Conservation Geography
Dr. Ankur Awadhiya, IFS
Indian Forest Service
Indian Institute of Technology Kanpur
Module - 4
Atmosphere
Lecture - 10
Structure and composition

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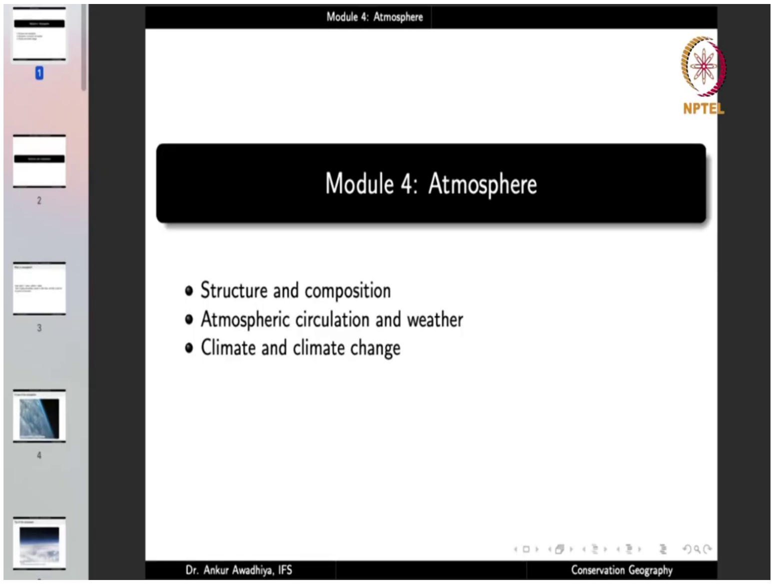

Namaste! Today we begin a new module, which is atmosphere. This module will have 3 lectures structure and composition, atmospheric circulation and weather and climate and climate change.

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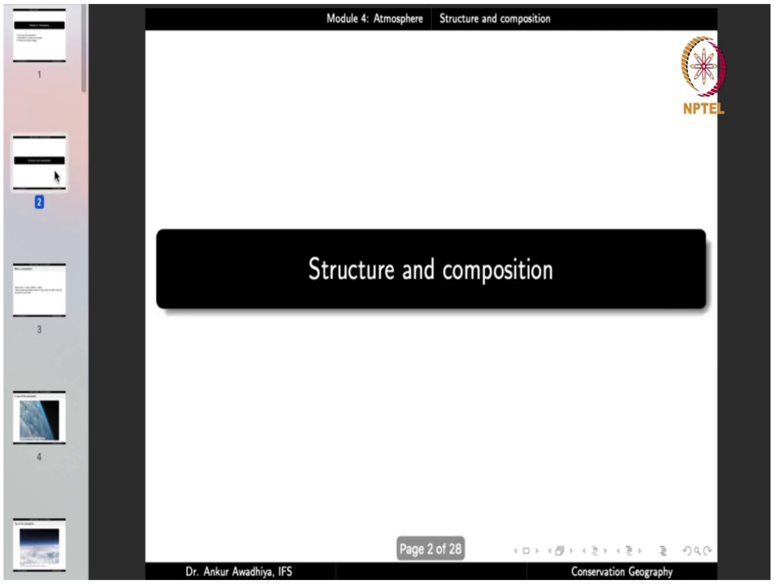

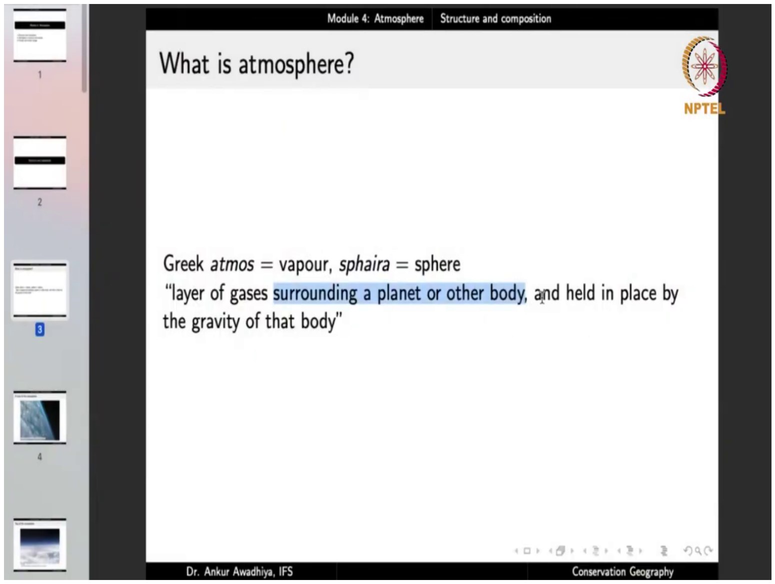
Module 4: Atmosphere
Structure and composition
What is atmosphere?
NPTEL
Greek atmos = vapour, sphaira = sphere
"layer of gases surrounding a planet or other body, and held in place by the gravity of that body"
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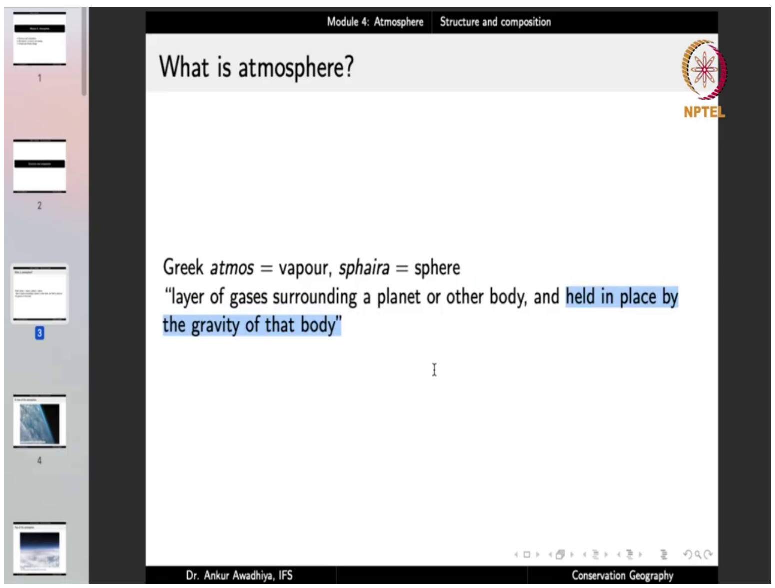
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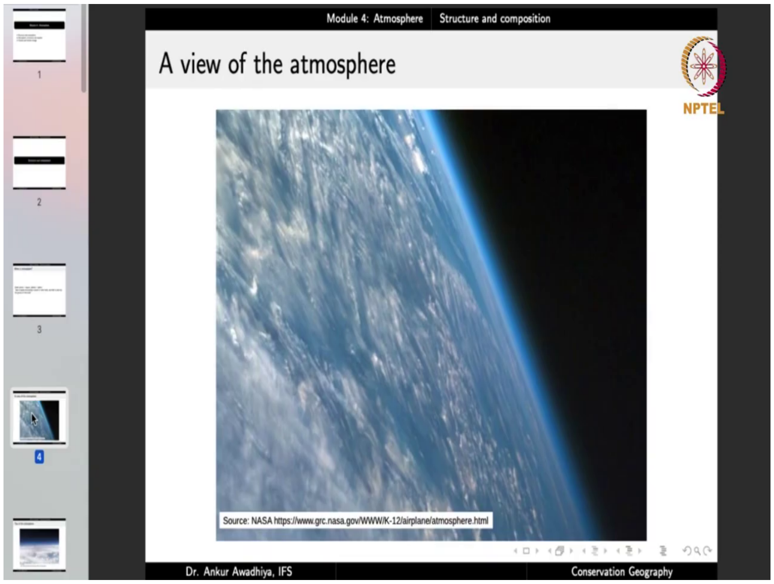

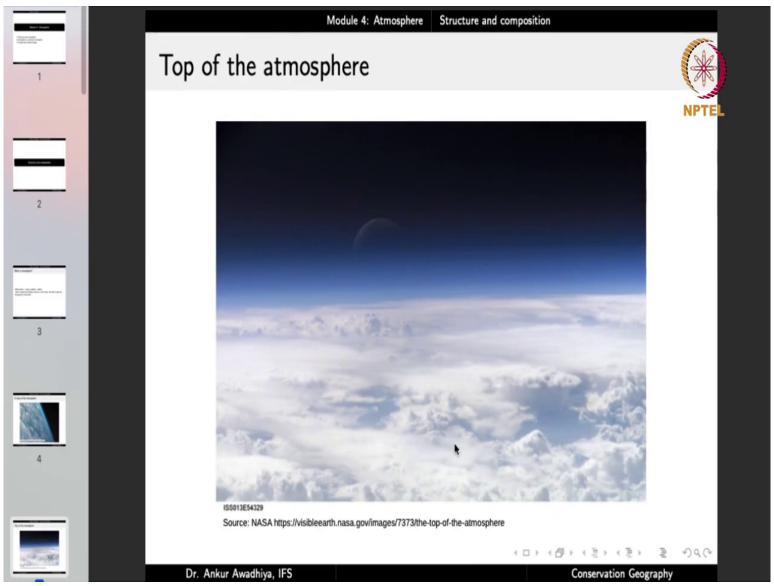

So, let us begin with structure and composition. So, what is atmosphere? The term atmosphere is derived from the Greek words atmos meaning vapour or gas and sphaira which means is sphere. So, essentially this is a sphere of vapour or a sphere of gases. So, we can define the atmosphere as a layer of gases surrounding a planet or other body and held in place by the gravity of that body.

So, what is the atmosphere? It is a layer of gases, where is this layer of gases it is surrounding a planet or any other body. So, we can have an atmosphere around say a moon or we can have an atmosphere around an asteroid. But this atmosphere is held in place by the gravity of that body.

So, a body will only have atmosphere if it has a substantially high amount of gravity, not otherwise.

If you look at the atmosphere of the Earth, this is how it looks like. So, this is a view of the Earth from above and this portion is the Earth and this bluish colour halo that we see around the Earth is the atmosphere. This is another view. So, here we have the Earth and this blue coloured thing that is the atmosphere, even have the atmosphere down here. So, these clouds also form a part of the atmosphere. So, all of this is the atmosphere. So, this is the top of the atmosphere.

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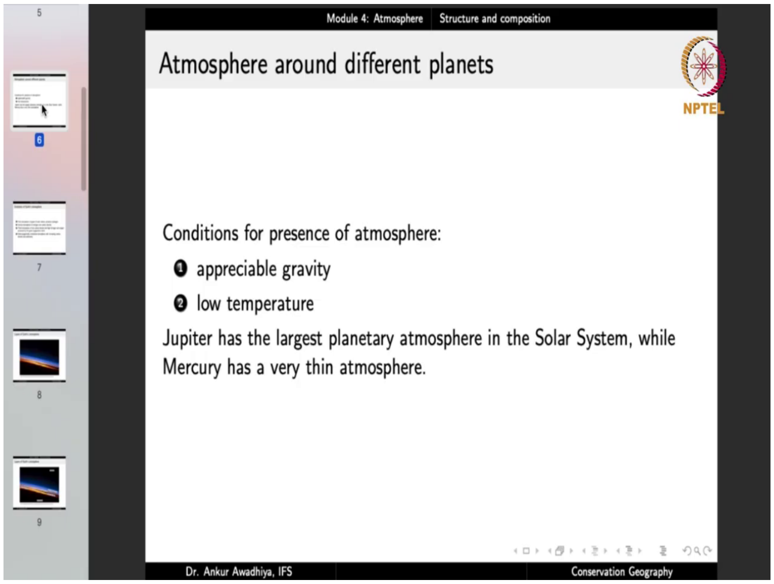

But how do we define a top and before that, what are the conditions for a planet or a body to have an atmosphere. So, essentially there are two conditions for the presence of an atmosphere, appreciable amount of gravity, because the atmosphere is held in its place, because of the force of gravity. If the gravity is less than the gases that are there in the atmosphere will slowly be released into the outer space and so the atmosphere will be lost and so, the planet or any celestial body needs to have a substantially high amount of gravity to have an atmosphere and gravity comes because of the mass of the planet.

And so, only those planets or those celestial bodies that have an appreciable amount of mass will have an atmosphere. The second condition is low temperature, because when the temperatures are high, the gases expand and when they expand, then they will move away from the planet and away from the planet, the force of gravity is less.

And so there will be a much greater chance for the particle or the molecule of the atmosphere to be released into the space and so there are two conditions. One is that the planet should have an appreciably high amount of mass and two is that the temperatures should be low. So, essentially, even planets or celestial bodies with lower masses can have an atmosphere if the temperature is substantially low.

On the other hand, if temperatures are very high, then even planets or celestial bodies within apprehensible mass might also not have the atmosphere because the atmosphere has been lost to the outer space. In our solar system, Jupiter has the largest planetary atmosphere, whereas mercury has a very thin atmosphere.

Now, Jupiter has the largest atmosphere because of two reasons. One, it has appreciable gravity because it is the largest planet and two the temperatures are low enough. On the other hand, Mercury is a small planet, it does not have an appreciable amount of gravity, plus it is very close to the sun and because of the high temperatures, the gases get lost to the space and so it has a very thin atmosphere.

