Introduction to Atmospheric Science
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Lecture – 37
Radiative Heating Profiles of the Atmosphere

Good afternoon. So, we are looking at the problem of vertical profiles of radiative heating rate.

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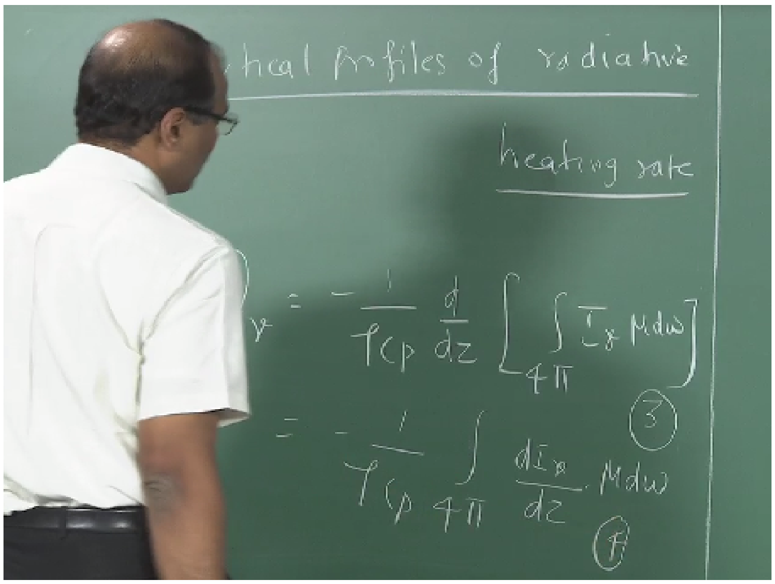

So, looking at the energy balance I think we got something like this for a particular let what is the equation number for this? This continuation of the last class the equation number 3. So, then we interchanged the differential and integral sign then we got this as.

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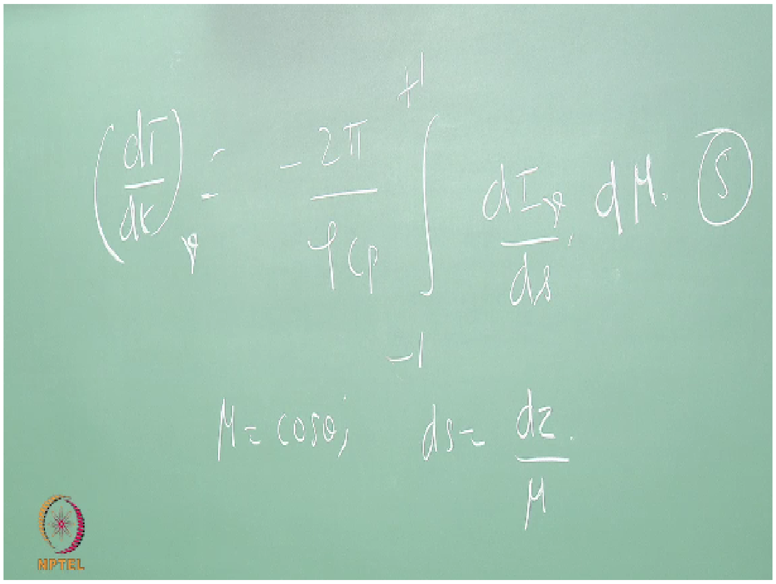

This was equation number 5. So, I think we went through very fast in the last class. Couple of points by integrating over the 4 pi solid angle and not 2 pi solid angle because it is a volume it is not from here to somewhere point number 1. Point number 2 regardless of whether you have a 2 pi solid angle or a 4 pi solid angle the azimuth angle is 2 pi only. So, that is why I have taken 2 pi. But instead of integrating cos theta from 0 to 1 we have -1 to +1.

So, the 2 pi for the phi azimuth angle and -1 to +1 takes cares of 4 pi solid angle. Then we are converting this dz to ds local coordinates which takes care of the view term. Now, this minus there is a rho also right. So this is from the RT equation, repeatedly I am saying we should not say RT equation but we say that. People will say CRC complex, CRC itself has complex. The dean also say CRC complex.

We also say CRC complex, CR complex. **"Professor - student conversation starts"** What is it? That is not nu, r. **"Professor - student conversation ends".** So, we substitute.

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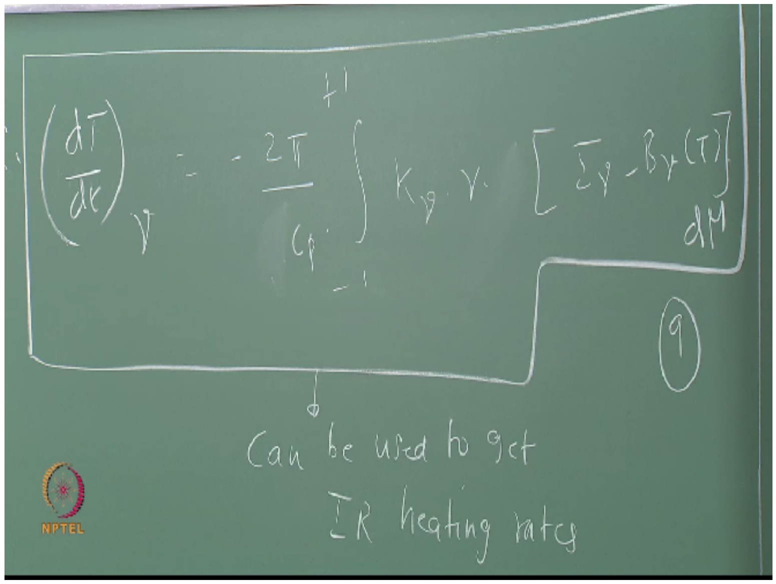

The equation 9 can be used to find out the vertical profile of the radiative heating rate for a particular wave number or for a particular frequency at a particular layer or particular level of the atmosphere. Is it okay so you can do it for various parts various wave numbers of the infrared part of the spectrum you can also do it for at various heights where you can get that kappa, kappa nu can be function of height you divide it into various levels and then take at each of the levels.

