Introduction to Atmospheric Science
Prof. C. Balaji
Department of Mechanical Engineering
Indian Institute of Technology-Madras

Lecture-03
Atmosphere-A brief survey contd … (Vertical structure of the atmosphere)

Okay. So, welcome back. We are still introducing the topic, the subject of atmospheric science. So, in yesterday's class we talked about the mass of the atmosphere which turns out to be some 5.11 into 10 to the power of 18 kilogram. And then, we saw that the means the mean the globally averaged surface pressure is 1 into 10 to the power of 5 or 1.013 into 10 to the power of 5 and so on, right.

And then, we looked at the chemical composition it was largely dominated by diatomic molecules. Nitrogen is heavy some 78 percent by volume, oxygen is some 21%, argon and then, other gases. Water vapor can vary as low as 10 parts per million to 5 percent depending on whether it is a desert region or it is a tropical region and so on, ok. So, the composition which we studied in which we discussed in yesterday's class is done at dry basis, dry air basis.

So, it is not H2O, is not factored into the calculations, ok. Then, we saw that using the chemical composition, we figured out that the molecular weight of air is about 28.92, 28.97 whatever. It is very close to 29 so; it is closer to nitrogen than oxygen, okay. So, 29, 28.92 or 97 kg per kg mole, all right. From that we figured out how to convert this volumetric or molar analysis into a mass based or a gravimetric analysis and we figured out that oxygen is 23% by weight.

So, the 21% has become 23% basically because oxygen is 32 molecules, has a molecular weight of 32, where nitrogen has a molecular weight of only 28. Out of the certain get out of all these gases, we marked certain gases with an orange pencil. So, we call them as greenhouse gases because they are capable of interfering with the electromagnetic radiation. What electromagnetic radiation?

Electromagnetic radiation can be incoming radiation or outgoing radiation. The incoming radiation is largely from the Sun, okay. The Sun is at a temperature of 5800 Kelvin. So later on, we will study in radio in atmospheric radiation that the Wiens displacement law:

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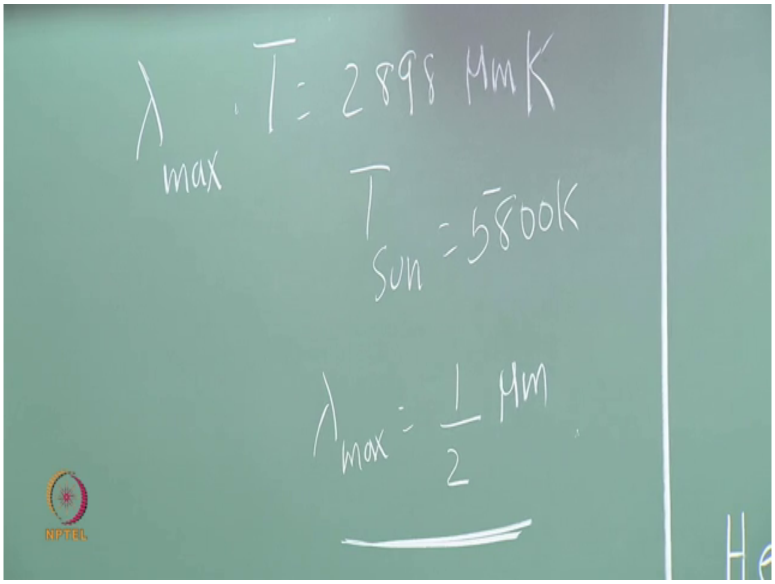

The Lambda max into T, the wavelength at which the maximum intensity of radiation occurs for a black body which is at a temperature of T is given by 2898 micro meter Kelvin. So, this 2898 can be approximated to be 2900. It so happens that the photosphere of the sun, the outer surface of the Sun can be assumed to be a blackbody at 5800 Kelvin. So, you get a magic number, lambda max is half a micrometer. It is beautiful because 0.4 to 0.7 micrometer is the visible part of the radiation.

So, that is why sun's radiation is very, very important and we are always trying to get this day light lighting all our tube light, everything, we are trying to mimic solar radiation. But this is not at 6,000 Kelvin and so on, right. So, the incandescent bulb will be at a temperature of 2900 Kelvin. Therefore sometimes they say it produces more heat than light, okay still it will illuminate the incandescent bulb tungsten bulb is a 2008 Kelvin.

But if it is 2900 Kelvin, the lambda max is about 1 micrometer which is just outside the visible part of the spectrum. You are already getting into the infrared part of the spectrum. Do not worry about all these terminologies. We will flush out all these terminologies as we enter into the atmospheric radiation chapter. So, the incoming radiation is half micrometer. By the same token, the surface of the earth is assumed to be at a temperature of 300 Kelvin, assuming this to be 3000 so the lambda max will be 10 micrometer.

That is the radiation coming out of the earth, right. So, these gas molecules have got peculiar properties where they absorb they can pass, they can allow radiation to pass through in one part of the spectrum. They do not allow radiation to pass through the other part of the spectrum and this is very important because the giving and taking is from bodies at different temperatures. Therefore it leads from imbalances and that is why we call them as greenhouse gases.

And they cause some warming and how much warming they will cover, if carbon dioxide increases by so and so and all this. That will be the subject of climate dynamics, climate science, climate change, climate dynamics which will be the last chapter of your course, all right. Now so, this is a brief overview of what we did in the last two classes.

