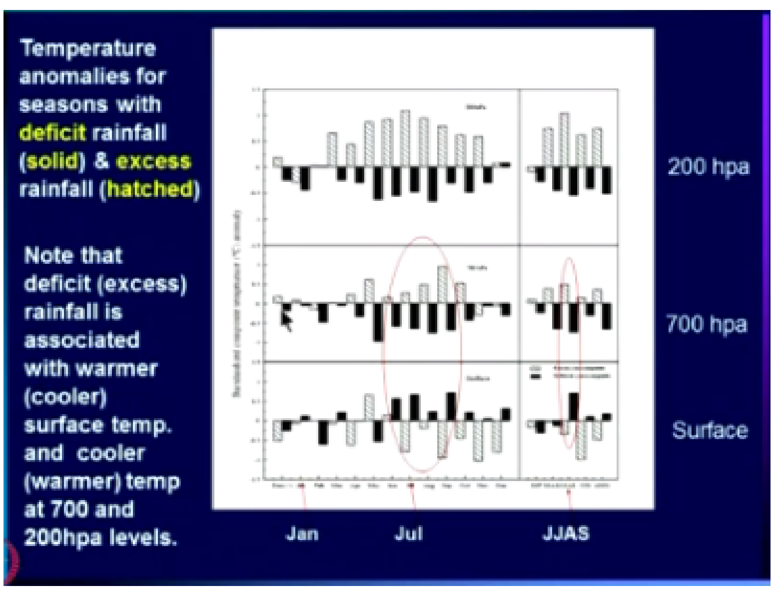

First look at the surface, okay and this is monthly now, this in January to December and these are seasons okay, so now notice that for each case, hatched corresponds to excess monsoon year and deficit rainfall or droughts are solid years okay. So, now when you come here, let us first look at

JJAS, you find that droughts are the solid bars; in droughts, the surface temperature anomaly is positive, whereas in excess rainfall years, it is negative, okay.

So, this is exactly what Simpson pointed out that when you have less rainfall, the land-ocean temperature contrast is more because the surface temperature anomalies positive, land is hotter than average, whereas land is colder than average when the rain is high okay. So, this is absolutely opposite of what one would expect, if the rainfall was governed by land-ocean contrast.

In fact, you see the same story for the individual months here, this is June, July, August and September, so you see exactly the same thing, all the solids are above positive anomaly, all the negatives; hatched are negative which means land is colder for excess rain. It is interesting that as you go to higher levels like 700 hpa, this is 3 km, here the cloud is already beginning to have an impact on the temperature.

So, there you find that all hatched things are above that is to say at 700 millibar, if you have more rain, you have higher temperatures, if you have droughts here, lower temperature. This is again consistent with our understanding of clouds and rainfall and what they do to the temperature and at 200 hpa, the same thing remains okay. So, this is exactly what the Simpson had said that the surface temperature anomaly; sorry this is Kothawale and Rupakumar.

But what Simpson had said was that shows by statistics, which is what I showed you generated by Kothawale and Rupakumar that the average temperature is much greater in years of bad rains which were the droughts than in years of good rains which is the excess monsoon rain that excess rainfall season that we looked at; they begin to doubt whether they know the real cause of the monsoon.

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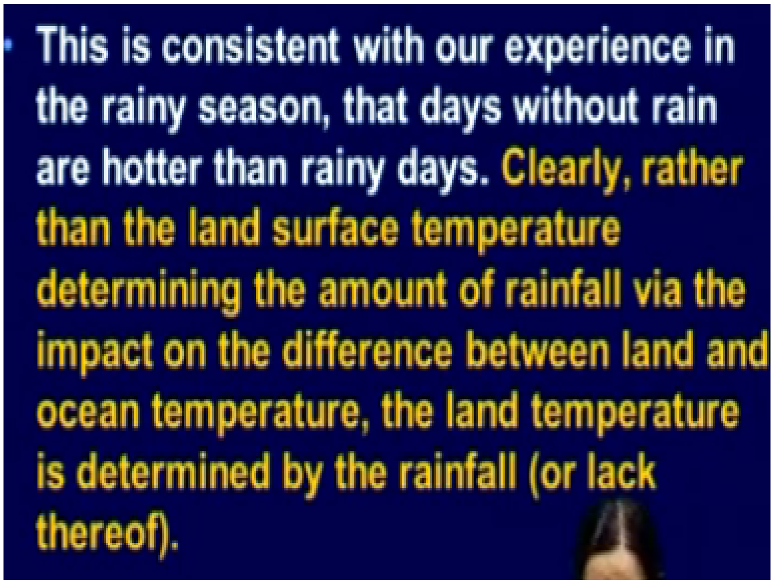

