Remote Sensing: Principles and Applications
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Lecture – 09
Radiometry – Part 3

Hello everyone, welcome to today's lecture on the course Remote Sensing: Principles and Applications. In this class also, we are going to continue with the topics of radiometry. Over last 2 classes, we have been learning different concepts of radiometry such as plane angle and solid angle; different quantities of radiometry like radiant flux, radiant flux density, radiance and so on. All these terms we have defined.

We have also learned the relationship between radiance and radiance flux density that is E= πL which is applicable only for lambertian surfaces. Then we also saw the inverse square relationship or inverse square reduction property of radiant flux density whereas radiance will remain constant within a given solid angle. So, these are all some of the properties about the radiometric quantities that we have seen.

Today, we are going to continue with what are like different directionality that is involved in remote sensing; what are different terms such as reflectance, Albedo and so on.

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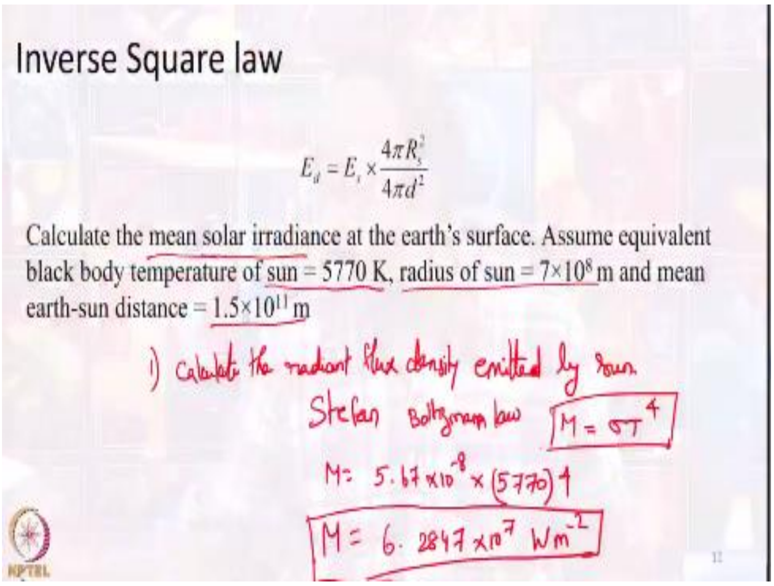

So, this is where we stopped in last class, we have done a problem to demonstrate the inverse square relationship where we used sun as an example, we calculated what is the amount of radiant flux density or exactly what is the radiant flux density that will be reaching the earth's surface from sun.

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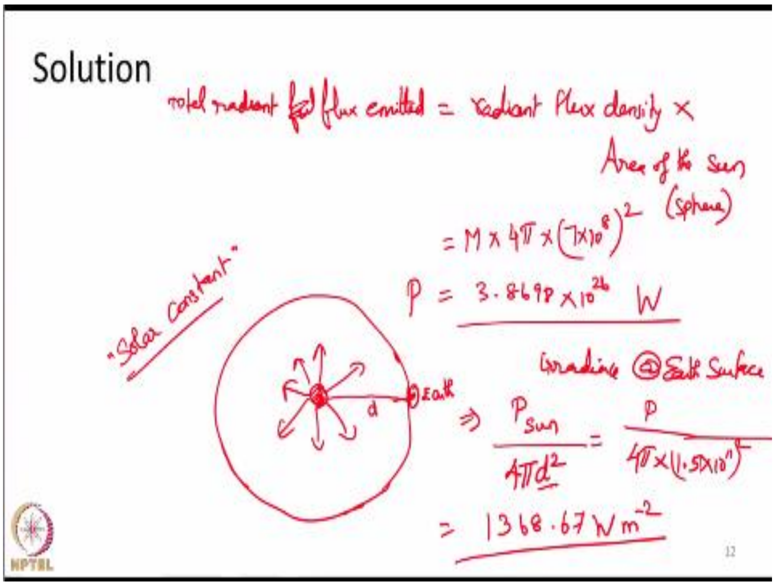

We have calculated a value of like 1368 watt/metre^2. And also said, we call this as the solar constant that is on an average, this will be the radiant flux density from sun that will be reaching the earth's surface. So, this uses the average distance between earth and sun. Please remember it. But as I already mentioned, the distance between sun and earth will vary with respect to like different days in a year. But we have chosen a average distance here.

