Remote Sensing: Principles and Applications
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Lecture – 07
Radiometry – Part 1

Hello everyone, welcome to today's lecture on the topic of Radiometry. So, what exactly radiometry is.

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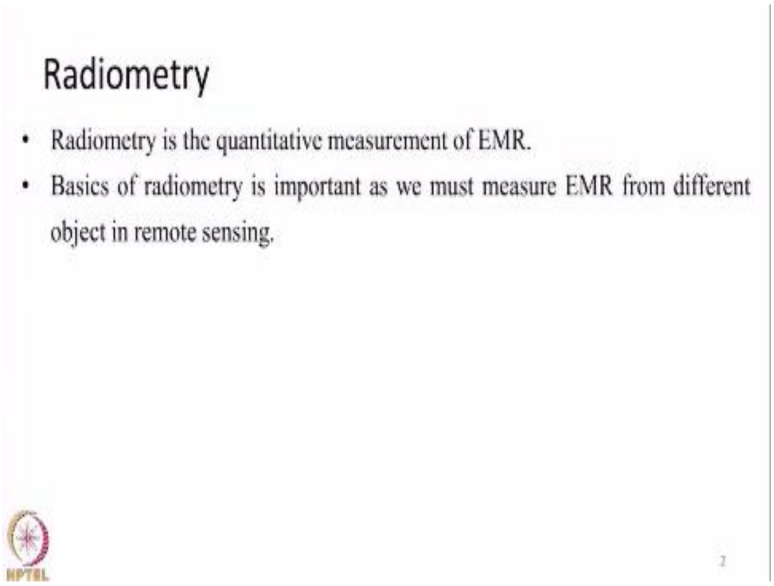

Radiometry is defined as the quantitative measurement of electromagnetic radiation. In remote sensing, we will be interested in measuring the amount of energy coming in towards an object or going from an object. So, we will be measuring from satellites, what is the amount of energy that is being reflected or emitted by any object.

So, for us to quantify the amount of energy coming out of an object, we need to know the various principles and the various terms associated with radiometry. So, radiometry essentially is a quantitative measurement of EMR in various wavelengths.

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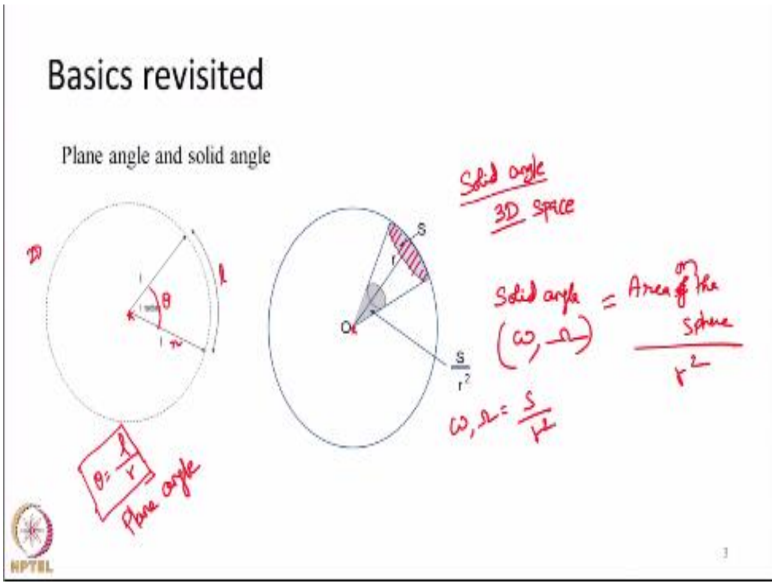

Before going into the concepts of radiometry, we will first revisit some basics that we learnt in high school mathematics. One of the major important concepts to know is solid angle. So, we know what a plane angle is. A plane angle is obviously defined in 2 dimensions that is why we call it a plane angle is defined as the ratio of the length of the arc '*l*' to the radius of the circle that the arc subtends at the centre.

So, if you have a circle and if you want to measure any angle like this, let us label it as θ. So, this particular angle θ from the centre point, it will be subtending one particular angle and the arc length that it subtends will have certain length. So, the length divided by the radius of the circle will give us the 2 dimensional angle or the plane angle.