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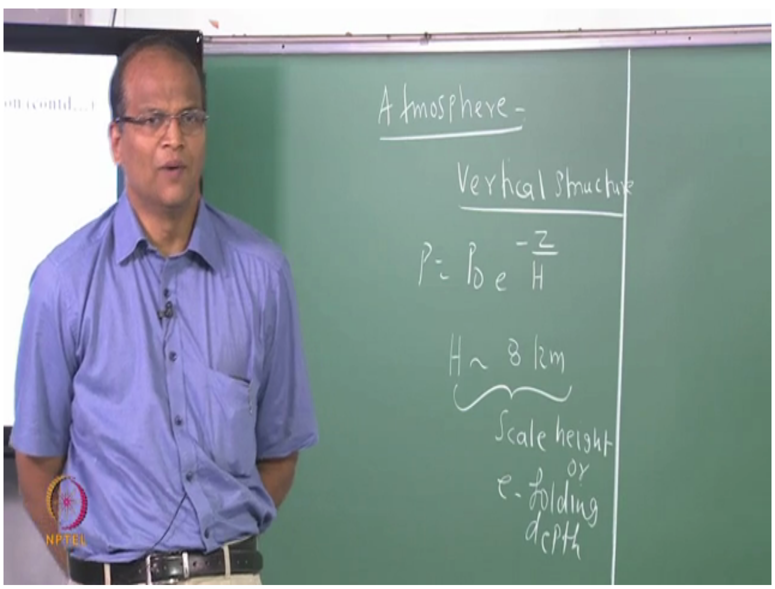

The, continuing with the vertical structure, we figured out that P = okay. So, the pressure varies exponentially with height. Where H is the scale height of the atmosphere so yesterday we saw we worked out in a problem that H turns out to be approximately 8 kilometres. So, the H is called the scale height or the e folding depth, okay. So, if Z = 8 kilometres P = P naught e to the power of -1 If Z is = 16 kilometres P = P naught in e to the power of - 2 if it is have put 30 or 40 km e to the power of - 4 or 4 is already gone 1 by 2 point 7 to the power 4 will be high value.

So it rapidly decreases; pressure rapidly decreases with height. There are two ways of plotting it. So, this by the way is called the Wien's displacement law, okay.

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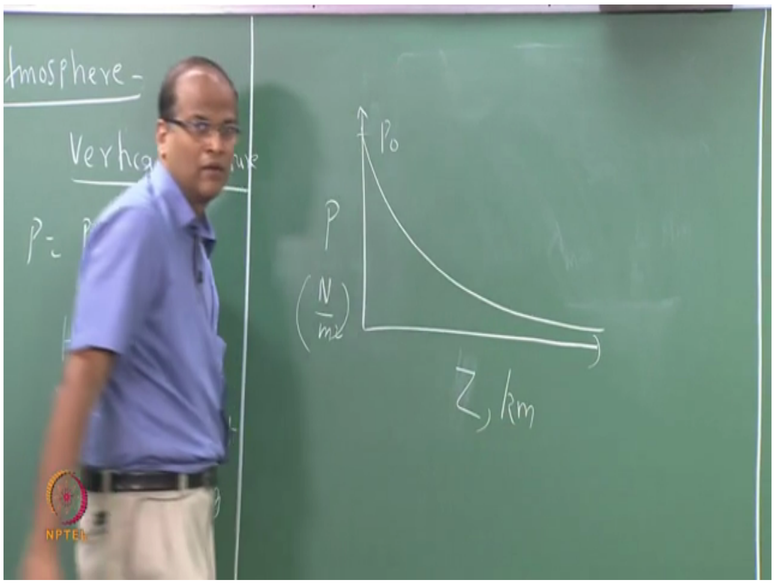

We said P was at high trait Z. This is P naught but this is an acceptable plot or the usual kind of plot in engineering. But in atmospheric science there is a peculiar way of plotting what is it peculiar way? Pressure will be in the x axis, Z will be in the y axis because Z it is analogous to how it will be when you actually see, right. So, from Z = 0 to some height. So we will interchange the coordinate and try to plot it.

This is going to be useful, let us not disturb this. I will come back to this. So, the main part of today's lecture is that the standard atmosphere so let us rework on this.

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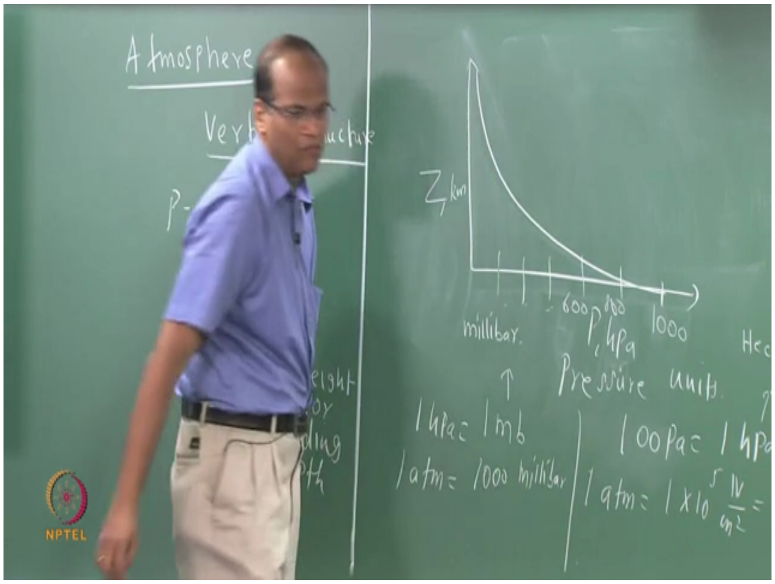

So, this is P and this is Z okay. But his Newton per meter square is a very small quantity. It is too small for us, okay and all this you will get very huge numbers here so we work with some other units for pressure, okay. What is one hector? Hecto is 100 hpa, okay. Hecto Pascal. Therefore, one atmosphere how many Hecto Pascal, 1000 correct, so you can rework this plot and say this hecto and start with 1000, okay.

And then, you can whatever 800, 600 and whatever. It is not the scale Do not try to prove me wrong we are just trying to look at the qualitative aspects of this. This fellow will be in kilometres all right and there is something which we use in is one more unit which we use in atmospheric science it is called the millibar okay; so, 1 hectopascal 1mb, and okay. This is minibar okay so one atmosphere is = 1000 millibar. Is it correct? I hope everything falls in place, okay.

