Climate Change Science
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Lecture – 4
Properties of Real Surfaces

In the last lecture, we talked about black body radiation's properties and we saw that photons emitted by a black body at 300 Kelvin and that emitted by a black body at 6000 Kelvin have completely different ranges of wavelengths. Now, this is a very important conclusion because radiation of the Sun is around 6000 Kelvin and that of Earth is around 288 Kelvin. So, the radiation emitted by the Sun and that emitted by the Earth do not have much overlap in wavelengths. So, when you look at properties of surfaces and of the atmosphere, we have to be very careful because the properties are very different where the Sun's photons are coming into Earth, and where Earth's photons are reaching space. So, this important distinction has to be understood. This is shown in the diagram below that radiation emitted by the Sun exists in a completely different wavelength range compared to that coming from Earth.

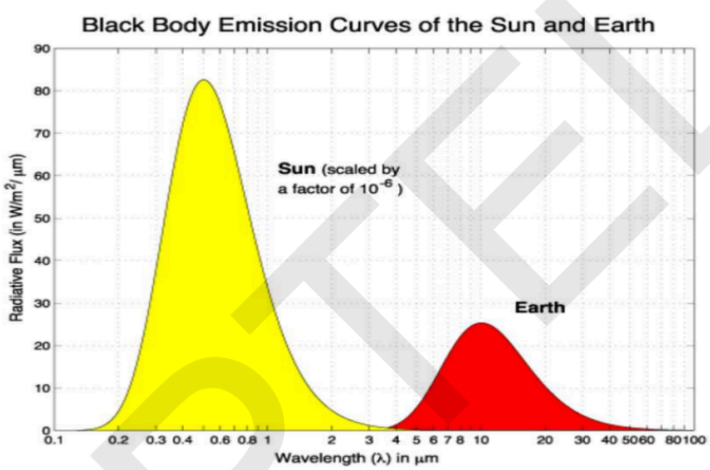


Figure 19.1: Blackbody spectrum of the Sun and the Earth.

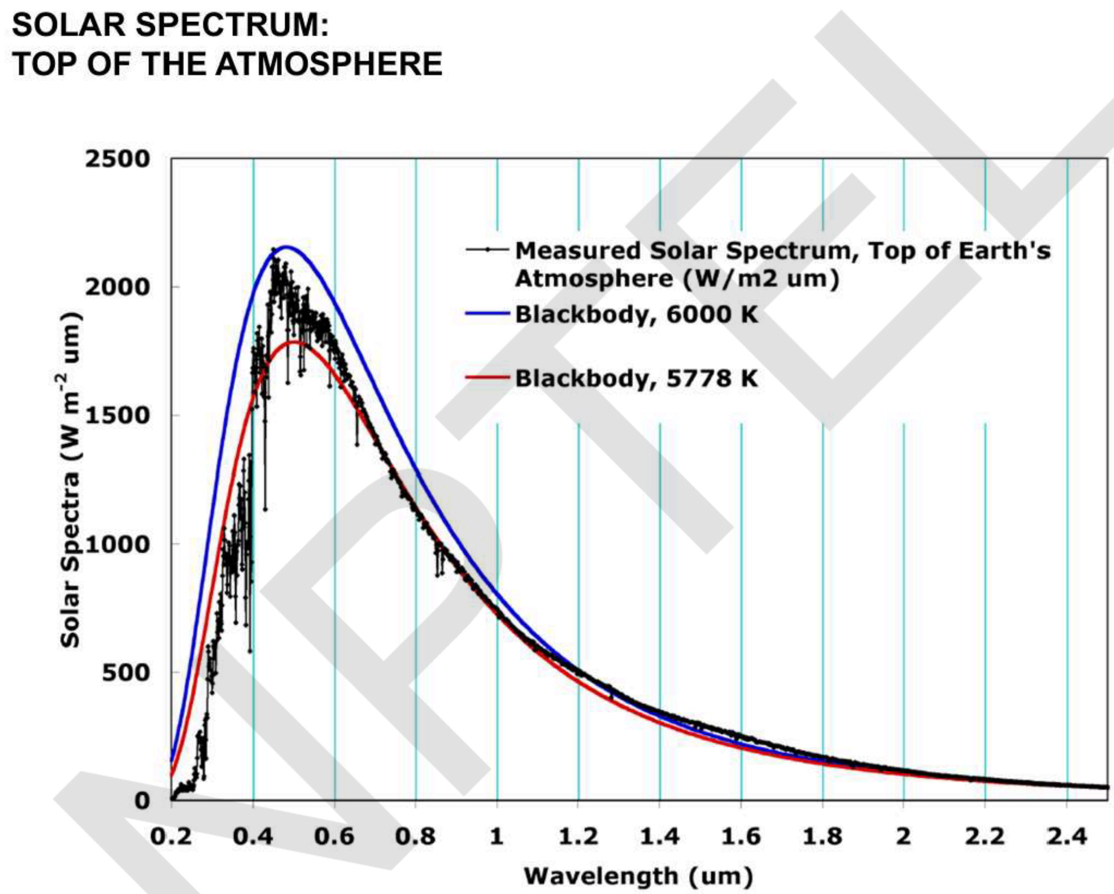
Note that the radiation emitted by the Sun and that emitted by the earth occur in different wavelength ranges.

This fundamentally alters the way we analyze the Earth's radiation budget. We have to be very careful because, for example, snow will reflect a lot of the Sun's radiation, but will absorb more of Earth's radiation. Take the Earth's atmosphere in this visible region; we know on a clear day Earth's atmosphere is totally transparent. The same atmosphere in the long wave region is almost totally opaque.

So, this is what makes Earth a very unique planet. It has an atmosphere which is almost transparent to the Sun's radiation, but almost opaque to Earth's radiation. This difference is what is called the Greenhouse effect. There are gases in the atmosphere which have different absorption properties in the region where the Sun emits radiation compared to the region where Earth emits radiation. This alters the way Earth's energy balance takes place.