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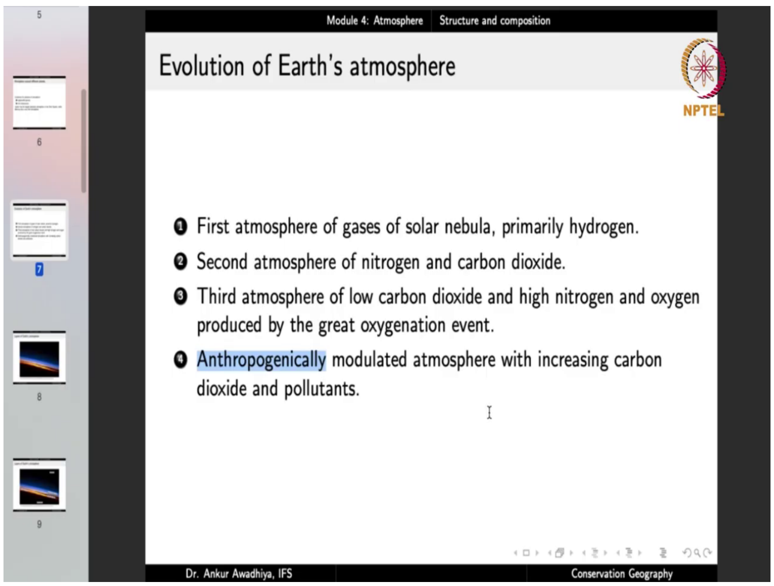

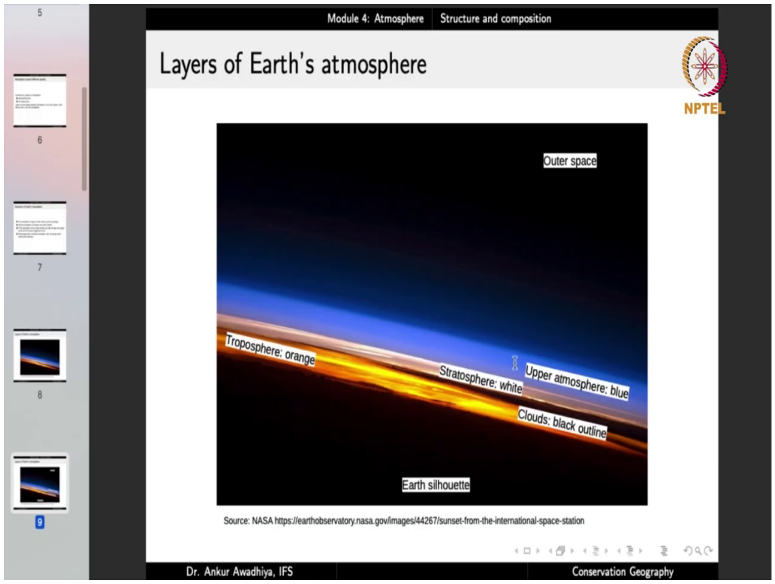

And we have observed the evolution of Earth's atmosphere in the second module and there we saw that the first atmosphere on the Earth comprised of gases of the solar nebula primarily hydrogen. So, this was the time when the Earth was just being formed and, in those days, the Earth was a molten body and the gases that were surrounding the Earth were primarily hydrogen.

So, these were the gases that had come from the nebula which has which had formed the sun and the solar system. Then the hydrogen got lost because it is a very low molecular weight substance. So, the hydrogen was lost and the loss of hydrogen was also exacerbated by the high temperatures that were presented and also the solar winds that were presented.

And after a while, we had a degassing episode, in which the substances that were forming the Earth, they released out gases, especially things like nitrogen and carbon dioxide and so, we had a second atmosphere, which was very rich in nitrogen and carbon dioxide. Then we have the third atmosphere of low carbon dioxide and high nitrogen and oxygen, which was produced by the great oxygenation event.

So, what is the great oxygenation event, once we had life that form on the planet, we had the plants and plants did photosynthesis, in the process of photosynthesis, they took a carbon dioxide, fix the carbon into biomass and released the oxygen back into the atmosphere and so, from a carbon dioxide rich atmosphere, it became a nitrogen and oxygen rich atmosphere.

And then, there is also a fourth stage of Anthropogenically modulated atmosphere with increasing carbon dioxide in pollutants. So, Anthropos is human being so anthropogenic is something that has been generated or that has been given birth to by the humans. So, today's atmosphere is an anthropogenically modulated atmosphere, in which case the amounts or the concentrations of carbon dioxide and pollutants have been increasing.

At the same time, we have also released quite a number of pollutants that did not occur naturally. So, in this case, we are now having a modulated atmosphere, it still has a majority of nitrogen and oxygen, but it also has a very large amount of pollutants and it also has an increasing concentration of carbon dioxide.

So, this is in essence, a reversal of the great oxygenation event. In the great oxygenation event, the plants had converted carbon dioxide into oxygen and today our activities are using oxygen and releasing carbon dioxide into the atmosphere. Now, if we look at the atmosphere from the side, we will observe that it is not a homogeneous thing, there are different layers.

So, here the black coloured is the silhouette of the Earth and we have this orangish colour thing then we have this whitish colour thing then we have the bluish colour thing, which tells us that the atmosphere is made up of several layers. So, what are these layers, this black is the outer space, this black is the Earth silhouette.

The orange colour thing is the troposphere, which is the layer of the atmosphere which is closest to the Earth. In the troposphere we also have clouds which are which can be observed here in this black outline. Above the troposphere, we have the stratosphere, which appears white in this image and above the stratosphere, we have the upper atmosphere.

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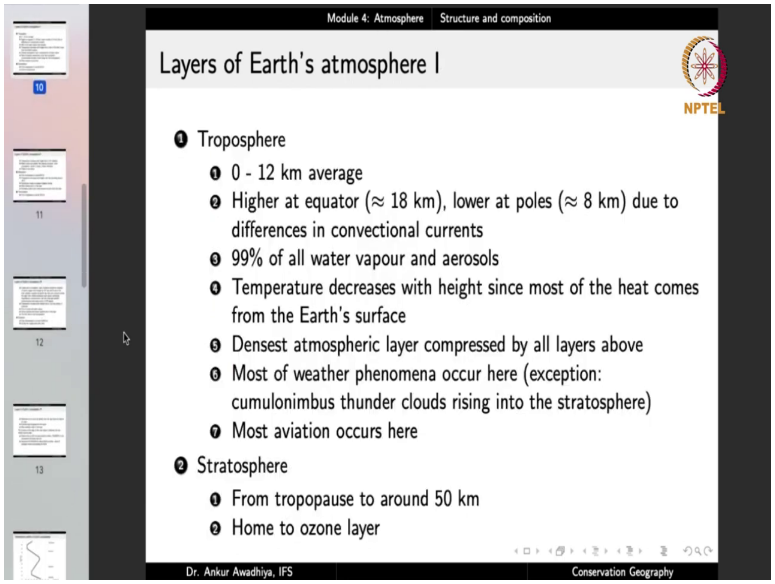

So, technically, we divide the Earth's atmosphere into several layers. The first layer is the troposphere, which goes from 0 kilometres which is the Earth's surface to 12 kilometres in height.

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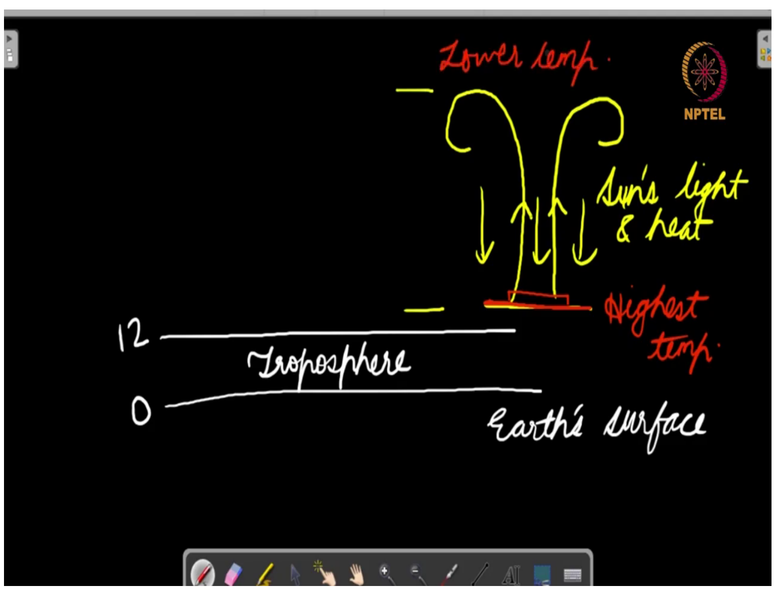

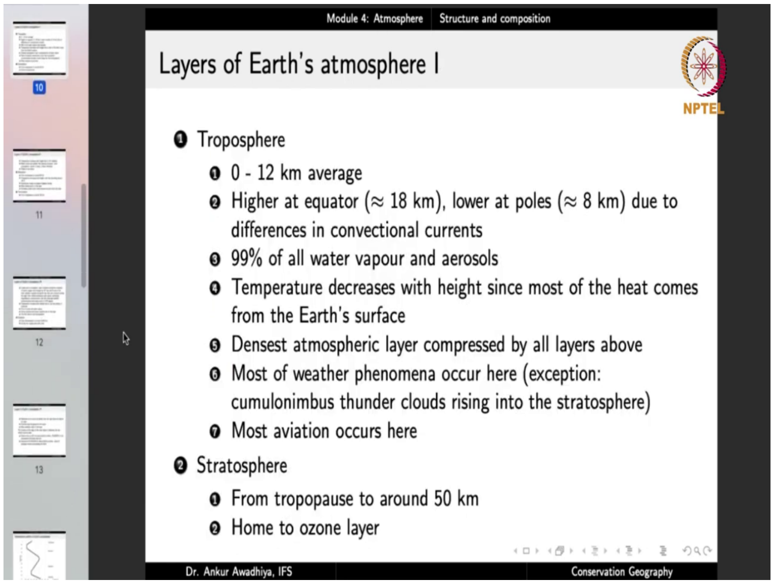

So, essentially if we draw the Earth's surface, so this is the Earth's surface, the first layer of the atmosphere is the troposphere. So, it goes from 0 kilometres to around 12 kilometres, but it is not 12 kilometres at all places it is higher at the equator that is around 18 kilometres and lower at the poles due to differences in convection currents.

So, what happens is that near the equators when the atmosphere is being heated up, it generates convection currents. So, in the case of convection currents, the hot air rises and because of this rising, the height of the troposphere is around 18 kilometres, near the poles where the temperatures are less, the height is just around 8 kilometres.

So, the troposphere is higher at the equator, and lower at the poles due to differences in convection currents. Now, you can relate this point to the fact that only those planets and celestial bodies have the atmosphere that have lower temperatures, because when the temperatures are very high, the atmosphere expands and when it expands too much, then it begins to lose the gases out into the outer space.

Now, similarly, because near the equator, the temperatures are high, so the atmosphere has expanded and so the troposphere is close to around 18 kilometres in height, whereas close to the poles where the temperatures are lower, the troposphere is only from 0 to 8 kilometres in height. Now, troposphere contains 99 percent of all the water vapour and aerosols emitted temperature decreases with height since most of the heat comes from the Earth's surface.

So, what happens in the case of troposphere is that most of the heating occurs at the surface. So, the sun's energy heats up sun’s light and heat, now that heats up the surface, it heats up the Earth surface, and once the surface is heated up, it gives out this heat to the lower layer of the atmosphere and from there, the convection currents take it upwards.

So, because of that, the temperature decreases with height because this layer is being heated from the bottom and so the highest temperatures will be here, so this is the highest temperature and, on the top, will have lower temperatures. So, temperature decreases with height since most of the heat comes from the Earth's surface.

Now, in this context, you can also correlate it with the fact that if you go to a hill station then typically the temperatures are lower. Because with an increase in elevation with an increase in height, the temperatures go down. It is the densest atmospheric layer, which is comprised by all the layers above.