So, these are some just like in mechanical engineering we use EMPA mega Pascal, bar, okay. So, 10 bar = 1 mega Pascal because Pascal is a very small quantity. It is like paisa. There is no value. Rupee itself has no value. So, the paisa is absolutely okay. So, this Pascal one Newton per meter square is a very small count okay for our application for physics people it may be very high well if they are doing something exotic, all right.

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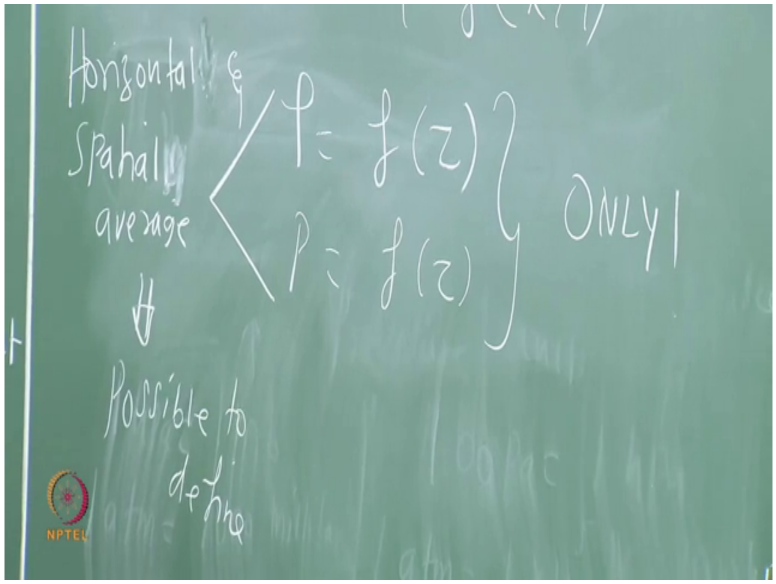

Now can I clear the board? I do not do anything to this to get back to that. So, continuing with this vertical structure the Rho and P, the Rho and pressure P Rho is the density and the pressure P the variation with Z is similar, okay. So, to a large extent Rho and P or not functions of X and Y, if you, if we still go ahead and use a Cartesian coordinate: X, Y is that for the earth system.

So, Rho P are not a function of X, Y which means it is possible for us to have Rho is a function of Z. P is a function of Z only, okay. So, when we talk about the density and the pressure where we just call it as Rho and allow for variations in Rho and P only as a function of Z then it is intrinsically implicit that they are carrying out a horizontal averaging and we are also averaging over time. So, it is average over a large time, it is spatially averaged over a large XY.

So, this means when whenever I am saying the pressure is varying with Z the density is varying with Z all the other integrations are carried out and it is a mean value with respect to the other coordinates okay horizontally and spatially. What is it horizontal? Horizontal and spatial what I am in trying to get it a horizontal and spatial average is possible to define, which means we can think of a standard atmosphere which varies only with Z and this standard atmosphere can be used in Africa, Asia, America, whatever.

That is the concept of standard atmosphere which I have given on the right side, okay. So, I have a PowerPoint this thing also.

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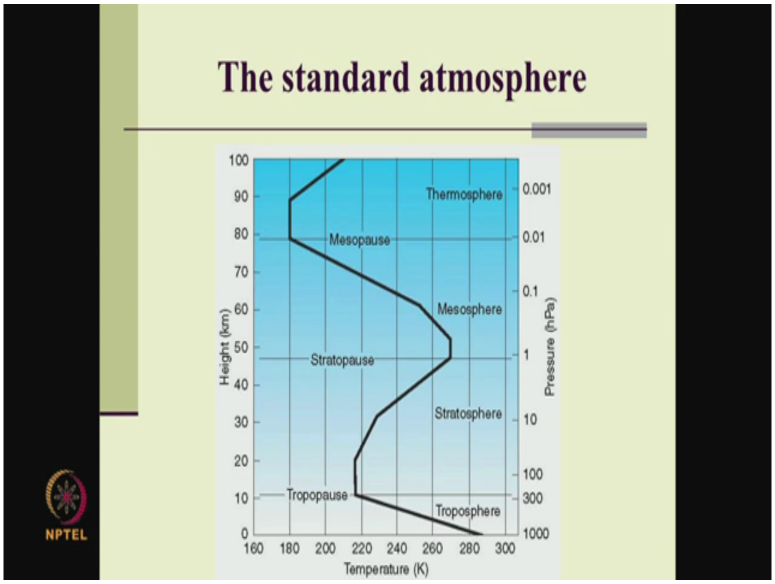

So, take a few minutes and then please copy down this. So, this is the standard atmosphere, so the x-axis is the temperature in Kelvin and the y-axis is basically the height in kilometres so we're interested only in about 0 to 100 kilometres as far as the atmospheric science is concerned and the temperature range is basically 160 to 300 Kelvin, okay. If you want, you can, you can take, take either of this, and whichever is easier for you to copy. Done? Okay. Now, if you see it has got something like a Z profile, right.

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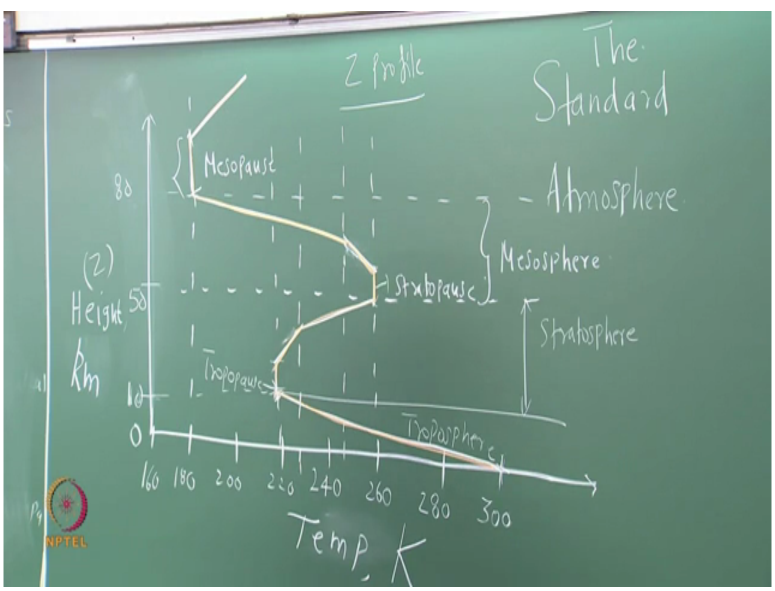