Extension of plane angle into 3 dimensions is what we call the solid angle. In solid angle, we are going to do our angular measurements in the 3 dimensional space that instead of a circle around the point, we are going to construct a sphere around the point. So, this particular sphere is going to again have a radius r. So, what we are going to calculate is, if we take any surface area S on the surface of the sphere, what is the solid angle subtended by this surface area at the centre of the sphere.

So, you just take analogy with the plane angle. In plane angle, we are calculating the angle subtended by the length of this arc at the centre for a circle with radius r. Similarly, in 3 dimensions space, we are going to consider the solid angle subtended by the area like a small surface area on the surface of the sphere at the centre of the sphere.

Solid angle is denoted by ω (omega). Two symbols will be used basically, different textbooks will use different symbols and it is defined as the area on the sphere divided by the square of the radius. So, as per the definition,

$$\text{solid angle, } \omega = \frac{S}{r^2}$$

So, essentially a solid angle is a 3 dimensional extension of plane angle. In plane angle, we will be talking about circles and arcs. In solid angle, we will be talking about a sphere and the surface area of the small element that is there on the sphere which is subtending a given solid angle.

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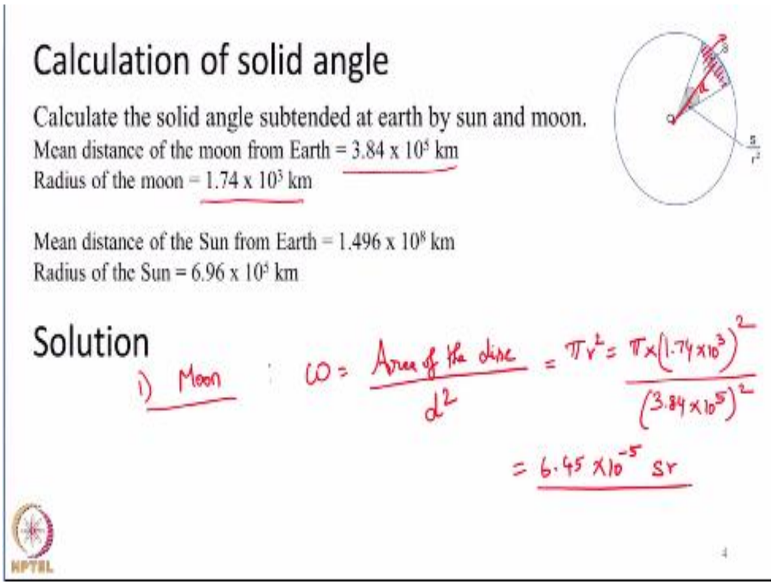

In order to make it more clearer, now, let us take 2 live examples. Normally, what we will do during daytime or evening time, we will stand outside and try to observe the sun or the moon with our eyes. So, when we see them, they will appear like a disc to our eyes. And that particular disc will actually subtend a solid angle in our eyes. So, when we see them, we perceive all objects in 3 dimensions.

So, that particular sphere be it like sun or moon, it will subtend a solid angle when we look up at them. So, what are we going to calculate now is, we are going to calculate what is the solid angle subtended by sun or moon on our eyes when we stand on surface of earth and we observe them. Okay. So, now just look at this particular figure, assume we are standing at the point O.

The point O is where the observer is standing and the observer is observing either the sun or the moon. It will appear as a disc to our eyes basically, we will see it like a circle when we look up in the sky. So, what we essentially want to calculate is, when we look up at those celestial objects, what is the solid angle subtended by them in our eyes. In order to know them, we need 2 quantities.

One is the surface area of the disc that is visible to our eyes and the second is distance ‘d’ between that particular celestial object either sun or moon and our point. So, if we know these 2 quantities, we will be able to calculate the solid angle subtended. First, let us start with the moon. Here, the question asked is, calculate the solid angle subtended at earth by sun and the moon. The data given are, the mean distance of moon from earth, radius of the moon, the radius of the sun and the mean distance of the sun from earth.