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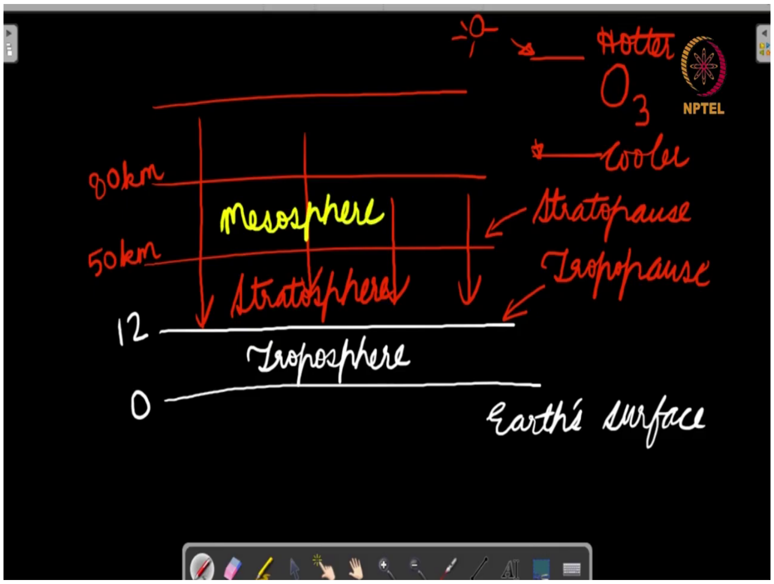

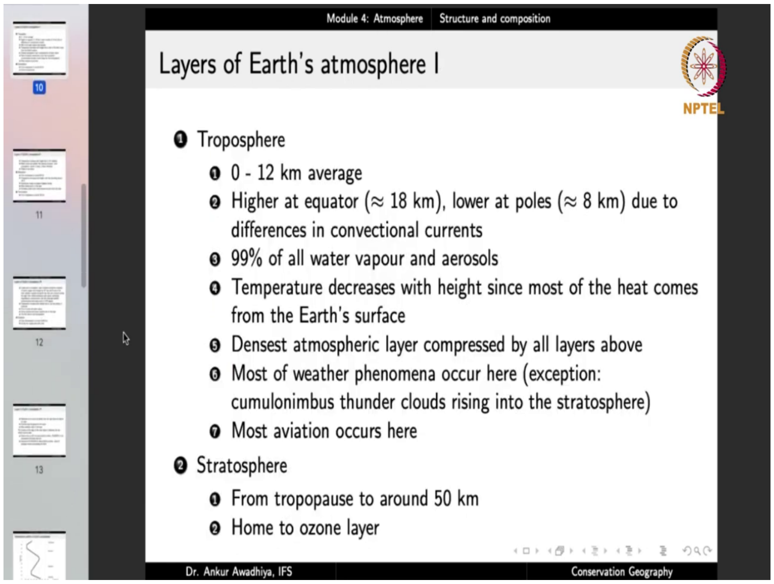

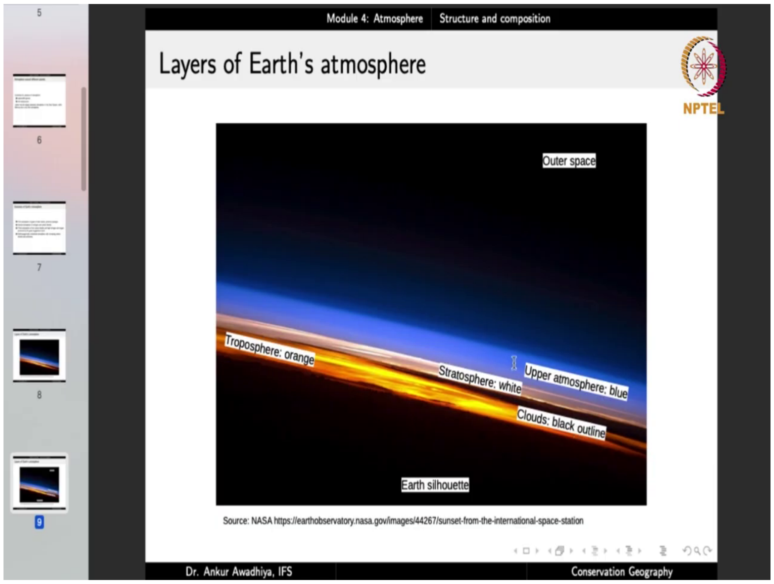

Because when we talk about the layers of atmosphere, in that context, we have several different layers and the Earth is very massive. So, the Earth is pulling all of these layers down and all of these layers are putting a pressure on the troposphere. Now, because of that, the troposphere is the densest layer because it is being compressed by all the layers that are above it.

So, troposphere is the densest atmospheric layer comprised by all the layers above. Most of the weather phenomena occur here with the exception of cumulonimbus thunder clouds that rise into the stratosphere. So, when we talk about the weather phenomena such as clouds or rain or snow fall or hills or storms, most of them are occurring in the troposphere with the exception of the cumulonimbus thunder clouds that rise into the stratosphere, most of the aviation occurs here. So, typically the smaller planes they fly in the troposphere.

The second layer is the stratosphere, it begins at the top of tropopause goes up to around 50 kilometres. Now, tropopause is the top of the troposphere. So, this is tropopause. So, this is the point where the troposphere pauses or ends. So, from here till around 50 kilometres, you have the stratosphere and stratosphere is what appeared as white in this layer.

So, this white coloured thing this is the stratosphere. The stratosphere is the home to the ozone layer. Now, ozone refers to O_3 and O_3 or ozone is the layer that protects the life on this planet from the ultraviolet radiation of the sun. So, this layer plays a very important role in supporting life on this planet. In the stratosphere, the ozone layer uses up the ultraviolet radiation of the sun.

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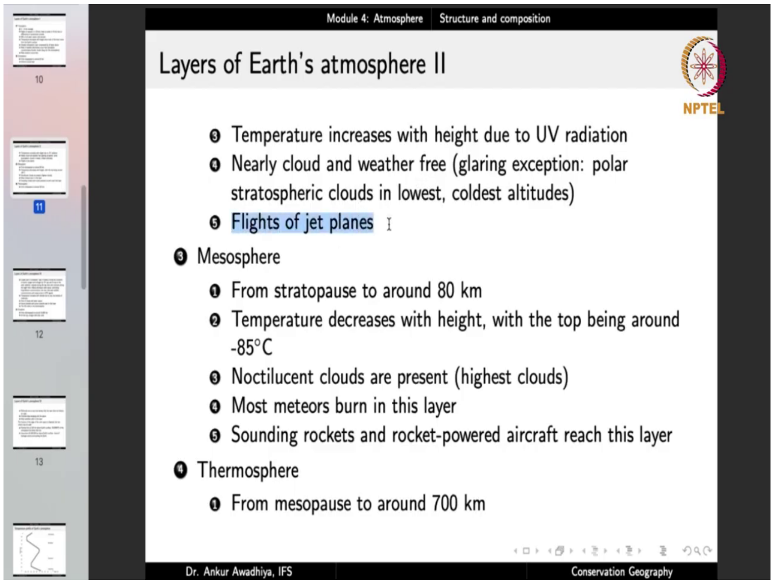

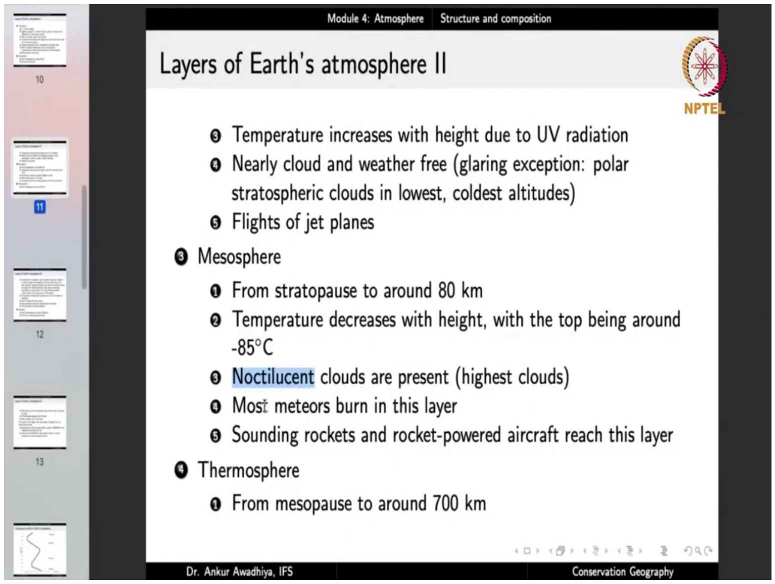
Module 4: Atmosphere | Structure and composition
Layers of Earth's atmosphere II
NPTEL
3. Temperature increases with height due to UV radiation
4. Nearly cloud and weather free (glaring exception: polar stratospheric clouds in lowest, coldest altitudes)
5. Flights of jet planes
3. Mesosphere
1. From stratopause to around 80 km
2. Temperature decreases with height, with the top being around -85°C
3. Noctilucent clouds are present (highest clouds)
4. Most meteors burn in this layer
5. Sounding rockets and rocket-powered aircraft reach this layer
4. Thermosphere
1. From mesopause to around 700 km
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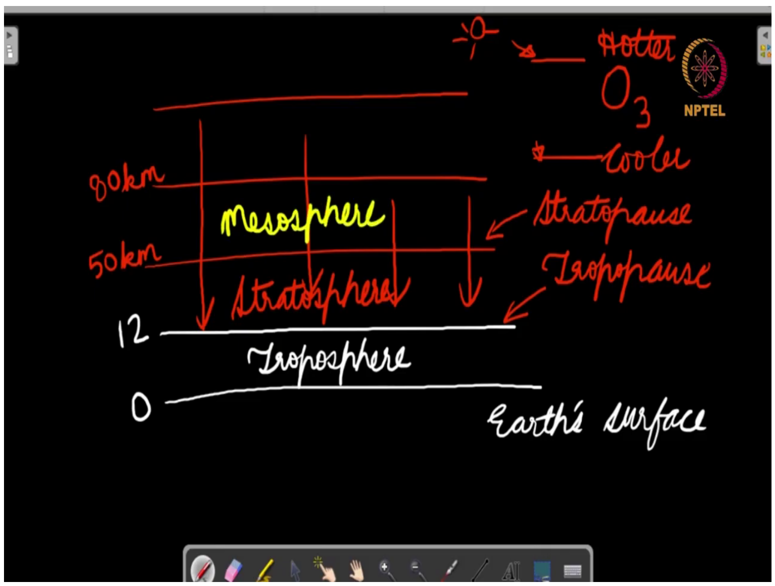
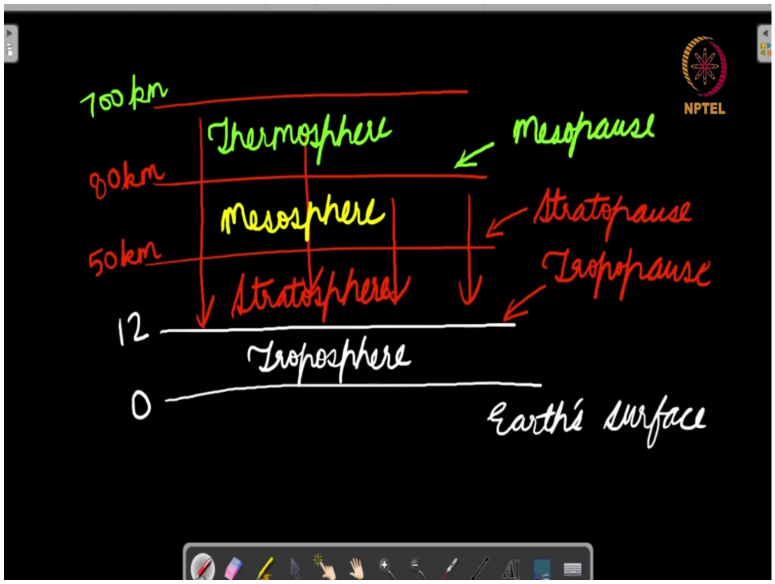

Hotter
O_3
NPTEL
cooler
80km
Mesosphere
Stratopause
50km
Stratosphere
Tropopause
12
Troposphere
0
Earth's surface



And because of that, the temperature increases with height due to the UV radiation. So, if we consider the ozone layer, if the sun is here, then the maximum amount of UV light will be received at the top of this layer, and less amount of UV light will be received at the bottom of this layer because this layer is using up the UV radiation.

Because of that the temperature here is high, so this portion is hotter, and this portion is cooler and so in the stratosphere, the temperature increases with height. Now, this is just opposite to that of the troposphere in the troposphere, the temperature was going down as we move up in the stratosphere, the temperature increases as we go up.

This layer is nearly cloud and weather free with the exception of polar stratospheric clouds in the lowest and coldest altitudes. So, apart from these stratospheric clouds, this is nearly cloud and weather free. Because of which most of the flights of jet planes are done in this layer. So, that they do not have to suffer the consequences of changing weather.

So, because this layer is free of weather phenomena, so it is very good for use as the layer where jet planes can be flown about this is the mesosphere. Mesosphere goes from stratopause to around 80 kilometres. Now, stratopause is the top of the stratosphere. So, this is strata pause and from here to around 80 kilometres, we have the next layer, which is mesosphere.

Now, the in the mesosphere the temperature again decreases with height with the top being around minus 85 degrees Celsius. So, in this layer, this is very similar to the troposphere, the temperature goes on decreasing with height as you move up the temperature it reduces.

noctilucent clouds are present in this there. noctilucent clouds are those clouds that appear as luminous bodies in the night nocti it is night lucent is light.

So, noctilucent clouds are those clouds that appear to be luminous in the night conditions. So, these are some clouds that are present in the mesosphere and these are the highest clouds most of the meteors burn in this layer. So, this layer also plays a very big role in supporting life on this planet, because most of the meteors are burnt in this layer.

So, they do not come crashing down on us and sounding rockets and rocket powered aircraft are able to reach this layer. After the mesosphere, we have the thermosphere, the thermosphere is from the misopause to around 700 kilometres. Now, you can observe that the thermosphere is a fairly thick layer of the atmosphere, it goes from misopause which is around 80 kilometres to around 700 kilometres. So, from 80 kilometres to 700 kilometres, we have the thermosphere and this top is the misopause. Now, thermo means temperature, so, this is a sphere of temperature.

