Remote Sensing: Principles and Applications

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Lecture - 10
Reflectance, Albedo and Related Quantities

Hello everyone, welcome to today's lecture in the course remote sensing principles and applications. In this particular lecture, we will be discussing more details about reflectance, albedo and related quantities, which we started in the last lecture.

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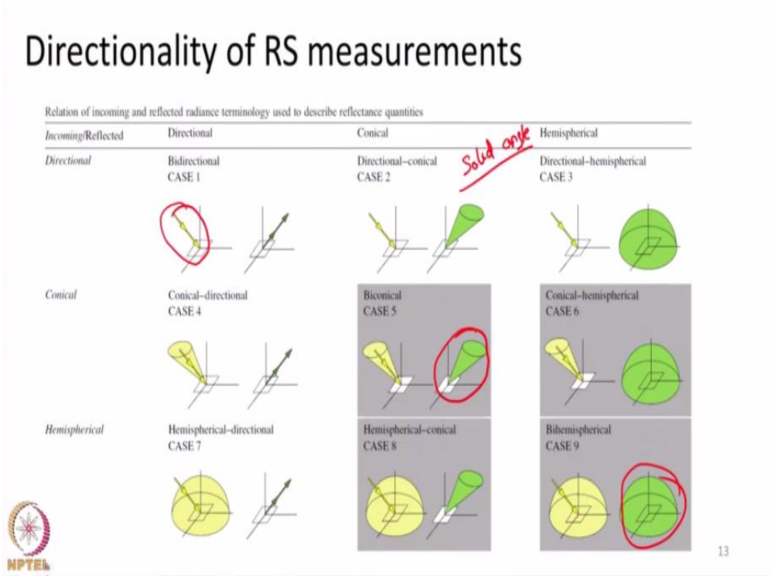

So, in the last lecture, I explained you in detail about how the nature of our measurements, the solid angle over which we integrate our measurement will influence our outputs. That is, we can consider incoming energy and outgoing energy in different cases. We can consider them coming in one particular direction. We can consider them to be measured over a conical solid angle or we can measure them or integrate them over an entire hemisphere.

So, based on these different solid angles, we make with respect to our point of observation, our output may vary. This thing I told you in the last class.

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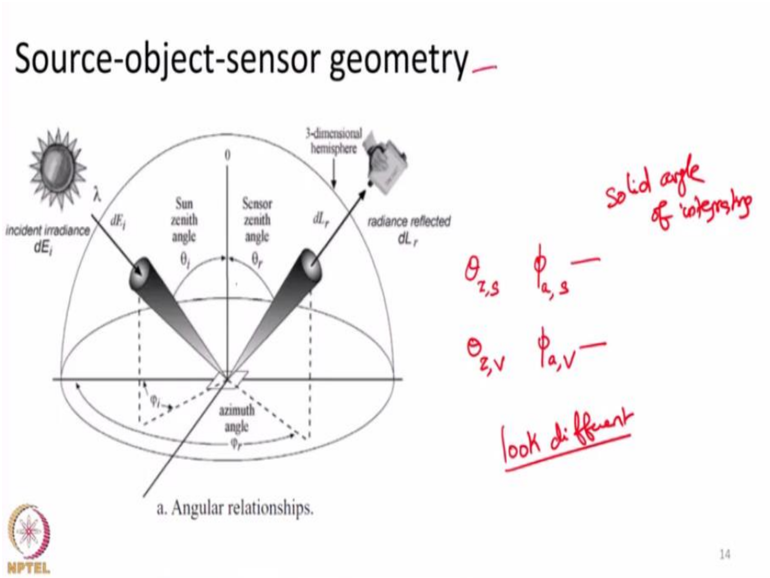

And one more thing I told you in the last class is how the source object and the sensor geometry is going to influence our measurements. That is what we call the zenith angle of the source, azimuth angle of the source and zenith angle of the viewing sensor and azimuth angle of the viewing sensor. And these 2 measurements in combination with the solid angle over which we are integrating is going to make the earth surface objects look different. So, this is what I explained as source object sensor geometry in the last class.