But now as you know that i nu –v is very painful that comes from the solution to the radiative transfer equation. Therefor some simplifications have to be made. So, can you used to get higher heating rate but it is difficult to use. So, we are looking at some approximate solutions. This is clear up to this stage. So, the important point should be noted are solid angle 4 pi is azimuthal angle 2 pi, the Zenith angle is –pi/2 to the +pi/2 instead of normally 0 to pi/2.

That takes care of this. The da nu/ ds as a rho this has a rho/cp because this comes from rho cp, dt/dt. So, rho and rho get cancelled. So, if you know what is a kappa nu at a particular wave number you know the particular wave number you know the particle wave number you know the particle density r. If you know i nu and p nu is not very difficult, p nu is plank distribution, i nu is the problem if you know what i nu is then it is possible for you to solve this.

Of course now with modern day computers there is no need for simplification you can straight away crack this and go ahead. But people looked at simpler solutions in earlier days and these simplest solutions are also elegant in the back of the envelope calculations you get a quick, you can get a first cut estimate of the heating. Let us see that.

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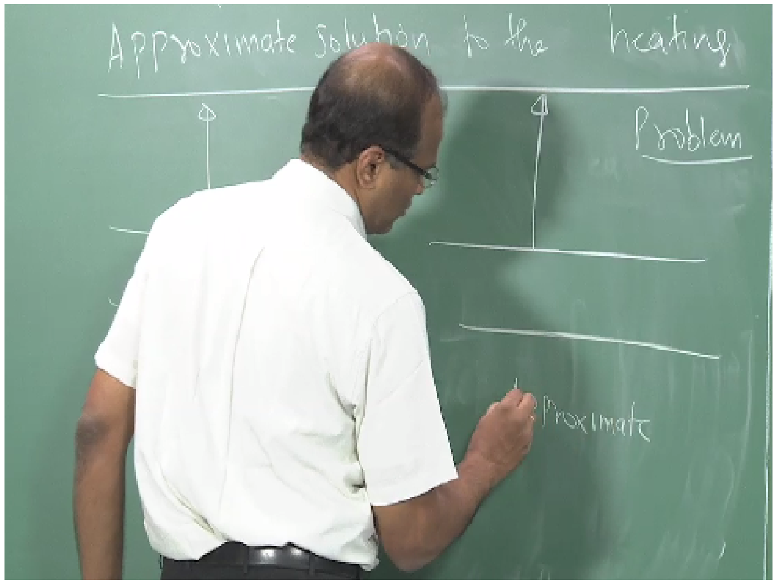

So, we have to look at the approximate solution to the heating problem. So, that figure I have already given. The arrow show the energy balance you can have radiation coming from the top of the layer to that layer. Radiation coming from that layer to the next layer, radiation coming from the bottom to this layer. Radiation going out from this layer to the bottom layer and then radiation going out from this layer to free space.

Now, many of these exchanges cancels out therefore you can consider as one layer because isothermally the lapse rate is isothermal, lapse rate is 0 so that whole thing is isothermal within this small layer you can consider one layer of air which has got all its constituency O2H2O, methane whatever? It is radiating to free space that free space can be taken to 3 Kelvin, 0 3 Kelvin whatever then it makes this life easier.

So, we can get a handle on this equation 9 and get some simplified equation with which you can plot and then we can get an approximated solution to this problem. So, with that approximate solution certain thing are possible. So, I do not want to tell you the story the story. I think isothermal layer of air has got multiple exchanges and this thing in the infrared part of the spectrum.

It can be shown that the forward exchanges, exchanges into it and exchanges out can be canceled and the only thing which remains is long wave radiation back into the open sky. So, that is what you are going to consider now. That is the case then 2 pi/cp now comes a I went too fast.

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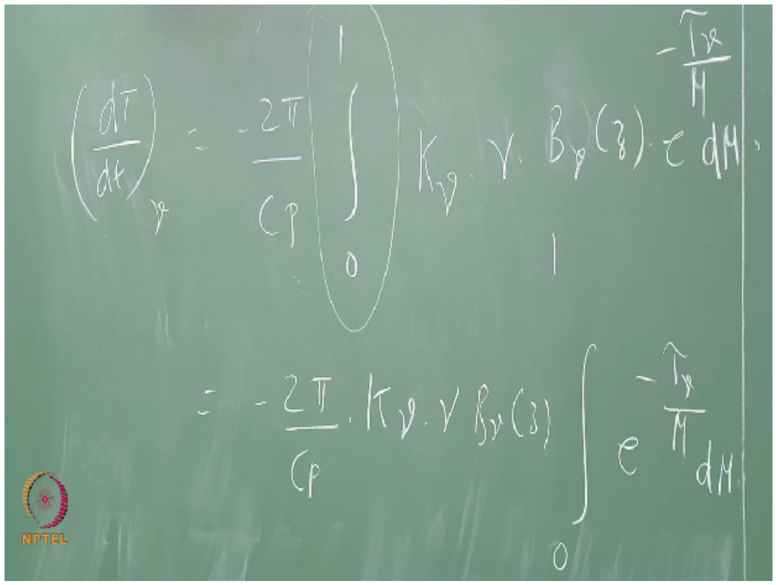

So, that -1 to +1 has become 0 to 1 that means only in the forward direction with the upward direction we are considering. Now you getting this? Now this is replaced by this. Correct, because we are assuming that exchanges are canceling each other but now I am also making another r, p nu, you can call it as z. It is B nu of T and T is a function of z. Is that okay? So, in my notes I have got it as z, you can put it as t or z because that can be related * e to the power of.