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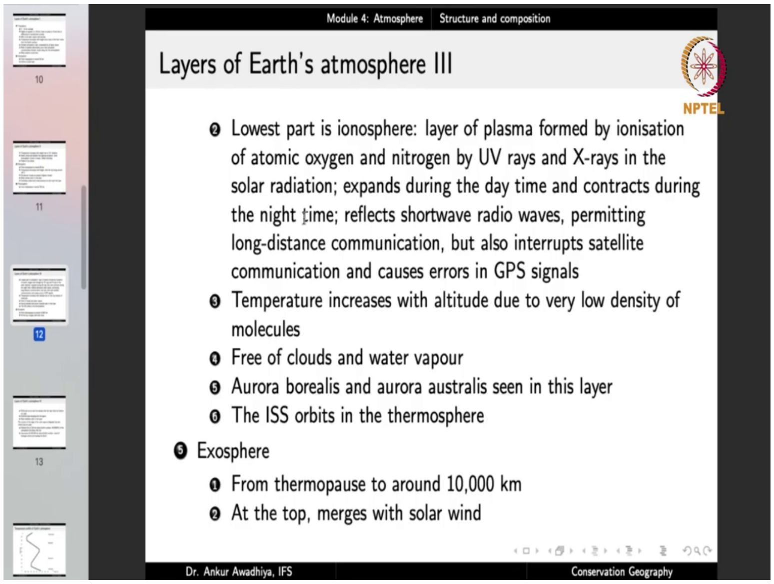

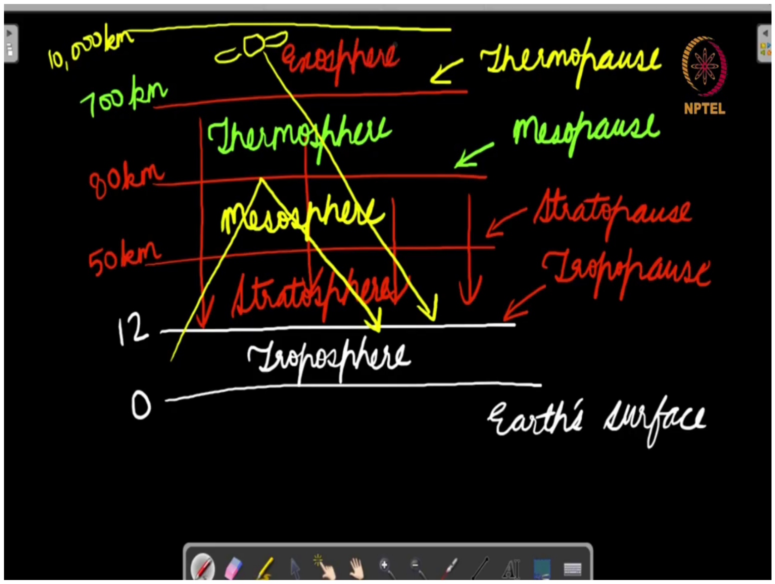

The lowest part is known as the ionosphere. Now, in this layer the temperatures are so, high that the atoms occur in the form of ions. Now, this ionosphere is a layer of plasma that is formed by ionisation of atomic oxygen and nitrogen by UV rays and X-rays in the solar radiation, it expands during the daytime and contracts during the night time.

So, what is happening here, because of the heat and high energy radiation that is UV rays and X-rays of the sun, the atoms get converted into plasma which is ions. So, the atoms become positively charged ions and the electrons are ripped apart. Now, this layer because it is dependent on the sun's energy for its formation.

So, during the daytime there will be a pretty tech is very clear in the night time when the sun's energy is not available, then it will shrink down. So, it expands during the daytime and contracts during the night time it reflects shortwave radio waves permitting long distance communication, because this is a layer which is a charged layer. So, it is able to reflect the radio waves, which permits long distance communication.

But it also interrupts satellite communication and causes errors in the GPS signals. So, what this lady is doing is it reflects the radio waves. So, if you have the radio wave it reflects it down which is good for us, but, at the same time if there are any satellites that are giving out signals, so, when the signals are beamed down to us, in that case, this layer also interacts with these signals.

So, it interrupts satellite communication and it also causes errors in the GPS signals of the global positioning system temperature increases with altitude due to very low density of molecules this layer is free of clouds and water vapour. So, again there is hardly any weather phenomena that goes on here. Aurora Borealis and Aurora Australia's are seen in this layer.

Now, what are the aurora borealis is the northern lights, Aurora Australia's is the southern lights. So, what happens is that the charged particles that are coming from the sun, they interact with the gases that are present in this layer and out of this interaction we get a beautiful display of light typically in green or pinkish use and they are typically observed in the night time Aurora Borealis is observed near the North Pole or Aurora Australia's is observed near the South Pole.

So, these phenomena of Aurora Borealis and Aurora Australia's they occur because of this particular layer and the International Space Station orbits in the thermosphere. Above it, we have the exosphere. So, it begins from the thermopause and goes up to around 10,000 kilometres, so thermopause is the top of this thermosphere. So, this is thermopause, and from here to around 10,000 kilometres is the exosphere. At the top, it merges with the solar wind.

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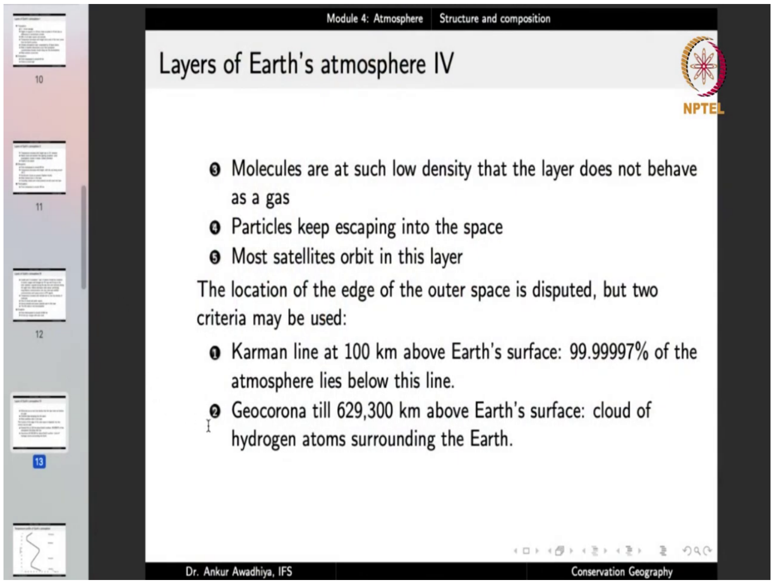

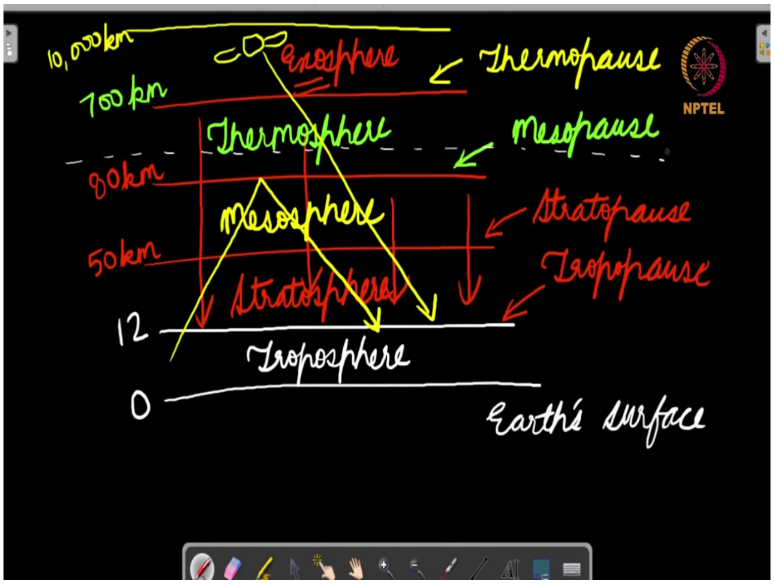

The molecules are at such low density that this layer does not behave as a gas, it behaves very much like vacuum. The particles keep escaping into the space, and most of the satellites orbit in this layer. So, this is exosphere exists outside. So, this is the outside sphere of the atmosphere. So, this is basically the portion where the atmosphere is now merging with the outer space.

Now, where does the atmosphere end? What is the end point of exosphere that is not very certain because the gases there are in such low densities, that it is difficult to pinpoint where the exosphere ends and so, the location of the edge of the outer space is disputed two criteria are commonly used the first one is the Karman line, which is around 100 kilometres above the Earth surface and we have 99.99997 percent of the atmosphere lies below this line.

So, we can see that anything that is above the Karman line. Now, if you look at this chart, Karman line will fall somewhere in the thermosphere. So, because 99.99997 percent of the gases fall below this layer, we can say that this is the edge of the atmosphere or otherwise, we can talk about Geocorona which is 629,300 kilometres above the Earth's surface. And this is the cloud of hydrogen atoms that are surrounding the Earth. So, we can make use of any of these two definitions for the edge of the outer space either Karman line which is 100 kilometres or the Geocorona which is 629,300 kilometres above the Earth's surface.

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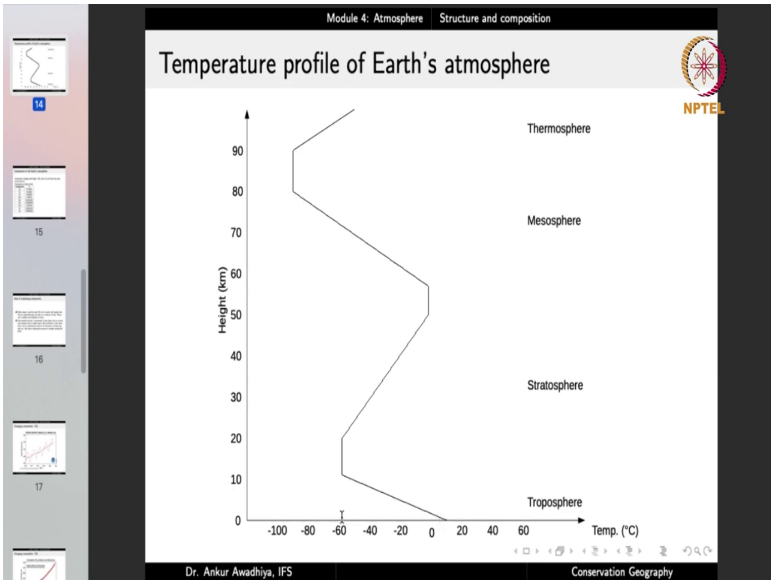

Now, we talked about changes in temperature in different layers of the atmosphere. So, this is what the temperature profile looks like. Now, in the troposphere, the temperatures go on decreasing as we go up. Now, in this chart on the x axis, we have the temperature on the y axis we have the height.

Now, the troposphere is close to around 12 kilometres, but it varies from 8 to 18 kilometres and in the troposphere, the temperatures go on decreasing with height. So, it goes from say around 10 15 degrees Celsius to around minus 60 degrees Celsius. In the stratosphere, the temperatures increase with height. So, they move from minus 60 degrees to close to around 0 degrees in the misosphere that temperatures again reduce. So, they go down to as low as minus 80 to minus 90 degrees in the thermosphere, they again increase. So, this is roughly the temperature profile of the Earth's atmosphere.

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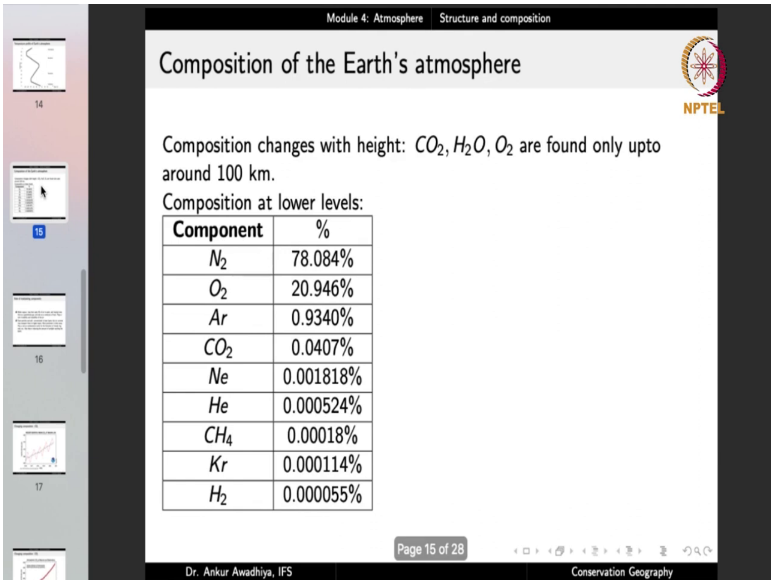

Now, let us look at the composition of the Earth's atmosphere what is the atmosphere made out of. So, here, it is important to note that the composition changes with the height. So, essentially, the heavier molecules will be found close to the Earth, the lighter molecules or even the lighter atoms can be found at a much greater distance.

If you talk about the heavier gases like carbon dioxide or water vapour or oxygen, they are found only up to around 100 kilometres they are not found about this limit. At the lower levels, this is the composition say around 78 percent of the atmosphere is nitrogen around 21 percent is oxygen and around 0.93 percent argon. So, these are the three major components of the atmosphere. Carbon dioxide is 0.04 percent then we have the other gases in very low concentrations like neon, helium, methane, krypton and hydrogen.