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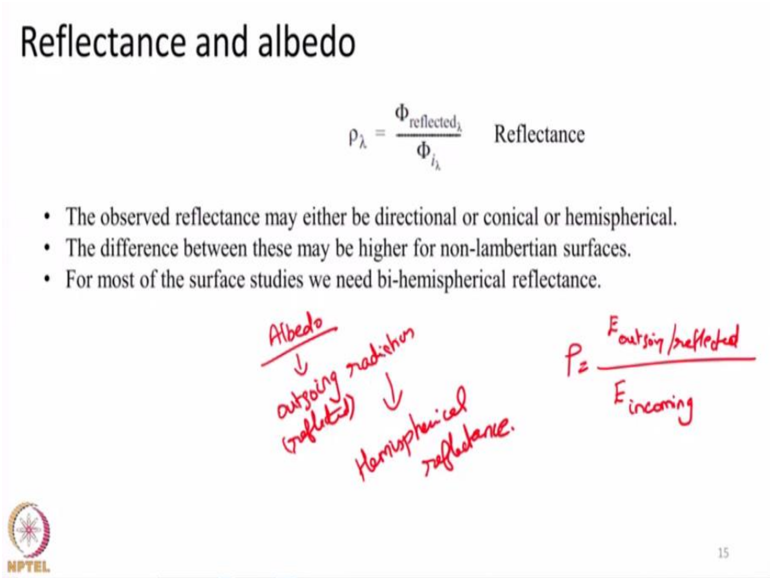

We also defined what reflectance and albedo is. So, reflectance the basic definition is irradiance outgoing, especially in reflected form. I am not talking about the emitted energy. I am just talking about the reflected energy from object of our **(02:26)** interest divided by E incoming. So, this is what is defined as reflectance. And I also said that based on the solid angle of the measurements and the direction in which we look the reflectance can be defined as like different quantities.

So, the first basic definition of reflectance can contain direction measurements. That is the measurements that has been made using remote sensing sensors will be from only one particular direction. Sensor can be located here, sensor can be located there, exactly overhead of the object. Sensor can be in different directions, integrating over the conical solid angle that it subtends on the earth's surface. So, this is the direction component.

This is what normally we measure. I also said for applications related to land surface modeling, snow studies, energy balance studies and all we will not be needing this directional component of measurement. But we need to measure the total energy that was reflected by an object within the entire hemisphere surrounding it. So, what essentially it means our sensor should not be looking from one direction.

It should quickly move in all directions, collect energy within the entire hemisphere, which is practically not possible. Our sensor will not be able to do that, especially from satellites. What we do, we take this energy that was observed from one different direction. We integrate it over using some mathematical functions over the entire hemisphere to get the reflectance of an object within the entire hemisphere. And that reflectance that we calculate over the entire hemisphere is what we call albedo. So, I make it more specific, the reflected radiation is integrated over a hemisphere surrounding the object of our interest, we call it as hemispherical reflectance. So, this is with respect to the outgoing reflected radiation. This is what we call albedo.