So, the next important topic that we are going to see is the directionality of remote sensing measurements. Now, we have some basic understanding of how the energy is coming; how the energy is going out. So, how the energy coming in and going out is depend on the direction which we look, is what we are going to see now.

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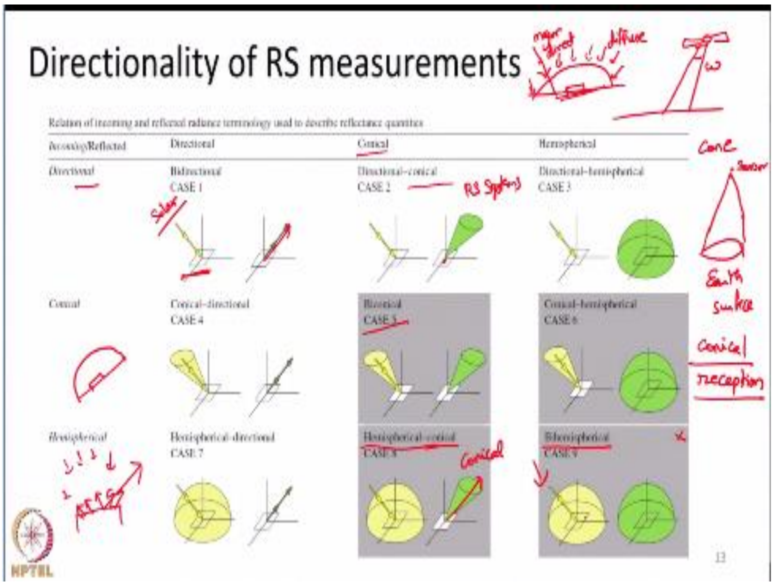

This particular slide, there are like different cases that have been mentioned which describes the directions in which energy will come in and the direction in which energy will go out. For the normal remote sensing purposes, what will happen is, let us assume a sensor in space and a land is here. So, each sensor will subtend a small solid angle on the surface. So, this would be like kind of a cone.

We can imagine a cone with an apex at the sensor and its base at the surface. We can assume it like this. So, this suggest most of the measurements that we do with respect to any remote sensing sensors essentially, will have a form of conical reception. Conical reception in the sense, the sensor will be collecting energy that is coming out from that particular cone that is solid angle as we defined it is kind of like a cone.

So, whatever the energy is there within the cone, it will reach the sensor. So, that is explained in cases here like where the reflected energy is conical. So, this is most likely an example of remote sensing systems. But please remember in these diagrams, the view geometry is slightly changed where the view geometry is returned from the point of land surface.

But in remote sensing, the same concept of conical will be there but from the sensor. On the other hand, if we look at the incoming radiation, we can consider incoming radiation either as a direct single ray of radiation or we can integrate the radiation with an entire hemisphere etc. So, the different examples that I will tell, say, for example, a bright sunny day.

So, for a bright sunny day, we can consider the incoming solar radiation as a single ray of directional radiation that is I already told you, that the solid angle subtended by sun is extremely small. And the distance between earth and sun is like quite large. So, what we can assume is, all the radiation coming in the sun comes from one particular direction as like a single ray of light.

We can consider that because it is like the assumption. It is an assumption, but, it is like a valid assumption that we can do considering the large distance between earth and the sun and also the very small angle subtended by the sun. So, we can consider if at all we are going to measure only the direct radiation from the sun, we can consider that as like the radiation coming in from only one particular direction.

On the other hand, I also told you that the radiation received by the earth's surface is a mixture of direct sunlight and diffuse skylight. what is diffuse skylight means? Diffuse skylight is the energy that is present in the atmosphere due to scattering of the sunlight. So, for any land surface or any feature on the earth's surface will not only receive a direct radiation from the sun. But also diffuse radiation from all directions surrounding it.

So, this is the major component of incoming energy that direct radiation from the sun whereas these things are all diffuse component of energy. So, any particular feature on earth's surface will receive both these. So, sometimes we may have to calculate the total energy that is coming in within the entire hemisphere surrounding the object of interest.