λT (µm K)	Blackbody fraction	λT (µm K)	Blackbody fraction	λT (µm K)	Blackbody fraction
600	9.29E–8	4200	0.51600	16000	0.97377
800	1.64E–5	4400	0.54878	18000	0.98081
1000	3.21E–4	4600	0.57926	20000	0.98555
1200	0.00213	4800	0.60754	25000	0.99217
1400	0.00779	5000	0.63373	30000	0.99529
1600	0.01972	5200	0.65795	35000	0.99695
1800	0.03934	5400	0.68034	40000	0.99792
2000	0.06673	5600	0.70102	45000	0.99852
2200	0.10089	5800	0.72013	50000	0.99890
2400	0.14026	6000	0.73779	60000	0.99935
2500	0.16136	6400	0.76920	70000	0.99959
2600	0.18312	6800	0.79610		
2700	0.20536	7200	0.81918		
2800	0.22789	7600	0.83907		
2897.772	0.25006	8000	0.85625		
2900	0.25056	8400	0.87116		
3000	0.27323	8800	0.88413		
3100	0.29578	9200	0.89547		
3200	0.31810	9600	0.90541		
3300	0.34011	10000	0.91416		
3400	0.36173	11000	0.93185		
3500	0.38291	12000	0.94505		
3600	0.40360	13000	0.95509		
3800	0.44337	14000	0.96285		
4000	0.48087	15000	0.96893		

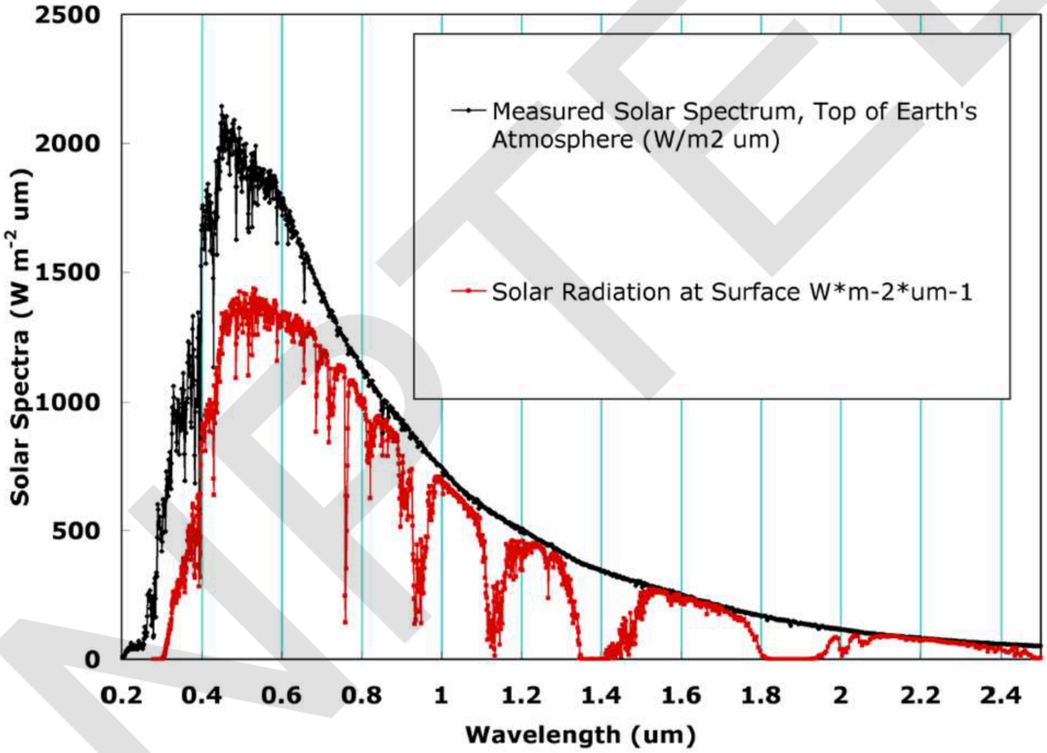
Now to calculate radiation at different wavelengths and broad fractions there you need this table. This table is available in any text book on radiation. In the back of the book, you will see this and you will be using this table when you do problems based on this course. So, in case you have temperatures which are such that the numbers are in between these two values, you can interpolate. It is quite accurate. So, this is what will be used for calculation of properties of surfaces.



Now here is a picture of the actual radiation emitted by the Sun in black line, which is not constant and varies with wavelength. Also, there are two black body radiation curves, one at 5778 Kelvin (in red) and one at 6000 Kelvin (in blue). Now, what this shows is the Sun approximately behaves like a black body between 5778 and 6000. Now, whether you assume the Sun to be 6000 K or 5778 K depends on your application.

If you are interested in energy balance, you want to make sure that the area under the red curve and the area under the actual Sun's radiation (black line) are equal. So, this red curve is so constructed that it has slightly higher values here in the ultraviolet and a slightly lower value here in the infrared, but the area under the curve of the red and this actual Sun's emission are equal. While the blue one is so drawn that the maximum value of the Sun's emission coincides with this blue curve at one wavelength. So, that is relevant for other applications, but for our purpose this 5778 or number very close to it is relevant because that is the approximate black body temperature whose radiation integrated over the whole wavelength has the same value as the actual radiation of the Sun.

SOLAR SPECTRUM:
TOP OF THE ATMOSPHERE AND AT THE SURFACE



Now, here is another observation of the Sun's radiation outside the Earth's atmosphere in black and at the surface which is in red. What this shows is that the atmosphere does absorb some radiation although we said it is not totally transparent. It has a lot of absorption here also in the visible as well as in the infrared. These absorptions are mainly by gases like carbon dioxide, water vapor, ozone in the ultraviolet region and these reduce the Sun's radiation at certain wavelengths. But notice that in other wavelengths, there is hardly any absorption. Now, what we observe is that the solar radiation at Earth's surface is given by the red line and this is for a clear day at a given location.

As you go to different locations, this number will change. And on a cloudy day it will be very different. But what this shows is that on a clear day, a certain fraction of the Sun's incoming radiation is absorbed by the atmosphere and it is typically around 20 percent.