Much more involved than a Z now let us spend a few minutes trying to understand this vertical structure of the atmosphere, okay. Now starting from 300 Kelvin at height Z = 0 the temperature linearly decreases up to a height of 10 or 12 kilometres, okay. So, the place where this activity takes place is called the troposphere. After a few minutes, we will say, we will try to articulate why it is decreasing, why is sometimes it is not increasing and so on, okay.

The first 10 kilometres what happens is the temperature decreases with height, okay. So, if you go to a hill station it is colder basically because the hill station is still in the troposphere, okay. Now as you reach some 10 kilometres height, okay the temperature becomes insensitive to height for a few kilometres maybe 8 to 10 kilometres. So, that region, where this region where the temperature is insensitive to height is a pause or a gap okay or insensitivity with respect to height, this is called the tropopause.

So, this is troposphere, okay. After crossing the tropopause, the temperature again increases and it exhibits 2 slopes, okay. We will articulate why it is exhibiting 2 slopes. Then, it reaches again local maxima at the height about height of about 50 kilometres, okay. So, this region is called the stratosphere, okay. Do not get misled by the terminology stratosphere. No, it is actually here. Yes, correct.

The stratosphere means the all the gases are stratified, there is no mixing because cloud activity is not there in the stratosphere. So, since it is stratified this, the concentration of the gases and the distribution everything will remain same for a considerable length of time. So, if aircrafts are flying in the stratosphere region and they are emitting this carbon dioxide and all this it will take a long time, they can be cleansed. It will take a long time for them to be cleansed.

There should be a big convective cloud which goes all the way up to them, up to that height and remove all that. Otherwise the cleaning a process is easier in that troposphere where there is violent activity. Yesterday evening also we got rain. That is no convection a lot of heat and then water because the sea is close by water gets evaporated.

And then one need, one starts going up; then, it reaches a 0 degrees it condenses and there is a wind from the ocean from the Bay of Bengal from Marina Beach it comes in; to first we are in Adyar, so, first we will get maybe the western fringes may not get that much. This is typical tropical convection. So, if you, if some gases are emitted in the troposphere and all that then there is a possible for cycling, for them to get flushed out.

But in the start; so, it is very dangerous if some things are left in the stratosphere. So, if you have some radioactive emission, if you take some nuclear explosion and these radioactive materials are pushed up to the stratosphere it will remain there for years, okay. So, that problem is there, okay. Now, that is the stratosphere as far as this thing is concerned up to 50 kilometres, okay. Then there is again a stratopause where the temperature does not change.

Then, the temperature decreases again and then up to 80 kilometres, so this is called the mesosphere, okay. Then, again it becomes invariant with respect to height for some region, this is called the mesopause after this it will keep continuously increasing with height. Then, your regular funda of, it is getting closer to Sun and all those things will apply. It will not apply in the first a silly question will be as you go up the sun's radiation will be less.

Why is it cooler in Ooty or Darjeeling compared to Chennai, a silly question right? But there it is why it is a silly question because it is not completely determined only by the radiation, okay. If you take a distance between Sun and Earth to be something, Ooty and this thing will be only 3 kilometres difference. If you take the radiation one way R square it it won't up you matter at all so what determines the temperature will be a balance of winds, moisture, clouds and all this heat the at least in the first order of first tens of few 10's of kilometres.

That funda of your closer to Sun all that will apply as you keep going up, okay. So, the dynamics controls the weather, the dynamics control the temperature distribution to a large extent; the radiation can also control. But radiation + dynamics will control the distribution in the atmosphere. So, this is basically the vertical structure. Now, we will have to dig a little deeper into this. If you consider shall we go to the other side, okay. So, I want to discuss something about this.

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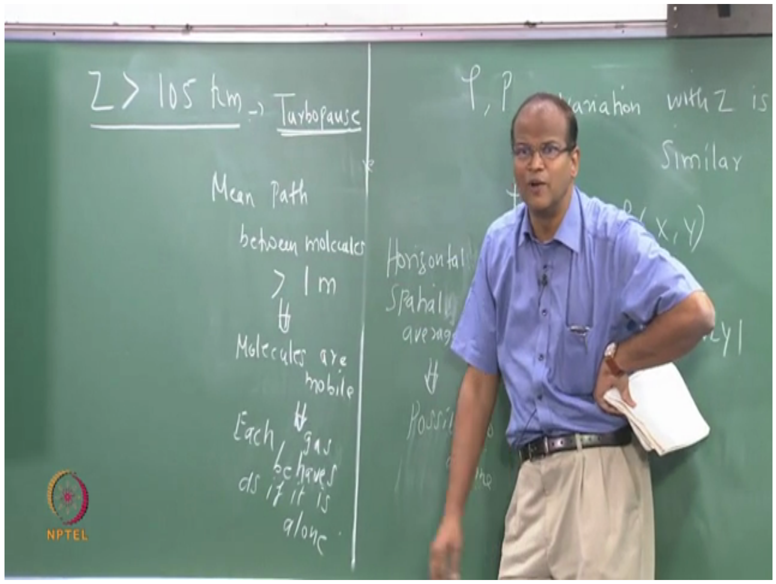

So, if it is approximately, if it is Z is greater than 105 kilometres, the mean path between molecules is greater than 1 meter, if the mean path between the molecules greater than 1 meter then, what does it mean? Individual molecules are sufficiently mobile, okay. When individual molecules are sufficiently mobile, each gas will behave as though it existed alone.