Say, a small object is present here. This particular object is going to receive energy from the entire hemisphere surrounding it whereas one particular component is a direct component from the sun. And it receives diffuse skylight from all of the directions. Similarly, most of the earth's surface features will also have the tendency to reflect back energy in all directions. That is, take example of the same object here, in response to incoming energy, the object will reflect a part of energy, like it will be reflected, scattered etc.

A part of incoming energy will be again transferred into different direction into the sky itself. When this happens, some objects may reflect in one particular direction whereas most objects have the tendency to reflect in many different directions surrounding it.

Hence, if we want to calculate the total amount of energy going out of an object, Then also we may in a need to calculate over the entire hemisphere surrounding the particular object. So, what I want to say is, the incoming energy from sun, the direct radiation can be treated as coming in from one particular direction. So, we call that particular incoming energy as directional but this is only an assumption.

The energy comes in the form of like a cone and that also from a very small solid angle. But still that particular energy from the sun comes in and falls on the surface through a conical means. But we can assume, it is coming from only one particular direction not within like a small cone whereas the energy going out from the earth's surface can be treated whether, it is going in one particular direction.

As if a remote sensing sensor observes like I already said sensors observe in form of a cone or we will also be in a position to measure the energy going out of an object in the entire hemisphere surrounding it. So, now, there are 3 different directional property associated with remote sensing base measurements. One thing, we will be interested in knowing the energy coming in or energy going out in one particular direction. Or we may be interested in energy coming in and going out of within one particular cone having a definite solid angle. Or we may also be interested in measuring either incoming or outgoing energy within the entire hemisphere surrounding the object of interest. So, 3 possible directionality exist in remote sensing. If we combine all of them, we get this 9 different possibilities given in this particular slide. That is what is given as 9 different objects. That is incoming energy treated as coming in from exactly one particular direction. Outgoing energy also treated exactly as going in one particular direction.

Similarly, I go to this case 5. Incoming energy is considered as coming in form of like a cone. Outgoing energy is also considered to be measured within a cone. And then come to case 9. In case 9, what are we doing? We are considering the incoming energy within the entire hemisphere surrounding the object which has a direct component and also like a diffuse component.

Outgoing energy also, we are considering the entire energy going out of an object within the full hemisphere surrounding it. So, here are some examples for these directionality in order to make it more clear. Normally, as I said sun's radiation or if you are using some highly collimated laser beam to illuminate some objects, we can consider them to be directional that is coming in from only one particular direction.

Say, I have a highly collimated source of laser beam. I can use that to illuminate a target which will give me a small point on the target of interest. That we can assume it to be directional, nothing is really directional in the measurements that we do. Because we cannot directly go on to measure a only one ray of light. Whatever we measure, even if you use like a small collimated beam of light, it will have a small circle projected on the object of our interest.

So, nothing is purely directional. We are assuming those incoming radiation as direction measurements. So, what I want to say is some measurements or some radiation sources, we can assume to be directional that is sunlight, bright sunlight under extremely clear sky days or like as I said, highly collimated source of laser light. These kinds of incoming radiation, we can assume it to be highly directional. But, outgoing radiation cannot be directional truly objects sends energy back in different, different directions.

Then we will talk about another example of a conical case. Conical cases, let us say, we are using some sort of a bulb to illuminate an object of our interest. We are in a dark room, we are switching on a bulb. So, essentially a bulb is kind of a small sphere which will radiate energy within a small solid angle in form of a cone basically if you imagine.

So, using a bulb as a radiation source is a very good example of conical case of incoming radiation. Similarly, as we already said, most of the remote sensing measurements with the sensors attached with it, have a conical form of collecting the incoming energy. So, that is we call it as by conical case where the incoming energy is also consistent within a cone. Outgoing energy also is considered whatever is coming within a cone.

So, what is a very good example of hemispherical measurements? As I said, if we consider the incoming energy in both diffuse and direct component, then we are essentially measuring the energy over the entire hemisphere surrounding an object. So, considering all these cases normally in remote sensing, we will be interested or we will be naturally doing hemispherical or conical. So, hemispherical here first refers to the direction of incoming energy, conical in the second term refers to the direction of outgoing energy.