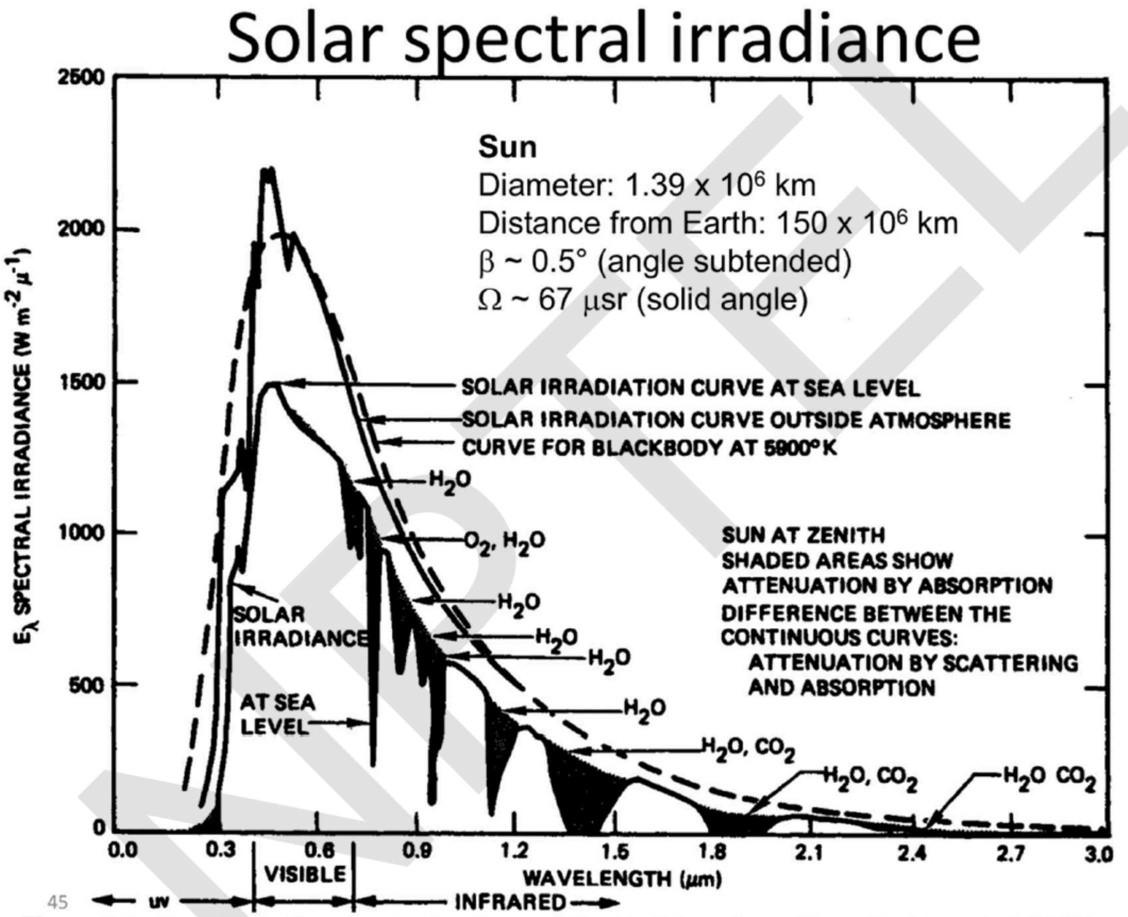
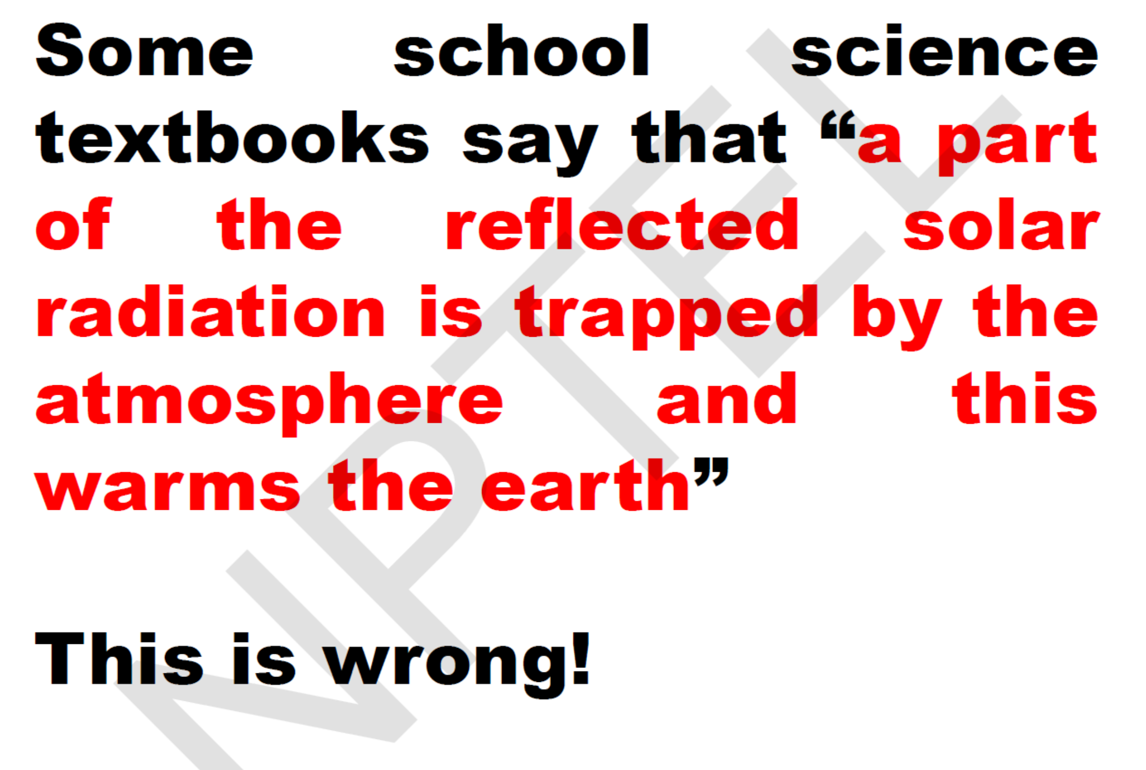


Figure 3-2. Sun illumination spectral irradiance at the Earth's surface. (From Chahine, et al. 1983.)

Now, this is the same curve shown in a slightly different way and here it is showing all these black regions that are the absorption bands of various gases, water vapour, oxygen, a lot of water vapour bands, some CO2. The main message I want you to get from this picture is that most of the absorption of Sun's radiation occurs through water vapour.