This is actually the integrating factor comes from the solution to this Schwarzschild's equation which you have seen. i0=i lambda =i lambda not e to the power of +0 to integral, correct. Then if you take that di/dx it will give that. If you take di/dx the first term will cancel off the second term will remain. Now, it is possible for you to kappa nu r. Problem number 48: For tau nu = .u, for tau nu = 0.2. So, this is what equation number? 10.

For tau nu = 0.2 obtain a simplified expression for an integral term in equation 10. Is the question clear? For tau nu= 0.2 obtain a simple expression or a simplified expression. There is a long time since we solved some problem. So, we will solve this.

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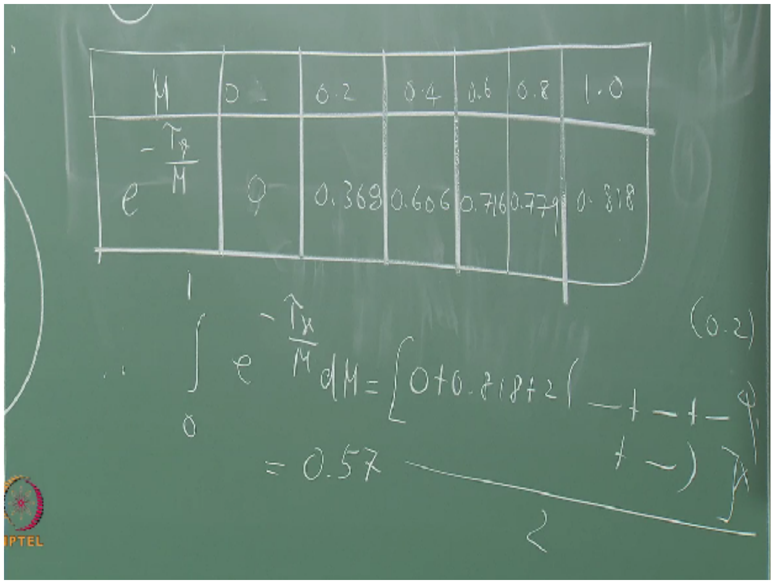

So, just get this and solve it using the trapezoidal rule numerically integrated. Please give the values. 1, that .2 is only representative you can show it for other things also. That is known what is the value. 0.3678, 0.4, 0.606, 0.6, 0.716. mu is the denominator. 0.716, 0.7789 I did it before coming to class, quickly so maybe I made mistake. This is fine. Then 0.818 is it okay? How is the trapezoidal rule work? First term + last term + twice all the other terms/2.

How does it work? So, into the interval width, right. Interval width was .2. This is will get into a spin. You try integrating it. Integral u dv is uv-integral v du that v du will again then it will keep on, keep on, how much is this? **"Professor - student conversation starts"** Akhil, 7. Okay, very good. 0.57. So, please do this.

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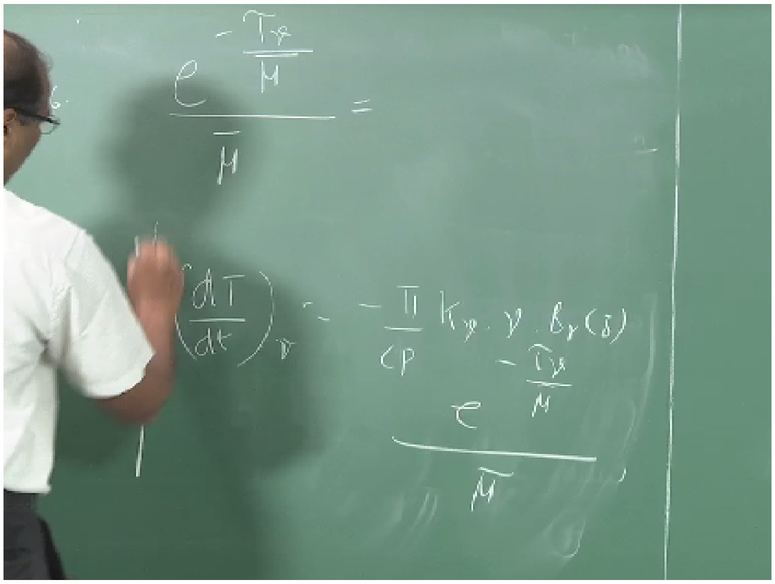

How much is this? mu bar is 1.66 or 1/mu bar is 1.66. How much is this? Sneha, something it will be half of this or twice of this something it is related to that. How much are you getting? 1.18, 1.66*.2 you have seen, so a to the power -.3 *1.6. How much are you getting? Do not substitute mu bar =1.66. 1/mu bar is 1.66 correct 1/mu bar is 1.66. How much are you getting? **“Professor - student conversation ends”.**

1.29. Okay, hang on you got some .575, 57 or 58 I do not know. 575 or something there is a 2 pi*2 we give you some 1.15 or 1.16 therefor this is approximately this is 1.19. So, this is approximately= instead of 2 pi 12 is swallowed by that .575*2. So, this will be –pi/cp K nu*r B nu* a to the power of – thing/mu bar/mu bar where mu bar is a diffusivity factor. Therefor without taking resource to a computer.