Similarly, if we consider both the cases if at all we are able to measure the energy within the entire hemisphere surrounding an object, we call it as by hemispherical measurements. Incoming energy is also considered within the full hemisphere. Outgoing energy also is considered within the full hemisphere surrounding an object.

This is really important concept to know because we will see later, based on the direction or based on where we are integrating, over which surface we are integrating, objects will look different. The next important concept to understand is the geometry between the energy source, object and the sensor. The last slide I detailed about the different ways of or different combinations of directions, which can come into play, when we do remote sensing measurements.

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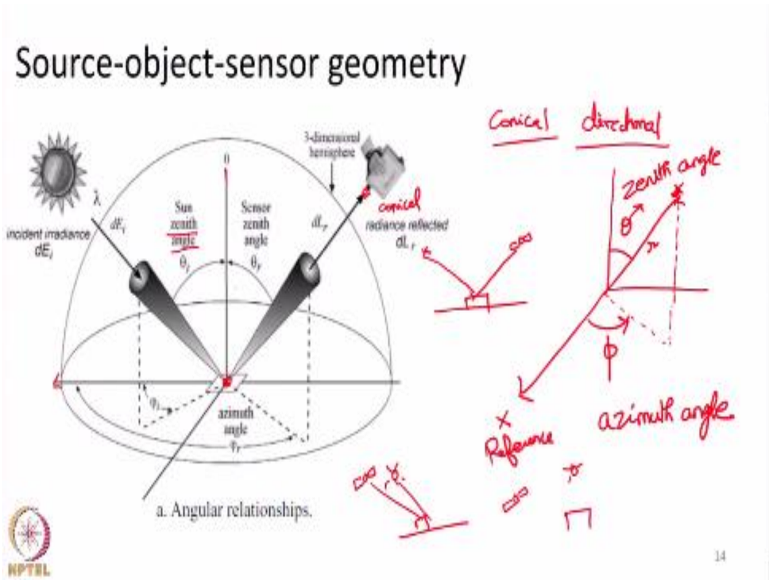

Here in this particular slide, what we are going to see is, how a source-object-sensor geometry affects our measurement. Please look at this particular thing. This is an object on the earth's surface and that will be irradiated by sun. We call it as irradiation on the object because sun energy is coming and falling on it. As I said, truly speaking, sun's energy should be considered as conical.

But under some circumstances, we can consider it also as like a directional incoming radiation that is coming in from only one particular direction as a single streak **(16:18)** of light. Whereas like outgoing radiation, as I said, if you have a sensor, I told you, it will be integrating energy in form of a cone coming towards it. So, this is with respect to the area over which we integrate the energy either are we integrating within a cone or are we integrating within a hemisphere.

But, one more important thing to assume is, even though we assume incoming energy and outgoing energy are coming in form of conical shapes, we are integrating energy in form over a cone, then the cone itself can be oriented in different, different directions that is we can give 2 directions to it. What is the direction with respect to vertical it makes, we call it as the zenith angle and what horizontal angle it makes with respect to a single direction of measurement. Let us say I have a point here in 3 dimensional space. If I want to give a coordinate to it, I can give coordinate using, one elevation angle θ and if I assume this as a reference direction x, this is treated as the reference direction, then I can measure the horizontal angle of this particular point and call it as the azimuth angle.

So, this is, I call the zenith angle that is the vertical angle. This, I call it as the azimuth angle and also if I know the radius R from this origin, I will be able to precisely locate this particular point in 3 dimensional space. I need 2 angles and one distance. But, if we are really interested only in fixing the direction of that particular point, it is good enough for us to know only those 2 angles.

The angle with respect to vertical call the zenith angle and the horizontal angle with respect to one reference direction call the azimuth angle. If we know those 2 angles, we will be able to fix that particular point in 3 dimensional space. Similarly, sun's energy, the incoming radiation and the outgoing radiation can have several directions.