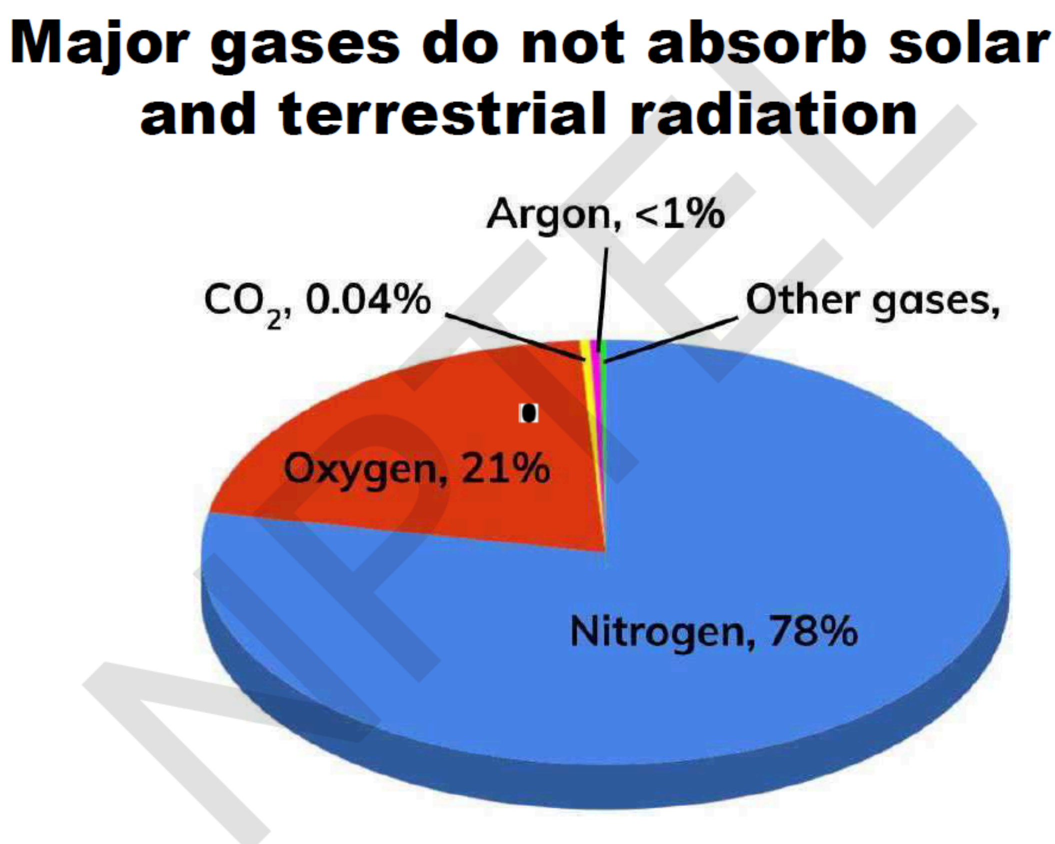
Carbon dioxide has a band around 2 micron, but it is a very weak absorption band. Most of the absorption is by water vapour and so it plays a role in the visible as well as in the near infrared. Now, if you look outside the Earth's atmosphere, it is this line and that dotted line is a black body curve which is fitted to that incoming radiation. We can estimate what is the radiation coming outside the Earth's atmosphere either from calculation which I will show or by actual measurement. Today, there are satellites that are there outside the Earth's atmosphere continuously measuring the radiation emitted by the Sun.

They measure it very accurately, integrate over all the wavelengths and what they measure is called the solar constant. It is not exactly constant, but it remains reasonably non varying. Now, that constant value that the satellite measures can also be calculated knowing the Sun's temperature and radius of the Sun and the distance between Sun and Earth. We will do that next. By the way, before I go further, I must point out that about 10 years ago, I saw a school textbook. Many of you may have used the textbook. It said that a part of the reflected radiation of the Sun is trapped by the atmosphere, it warms the Earth. This is wrong.



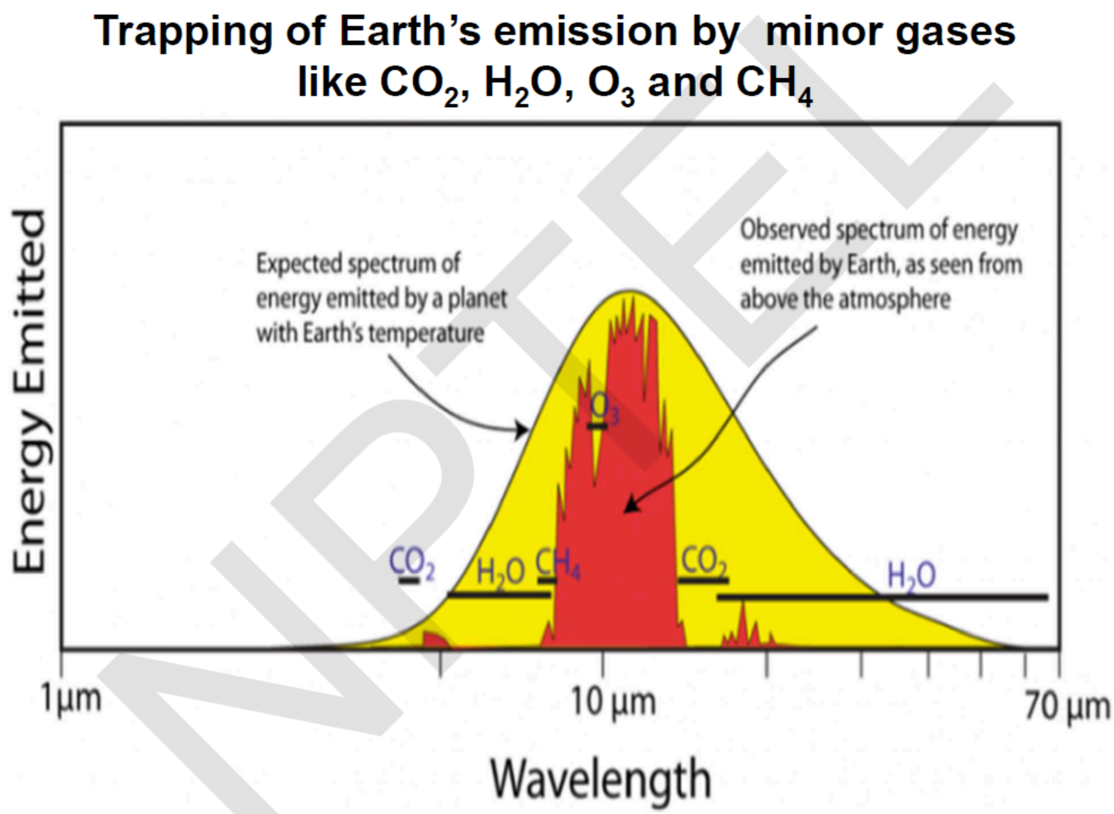
Earth is warm because radiation emitted in the region beyond 4 micron is absorbed by the atmosphere. The amount of radiation absorbed in the solar region is quite small, that does not warm the Earth as much as what happens in the region beyond 4 micron. Now, the reason why I am saying this is because, you go to do a Google search, and there are many websites in which they say that the greenhouse effect occurs because carbon dioxide absorbs the Sun's radiation. **Carbon dioxide does not absorb the Sun's radiation, it mainly absorbs the radiation emitted by the Earth.**