So, first we will start with moon. So, the solid angle ω is given by the area of the disc divided by square of the distance d. The disc is essentially a circle and we all know that area of a circle is πr^2 and the radius of moon is given as 1.74×10^3 km and the distance between earth and the moon is 3.84×10^5 km. So, this is like average distance if you stand on different points on earth during different times in a year, this distance will change. But this is the average distance all throughout the year we can assume. So, this distance squared.

$$\omega = \frac{area\ of\ disc}{d^2} = \frac{\pi r^2}{d^2}$$

$$\omega = \frac{\pi \times (1.74 \times 10^3)^2}{(3.84 \times 10^5)^2}$$

$$= 6.45 \times 10^{-5} steradian$$

The unit of solid angle is steradian whereas the unit of plane angle is radian. So, you essentially have to upend your answer with the unit of Solid angle as steradian. So, what essentially it means, when we look up into the sky, it subtends a solid angle of around $6.45 \times 10^{-5} steradian$. It is actually like a very small quantity.

Like if you take a point and put a sphere around it, say you are standing if you place a sphere around you, the total solid angle within that particular sphere is 4π steradian. Just compare it with analogy to a circle, if you draw a circle around the point we say the total angle within the circle is 2π radians. Similarly, when we consider a 3 dimensional space, for a solid angle, the total solid angle within a full sphere is 4π steradian.

So, here in this case, if we look at the answer that we got for moon, we can see the angle is very small $6.45 \times 10^{-5} steradian$. So, moon actually subtended extremely small angle in our eyes, when we see them. Now, next we will calculate what is the solid angle subtended by sun.

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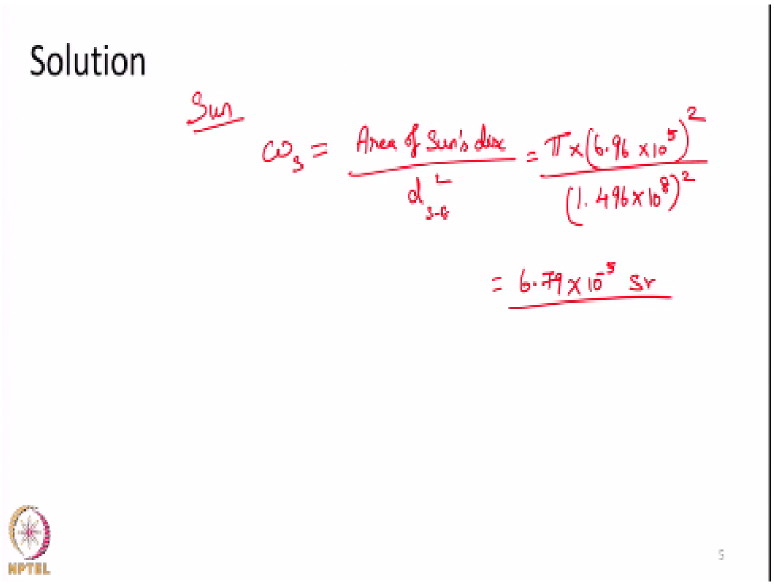

Exactly, the same thing solid angle subtended by sun at earth is equal to area of sun 's disc divided by distance between sun and earth whole square. So, area of sun disc is again, we will see it as a circle when we look up at it and the distance given is 6.96×10^5 kilometres whole square divided by the distance between sun and earth as given is 1.496×10^8 kilometres. So, we are squaring it.

If we calculate it, we will get 6.79×10^{-5} steradian. So, if you compare the results or the answers of the solid angle subtended by sun and moon, you can see both of them are quite similar. With moon, the solid angle subtended is little bit smaller, that is, on an average days like when the earth and sun are in its average distance, the sun will appear bigger to our eyes because it is subtending like a biggest, largest solid angle.

It will appear bigger to our eyes. Just imagine one scenario, we heard about total solar eclipses. Total solar eclipse are the days in which the moon will completely obscure the sun. We have seen such days in news channels, they will telecast how it is happening, I think in the year 2018 or 2019 it happened over US that many people witnessed it. It is like a important celestial event.

So, what will happen when we look up at it. We will not see an object when something before it completely hides it essentially that is the idea. So, we all know what solar eclipse is. Solar eclipse is, sun is behind; moon is in front; the moon completely obstruct the sun that is what solar eclipses. You will look at the solid angle values given here. The moon solid angle is 6.45×10^{-5} steradian. Sun solid angle is 6.79×10^{-5} steradian.