Or writing a Fortran code or a C++ code by some simplification we are able to get the dt/dt of nu in the infrared part of the spectrum. This is an approximate solution. So, this is called a cooling to space approximation. We can find out at various levels of that atmosphere what is the contribution in the short way part and long way part of the spectrum of carbon dioxide, water vapor, ozone and so on. We just simplify the calculations. Now, I will show.

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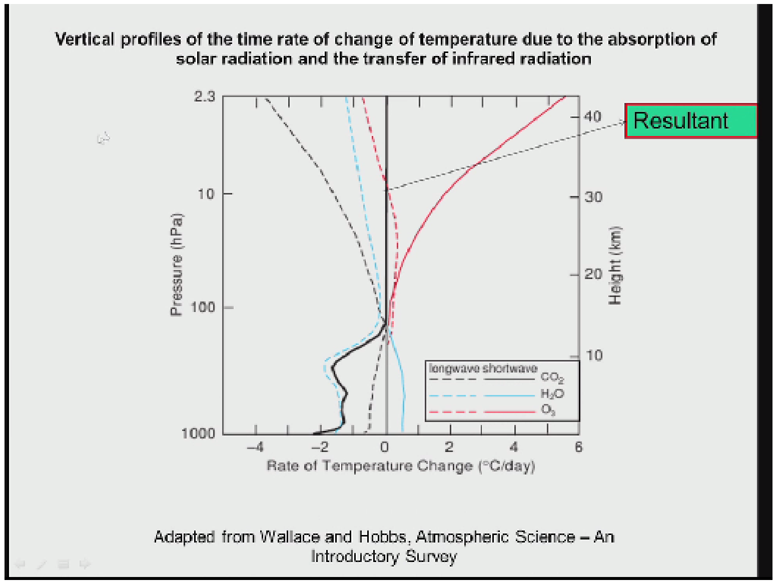

So, this is the height. The ordinate is a height. Here is the rate of change of temperature. Right side is positive, left side is negative. So, the long wave is given by dash lines and the short wave is given by the solid lines. Let us look at contribution of water is positive in the lower half of the atmosphere then it decreases it becomes negative in the upper part of the atmosphere. As far as carbon dioxide is concerned carbon dioxide is same as the solid line and leave this O3.

Let us leave the carbon dioxide now for the present. O3 there is nothing in the lower part because there is nothing in the troposphere, O3 is not available as you go up you can see the contribution to the short wave and long wave part of the spectrum. Carbon dioxide is hidden in the solid line. The thick solid line represents the resultant. Now, if you see there is decrease of dt/d tau so there is cooling in the troposphere because of the net radiation.

The net effect of all this radiative heat transfer using all your kappa nu i nu r*e to the power *- all that is basically there is cooling in the troposphere in the stratosphere all these effects cancels out. And so there is no dt/dt in the stratosphere so it is almost at the rate of change of temperature this is per day. It is almost 0 in the stratosphere. So, stratosphere is always close to radiative equilibrium.

The troposphere is not in the radiative equilibrium therefore there is temperature difference between the day and night. There will be some cooling which will be taking place. Stratosphere experience is no cooling. Is that okay. And why is the water vapor effect is not there pronounced at higher altitudes and all that in stratosphere you do not get so much water vapor. All right, the last part which we want to discuss.

Before closing this chapter is basically remote sensing I have already today you. Remote sensing, first I will discuss this and then the remote sensing.

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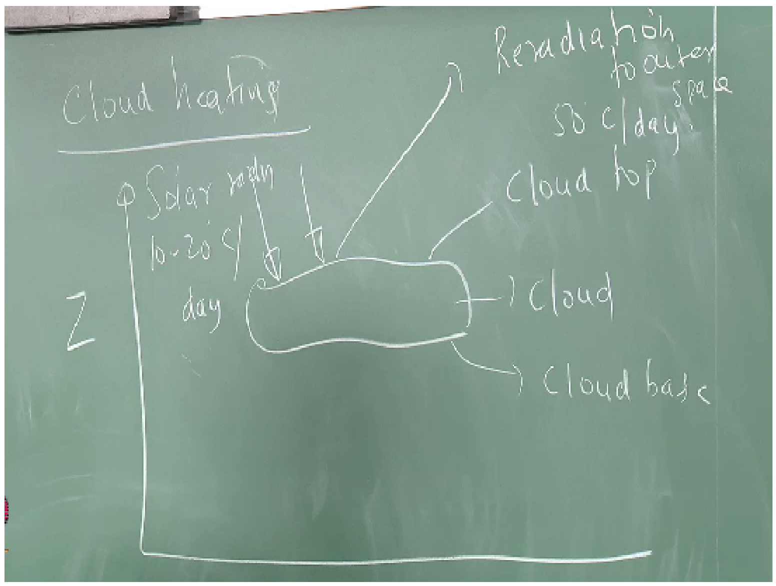

It is an important physical concept the heating of clouds. This is z so there is a cloud like this. There is a cloud like this. This is a cloud base. This is the cloud top. Please tell me what are the radiative transfer processes which are taking place from the cloud, solar radiation. Solar radiations can cause up to 10 to 20 degrees per day that much amount of heating it can cause. Then reradiation, assume that there are no clouds above it there is reradiation to free outer space.