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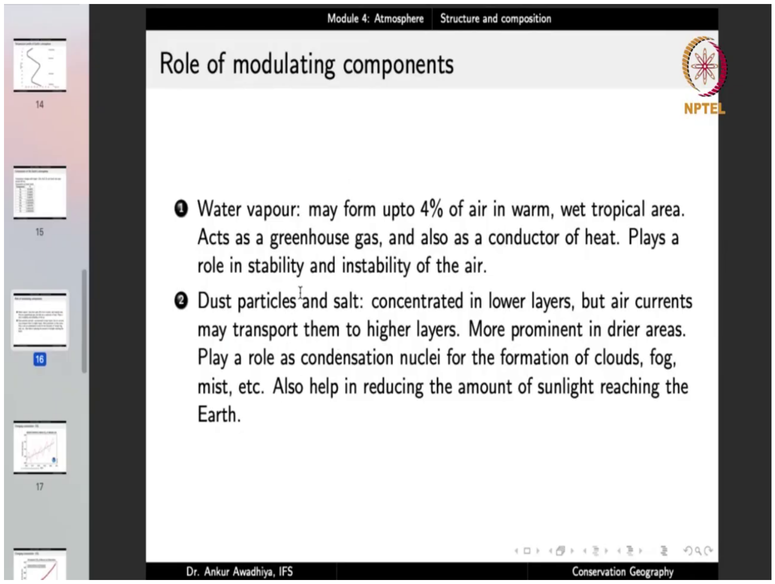

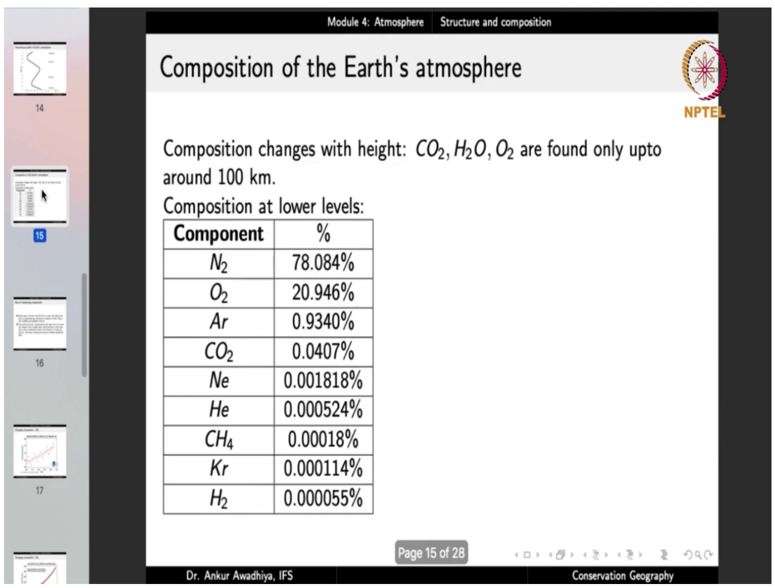

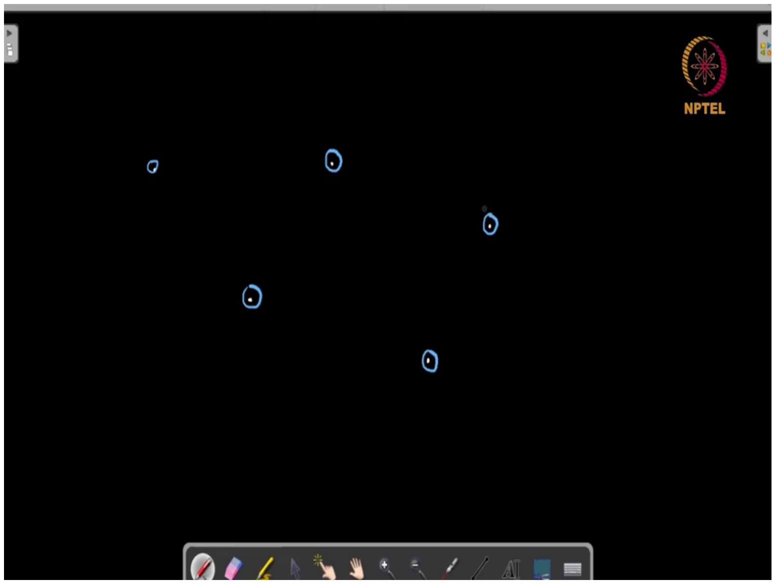

And in this context, it is important to note the role of two modulating components. The first is water vapour and the second is dust particles and salt. Now, both of these modulating components are typically found close to the Earth's surface. So, they are mostly found in the troposphere, water vapour may form up to 4 percent of air in warm and wet tropical areas.

So, in the here we were talking about these amounts, but in the tropical areas in the wet areas, water vapour may form up to 4 percent of the air. It acts as a greenhouse gas which means that it keeps or it traps the energy of the sun in the atmosphere, it does not permit the long wavelength infrared radiations to escape from the Earth's surface.

So, it is a greenhouse gas very similar to carbon dioxide and it is also a conductor of heat. So, essentially, air as such is a bad conductor of heat, but with the presence of a large volume of water vapour the conductivity increases it plays a role in the stability and instability of the air, which also means that it plays a role in different weather phenomena.

The second modulating component is dust particles and salt, they again are concentrated in the lower layers, but air currents may transport them to higher layers, they are more prominent in drier areas, the water vapour plays a role in wetter areas, dust particles in salt play a role in drier areas. They play a role as condensation nuclei for the formation of clouds, fog mist et cetera.

Now, what is a condensation nuclei when we have water vapour in the atmosphere, and the temperature is going down, then the water vapours need to condense. Now, where will they condense, so for that they require condensation nuclei. So, these dust particles or salt particles, they act as condensation nuclei, which means that water can condense over them.

And when water condenses over them, it leads to the formation of droplets of water. So, water from water vapour is getting converted into droplets and these droplets can later on form rain or snow or hail whatever. So, they play a big role as condensation nuclei for the formation of clouds, fog, mist et cetera. They also help in reducing the amount of sunlight that is reaching the Earth.

So, they reflect the sun's energy and so they reduce the amount of sunlight that is coming to the Earth. Now, in this context, you will remember that when we talked about the extinction of dinosaurs around 65 million years ago, we said that, that the meteor that collided with the Earth, it collided in a location that was high in sulphate rocks that was high in gypsum and when the meteor collided, then it resulted in a vast amount of release of energy and this energy was so high that this gypsum was released into the upper portions of the atmosphere, where it stayed.

And when it stayed there, then it was able to stop or greatly reduced the amount of sun's energy that was coming to the Earth, because of which there was a big cooling period and it led to the deaths of a vast number of species. Now, when we talk about the role of dust particles and salt particles, it is similar to the role of those sulphates when they are there in the upper layers of the atmosphere, they are able to reflect the sun's heat back and so the amount of energy that comes to the Earth reduces. So, this is a rule of the modulating components, water vapour, and dust particles and salt.

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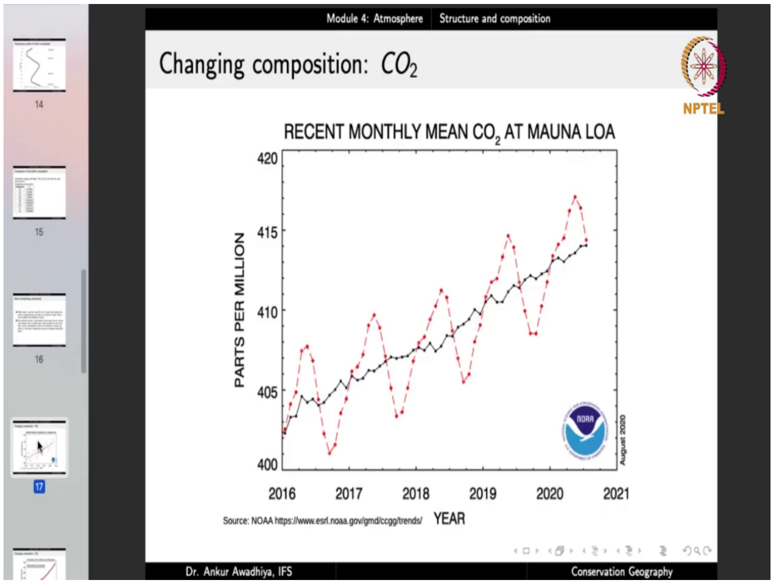

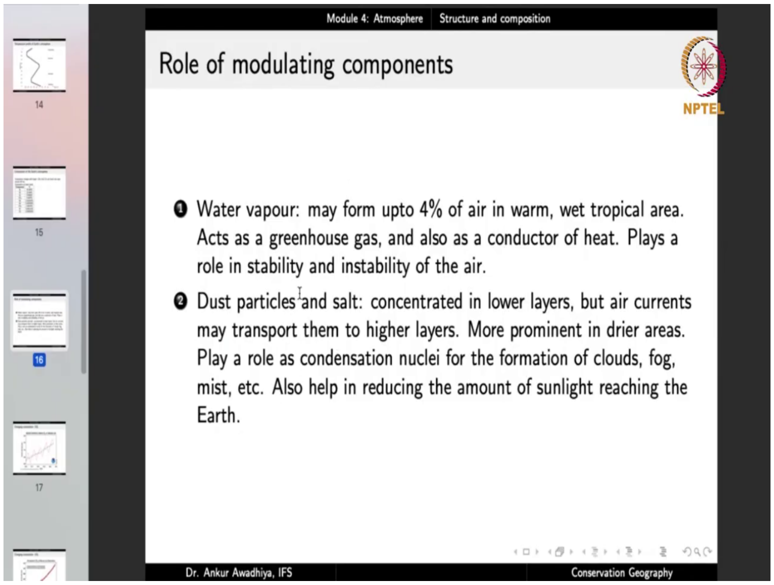

Now, it is important to note here that the composition of the atmosphere goes on changing these modulating components, they change on a daily basis, but even other gases are also changing in their concentrations. So, if we look at the amount of carbon dioxide that is there in the air, we will find that this amount goes up and down, up and down, up and down every year, you will find an increase and decrease.

Now, why is that so? You will find that the amount of carbon dioxide has got a lot to do with the amount of photosynthesis that is occurring on this planet. So, we talked about the great oxygenation event the plants took up carbon dioxide and released oxygen and they are doing the same thing even today, wherever they are doing photosynthesis.

Now, when you have the growing season, the plants use a carbon dioxide and so the concentration of carbon dioxide in the atmosphere goes down when you do not have the growing season, but other things such as automobiles or industries, they are still spewing out carbon dioxide. So, in those seasons, the amount of carbon dioxide will rise again then again in the growing season, it will go down then when it is not the growing season the amounts will again rise.

So, essentially this is what we are observing here every year. So, if you talk say between 2018 and 2019, there was a peak and there was a bottom line. So, you get this up and down curve for carbon dioxide. Now, this is on a more finer temporal scale here we are talking about a yearly variation.

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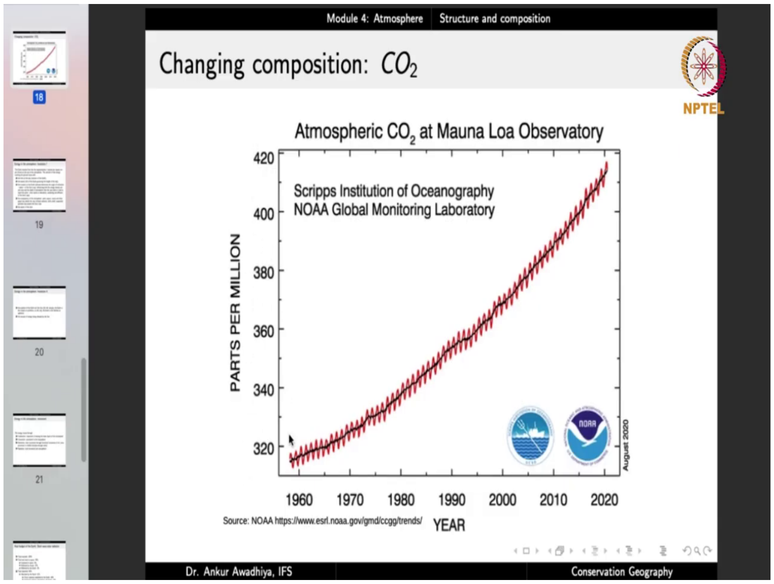

But even over long durations of time, we find changes in the composition. So, if you look at the amount of carbon dioxide in around 1960, so it was less than 320 parts per million in the air, which means that out of every 1 million parts of the air less than 320 was carbon dioxide. Today in 2020, it is reaching close to around 420. So, every year the amount of carbon dioxide has been increasing and this is mostly because of our rampant use of fossil fuels.

So, when we use up coal and petroleum and natural gas, we are using up the carbon that was trapped by the plants and animals way back and that was stored down deep down in the Earth. So, we are taking out that carbon that was taken away from the atmosphere, we are burning it and we are relating it back into the atmosphere in the form of carbon dioxide.

Now, when we talk about the anthropogenic influences on the climate, this is one big anthropogenic influence. We find this increase in carbon dioxide over the years primarily because of the activities of human beings and this is not a small change. Because in a span of around 60 years, the carbon dioxide concentration has increased by around 30 percent. So, 30 percent of 320 would be close to around 100 and we have an increase in 100 parts per million.

So, a 30 percent increase in carbon dioxide in just over in just around 60 years is a big change. It is a huge change. So, the composition of the atmosphere is changing with time and these days we humans are playing a big role in bringing out this change, especially in the case of carbon dioxide and especially in the case of various pollutants.