Let us imagine a land surface and sun is here, sensor is here, this can be one particular directional component where it will have one zenith angle and one azimuth angle. Sometimes, sun may be here, sensor also may be here, the same azimuth angle orientation. Sometimes, sun may be directly overhead, sensor may be lying somewhere here. So, these are all different possibilities that can occur in remote sensing.

There are very few examples but really speaking, the direction of incoming radiation and outgoing radiation, the direction in which we observe can have many different orientations, many different combinations. Taking this directionality and combine this with the area over which we are observing, are we observing in just only one direction, which is almost I said, impossible; are we observing over like a small cone some like a small solid angle. Or are we going to observe over like a entire hemisphere covering the object of our interest. All these things and this directionality properties come together. And this makes remote sensing a little bit complex. Complex in the sense, there may be a same object on the surface, but based on the the solid angle in which we are integrating and also the direction in which we are looking, will make the object to look completely different when we get the remote sensing signals.

Later, we will see what signals we will get, how those signals will look and all. But, here just understand that the same object will look different when we integrate over different areas, that is, if you are integrating over a conical solid angle or are we integrating over entire hemisphere or from which direction we are doing it. All those things will always introduce some sort of uncertainties or some differences in the remote sensing measurements that we make.

And this is what we call as the difference in the object properties due to variation in the illumination and viewing geometry. So, the illumination geometry refers to and the way, in which the incoming radiation is coming, viewing geometry refers to the way in which we are looking at the object and making our measurements. So, this illumination, source and the sensor geometry is going to play a major role in all our measurements.

Almost all natural objects will look totally different when we observe from different, different scenarios. That is, even if we take an example of measuring only in one particular direction over a cone or if you want to integrate the entire energy with an entire hemisphere, the output we received from the object will be different. At one time the output, we received maybe one number. And the second case output we received maybe completely a different number like a different output. So, this will definitely influence our remote sensing measurements. And this we always have to keep in mind when we use remote sensing data for our applications.

Now, we have come to a point of defining important properties or important definitions related to remote sensing measurements. That is called the reflectance and albedo. In remote sensing, I already told you that the major interest that we measure is what is the amount of energy going out from an object. Say, an object is here. So, what is the amount of energy going out from an object is what we are going to measure in remote sensing. This particular energy can be reflected sunlight, that is, sun will give us energy or radiation.

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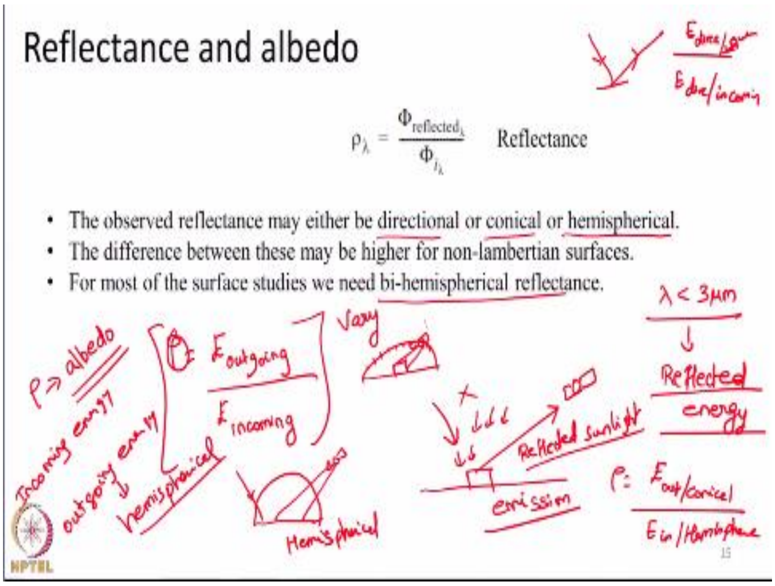

And part of this incoming sunlight will be reflected by the object. So, that is what I call reflected sunlight or the skylight component, also, the diffuse radiation also will be reflected. So, essentially it is a reflection or it can also be an emission from the object. Emission means, we remove all these external energy sources. What is the energy just going out from an object due to its own internal energy content or due to its own temperature. That is what we call emission.