So, sun naturally should appear larger to our eyes when we look at it. So, sun is larger; moon is smaller but total solar eclipses can also occur. Can you please think of a reason why? Please pause the video for a second and think and then you can play the video for the answer. The answer for the question is the distance that we have used here is the mean distance between earth and the sun.

So, the distance between sun and earth and moon and earth will be keep on varying based on where those objects are; where the earth, sun and moon are with respect to their individual orbits. Each of them have their own orbits. Sometimes, earth goes closer to the sun in its orbit. Sometimes, moon comes closer to the earth. So, this distance that we have used is not constant. It will vary with seasons or different days.

During total solar eclipses, the moon comes very closer to us. So, the d squared term in the denominator will go down and the solid angle will increase. So, that is because as the distance changes that radius of the moon is going to remain the same. The moon disc or the solar disc area is going to remain the same that is not going to change. But as the distance changes with different days, moon will appear bigger to our eyes on certain days like full moon, Super moon, etc,.

So, those days, moon will come closer to us. Moon will appear much bigger actually. So, on those days what will happen? Moon will subtend a larger solid angle than sun that is why moon is able to obscure sun during total solar eclipses. So, solid angle is essentially how much area an object covers in our vision when we look at. Simply put, so, larger the solid angle, larger the area an object will cover in our vision when we see.

If it is very small, it will subtend a very small solid angle. So, as the object is growing bigger and bigger or as the object comes nearer to us, it will appear larger to our eyes naturally and hence it will subtend a larger solid angle that is the concept, how much area an object covers in our vision. That is all. Now, we have seen the basics about plane angle and solid angle have solved the problem also.

Now, we are going to get into the radiometric terms and it is definitions. So, what are these radiometric terms or radiation quantities?

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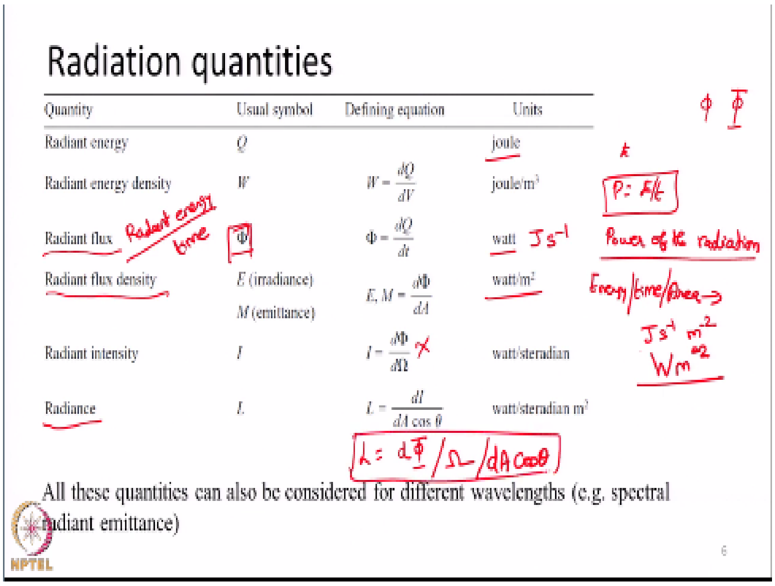

In the earlier lectures, I was repeatedly mentioning energy radiation, radiant flux, radiant flux density, all these terms. Those terms may appear similar when we hear them for the first time, but the way in which they are defined, the way in which they are measured actually is very different. So, in this particular lecture, we are going to talk in detail about the different quantification of this energy measurement.

The first and basic quantity in energy measurement is energy itself. So, what energy is. Energy is the ability to do some work, say I am going to push some heavy object and move it. That means I am spending some energy some to move the **(14:50)** body. I am transferring it through my hands to the object and I am moving it. So, energy is the capacity to do work.

Similarly, radiation also what is coming from the sun or what is emitted by earth. The radiation also has energy. So, the basic term is energy. The unit of energy, we all know joule. So, that is the basic quantity. Say, whatever be the object, whatever be the timeframe what is the total energy contained within it, we can define or calculate using some extent.