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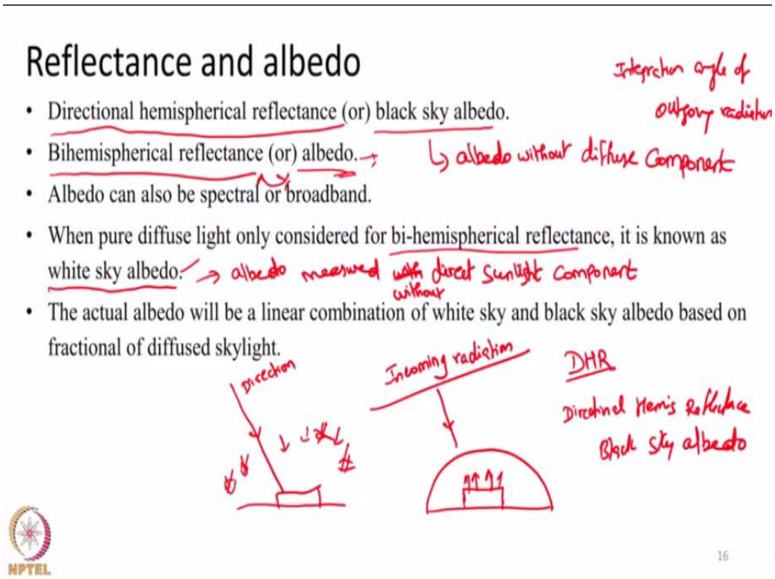

Now, in the definition of albedo, we just talk about the integration angle of outgoing radiation. Also there is one more component of incoming radiation. So, what exactly is incoming radiation, how the incoming radiation is integrated is again going to differentiate or classify this albedo further. First thing we talk about what is known as a black sky albedo or we call it as the directional hemispherical reflectance DHR in short.

Directional hemispherical reflectance, what is this? I already told you that during very bright, extremely clear sunny sky days, we can assume the solar radiation to be coming from one particular direction. Assume the sky is totally clear and no diffused component is present. Hence, the incoming radiation is coming from only one direction.

Under such scenarios, if we are able to make measurements or to model the outgoing energy over the entire hemisphere surrounding it in response to this single direction of incoming energy, we call it as directional hemispherical reflectance or in a simple parlance we call it as black sky albedo. That is the sky is not giving any energy source. Sky is not acting as energy source.

The energy source is only the direct solar radiation we call it as directional hemispherical reflectance. On the other hand, over most natural cases our every day to day life, the atmosphere will not behave like, will not behave completely clear. Atmosphere will do scattering, the scattered radiation from the atmosphere will fall on an object. So, essentially the total radiation received by the object will have both the direct component and diffuse component.

So, if we want to calculate the total energy that came in and irradiated on the object, then we should take the entire energy that came in within the entire hemisphere surrounding an object. Because energy can come in from any direction surrounding the object of our interest one direct sunlight plus diffuse skylight from any possible direction.

This sort of incoming radiation that is where incoming radiation is also coming in within entire hemisphere surrounding an object, outgoing radiation also we have to measure over the entire hemisphere surrounding an object. And reflectance we measure over or we model over such scenarios. We call it as bi-hemispherical reflectance. Generally it is albedo.

Albedo can be referred to anything but albedo in a broadest sense refers to bi-hemispherical reflectance. So, if we come across the term albedo in any sort of like textbooks related to climate, meteorology, snow, cryosphere studies and all you can always associate it with bi-hemispherical reflectance. And one more point is black sky albedo, I already told you. There can be another theoretical scenario.

One of the theoretical scenario is direct sunlight is totally absent; whatever the object receives is pure diffuse component. practically speaking, such scenario may happen during highly cloudy days extremely cloudy, completely dense clouds covering us, which obscures the sun totally like during monsoon season and all we might have observed such scenario. The sky will be completely covered with dark clouds filled with rainwater.

And it may be going to rain anytime. Under such scenarios, we will not be able to see the sun. So, practically speaking sunlight is completely obscured. And whatever light we receive during that time is entirely diffuse in nature. So, direct radiation is almost absent. Whatever we receive is entirely diffuse in nature. If we measure reflectance of an object, under such circumstances where it is irradiated only by diffused skylight, we call that particular reflectance as white sky albedo.

So, please remember there are like a lot of different things here and this is for your own knowledge. First thing I told you directional hemispherical reflectance where only direct sunlight is considered diffused component is removed. Second case, the most practical thing we encounter in our everyday life is every object will be receiving energy both from direct sunlight and diffused skylight.