So, what Simpson has shown is that; you cannot explain the observed space time variation of rainfall by assuming that the rainfall is related to land-ocean temperature contrasts okay, so this is a very important statement he made back in 1921 and in fact this is consistent with our experience in the rainy season that days without rain are much hotter than rainy days, right. So clearly, rather than the land surface temperature determining the amount of rainfall via the impact on the difference between land and ocean temperature.

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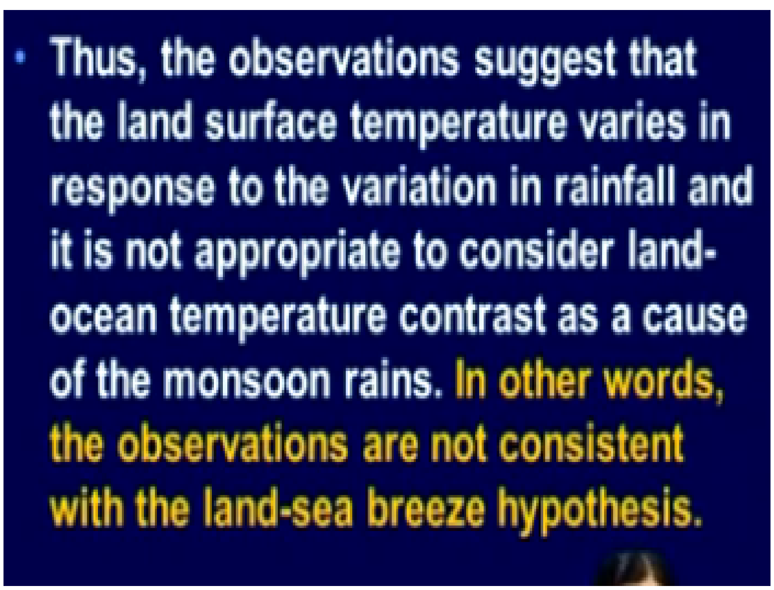

The land temperature is determined by the rainfall or lack thereof, so if you have do not have rain, it is hotter and if you have rain, it is colder. So, this in fact shows that the observation suggests that the land surface temperature varies in response to the variation of rainfall and it is not appropriate to consider land-ocean temperature contrast as a cause of the monsoon rains okay, beginning with reminding you of what Halley gave us the title to his paper.

What is the cause of the monsoon winds? He said, he was more concerned with wind but if we ask, what is the cause of the monsoon rains? We cannot attribute monsoon rains to land-ocean surface temperature contrast okay. This cannot be considered as a cause of the monsoon rain in other words, the observations are not consistent with the land-ocean hypotheses, land breeze, sea breeze hypotheses.

So, we now have to think of another hypotheses for the system which is responsible for monsoon rains, the hypotheses that monsoon is a gigantic land-sea breeze does not in fact, give results which are consistent with observations of space time variation of monsoon rainfall and this is very simple space time variation , variation of monsoon rainfall between droughts and good monsoon seasons, variation of monsoon rainfall over space between the eastern part of the monsoon, drought zone over Orissa.

And the eastern regions vis-a-vis Rajasthan and the north western region, so land-ocean temperature contrast cannot be considered as the primary cause of the monsoon over India and the Indian monsoon cannot be thought of as a gigantic land-sea breeze. This is the conclusion we have come to, now that we have shown that one hypothesis is wrong, we have to show what is right.

Before we can start interpreting what is monsoon variability, so in the next lecture, we will look at what I believe is the correct hypotheses for the basic system responsible for the monsoon. Thank you.