The greenhouse effect is the effect which we observe because carbon dioxide and water vapor absorb Earth's radiation that is beyond 4 micron almost completely. So, if somebody says the greenhouse effect is because CO_2 traps the radiation reflected by the Sun's radiation, they are wrong. So, please make sure that you know that some textbooks have made this mistake. They have corrected it now, but there are old textbooks which still have this idea of the greenhouse effect. Now, the most important point about the Earth's atmosphere is that all of you know that nitrogen, oxygen and argon occupy 99.9 percent of the atmosphere. So, 99.9% of the atmosphere is composed of N_2, O_2 and argon and these three gases do not absorb either the Sun's radiation or the Earth's radiation. They are totally transparent. So, they hardly play any role in the Earth's radiation budget.



They play a minor role that I will mention later in the course. But, for all practical purposes these three gases do not play a role and that is why minor gases like carbon dioxide and water vapour play a very dominant role because the major gases are doing nothing. The major gases allow Earth's radiation to go through, allow the Sun's radiation to go through. So, they do not have a big impact on Earth's surface temperature. But these minor gases, carbon dioxide, water vapor, ozone and methane are mostly transparent to the Sun's radiation between 0.4 and 4 micron. They are totally opaque to radiation emitted by Earth. So, they have a huge impact on Earth's surface temperature. So, this is a thing you must understand, suppose carbon dioxide, methane, water vapor and ozone were not there in the atmosphere. They are minor gases. Let us say they do not exist. Then the Earth's temperature will be 255 degrees Kelvin. I will show that in the next few slides. That means it will be minus 33 degree centigrade. That means Earth will be completely ice covered.

But it has not been ice covered in the last couple of hundred million years. So, we know that something is happening. Some minor gases like CO_2, methane, water vapor and ozone are playing a very important role in increasing the Earth's temperature from 255º Kelvin to 288º Kelvin. 33º centigrade warming is occurring not due to nitrogen, oxygen or argon, but by minor gases. This is the most important feature of the Earth's atmosphere, which makes it very unusual.



So, this must be well understood because Earth's mean temperature is controlled by these minor gases. That is why we have to make sure that we do not allow the amount of CO_2 to go on increasing because if it did, Earth's temperature would go on increasing more and more rapidly. Now, to show that more clearly, in the above diagram, I have shown here what would be the Earth's emission if the atmosphere was not there and the actual emission measured by satellite is in the red. So, you can see that only in a few wavelength ranges around 10 microns where neither CO_2 nor water vapor absorb much of Earth's radiation, it escapes to space. Rest of the radiation is trapped by CO_2, methane, ozone and water vapor and does not go to space. So, this important feature of the minor gases is what controls Earth's temperature.

Now, let us make an estimate of how much radiation is coming from the Sun. Let us assume Sun is a black body at temperature T_s, 's' subscript refers to Sun's temperature here. So, if it is a black body, it will emit radiation equivalent to this area of the Sun: $4\pi R_s^2 \sigma T_s^4$. That is the radiation emitted by the Sun and this radiation will move through the atmosphere, move through the space which has no atmosphere and reach a point just outside the Earth's atmosphere without change; except that because the surface area of the sphere through which it is going is increasing as the radiation goes out, the density of the radiation goes down as $1/r^2$, that all of you have studied in your high school physics.

How much radiation is coming from the Sun?
Assume sun is a blackbody at T_s
Energy emitted by sun in all directions is
$4\pi R_s^2 \sigma T_s^4$ and the density of this radiation reduces as at arrives near the earth's surface which is at a distance of L_{SE} from the sun. Hence the energy density just outside the earth's atmosphere will be

$$S = \{4\pi R_s^2 \sigma T_s^4\}/\{4\pi L_{SE}^2\} = \sigma T_s^4 \{R_s/L_{SE}\}^2$$

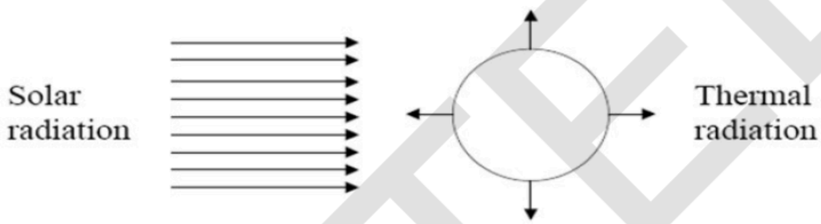
If we assume $T_s = 5765$ K, $R_s = 0.7$ million km
and the sun-earth distance is 150 million km
We obtain the value of $S = 1364\ W/m^2$
This is close to the value of sun's radiation (perpendicular to the rays) measured by satellites orbiting the earth

So, the radiation reaching just outside the Earth's atmosphere is radiation leaving the Sun divided by the radius of the sphere, whose radius is the distance between Sun and Earth. L_{SE} is the distance from the Sun's center to a point just outside the Earth's atmosphere. If you do that, you get what is the amount of radiation occurring per unit area normal to the rays that is $\frac{\sigma T_s^4}{\left(\frac{R_s}{L_{SE}}\right)^2}$; if you assume the Sun's temperature to be around 5765 Kelvin and the radius of the Sun is to be 0.7 million kilometers and the distance to be around 150 million kilometers, all of you know these numbers.