If we measure albedo under such circumstances we call it as bi-hemispherical reflectance. There can be some circumstances where the diffused skylight only is present direct sunlight is absent. We measure reflectance under such circumstances. That has a name of white sky albedo. That is, white sky albedo is albedo measured without direct sunlight component.

I write the word measured, but practically this will not be measured this will be modeled using some functions. Whereas black sky albedo is albedo without any diffuse component. So, black sky albedo means the incoming energy has only direct component. White sky albedo means the incoming energy has only diffused component but measured over the entire hemisphere so no direct component.

But always remember if we say the word albedo when the outgoing radiation is measured in the entire hemisphere surrounding an object. So, if you are talking about measuring outgoing radiation reflected radiation in any one particular direction, as we normally do in remote sensing things we call it as reflectance. But if we convert this reflectance into the entire hemisphere surrounding an object of interest, we call it albedo.

And even this albedo, we can further sub classify it as white sky albedo and black sky albedo whether diffuse or direct component is present. And also one more thing to notice, we talked about lot of things, measuring energy quantities, albedo, reflectance and so on. They can be measured over either small spectral bands like only green band 0.5 to 0.6, only red band 0.6 to 0.7. Like this small bands we can measure or we can measure even over like larger bands. I want to measure over entire IR 0.7 that is near infrared band 0.7 to 1.4 micrometers that is possible. So, the quantities such as reflectance, albedos and even the earlier terms like radiant flux density and everything, whatever measurements we are going to make we can measure in any different bandwidths.

We can measure in small bandwidths or we can talk over in entire visible range entire infrared range and so on. So, if you are talking about small bandwidths like only red, green, blue, small portion of a NIR **(13:20)** we call it as spectral measurements. Like what is the reflectance in red band, what is the albedo in green band and so on.

If we talk about very broad wavelength entire visible 0.4 to 0.7, I talk about albedo of an object in the visible bandwidth, reflectance of an object in the entire NIR bandwidth and so on. So, the measurements can be made over a large wavelength range or over a small wavelength range also based on our needs, our sensor characteristics. please remember that. And also, one more thing is the actual albedo.

That is the actual true bi-hemispherical albedo can be calculated as a linear combination of white sky and black sky albedos. So, this is like later in the course, we will be talking about lot of data products available. So, these albedos are available from satellites for sensors such as MODIS, where if we take they will give us white sky black sky albedos for converting them to normal bi-hemispherical reflectance or normal albedo. We can treat them as a linear fractions and do it.

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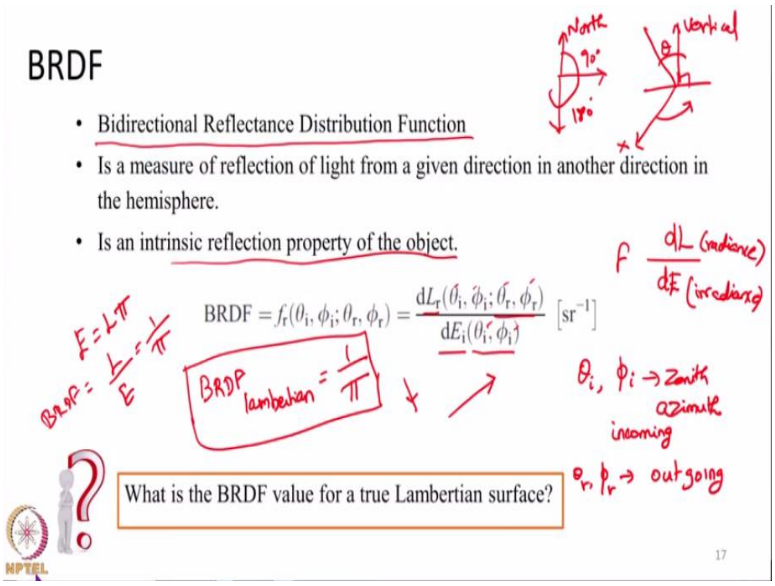

The next important property that we should always have in mind is BRDF. That is bidirectional reflectance distribution function. What is this? In the last lecture, when we discussed about the source object and sensor geometry, I told you that objects will look different when we observe the object from different directions. So, we know objects will look different.