This can be 50 degree centigrade per day. This is the earth surface here also some heating take place is not it? What is this heating? The heating which is taking place because earth is emitting to the bottom of the cloud. Let us look at the night time. The solar radiation is not there. There is a heating from this. But this is not sufficient to take care of this reradiation to outer space. Outer space is basically is at 0 or 3 Kelvin.

The cloud may be at 270 or 280 Kelvin or whatever. Therefore, the cloud continuously lose heat by radiation its temperature decrease actually this further enhances the lapse rate therefore this naturally promotes convection. So, convective actives are more during the night. That is why night, early morning, morning allright suddenly you will early morning Chennai there will be heavy rain. The Chennai morning heavey rain is not fully understood.

Bangalore they call office rain exactly at 5.30 in the evening, Bangalore it will rain, Bangalore people will know 5.30 in the evening it will rain, exactly. So, 4.30 onward it will become Chennai morning 5 O Clock it will rain. If it is cool they will declare holiday by 11 O Clock everything is fine. So, that morning rain is subject matter of if somebody want to do a BDP you can do it with me. We will investigate the morning rain we will take satellite data this thing.

We will put some model. You do aqua plan and we can do some, somebody is interested. That morning rain is night time and morning time this solar radiation is not there. It was a heavy reradiation from the cloud. The cloud cools off therefore it promotes convection. But during day time these 10 to 20 degrees per day there is a solar radiation coming out of the cloud. So, this rapid cooling is partially controlled.

That is why during the day 11 O Clock, 12 O Clock you do not see heavy convection unless of course there is a big system already a depression or a turf is there. Also the convection is pronounced more convective rain is pronounced, is seen more in the evening time and early morning time. Now, do we have internet on this? The last part just minutes I will just give a 3-minute course on remote sensing.

I have already talked to you about this. Remote sensing you can do in the visible part of the spectrum, infrared part of the spectrum. In the visible part of the spectrum it is available only during day time original satellites they use to have pictures in 30, 40. If you get pictures of clouds they will say it is a big achievement and all that. But night time it is not available it will give you only the distribution of clouds.

Okay, no more information beyond this is not available but if you do by infrared, first of all 24/7 coverage is there. And the radiation which is coming from the top of this clouds can be captured and then you use the Planck's distribution we can find out what is the cloud top temperature. Correct, you can equate it you can equate the radiance to C1 lambda to the power of phi e to the power of CT. If you know what is the lambda.

Okay, you can get the cloud top temperature when you get the cloud top temperature from other information if you know what is the lapse rate of the atmosphere you can actually find the height of the cloud. So, the height of the cloud can be inferred remotely then you can find out the distribution of clouds in various regions where and then you can see whether a convective storm is building up and so on. So, cloud top temperatures can be obtained.

This visible part of the spectrum is more okay for distribution of clouds and aerosols and other things.

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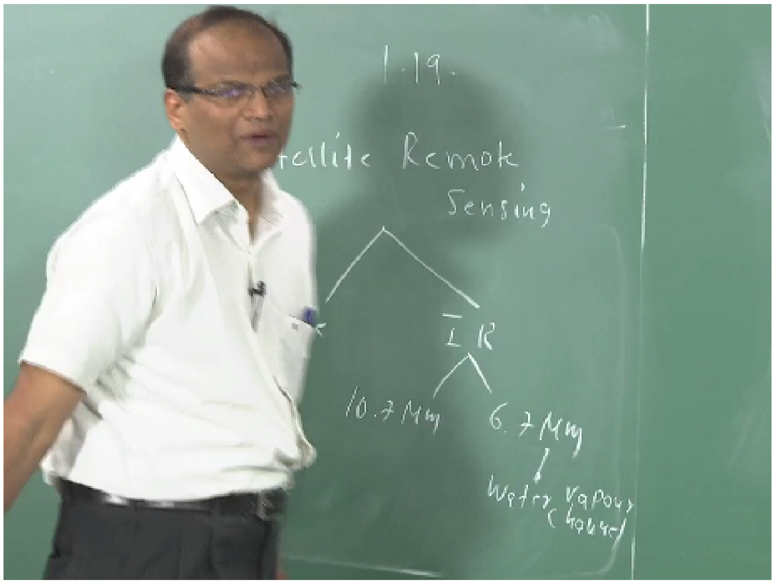

In IR there is a 10.7 micrometer channel then you also have a 6.7 micrometer. It is basically the water vapour channel. You can actually see the concentration of water vapor and all this. Let us see the water vapour channel.

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Right now we have two satellites whose pictures are coming to us regularly. The INSAT 3D and Kalpana.