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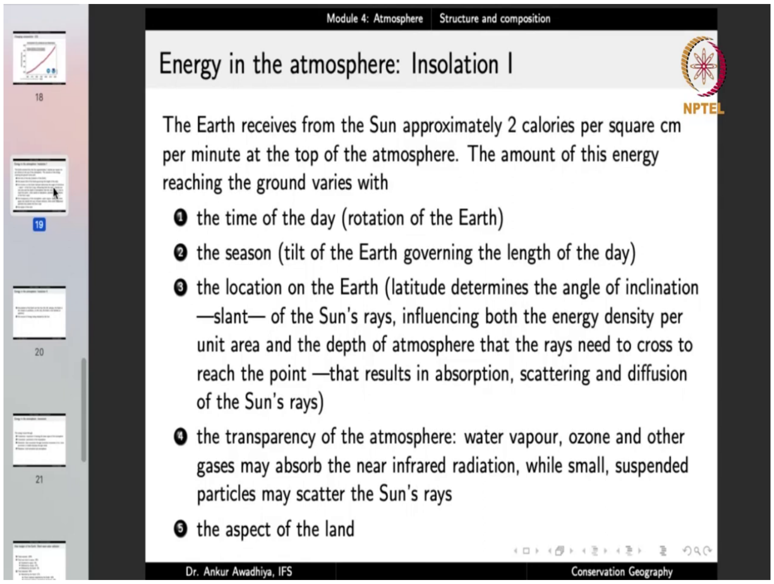

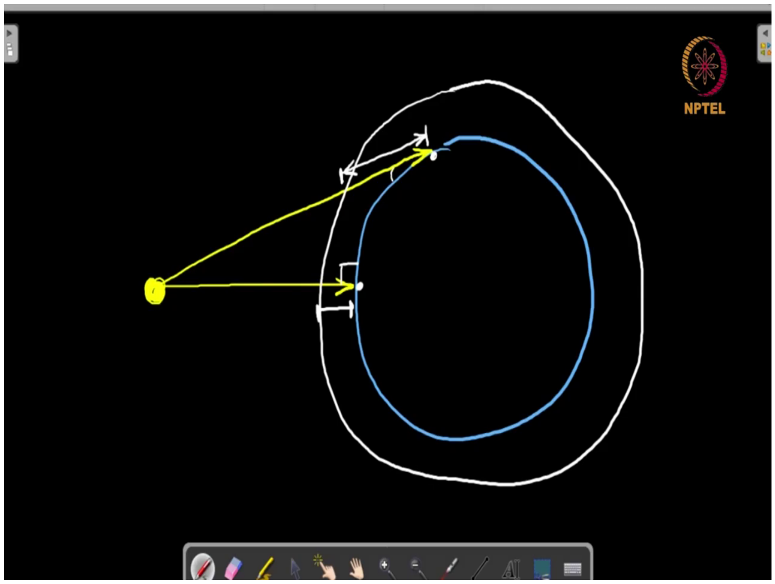
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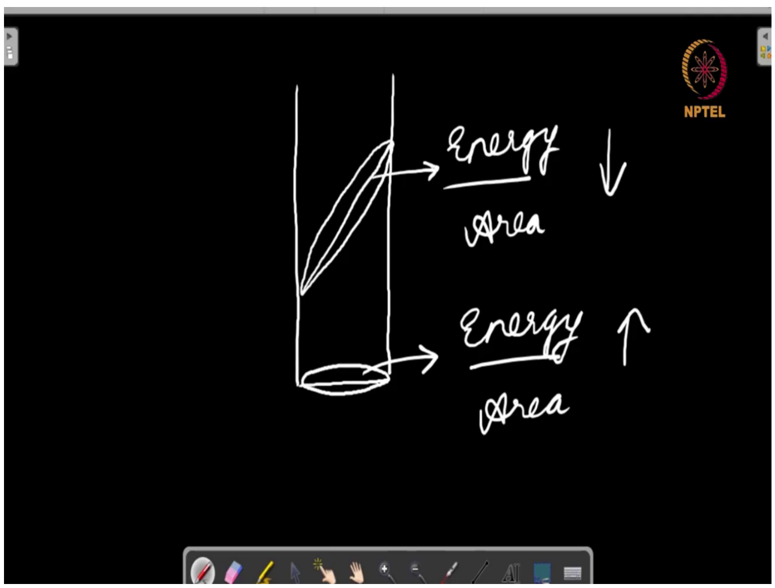
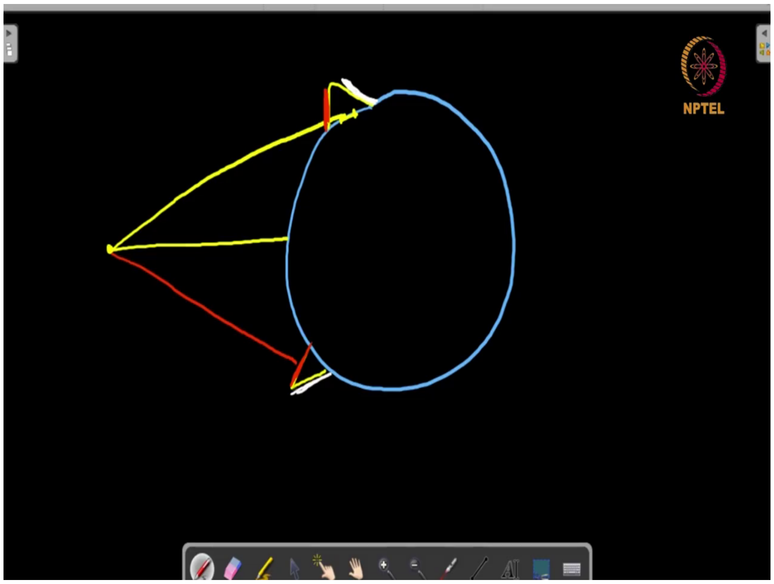

NPTEL
Energy / Area ↓
Energy / Area ↑



Let us, now have a look at the energy in the atmosphere the Earth receives from the sun approximately 2 calories per square centimetre per minute at the top of the atmosphere. So, the sun is the primary source of all energy on this planet and the amount of energy that we are getting is close to around 2 calories per square centimetre per minute on the top of the atmosphere.

Now, this amount of the amount of this energy that reaches the ground varies with the time of the day, which is because of the rotation of the Earth. So, the amount of energy that we get during the daytime is much greater than the amount of energy that we get during the night time. So, that is obvious, because, during the daytime we have the sun during the night time we do not see the sun.

So, the amount of energy that we get, it depends on the time of the day, it also depends on the season, because of the tilt of the Earth that governs the length of the day. Now, in the summer season, we have longer days and shorter nights in the winter day in the winter seasons, we have shorter days and longer nights. So, the total amount of energy that a place would receive in a summer time will be typically much greater than the amount of energy that it will receive in the wintertime.

Because in the summer time, the length of the day is much greater and so, the Earth receives or that location receives the sunlight for a much longer period of time. It also depends on the location on the Earth, latitude determines the angle of inclination or the slant of the sun's rays, which influences both the energy density per unit area and the depth of the atmosphere that the rays need to cross to reach that point.

So, essentially, what we are saying here is that if we consider the Earth and the sun so, because the sun is very far off, so, let us represent it by is a smaller circle. Now, the sun's rays when they hit this point, they are reaching roughly at 90 degrees, but when we consider the sun's rays reaching at say this point, they are reaching at an angle.

Now, if we draw the atmosphere around the Earth, then in this case, when it when the sun's rays were reaching at a point near to the equator, they had to cross this much distance of the atmosphere this much thickness of the atmosphere, but to reach this point, they have to travels this much distance which is much greater.

So, essentially, these rays of the sun have to pass through a thicker amount of atmosphere and in this process, quite a lot of sun's energy may get dissipated out some portion may get reflected back some portion may get scattered and so, the typically the amount of energy that this point will get will be much greater will be much lesser then the energy that this point will get.

So, the amount of energy that reaches the ground, it also varies with the location on the Earth. The latitude determines the angle of inclination or slant of the sun's rays. In this case, the angle of incidence is close to around 90 degrees from the surface. In this case, we have a much-slanted position this influences both the energy density per unit area and the depth of the atmosphere that there is need to cross energy density, because if we consider a beam of light, if we calculate the energy over this area versus the energy when it is received at a slant, so the energy over this area.

Now in this case, because the area is large, so the energy per unit area becomes less here because the area is less so the energy per unit area is higher. So, essentially, when the sun's rays are hitting at an angle. So, at this point when it is falling vertically, the area is less and so the density is high, when it is hitting at an angle, the area is more and so, the energy density is less.

So, the location on the Earth latitude determines the angle of incidence or slant of the sun's rays influencing both the energy density per unit area and the depth of the atmosphere that needs that the rays need to cross to reach the point. Now, more the depth of the atmosphere, you will have more amount of absorption in the atmosphere, more amount of scattering because of the atmosphere, more amount of diffusion because of that atmosphere.

So, because of this, the sun's rays are getting lost before they reach or before they hit the Earth's surface and so, at higher latitudes that is near the poles, the amount of energy that is received by the Earth is lesser than the amount of energy that is received say at a location near the equator. Now, the amount of energy reaching the ground also varies with the transparency of the atmosphere, what is the amount of water vapour ozone and other gases that are there in the atmosphere that absorb the radiation what is the amount of small and suspended particles such as dust and salt or say sulphates that reflect or scattered the centuries.

So, the transparency of the atmosphere also has a huge bearing on the amount of energy that is received at a location on the Earth. So, we are talking about the ground surface and if the transparency of the atmosphere is less, in that case, less amount of energy will reach on the ground. And it also depends on the aspect of the land, aspect meaning that if you talk about the northern hemisphere's, then typically the certain aspects of mountains they receive more amount of light as compared to the northern aspects.

Now, this is because when we talk about so, in this image say there is a mountain here. So, the southern aspect which is this aspect, this will be getting more amount of heat or more amount of energy whereas, this aspect will typically be in the shadow area for most of the time. Similarly, when we consider a mountain in the southern hemisphere, then the northern aspect will be getting more amount of energy because of the sun, whereas, the southern aspects will be mostly in the shadows and so, they will receive less amount of energy.

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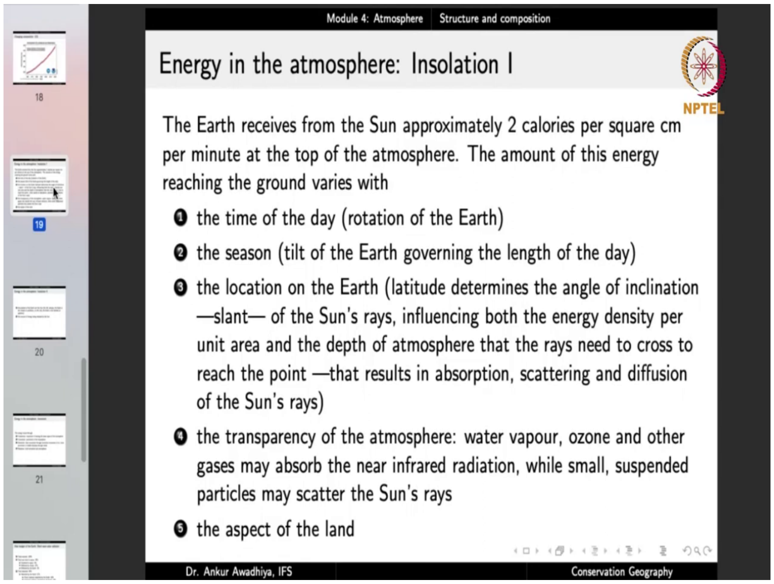

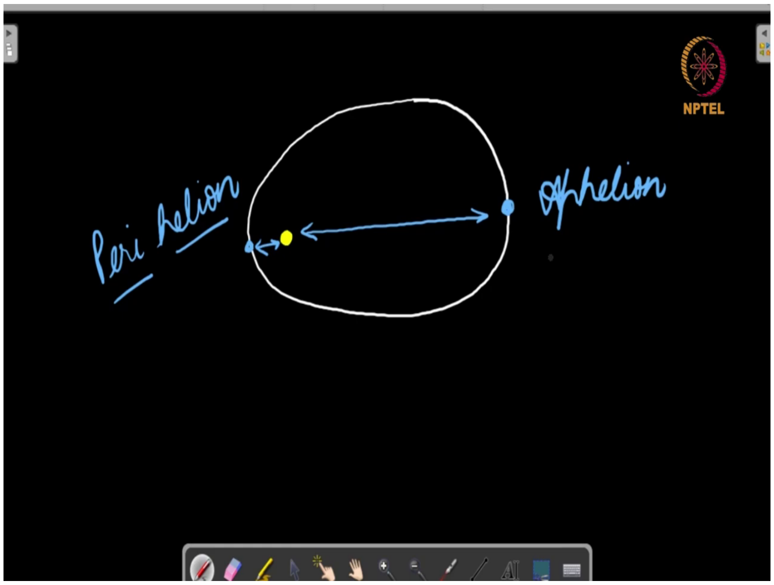

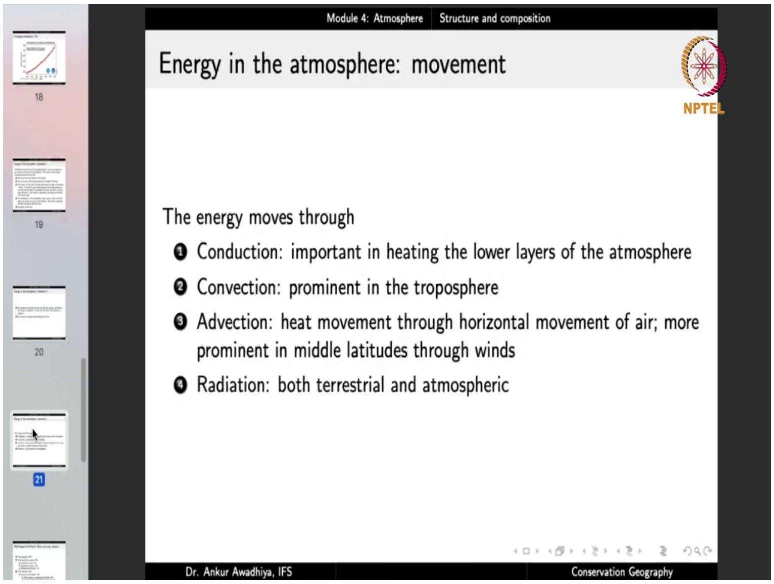

It also depends on the position of the Earth with respect to the sun, on 3rd January the Earth is closest at perihelion and on 4th of July the Earth is farthest at the aphelion. Now, what does that mean? If we drew the so, this is the sun and this is the orbit of the Earth and let us say the Earth is at this location. So, when the Earth is at this location, the Earth is at a very great amount of distance from the sun whereas if the Earth is at this location, the Earth is very close to the sun.