This homogeneous mixture of nitrogen carbon dioxide all that which you study, which we discussed in yesterday's class, will not be applicable after this 105 kilometres, okay. Gases behave as if they existed, okay. Molecules are mobile, each gas behaves, okay. So, this and it, 105 kilometres is called the turbo pause, okay. Is that okay? Now, what other things are evident from here. Any comments, what are the other things you can.

So, if each molecule each gas species behaves as if it is alone what will happen after a 100 kilometres. The lighter, the lighter species has a chance to go up. It is quite possible that the hydrogen may completely escape the Earth's atmosphere. It is possible so that is called the hydrogen cycle. Hydrogen is the lightest, so the hydrogen may just, the hydrogen may just escape. Some hydrogen may just escape out of the Earth's atmosphere, it is possible.

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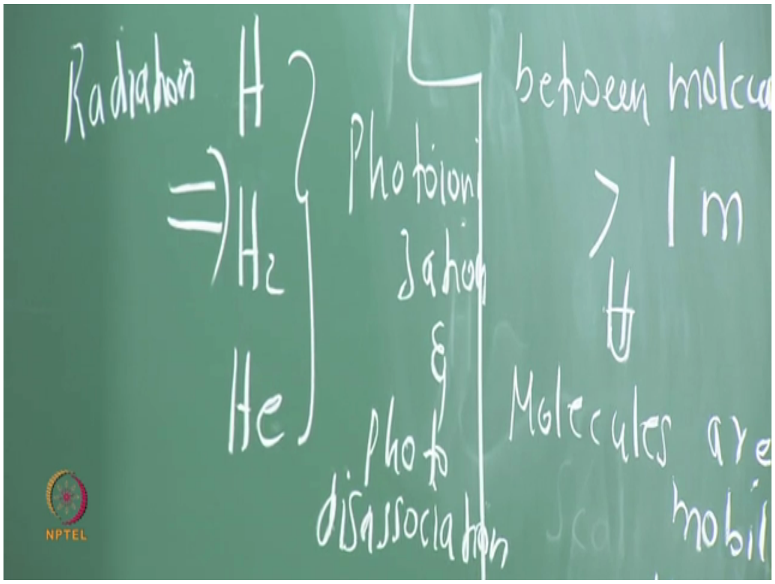

Then, if these gases are present, for example, in this region you have H, H2, Helium; they are all very light gases molecular weight of one, okay. In this atomic form, hydrogen is atomic form, molecular form and helium, okay. But what is happening is, there is a strong irradiation which is coming, because of which there are two processes which are taking place photo ionization and photo dissociation, okay.

So, this will decide the fate of the, so this will result in actually, this photo ionization photo decision also increase the energy content, that is contributing to the increase in temperature in these regions, which we call as the thermosphere, okay. Now, let us look at the physical processes, which are taking place here.

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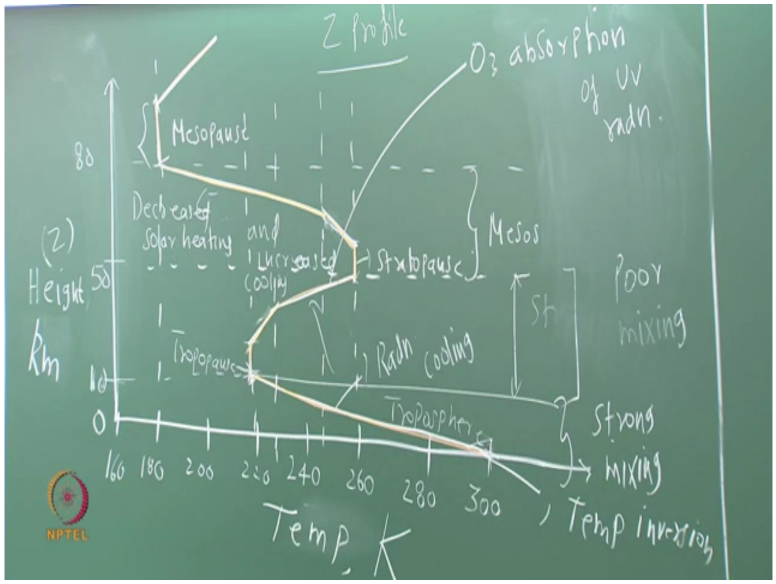

What about mixing the first 10 kilometres it is strong mixing or weak mixing; strong mixing, very good. Then, in the stratosphere, poor mixing correct. Okay now, why is the temperature decreasing so they're actually basically, there is a radiation cooling also. There is an absorption of radiation, there is an emission of radiation. The emission is much more than what is absorbing so generally in troposphere there is a radiation cooling.

Then here, there is ozone absorption, okay; O3, absorption of ultraviolet radiation that is happening in the stratosphere, okay. And radiation cooling is also taking place there is a competition between these two the absorption overcomes this radiation cooling therefore the temperature increases in the stratosphere, okay. This activity, this absorption because ozone is not so much present in the troposphere the heavy absorption of ultraviolet duration radiation by O3 molecules is not a big activity in the troposphere.

So, the temperature increases but even in these cases there can be regions where temperature locally increases, instead of decreasing such things are called local temperature inversions, okay. Suddenly it may go like this, okay within the boundary layer this may cause some, so this is called the Ramdas effect and Ramdas layer, Ramdas effect and so on. Some people have researched this particularly during night time some temperature inversion takes place or in early morning dew and these things, there are some conditions which are created.

So, this, what is temperature inversion means if generally in that layer temperature is decreasing with height locally suddenly it increases with height somewhere, then, it is an inversion or it is supposed to increase with height, suddenly it decreases, it is an inversion, okay. This temperature inversion is common in the troposphere in desert regions, okay. So, this temperature inverse inversion is also some people say is responsible for the reverse swing and other things in cricket which is available on certain which can be effectively used only under certain conditions, it works, and right you studied that.