You will get a value very close to the observed value of 1364 watts per meter square. This quantity is called the solar constant. It is measured accurately by satellites which are circling the Earth just outside the atmosphere. So, this is the radiation arriving just outside the Earth's atmosphere and it is not very much. It has a small variation due to the solar cycle which we will talk about.

But most of the time it is fairly constant. This is called the solar constant. That is the mean amount of radiation arriving per square meter of Earth's atmosphere averaged over the whole year. So, this is the solar constant which comes here. If we neglect the Earth's atmosphere right now, temporarily, then the Earth will emit radiation in all 4π direction, where r is the radius of the Earth, $4\pi R^2 \sigma T_g^4$ is the Earth's temperature to the power of 4.

Overall energy balance of the Earth



If there is no atmosphere,

$S\pi R^2 [1 - \rho] = 4\pi R^2 \sigma T_g^4$

S= Incoming solar Radiation =1364 W/m^2

R= Radius of the Earth

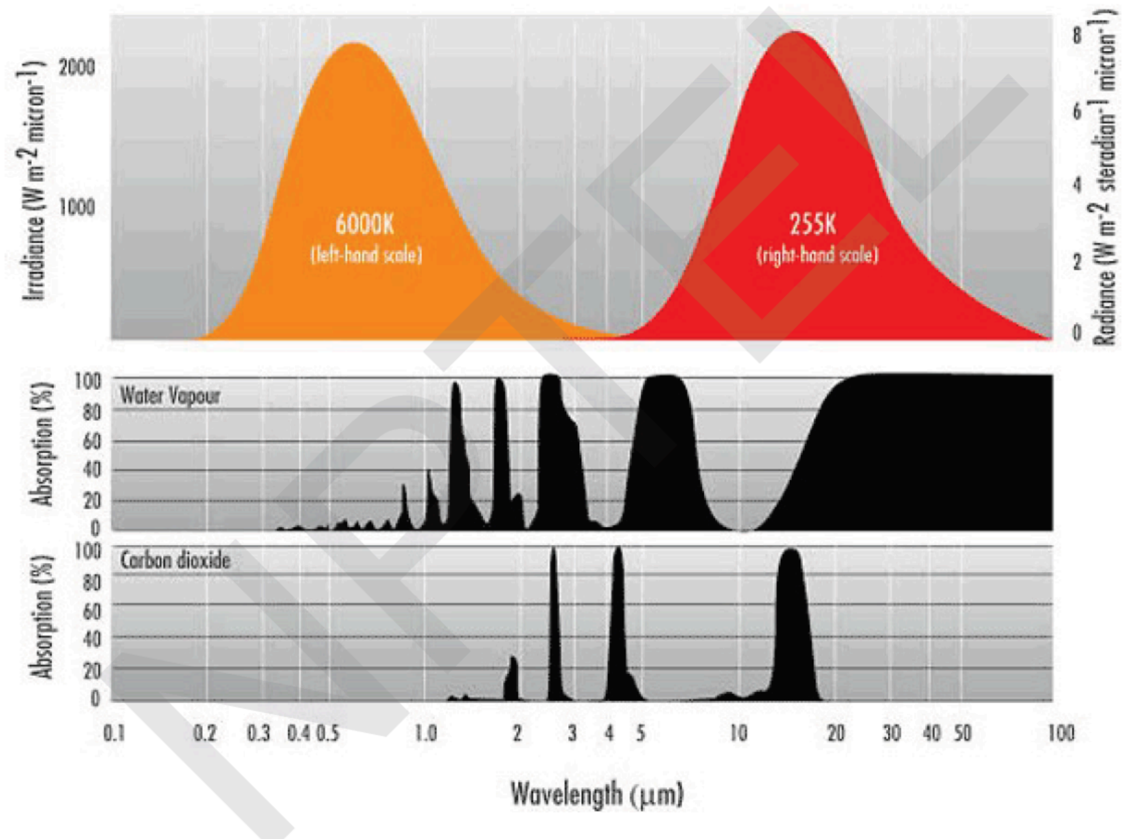
ρ = solar radiation reflected to space(called albedo)

If albedo is 0.3 T_g = 255 K (without atmosphere)

So, the radiation arising from the Sun minus what is reflected which is called the albedo by astronomers. So, $S\pi R^2(1 - \rho)$ is what is absorbed; whatever is not reflected is absorbed by the Earth atmosphere system. So, this balance between energy absorbed from the Sun and the energy emitted by the Earth without atmosphere; this balance for the value of albedo 0.3 which is measured by satellite will give you 255 Kelvin. The temperature I mentioned would have been the Earth's temperature if there was no atmosphere.

So, if there is no atmosphere on Earth, Earth would have been very very cold. 255 Kelvin is much lower than the freezing point of water. So, under those conditions Earth will be completely ice covered and nothing can live on Earth. This is what is sometimes called snowball Earth. So, that can occur only if the Earth's atmosphere is almost not there.

But we know that the Earth's surface temperature is close to 288 Kelvin. So, we must presume that the Earth's atmosphere absorbs radiation emitted by the Earth and alter this balance. Our aim is to understand this new balance. So, before I go further, I want to compare the black body emission by the Sun and by the Earth at this temperature which we just calculated. In the diagram below, you see that both water vapor and carbon dioxide are shown as absorption bands as a function of wavelength.



What you notice is that where the Sun emits radiation, there is hardly any absorption by carbon dioxide, little bit by water vapor. But where radiation from the Earth is coming in, there is a lot of absorption by water vapor especially and also by carbon dioxide. This is what alters Earth's energy budget, the radiation absorbed by carbon dioxide, water vapor, methane and ozone. So, to understand this part, we must understand the radiative properties of the atmosphere and Earth's surface. So, Earth's surface does not absorb all radiation that is coming on it. So, it is not a black body like the Sun.

The properties of surfaces which are not black bodies are defined by a quantity called emissivity and absorptivity. Absorptivity talks about how much radiation is absorbed by that surface and emissivity talks about how much is emitted at a given temperature compared to a black body. So, the hemispherical spectral emissivity of any surface is defined as the ratio of the actual radiation emitted by the surface averaged at a given wavelength compared to a black body at the same temperature. So, spectral absorptivity is the ratio of energy emitted by the surface to the black body and hemispherical spectral absorptivity is the ratio of energy incident to energy absorbed. There are two quantities: emissivity and absorptivity. They are not the same and we will talk about how they differ.