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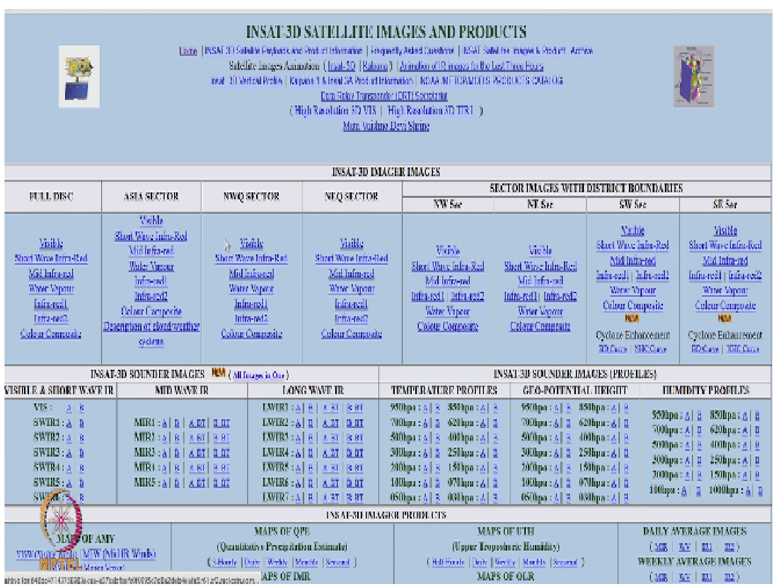

So, INSAT 3D mid infrared. Let us see the situation now in India.

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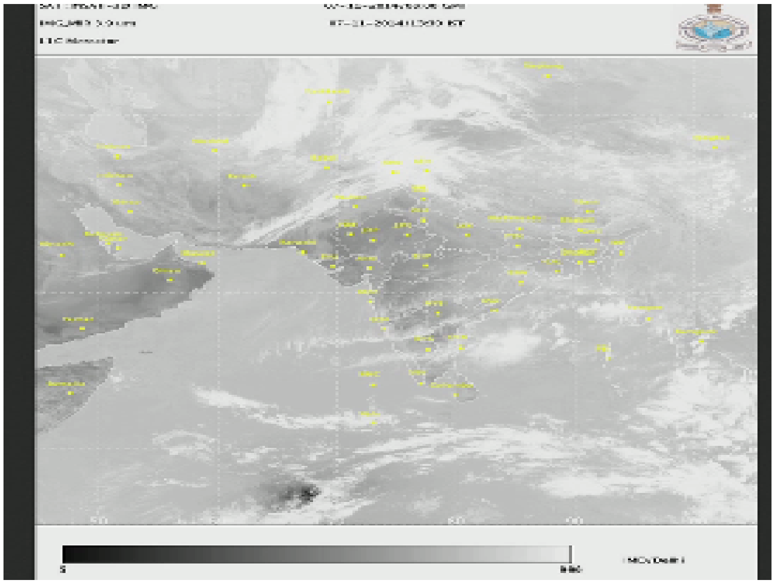

So, this is 7 November GMT is 8 O Clock, 1.30 it is not far off just an hour back. So, not much activity you see that there is a system with east of Chennai which is likely to go up. And if you want to see the water vapour channel that will give you an indication of water vapour relative humidity.

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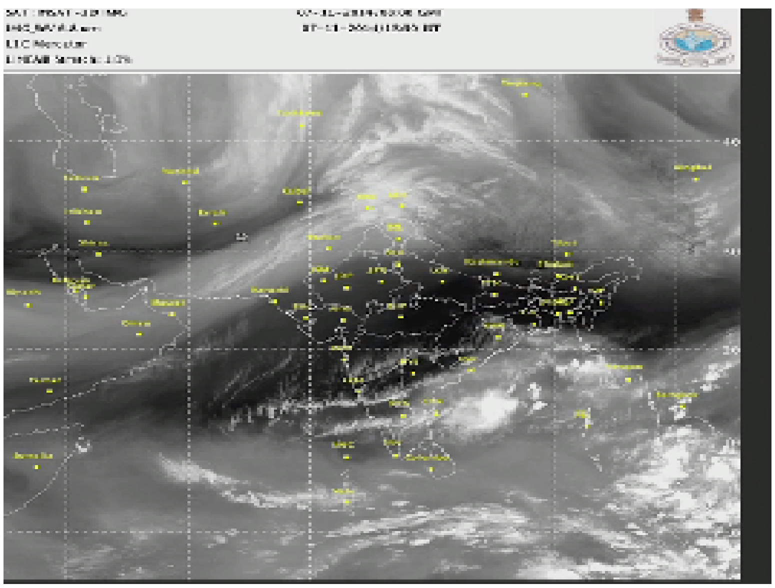

There are some clouds there is some water vapour of Chennai but the main activity is here now. The older satellite which is the INSAT 3D infrared picture you see.

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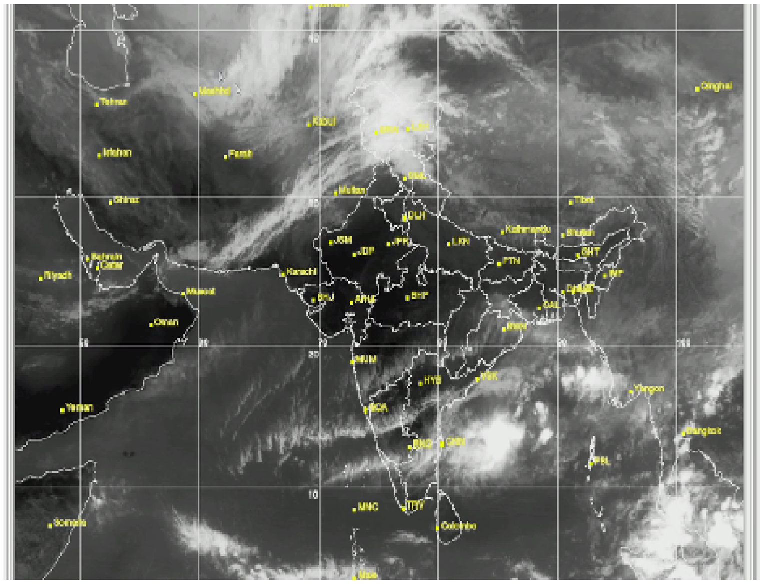

8.15 that is 1.45. Now, the sum totals the integral over the complete wave length the outgoing long wave radiation can also be captured that is called the OLR. So, the Kalpana you can see the outgoing long wave radiation.