So, that if you want you can go to science directly look at the pages, I do not know whether it is extensive research but there is a particular amount of moisture dew and temperature conditions as there, there is an inversion then with a bowler that is the right kind of thing you can get some surprised swing, okay which is called the inversion, okay. So, if you are interested in all this there is a separate subject of study called sports aerodynamics.

How a golf ball okay how the dimple in the golf ball increases or decreases so there is a separate field of study called sports aerodynamics, okay. You can specialize in that later on, okay. Now, what about this region? Okay so, there is a decrease solar, there is a here, sorry here there is a decrease solar heating, somebody should raise you are contracting yourselves how can we be discrete decrease all our eating I am going closer to the Sun.

No, baba decrease in solar heating because gases are not present. The solar heating absorption and cooling is because of these mischievous fellows who are this mischievous follows carbon dioxide, ozone, whatever, all these, ok. As you go up those fellows are reduced; the concentration of this is reduced. Therefore, but incoming radiation is there, ok. Decrease solar radiation and increased cooling ok.

So, we cannot, if all this logic does not apply it to the only thing is basically if you do a measurement using a balloon you will get this. And second, if you do the radiative transfer simulations on your computer, you will get this. Therefore, this profile is indeed correct. Now, we have to have now to be at peace with ourselves we need to have a logical explanation of why this happens. So, this is an explanation. There could be better explanation that is called theory, ok.

There could be better explanation but we know that if you do the radiative transfer model if you decrease a concentration and all this you can get you can simulate a different profile which actually confirms that our hypothesis that, there is increased cooling, there is a decreased cooling, there is O3 and all that is actually correct. So, both by systematic studies we can show that, all right. So, this is a very important this is very, very important, okay.

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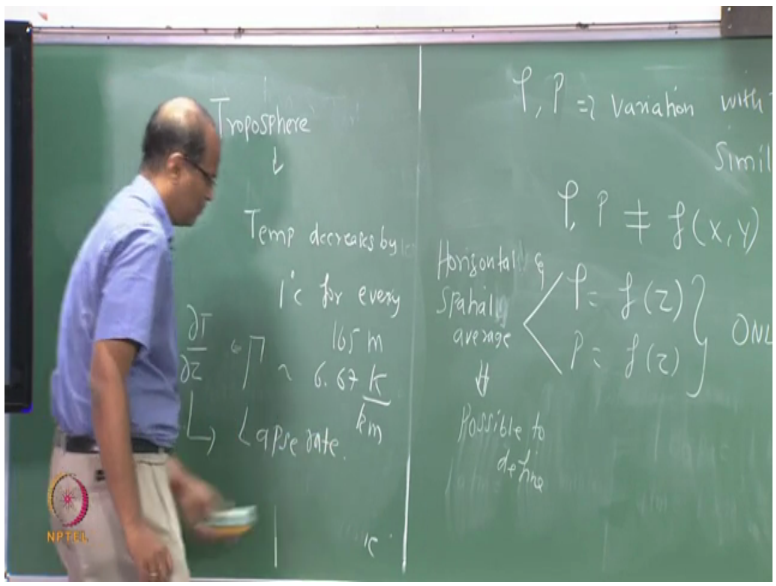

So, this, whatever you studied, temperature decrease with 1 degree centigrade 165 metres of this order, right, actually called gamma okay. So, this gamma is basically dT by dZ, this is called as the lapse rate of the atmosphere of the troposphere, okay. I am not drawn properly. It is okay you corrected. It is a standard atmosphere. There you make it 9 or 10 or we sorted all these things in a little later, okay.

So this is about yeah now what I have done is 6.6 and how much do you get per meter point it is like 80 Kelvin? What happened now? Let us start with, 80 Kelvin for 10 kilometer, so you wanted a 70 rate so I should have started at 290 is okay. You can adjust leave it this is only I told you this is only approximate, right. You correct it. Now, post facto here. It is good that you are thinking. What are you saying is he's getting 80 Kelvin per but the mistake he made was the mistake he made was he took it as one kilometer okay this 10 kilometer yes or no?

So, let it get dealt 80 K divided by 10 now so it is 8 so I am off by you can get some marks for me. I am off by some 1 or whatever, all right, Fine. Now, this troposphere is a very important fellow because we found out that 5 and half kilometres, in 5 and half kilometres, how much of the mass of the earth is how much of the mass of the atmosphere is present? Now tell now problem number 5.

Problem number 5: Determine the mass of the atmosphere or determine the fraction of the mass of the atmosphere in the troposphere. Determine the fraction of the, so the proxy for that would be the pressure, right, all right. And the g you are assuming constant. You can again exhibit by taking g is = g naught 1 by R squared + Z squared whereas you are reaching up to the center of the earth all that ge calculations you can do you know 9.81 maybe 9.805 back all that.
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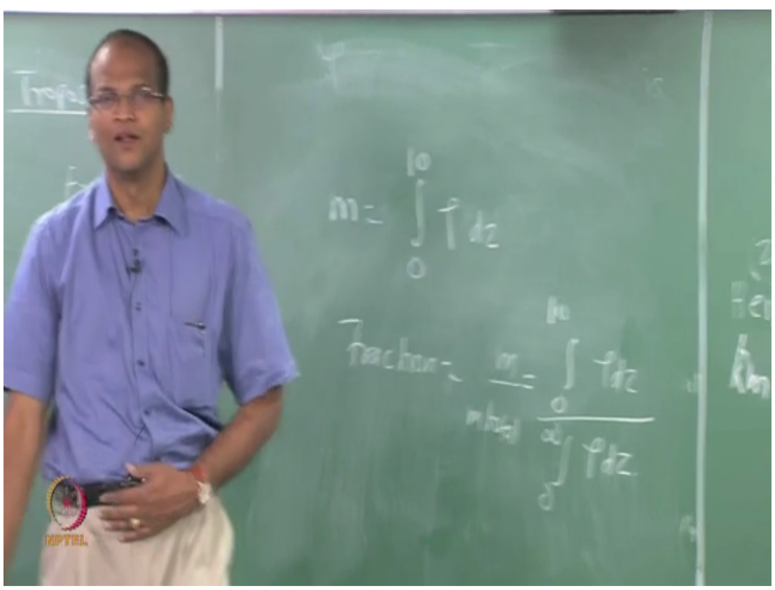

So, problem number 5, what is the fraction of the mass of the atmosphere that is contained in the troposphere, okay? How much is it? Using this P by P naught, is it not? And what do you do? You calculate the P and then the m or what is it? Are you going to work out like this or how you find out, what is the m, m is = integral Rho dz, okay. Then, 0 to 10 okay fine. So, fraction is this is real fun, because I did not come prepared I just shot a good question.