Now, this point is known as perihelion. Peri is near and helion and his son and this point is known as aphelion. So, if the Earth is at the perihelion, perihelion is on 3rd of January, the amount of energy that the Earth receives is more when the Earth is at the aphelion on the 4th of July, the amount of energy received is less because the Earth is at a greater distance from the sun and with more and more distance the energy density reduces and it also depends on the amount of energy being released by the sun.

So, there are typically certain periods when the sun is giving out more amount of energy and there are certain periods when the sun is giving out less amount of energy. Now, this depends on something that is known as the solar cycle. Now, solar cycle is a 11-year cycle. So, it repeats every 11 years and in these 11 years, there will be a time point when the amount of energy is the highest and there is a time point when the amount of energy received is the lowest and so the amount of energy that a point on the Earth gets from the sun depends on all of these factors.

So, it will depend on one the time of the day, whether it is noon whether it is early morning, late evening night, so depends on the time of the day, it depends on the season, is it summer season winter season, in the summer season, you get more amount of sunshine, because the days are longer, it depends on the location on the Earth that are near the equator get more sunshine areas that are far off, they received less amount of energy.

The transparency of the atmosphere, if the atmosphere is less transparent, say because of dust particles or salt particles or sulphate particles, or because of certain gases that absorb the infrared radiation in that case, less amount of energy will reach to the surface, it depends on the aspect of the land in the northern hemisphere, the southern slopes get more sunshine in the southern hemisphere in the northern slopes get more sunshine. It depends on the position of the Earth with respect to the sun, whether it is at the perihelion aphelion or somewhere in between, and it also depends on the amount of energy that is being released by the sun. So, this is the energy that gets into the atmosphere.

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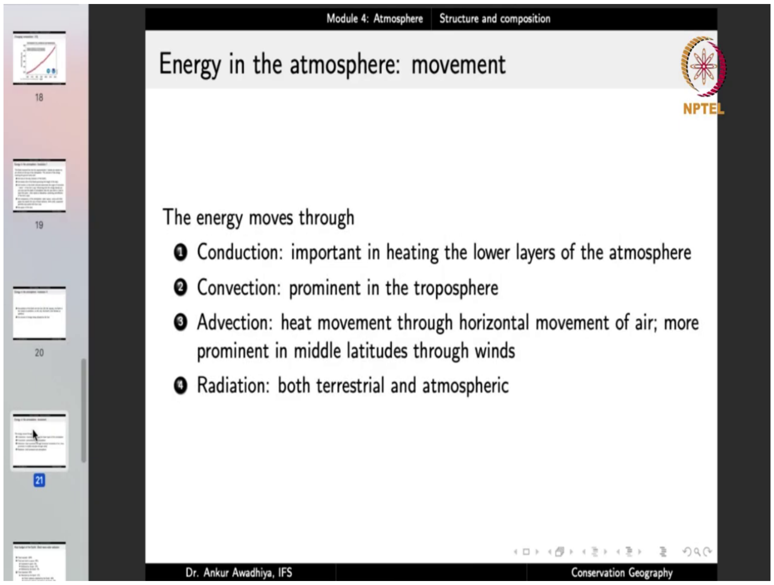

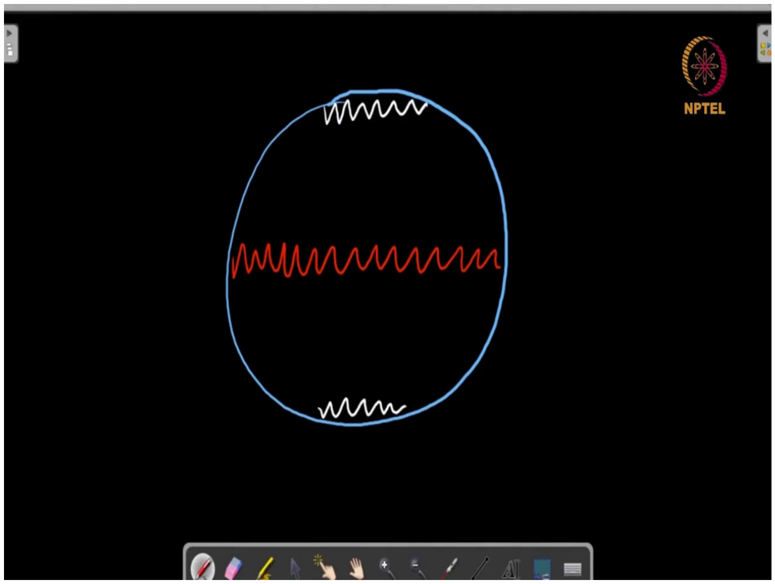

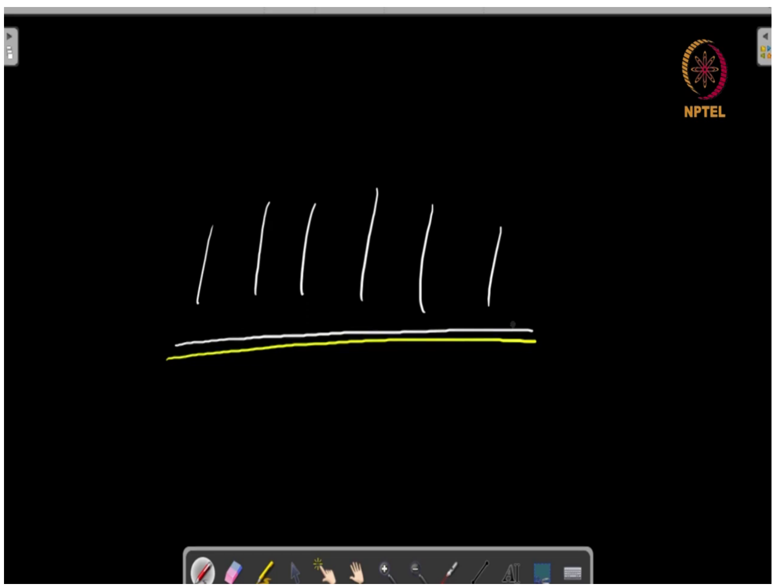

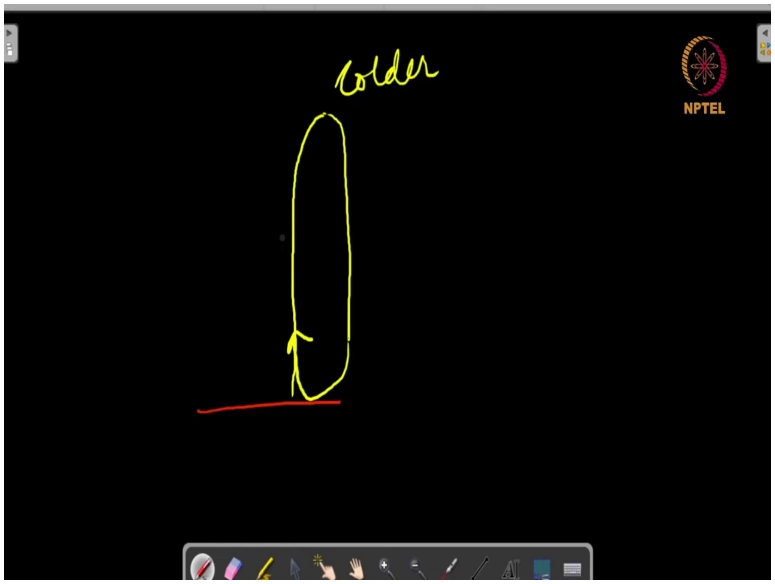

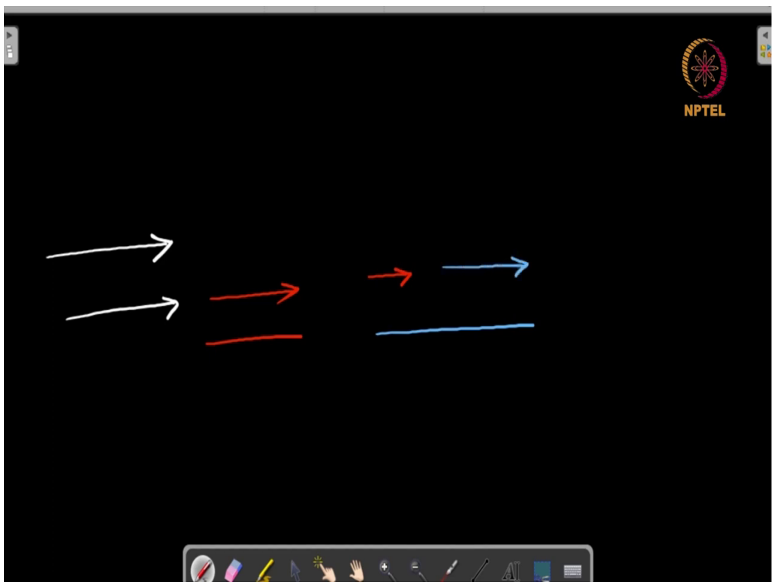

What happens once you have this energy in the atmosphere or once you have this energy on this planet? What is this energy do? Now, one major thing that the energy does is that it supports all life on the planet. But from the geographical point of view, it also does one other thing it regulates the weather patterns, it regulates the flows of various fluids.

So, it regulates the movement of ocean waters, it regulates the movement of air and with the air, it regulates the movement of rains and it does so, because the energy moves. So, what is happening is that you have the Earth and areas that are near the equator, they are getting more amount of energy whereas areas that are near the poles that are getting less amount of energy.

Now, once you have a system in which there is a certain location that is hotter and another location that is colder, then typically energy will tend to move from the hotter region to the colder region. And when this energy moves, it moves through a medium typically this medium is the water or the air and when this energy moves, it moves the air and the water with it.

So, typically, the movements or the movement of energy can occur through 4 different ways. The first one is conduction, conduction means the movement of energy from one body to another, which are in direct contact with each other. So, basically, if you have this pen, which is hot and if you touch this pen, you will feel that this pen is hot, because the energy is moving from this pen into your body.

Now, because this is happening through this touch, so we will say that this is because of conduction and it is important in heating the lower layers of the atmosphere. Why? Because when we talk about the troposphere, what is happening is that this Earth surface is getting heated up and when the Earth's surface gets heated up the air that is right next to it, it also gets heated up.

So, conduction plays a very important role in heating the lower layers of the atmosphere, but then the air is not a very good conductor of heat, it is a bad conductor of heat. So, once the lower layers of the atmosphere have been heated, this conduction cannot go on for a very long distance. So, the other modes come into play. Once such mode is convection, which is prominent in the troposphere.

Now, in the case of convection, what happens is that once the lower layers have been heated, the wind the air molecules themselves will rise and then in the upper layers when it is colder, then it will become denser and then it will come down. So, there will be a moment in a cyclical pattern. So, the hot air rises, it rises because the hot air expands when it expands the density reduces and with reduced density this air becomes lighter and it moves up.

Now, when it moves up, it takes the heat energy together with it. On the upper layers it becomes colder. When it becomes colder, it again shrinks and when the packet of air shrinks, the density increases it becomes heavier and then it comes down. So, these are convictional currents that also play a role in moving the heat and they are very important especially in the troposphere, third, we have advection, advection is heat movement through a horizontal movement of air, which is more prominent in middle latitudes through the winds.

So, essentially in the case of advection if you have a hot surface and say this is a cold surface, once you have wind that is moving over this hot surface to this cold surface, so, when the air comes in contact with this hot surface, the air becomes hotter and then this hot air comes over the cold surface and it releases the heat energy here and then it becomes colder.

So, in this case, the heat energy is moving or the thermal energy is moving, because of the horizontal movement of the air because of the because of the wind patterns. So, this kind of a moment of heat is known as advection. A yet another mode is radiation both terrestrial and atmospheric in which the energy moves from a hot surface in the form of infrared radiations.

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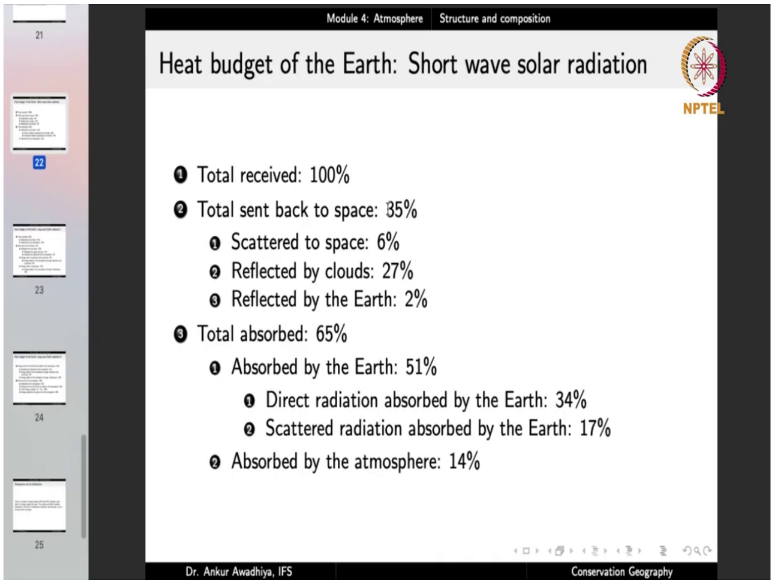

So, if we look at the heat budget of the Earth, what happens to the energy that is being received on this planet? So, if we consider that total amount of energy received is 100 percent then this 100 percent is divided into two parts, total sent back to space is 35 percent and 65 percent is absorbed. Now, totally sent back to space occurs by 3 modes, one is scattered to space, which is 6 percent reflected by the clouds is 27 percent and reflected by the Earth surfaces 2 percent.