Now, let us say rather than energy, we need to know what is the amount of energy coming in per unit time that is, say I have lit up a stove. I am keeping a pot of water filled over it. So, what I want to calculate? What is the amount of heat energy being transferred from the stove to the pot of water, I kept on top of it? If I switch on the gas stove, leave it for so much time and measure everything together, I would have calculated the total energy content. Okay.

The heat energy supplied is this much. On the other hand, if I want to calculate the energy per unit time, so, what I should do? I should measure the total energy transfer from the stove to the pot of water. Somehow I should measure it. Simultaneously, I should measure the time taken for this heat transfer say, the water was cool and then I stopped the process when it started boiling say, took some 10 minutes let us assume.

So, what is the total amount of energy transfer? I should calculate it and divide it by 10 minutes in order for me to calculate what is the amount of energy transferred per unit time. That is every second what is the amount of unit transfer energy transfer and that particular term that is energy per unit time, we call it as radiant flux. So, what is the amount of radiant energy per unit time.

If you look at this with respect to energy and power, power is equal to energy by time, these are all definitions, you have learnt in school physics. So, essentially radiant flux is nothing but the power of the radiation. That is what is the amount of energy per unit time. So, for energy, the unit is joule; for power that is radiant flux, the unit is joule per second or watt on the other hand.

So, joule per second is defined as one watt, that is what is the amount of energy spent per unit time. So, the symbol to denote is a capital letter ϕ. Okay. This is the conventional symbol used to indicate radiant flux. Now, what have we done? We have calculated the amount per unit time.

Now, my interest is, let us go back to the example of stove and water pot. In addition to calculating the energy per unit time, I also want to calculate what is the amount of energy per unit time per unit area of pot. That is let us assume the pot is quite big say it has a radius of around 2 metres, very big pot. It will cover like a huge area. Per unit area of the surface of the pot, what is the energy I spent per unit time? How it will be calculated? I will first measure the total energy content I supply; I will measure the total time taken for it then I will also measure the area of the bottom of the vessel.

Then I will divide the total energy by time and also by area. So, here I will be getting the energy I spent per unit time per unit area. This quantity, we call radiant flux density that is what is the amount of energy per unit time per unit area. So, the units for this is joule/second/metre^2 or watt/metre^2. So, conventionally we will write it as watt/metre^2.

In remote sensing, we will be interested, normally in remote sensing of earth's surfaces. We will be having a lot of objects on the earth's surface and that object will receive energy from the sun. Similarly, that particular object will emit energy on its own or deflect energy from the sun.

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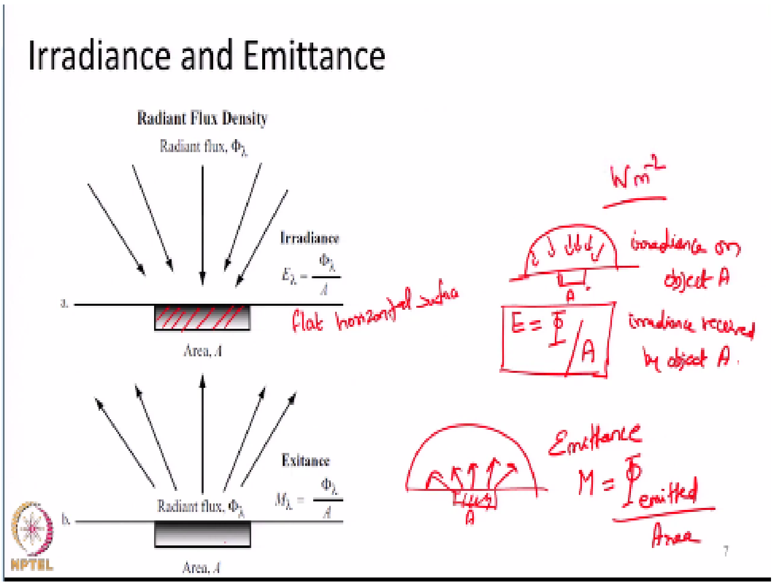

So, for remote sensing purposes in this radiometric term, the exact definition of radiant flux density is something like this. Let us say, we have a small area here on a flat horizontal surface. The area is A. So, I am going to construct an hemisphere surrounding it. So if I stand here, I will be able to see only hemisphere around me. So, what is the energy falling on it, falling on this particular object from within the entire hemisphere. So, I will say, I am going to use a symbol of E. E is equal to the energy coming in. So, this energy I am going to represent it as radiant flux energy. I am going to divided by the area A.