I hope we get the answer. Rho dz divided by 0 to infinity Rho dz, very good. Rho we can substitute P = Pv or d here how do you, how do you want to proceed? Volunteers, anybody who got this, how do we calculate the mass? But T will be a problem know, that the lab said we packed the lab straighter. How do we calculate the mass in the first class, okay? So, this will require ideal gas equation, right.

Have you done it already please do it. I can erase this now. At 10 kilometres you want to find the pressure, okay very good.

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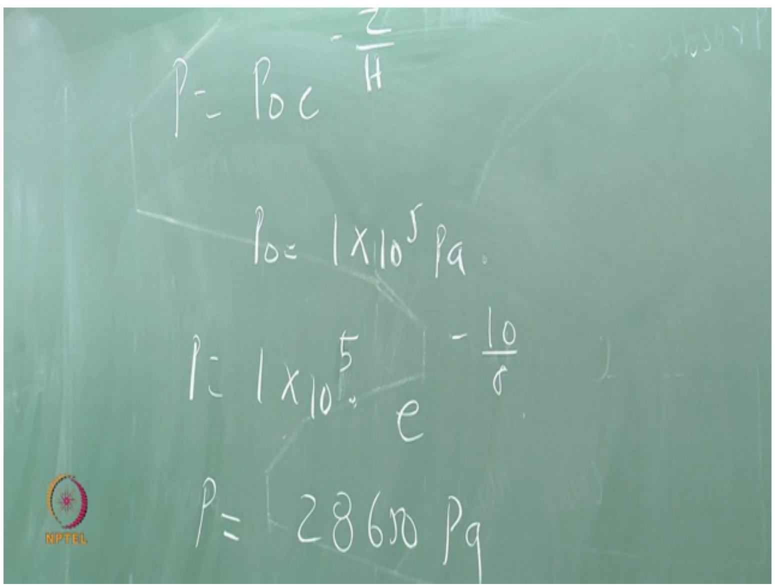

P naught, you are taking 1000 okay that guy started e to the power of - 10 by e. How much is it yeah? Please 0.28650 pa. Now, 10 power 5 to 8 tell me in Pascal to 8 now how do you proceed it is not as easy as you think. What is it easy now then you just want P by P naught, okay. So, I already told you that Rho and P follow a similar variation so P by P naught, is okay.

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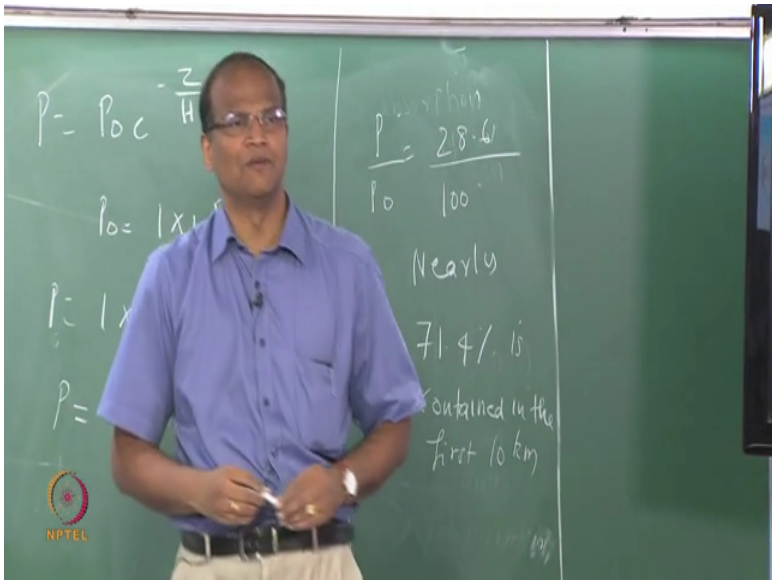

So it is contained the first 10 kilometres, correct. Correct me if I am wrong. Is it okay? On the troposphere height will also vary. Sometimes it is 10 kilometres and sometimes its 20 kilometres and so on. So, it is fine. So, generally the thumb rule is the tropospheric air accounts for 80% of the total mass of the atmosphere, okay. So, the cloud processes play a major role in the troposphere, okay.

Precipitation, cloud processes and all these play a major role in the troposphere. The cloud processes play a limited role in the stratosphere. That is why if you dump something in the stratosphere it is going to take a long time for it to cleanse, okay. Heating, heating by O3 molecules, okay, Heating by O3 molecules is the highest around 40 to 50 kilometres of the Earth's atmosphere.

So the TOMS, the total, the total ozone mapping spectrometer is designed in such a way the sensor is designed in such a way that will try to measure the ozone which is where whose absorption is speaking around 40 to 50 kilometres. That we can, so we can so this is basically atmospheric remote sensing. So you can do that okay. Then, finally as H increases the temperature, keeps on increasing that is called the thermosphere, okay.