So, most of the energy that is sent back to the space is because of reflection because of the clouds the reflection by the Earth occurs because of the different albedos that different surfaces have albedo is basically the reflectivity that a surface has. So, for instance, snow which is white in colour has a very high albedo, it reflects most of the energy whereas, a dark black coloured road surface has a very low albedo because it absorbs the energy does not reflect it back.

So, 35 percent of the energy is directly sent back into the space only 65 percent is absorbed and out of this 65 percent as much as 51 percent is absorbed by the Earth and only 14 percent is absorbed by the atmosphere. So, most of the energy as much as 51 percent of the total incident energy is absorbed by the Earth.

So, the lithosphere plays the largest role. Now, in this case, this 51 percent comprises of 34 percent which is absorbed in the form of direct radiation. So, this is the energy that is coming from the sun and it is directly getting absorbed by the Earth and we have 17 percent of energy that is a scattered radiation that is also absorbed by the Earth. So essentially, we have now this 60 this 65 percent of energy that is left in our planet.

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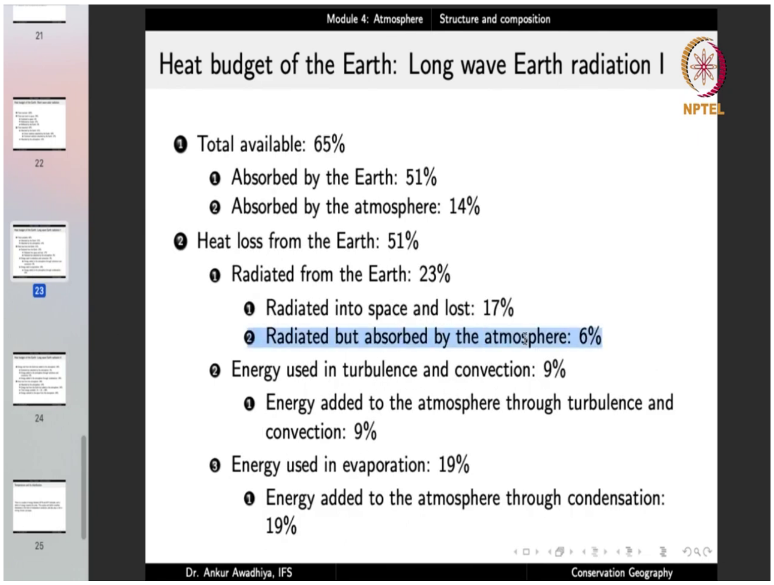
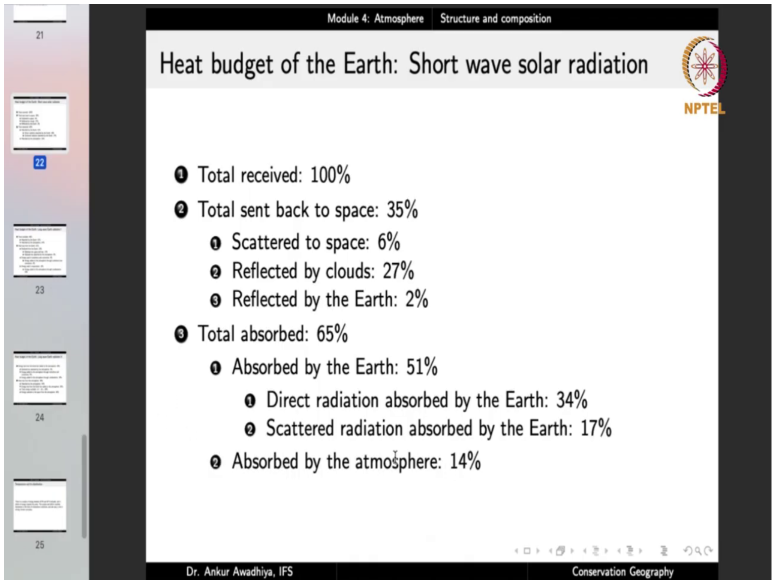


Heat budget of the Earth: Long wave Earth radiation I

1. Total available: 65%
   1. Absorbed by the Earth: 51%
   2. Absorbed by the atmosphere: 14%
2. Heat loss from the Earth: 51%
   1. Radiated from the Earth: 23%
      1. Radiated into space and lost: 17%
      2. Radiated but absorbed by the atmosphere: 6%
   2. Energy used in turbulence and convection: 9%
      1. Energy added to the atmosphere through turbulence and convection: 9%
   3. Energy used in evaporation: 19%
      1. Energy added to the atmosphere through condensation: 19%

Heat budget of the Earth: Long wave Earth radiation II

3. Energy lost from the Earth but added to the atmosphere: 34%
   1. Radiated but absorbed by the atmosphere: 6%
   2. Energy added to the atmosphere through turbulence and convection: 9%
   3. Energy added to the atmosphere through condensation: 19%
4. Heat loss from the atmosphere: 48%
   1. Absorbed by the atmosphere: 14%
   2. Energy lost from the Earth but added to the atmosphere: 34%
   3. Total energy available: $14 + 34 = 48\%$
   4. Energy radiated to the space from the atmosphere: 48%



So, total available is 65 percent out of which 51 percent was absorbed by the Earth and 14 percent was absorbed by the atmosphere. So, what happens to this absorb energy? Now, this energy is then lost back into the space, because if you do not have an equilibrium of the amount of energy that is absorbed and the amount of energy that is released back.

So, in that case, we will have a situation in which the planet either warms or it cools. So, if more amount of energy is absorbed a less amount of energy is released back in that case, the planet will slowly start to warm if less amount of energy is absorbed and more amount of energy is released back which means that the pools of energy inside the Earth are also being radiated back or sent back into the space in that case the Earth will begin to cooled down. Now, because the Earth more or less maintains its temperature, so we say that the total energy that is incipient is the energy that is lost from the Earth as well.

Now, out of this 51 percent all of 51 percent will be lost 23 percent is directly radiated from the Earth. So, out of this 17 percent is radiated into the space and lost forever and 6 percent is radiated but absorbed by atmosphere, 9 percent of the energy is used in turbulence and convection which means that it moves from the Earth into the atmosphere 19 percent of the energy is used in evaporation and all of this energy also becomes added to the atmosphere when there is condensation. And so, the total energy that is lost from the Earth, but added to the atmosphere becomes 34 percent which is 6 percent which is radiated and absorbed by the atmosphere, then this 9 percent and this 19 percent.

So, 6 and 9 and 19 becomes 34 percent. Now, the energy that was absorbed by the atmosphere was 14 percent. So, we added here energy absorbed by the atmosphere is 14 percent and this is from the direct radiation. So, from the sun's radiation 14 percent was absorbed then 34 percent is getting from the Earth. So, you total have now 14 plus 34 is 48 percent and this 48 percent of energy is later on radiated from this to the space from the atmosphere. So, this is the heat budget of the Earth.

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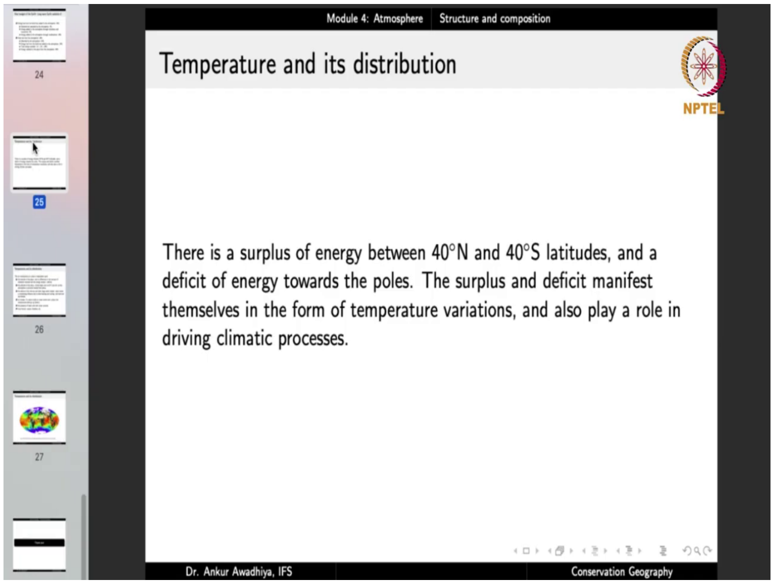

And overall there is a surplus of energy between 4 degrees north latitude and 4 degrees south latitude and a deficit of energy towards the poles. Now, this is because the regions near the equator, they get more amount of energy than is lost, whereas, the regions near the poles, they get less amount of energy that is lost then is lost. And so, we have a surplus of energy near the equator and we have a deficit of energy towards the poles. Now, the surplus deficits manifest themselves in the form of temperature variations and they also play a role in driving the climatic processes that will observe with the next lecture.

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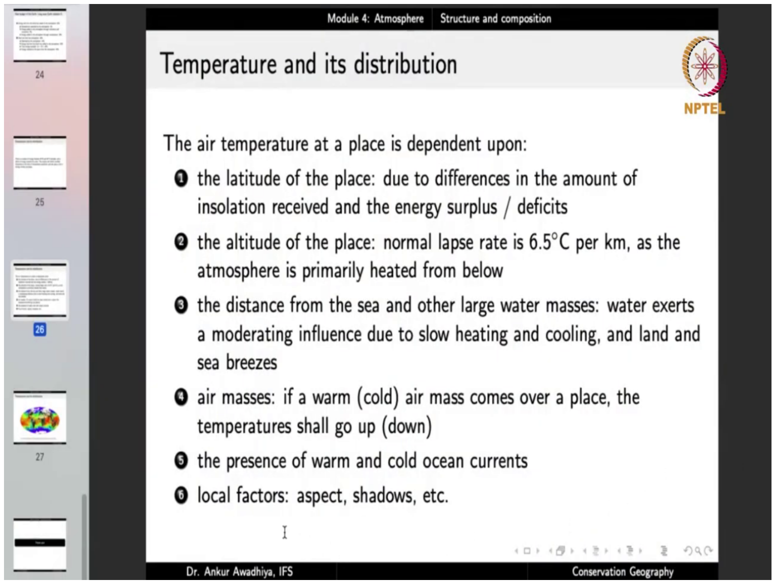

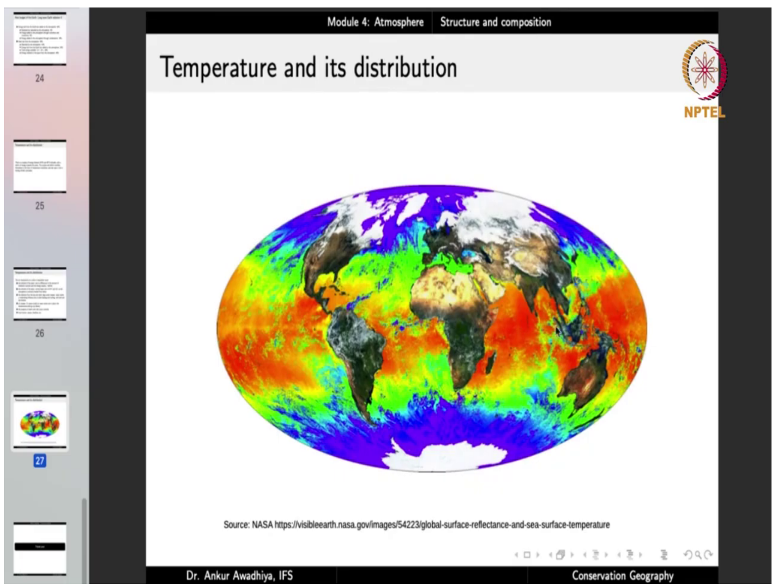

Now, that when we say that it manifests in the form of temperature variations, what does temperature depend on the air temperature depends on again the latitude of the place which gives the whether it is a surplus or a deficit, it depends on the altitude of the place because when we talk about the troposphere, the temperature reduces as we go up.

So, there is a lapse rate which is 6.5 degrees per kilometre and as the atmosphere is primarily heated from below, so, if you go up the temperature goes down the distance from the sea and other large water masses which exert a moderating influence will observe this in more detail later. Air masses, so, if there is a warm or a cold air mass that comes then you will have a change in the temperature because of advection. The presence of warm and cold ocean currents.

So, even if there is a location that is otherwise cold but is getting a warm ocean current, then the temperatures will go up. If an area is otherwise warm, but is getting a cold ocean current, then the temperatures will go down. So, they also play a role in the temperature distribution and also the local factors such as aspect and shadows and if you plot a temperature distribution on the planet, we will find that it goes something like this. So, the equator is are much more warmer, the poles are much more colder, and otherwise we get such a distribution of temperatures. So, that is all for today. Thank you for your attention. Jai Hind!