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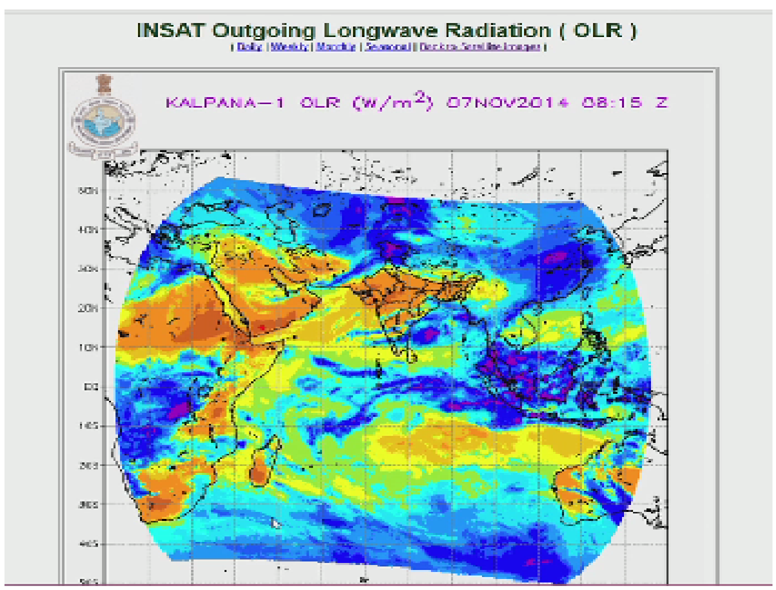

Watts per meter square as you can see either heavy clouds in the outgoing dips. So, it is between 100 and 150 that violet colour and the OLR represents the system. Orange colour can be very high can be seen over the desert regions. Somewhere it is very hot here. All right, Rajasthan will always be like this. So, Chennai is little cool you see the cloud cover is there. Now, if you want to see the wind pattern. You can see what is called the cloud motion vectors.

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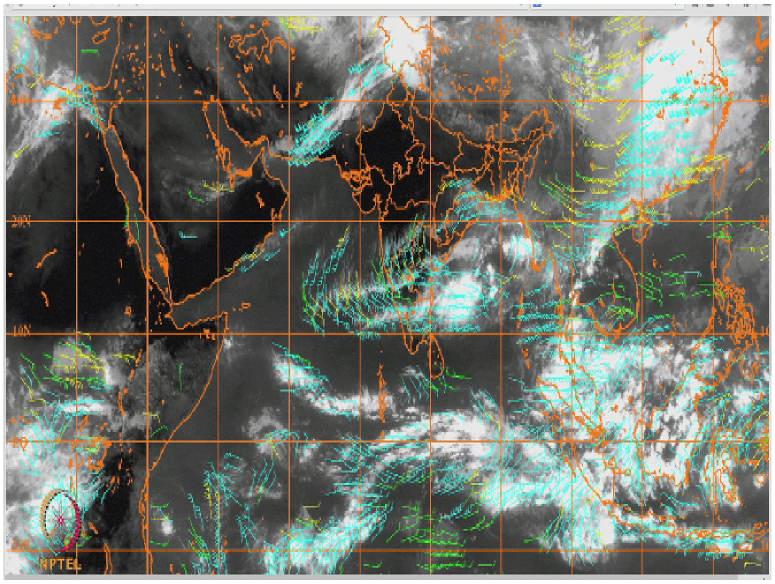

So, the cloud motion vectors the number of this thing pointers give you so many nautical miles per hour. So, this is the wind pattern. So, the winds are coming from this north east and they will go like this. What about the precipitation estimation?

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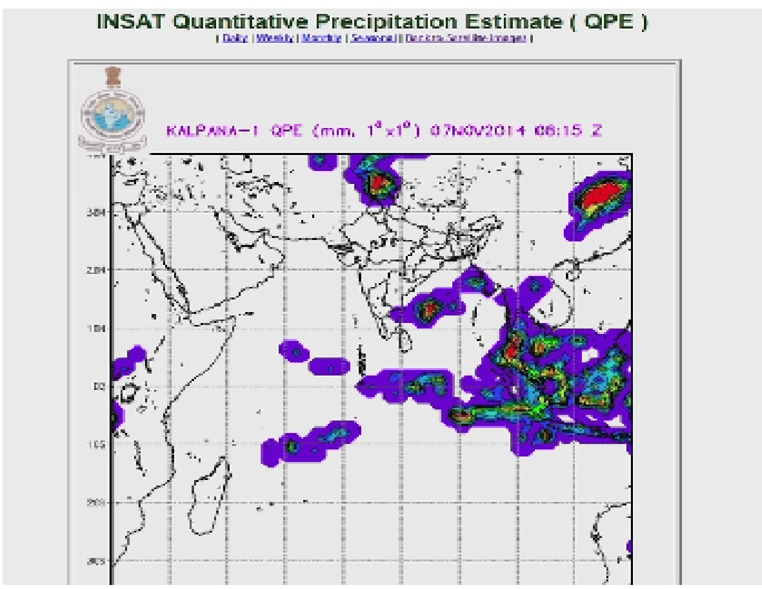

So supposed to be raining little bit in Chennai it is not right now. But this is subject to error. But you have to worry about this orange and red colour in all that means it definitely raining in those places. What you can do is you can actually go to Chennai, as has got a website. The Indian Meteorological Department of Chennai. This is from Nungambakkam. So, they numerical weather model.