Radiative properties of real surfaces

Earth's surface does not absorb all the radiation incident on it and hence it is not a blackbody. The properties of non-blackbodies are defined by their emissivity and absorptivity

The hemispherical spectral emissivity is defined as the ratio of actual radiation emitted by the surface to that of a blackbody at the same temperature. The hemispherical spectral absorptivity is defined as ratio of energy absorbed to energy incident.

So, the definition of spectral emissivity is actual emission to emission by black body at the same temperature. Absorptivity is radiation absorbed by a surface at a given wavelength to that incident at that wavelength. This is hemispherical spectral absorptivity. According to Kirchhoff's law, these two will be equal if the surface emission, absorption and reflection are independent of angle. Such surfaces are called diffuse surfaces. In this course, we will assume that all surfaces are diffused surfaces as I pointed out earlier which is strictly not correct. But, in the first course to make life easy for us, we will assume that. In advanced courses they will not make the assumption, life will get more complicated. But if we assume that the surface absorbs equally in all directions then we do not worry about angle and so it makes our analysis simpler. If you do that then hemispherical spectral absorptivity is equal to hemispherical spectral emissivity.

This is a very important law and we will be using this very often because we need to measure only one quantity either absorptivity or emissivity, then we know the other quantity. Now, you must remember that we are only saying at a given wavelength these two are equal. As you vary wavelength, absorptivity and emissivity will vary in different ways. So, we have to look at how they vary. So, when you integrate over a wavelength you have to know what is the kind of radiation coming in and at what temperature the surface emits radiation, they are not the same.

For example, the Sun's radiation is coming between 0.4 and 4 micron, but Earth's radiation is emitted between 4 micron and 100 micron. So, Earth's emissivity averaged over all wavelengths will not be the same as Earth's absorptivity over all wavelengths, because the wavelength at which radiation is coming in is not the same as radiation emitted over the surface. So, this equation is okay at a given wavelength, but when you later on average the wavelength, we need to be very careful. Now, this idea that a surface is a diffuse emitter or a reflector is based on the assumption that radiation emitted by that surface is equal in all directions.

That is strictly not right. Surfaces do show emission which depends on angle, but that change due to varying angle causes a small error in the calculation of the hemispherical quantity, but it is not a large error. So, we will not worry about it in this course, although in advanced courses they will talk more about it. Now from the spectral quantity, we have to go to total quantity, average over all wavelengths because ultimately, we want to do energy balance. Energy balance is the balance between energy absorbed and energy emitted by the Earth's surface atmosphere system, averaged over all wavelengths. So, we have to do integration over wavelengths.

Hemispherical spectral emissivity

$$\varepsilon_\lambda = \frac{e_\lambda(T)}{e_{\lambda b}(T)}$$

Hemispherical spectral absorptivity $= \frac{\text{Radiation absorbed}}{\text{Radiation incident}}$

$$\alpha_\lambda = \frac{dQ_{\lambda a}}{dQ_{\lambda i}}$$

According to Kirchhoff's law

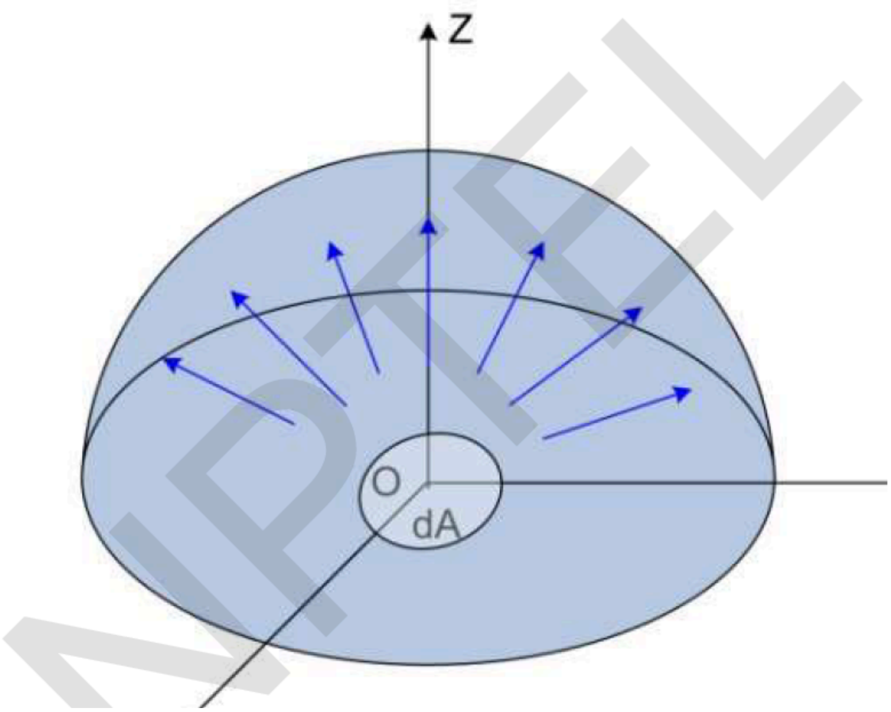
$$\varepsilon_\lambda = \alpha_\lambda$$

for surfaces whose emission and reflection are independent of angle . Such surfaces are called diffuse surfaces

First we want to define a total quantity. Total emissivity of a surface is what the surface emits at all wavelengths divided by what the black body emits at the same temperature at all wavelengths. This is the definition and from Stefan and Boltzmann's law, we know what is e of b and we obtain e by integrating the emissivity of the surface with the black body emissive power and we divide by σT_s^4. So, epsilon will not be equal to 1 because epsilon lambda is not equal to 1. It is less than 1 normally.

Same way we come to absorptivity. Absorptivity is to be integrated in terms of incoming radiation. Absorptivity is all about how much of the incoming radiation is being absorbed. It is different from radiation emitted by a surface. So, we have to look at how much radiation is coming in. If it is the Sun's radiation, we have to take the Sun's intensity, multiply by what is absorbed at that wavelength, integrate over all wavelengths, divide by radiation coming at all wavelengths from the incoming radiation.