So, the definition of radiant flux density is, if we have a small elemental area on a flat horizontal surface and constructed hemisphere surrounding it, whatever the energy falling on that particular area, from the entire hemisphere per unit time, we call it as radiant flux density. So, radiant flux density means, amount of energy per unit time per unit area and the units we use it for this is watt/metre^2.

Now, there are 2 terms involved. One is irradiance and another term is emittance. What is the difference between irradiance and emittance? Definition wise, they are the same, but the direction in which they are moving will define whether it is irradiance or emittance.

If the object A is receiving energy from space or receiving energy from some other source, we call it as irradiance on object A or other hand we will also write it as irradiance received by object A. On the contrary, if A is an object that is emitting energy, now, again a flat horizontal surface and object A is there with a different area. I am arranging to construct the hemisphere around it. Now, this object is emitting energy into this hemisphere surrounding it.

So, I am measuring the energy emitted by it in the entire hemisphere, I am calculating the time taken for it. I have known the surface area of this. This is what I call as emittance. What is the energy emitted? So, the symbol we use is M. M is defined by again the ϕ but now, this is emitted divided by the surface area of the object. So, whether any surface is receiving energy or whether a surface is emitting energy, we call it as irradiance or emittance.

But technically, both of these irradiance, emittance, we should call as radiant flux density that is the correct technical term but, based on the direction whether it is coming towards an object or whether going out of an object, we will classify it as irradiance or emittance. So, here please note, we have considered a flat horizontal surface and the energy we have taken is the entire hemisphere surrounding it.

So, essentially, we are talking about like a 2π solid angle surrounding a given object. Say, if I stand here, the solid angle surrounding me is like, I can put a full hemisphere covering myself. So, the solid angle around me is 2π radians. So, what is the energy falling on me from the other sources within this 2π radians is what is radiant flux density. Now, we go back to the previous slide to look at the next most important term.

The next most important term I want all of you to like pay attention to is what is called radiance. So, what exactly is radiance is, we will move to further slides.

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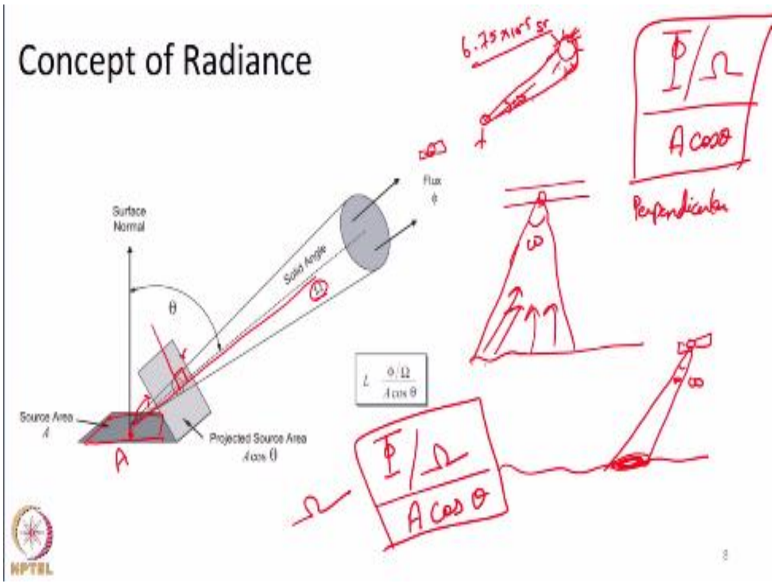

So, this particular slide will tell us what radiance is. Let us go back to our example of the sun and observer problem that we already solved to calculate the solid angle. Okay. Sun is here, an observer is standing here. The observer is looking at the sun, as we already said, the sun is going to subtend solid angle. So, this is solid angle ω .