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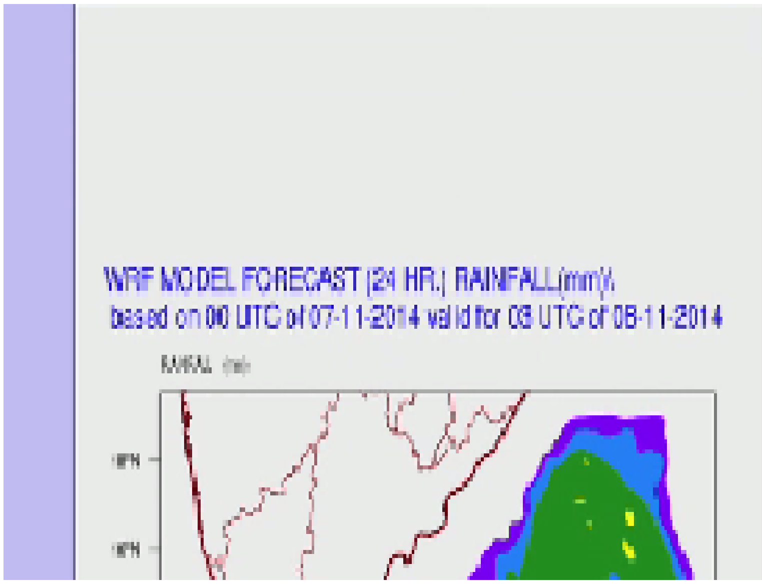

This WR what we also run wether research and forecasting model. This gives the rainfall 24-hour rainfall if you start with the model from today 5.30 and calculations have been done up to tomorrow. So, this is the rain for the day 1, prediction.

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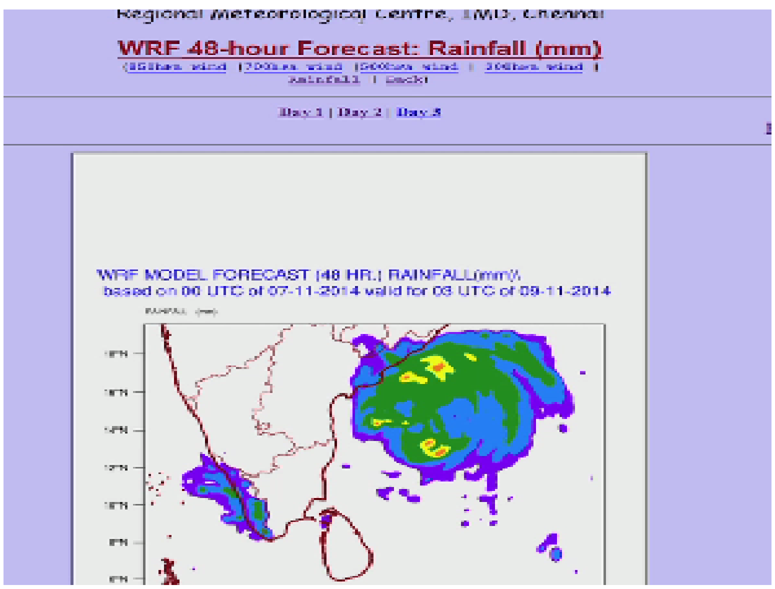

This is the day 2 prediction that is day after tomorrow morning. So, Andhra.

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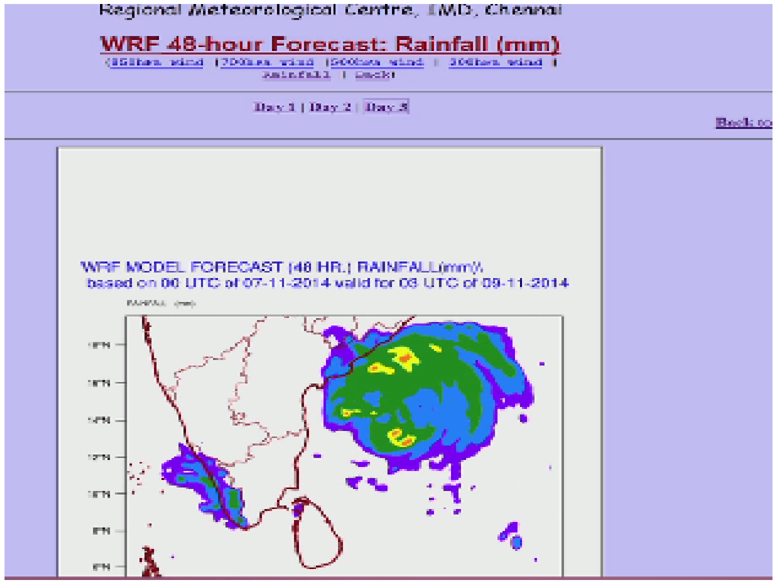

Then day 3, valid up to Monday morning. So, the system is pushing is going towards north west. So, it is dissipating as you can see the orange colour is going up. So, we will still get some rain because Chennai is 13 degree. So it will get some rain day after tomorrow. If you want, you can do other things so you can keep on spending time. So, that is about it and you can actually animate this and then if have a time series you can predict also. But if you have a time series you can predict also. But if you have Doppler radar is more acquire.