So, the energy we receive in remote sensing can either be reflected energy or emitted energy. If we observe or if we make measurements in wavelength range, less than 3 micrometres, typically, whatever energy we are going to measure is essentially the reflected energy. This, we will see in detail in the coming lectures, but the measurements we make in less than 3 micrometre wavelength is essentially the reflected energy from the earth's surface.

So, based on this reflected energy or outgoing energy, we can define certain energy quantities. What are they? One is reflectance. Another one is albedo. What are these things? So, the reflectance is defined as the ratio of incoming energy to outgoing energy, basic, the very simple definition is reflectance ρ is equal to, radiant flux density outgoing divided by radiant flux density incoming. This is what is known as reflectance, radiant flux density incoming and outgoing.

The definition wise, it may look extremely simple, but look at the practical aspects of this. As I said before, the direction of incoming energy and outgoing energy will vary and also the nature of integration of incoming energy whether it is coming over like a conical projected area or whether it is coming over like entire hemisphere, it depends on the measurements we make.

So, based on the directionality of the measurements, the quantity of reflectance that we measure is going to vary. The observed reflectance may either be directional or conical or hemispherical that is I just defined ρ as E outgoing/E incoming. It can also be, E can be coming exactly in one direction and outgoing in exactly one direction. So, this is E directional outgoing by E directional incoming.

Second cases, let us say, sun ray is coming, we are going to consider both the diffuse radiation and direct radiation. In that case, we have to make measurements of incoming energy in the entire hemisphere surrounding the object. So, here, we are making a hemispherical case of incoming energy. And let us say, we are using a normal sensor in space which integrates energy over a conical solid angle.

So, that case, ρ will be defined as E outgoing over a conical integration area, E incoming which is measured over entire hemisphere. So, these are like different, different possibilities which can come into play, over which solid angle we are integrating the energy. This is going to make the reflectance values to differ, especially for objects which are non-lambertian.

Non-lambertian in the sense, I already told you, if we change the direction of the way we look, objects will look different. Look is not the visual look that we see but, in other wavelengths, the signals coming out of an object will be different. So, the reflectance value being measured here is going to be different based on the solid angle over which we are making our measurements.

Are we making measurements exactly over one line? Are we making measurements over an entire hemisphere? Are we making measurements over a conical surface? This is going to make matters very different. That is why we have defined 2 different properties, reflectance and albedo. Normally, the reflectance measurements we make, will have some sort of directional component of measurements that is, say, a sensor may be located here.

It may be like observing the land surface within a conical solid angle and what is the energy that went in the direction you would have measured and we have calculated a reflectance. But for some applications, especially like cryospheric land surface model and all, we will be in a position to measure the total energy that came into an object and total energy that went out from an object. That is in both incoming and outgoing cases, we should be measuring the energy over the entire hemisphere surrounding an object.

So, for natural measurements, it is not possible. Our measurements from remote sensing are highly directional. So, using some mathematical functions, we will be converting this directional measurement to an entire hemispherical measurement. So, if we are reporting this reflectance value over an entire hemisphere like a bi-hemispherical nature, then we call that particular reflectance as albedo.

That is, incoming energy can be directional or conical, hemispherical whatever, but the outgoing energy should be measured in a hemispherical way. Hemispherical way in the sense, the outgoing energy must be measured over the entire hemisphere covering the object. So, I already told you, in remote sensing measurements, direct measurement is not possible from satellites, we need to do some sort of model based conversions to convert our directional measurements from a cone to hemispherical measurement.

So, what is the reflectance is. The reflectance is the ratio of outgoing energy to incoming energy. But, it can have directional component like the sensor might have looked for many different directions over a conical solid angle and we would have got reflectance. But normally, we define for most applications, we will be needing reflectance values where the outgoing energy is measured within the entire hemisphere that has covered the object of our interest and we call that as albedo.

So, please remember this. There is a difference between reflectance and albedo. Reflectance has directional component, whereas albedo, our measurements over the object of interest should cover the entire hemisphere surrounding that particular object. This is with respect to the outgoing radiation. Okay.

So, in today's lecture, we discussed in detail about the directionality of remote sensing measurements and also we defined quantities such as reflectance and albedo. Next lecture, we will continue a little bit about this in order to make ourselves more clearer.
Thank you very much.