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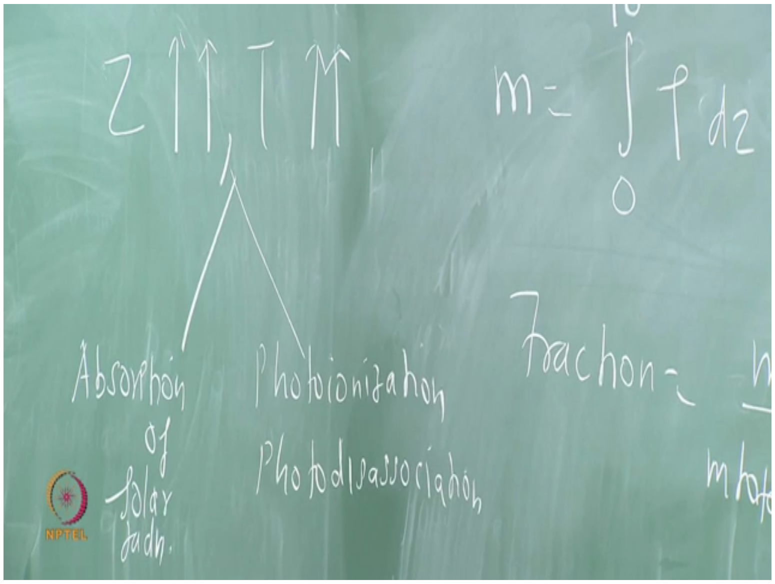

So in this thermosphere, as Z increases, T increases, so, this is okay all right. So, this is the vertical structure of the atmosphere. The vertical structure of the atmosphere is preserved throughout the globe okay. But at any given level in the atmosphere the temperature varies with latitude, please do not forget that. At any given height, the temperature varies with latitude.

That is why Northern Hemisphere Europe is colder than the same finite meters height the temperature will be much lower in Europe compared to Chennai for example, okay. So the structure remains the same but within a particular Z, at a particular Z, the temperature varies with latitude. I will write it if you want.

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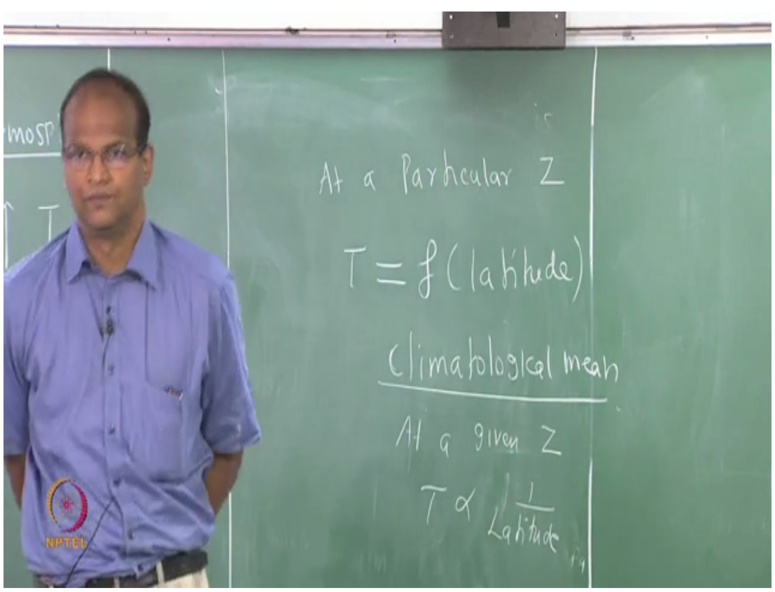

The T is a function of the latitude now if you take what is called as a Climatological mean, what is a climatological mean? You send a balloon; get the temperature versus height in that place, Monday, Tuesday, Wednesday, January, February, upto January to December, January to December, January, December. You do it for many years then you take an average that is called a climatological mean.

You send the same balloon in Chennai Nungambakkam or Meenambakkam in Chennai, the average over many years is called the climatological mean. So, if you look at the climatological mean data, at pretty obvious, right. North Pole will be vary okay, so I think whatever I wanted cover in today's class is done. So, this is very important they used to call it in the US standard atmosphere for whatever reason. I think you can call it as Indian standard atmosphere also.

Why should we call it as a U.S. Standard atmosphere? So, this is standard atmosphere whose structure, whose shape will be the same regardless of the location you are taking, but some slight variations will be there. So, if you average it over several years, so you get what is called the climatological mean. So that climatological mean so you say at a given Z temperature will vary with 1 by latitude and species like nitrogen, argon, carbon dioxide, they are well mixed, they are well distributed throughout the atmosphere.

Therefore if you take carbon dioxide concentration in one place it is expected to be the same everywhere, okay. The lighter species are to be found at the higher levels and these fellows have a chance to do the all this process like photo ionization, photo dissertation apart from the increased temperature in thermosphere there is also a possibility for them they escape the Earth's atmosphere.

So, this is a very important component in the study of atmospheric science, the study of the temperature profile. We did so many things you should know when the pilot is taking his aircraft you should know what is the outside temperature, if it does not have atmospheric science knowledge, he cannot adjust this AC because when the flight is flying at 12 kilometres, but then I would say temperature is - 52 degree centigrade.

So what he does is he heats the cabin such that people are comfortable between 22 and 25 degree centigrade. So, you should have a knowledge of what is a pressure outside; that pressure if it is exposed, then there would not be any oxygen people will die. So, he has to increase the pressure he has to pressurize the cabin, has to air-condition the cabin and all this.

And because of this pressure differences, so there are stresses which are occurring therefore it should be structure even the glass it should be structurally stable such that this difference in pressure and all this it can manage. Otherwise it lead to windshield cracking and all that which you're looking since you are reading in papers nowadays, all right. So, we will stop here in tomorrow’s class, I want to complete this introduction lecture where we look at winds and precipitation.

What are the various types of winds and the precipitation patterns with that this first chapter will be over? Then, we go to the second chapter where we look at the various components of the Earth's climate system including the mantle, the Earth's crust, and the ice content in the earth and then we leave the atmosphere alone because after, after this chapter is over the remainder of the course is only on atmosphere.