Suppose the incident radiation is proportional to a black body at temperature Ti, we are lucky. So, we can replace this by the blackbody intensity multiplied by pi so that we get emissive power. Then we can define total absorptivity as we replace alpha lambda with epsilon lambda.



$$\varepsilon = \{\int \varepsilon_\lambda \, e_{\lambda b}(T_s) d\lambda\} / \{\sigma \, T_s^4\}$$

$$\alpha = \{\int \varepsilon_\lambda \, e_{\lambda b}(T_i) d\lambda\} / \{\sigma \, T_i^4\}$$

We have used Kirchoff's law $\varepsilon_\lambda = \alpha_\lambda$ **for diffuse surfaces**

Note that the difference between the two equations is in the manner in which total emissivity or absorptivity is calculated.

In the case of total emissivity we weight it with blackbody emission at the surface temperature but for total absorptivity we weight with the blackbody emission of the source which is at temperature T_i .

To calculate the absorption of solar radiation by the earth's atmosphere we will set T_i is equal to T_{sun} .

If we want to calculate the absorption by the atmosphere of radiation emitted by earth's surface, then we need to set T_i equal to T_{earth} .

Here we can apply Kirchhoff's law. But we have to multiply by the hemispherical spectral absorptivity of a black body at the temperature of that black body, in our case the Sun. So, to obtain absorptivity of the Earth atmosphere system, we must multiply epsilon lambda not by the surface temperature of the Earth, but temperature of the Sun because that is the incoming radiation. So, I want you to understand the big difference between total emissivity and total absorptivity, although we assume that spectral emissivity and spectral absorptivity are the same. That is ok at a given wavelength, but if you are integrating over all wavelengths and the surface emission is very different in wavelength compared to incoming radiation, you have got to be very careful. You have to make sure that absorptivity is calculated based on the incoming radiation while the emissivity is calculated based on surface temperature. This is a huge difference which you must keep in mind that although epsilon lambda is equal to alpha lambda, epsilon is not equal to alpha on Earth because the Earth's emission is in the wavelength range from 4 micron to 100 micron, while the Sun's emission is from 0.4 micron. Two are totally exclusively separated.

Because of that, the answers you get are very different. I want you to make sure that you understand this difference very clearly. So, I repeated that again so that you understand that. In the case of calculating total emissivity, we weight the spectral emissivity by the black body emission at surface temperature. But for total absorptivity, we weight it with the black body emission of the source, in our case the Sun which is at a temperature Ti which is the same as Tsun. So, this is the big difference between calculation of total absorptivity and total emissivity.

Since the earth's atmosphere is more transparent to solar radiation (that occurs between 0.4 to 4 microns) than to the radiation emitted by the earth's surface (that occurs between 4 micron and 77 microns), α_{sol} is around 0.2 while the absorptivity of earth's atmosphere to the emission from the earth's surface is around 0.95

Since the temperature of atmosphere is close to that of the earth's surface $\alpha_{atm} \approx \varepsilon_{atm} = 0.95$

Note,however, that $\alpha_{sol} = 0.2 \neq \varepsilon_{atm}$

Kirchoff's law is not valid here because Tsol >> Tatm

I want you to make sure that you understand this distinction because this is what confuses most students when they encounter this subject. They do not understand where alpha and epsilon are different, although alpha lambda and epsilon lambda are the same for any surface. This is because Earth's atmosphere is more transparent to solar radiation that occurs between 0.4 and 4 microns than to radiation emitted by the Earth's surface that occurs between 4 microns and 77 microns. Because the Earth is transparent in the visible, absorptivity of solar radiation is around 0.2. While the same atmosphere when it absorbs the emission by the Earth's surface, its emissivity is around 0.95. They are nowhere near each other. One is 0.2, one is 0.95. I want you to see the difference, the huge difference. Now, since the temperature of the atmosphere, which is lower than the surface temperature, is not very much lower. So, if you look at the Earth's atmosphere, its emissivity is close to that of its absorptivity, which is around 0.95. That is because the temperature of the atmosphere is close to surface temperature, not equal to but close to.

Now, this difference is very very different and you have to understand that we are in a position to set the atmospheric absorptivity of Earth's radiation to be the same as the emissivity of the atmosphere equal to 0.95 but atmosphere absorbing the solar radiation is much smaller than emissivity of the atmosphere. This is because the Sun's radiation, which is around 5700 Kelvin, is much much greater than the temperature of the atmosphere. I want you to clearly understand that because the Sun's radiation is so much higher than the temperature of the atmosphere or Earth's surface temperature, we cannot equate alpha and epsilon. But, we can equate alpha and epsilon for the infrared emission with the atmosphere and infrared absorption with the Earth's atmosphere because the atmospheric temperature is closer to Earth's surface temperature. It is an approximation, not exact, but it is quite good.

To make the point further clear, because it is a very important part of the course, I define the absorptivity of the Earth's atmosphere to the surface temperature of the Earth, emissivity of the atmosphere to atmospheric temperature, just how emissivity is defined, and the absorptivity of the atmosphere to solar radiation, which is weighted by Sun's spectra. So, although this is equal, we find that these two are equal because these two are close.

$$\alpha_a = \left\{ \int \varepsilon_\lambda \, e_{\lambda b}(T_s) \, d\lambda \right\} / \sigma T_s^4$$

$$\epsilon_a = \left\{ \int \varepsilon_\lambda e_{\lambda b}(T_a) \, d\lambda \right\} / \sigma T_a^4$$

$$\alpha_{sol} = \left\{ \int \varepsilon_\lambda \, e_{\lambda b}(T_{sol}) \, d\lambda \right\} / \sigma T_{sol}^4$$

Assuming atmosphere is a diffuse emitter.

$$\boldsymbol{\varepsilon_\lambda = \alpha_\lambda}$$

T_a is around 252 K , T_s is 288 K, and T_{sol} is 5780 K
Hence,

$$\epsilon_a \approx \alpha_a \quad \textbf{but} \quad \epsilon_a \neq \alpha_{sol}$$

One value is 288 K and the other is 285 K. And T_{sol} is 5780 K. So, again I want to repeat this. We are in a position to assume atmospheric emissivity and absorptivity are close to each other, but atmospheric emissivity and absorptivity is not equal to the absorptivity of the atmosphere to solar radiation. So, this point must be clearly understood.

I will stop the lecture at this point. We will continue in the next class on this topic. This topic is very critical to understand Earth's global mean temperature.