So, whatever the energy coming in from the sun is actually coming within this particular solid angle because the observer is looking at the sun and the sun subtends a solid angle of this and whatever the energy the observer receives is actually coming within this entire solid angle. Similarly, say if you are flying on an aeroplane, say there is an aeroplane and an observers got a window seat and trying to see whatever is there on the surface.

So, what we will see? We will be able to see something like a cone and whatever solid angle we can see, we will be receiving all the energy coming and our eyes can see it. Same concept is what radiance is towards satellite or in remote sensing parlance. In remote sensing parlance say, a satellite will have a sensor. So, that we will take from the example of a sensor, let us say, sensor is placed here.

It is seeing something on the earth's surface. The sensor is kind of like a small element like our human eyes. So, when we sees the earth's surface based on its sensors orientation and properties, it will have a small solid angle subtended within it. So, whatever the area is covered within the solid angle, it will observe. So, whatever the energy coming in within that particular solid angle, will reach the sensor.

So, essentially the energy within that particular solid angle, what is the energy coming in that particular direction is what we are interested upon. And conceptually, this is what is known as a radiance. So, now, we will go to the exact definition of radiance. Take a small area on a flat horizontal surface. The area of the surface is A. I am placing a sensor here let us assume, there is a observer standing, some energy source is there. So, now, we are looking at an angle of θ from the surface angle. So, now, the direction is like not in like perpendicular to the surface, it is the direction in which we are looking is having an angle of θ with respect to the surface normal. Okay.

So, if this is the case, if I want to calculate what is the amount of energy that is going out from this particular area, in this particular direction of θ at a given solid angle the given solid angle ω or ϕ whatever we can call is what is known as radiance. So, radiance is essentially what is the amount of energy that is amount of radiant flux going on per unit solid angle divided by the projected area of the surface.

So, what is the projected area of the surface means, if I am looking at some other direction, inclined angle of θ, the area will not appear like A but it will be projected, it will have an angle of A cos θ that is the area will appear different. What essentially I am doing is, I am trying to project this area perpendicular to the direction of motion of radiation.

So, I am projecting this particular area in a direction perpendicular to the motion of radiation. And what is now this projected area is, say, we have learned like a projections and how surfaces will change when we look from different perspectives like some engineering students will be there taking this course and you would have learned about like projections how the area will change.

Like, very similar example, if we take a large circular object on the ground, if you are flying in an aeroplane, if you see it from different directions with different viewing angles, the same circle may appear as an ellipse; may appear like a smaller circle; elongated ellipse and so on. Its shape will be keep on changing. So, essentially the area that you are seeing is projected in that particular plane.

Same concept, whatever the area was there on the flat horizontal surface, you are actually projecting it as if in a direction perpendicular to the direction in which you are seeing it. So, radiance is nothing but the radiant flux divided by, what is the total solid angle, divided by the projected area and where the area is projected and in direction perpendicular to the look angle.

So, now, we go back to the slides where I have given the various definitions. Radiance is denoted as symbol l, is given by dϕ, that is radiant flux, that is what this energy per unit time divided by what is the total solid angle within which it is going divided by what is the projected area d A cos θ. This is what is known as radiance.

Just to give one more example, I go back to our earth and the sun problem. The earth and the sun problem whatever the energy coming in from the sun comes within this particular solid angle. Say, we calculated it as roughly 6.75×10^{-5} steradian. So, whatever the energy coming in from the sun is going to come from this particular solid angle only.

And if my vision is perfectly perpendicular to the direction of motion of sun, so, what is going to happen? What is the area of sun that is I am looking at my eyes and what is the energy coming within this particular solid angle is what defined as the radiance. So, radiance is nothing but the energy or the radiation within one particular direction.

Simply put, if I look in this particular direction in a given solid angle, what is the energy going out or coming in. So, it varies based on direction. So, just to summarise what we have learned in this particular lecture, this particular lecture, we have learned about plane angle and solid angle. We have also learned about certain radiometric quantities that is we defined what energy is, then we defined what radiant flux is that is energy per unit time, then we defined what radiant flux density is energy per unit time per unit area.

Then we also defined what radiance is. So, radiance is defined as the radiant flux per unit solid angle per unit projected area. So, radiance is highly directional. Maybe in the next class, we will go a little bit deeper into this concepts and look more into it in order to understand it better. Thank you very much.