But I also told for some measurements, we need to integrate over the entire hemisphere, we should not be having directional measurements, we should be having a total hemispherical integrated measurement. How is that possible? How to model the objects behavior when we look from different angle? That mathematical function, which helps us to model this directional property of an object is called BRDF bidirectional reflectance distribution function.

So, what is the definition of BRDF? BRDF is defined as the ratio of (the radiance of an object that is reflected or outgoing from an object) reflected radiance to incoming irradiance that is the radiance going out of an object divided by the irradiance received by the object. This is the basic definition of BRDF. But here I have lot of angular elements attached with it. What are these?

The angular elements here gives us the direction in which incoming energy is coming and the direction in which outgoing energy (reflected energy) is going out. θ_i and ϕ_i indicate the zenith and azimuth angles of incoming radiation whereas θ_r and ϕ_r are the zenith and azimuth angles of outgoing radiation. So, I just repeat. Zenith angle is angle measured with respect to the normal to the surface or with respect to vertical, I will say, with respect to vertical is what we call zenith angle.

And azimuth angle is the horizontal angle we measure with respect to some reference direction. Normally the direction we measure clockwise from north we call it as azimuth. Like east is 90 degree east is at 90 degree azimuth from north. South is at 180 degree azimuth from north and so, on. So, from any one particular reference direction, the horizontal angle we measure is called azimuth.

And the angle we measure from the vertical line is what we call zenith. And I also told you in the last class that if we have these two angles, zenith and azimuth angles, we can fix the direction of incoming radiation and also the outgoing radiation. If we have θ_i and ϕ_i, we can fix the direction of incoming radiation. Similarly, if we have θ_r and ϕ_r, we can fix the direction of outgoing radiation.

So, this BRDF is a mathematical function which will tell us how an object will behave for incoming radiation and outgoing radiation in almost all possible combinations for a given θ_i and ϕ_i. And for a given θ_r and ϕ_r, what is the ratio dL by dE? This is BRDF. So, essentially it is kind of like one mathematical function. So, there are like different ways to get this BRDF using ground measurements and all.

People use definite instruments for this and measure the object's property using different directions and derive this BRDF. What is the benefit of deriving this BRDF? Once we have this BRDF defined for an object, it will be helpful for us in calculating the different directional reflectances and different albedo quantities. Like I said, what the sensor measures is directional, it integrates energy over a cone.

I also said for some applications we will be needing albedos which is energy integrated over the entire hemisphere, how to go about it? we should know the BRDF of an object. If you know the BRDF of an object, there are like mathematical functions. Anyway the functions we are not going to discuss in this course. There are different mathematical ways in which we can convert this directional conical measurement from a sensor into a hemispherical measurement.

That is possible and BRDF helps us in achieving this. So, BRDF is an intrinsic reflection property of the object. How an object will look if we look from one particular direction and when the object is irradiated from one different direction. So, before we proceed further I have one question for you. Can you just think of what will be the BRDF value for a Lambertian surface?

Please pause the video and related to the earlier relationships we talked in radiometry and try to guess an answer for this. Please pause the video and think for a few seconds. The answer for the question I asked is the BRDF of a truly Lambertian surface will be $1/\pi$. For a Lambertian surface it is not actually a function, it is actually a constant that is $1/\pi$. Why? Because for Lambertian surface we know $E = L\pi$. BRDF is defined as L/E.

So, if we take this L/E as BRDF, then BRDF will become $1/\pi$. This is only for purely Lambertian surfaces. Just remember one thing, at this stage it is very easy to get confused between BRDF and reflectance. But they are entirely different. They are not one and the same. Just look at the definition of these quantities.

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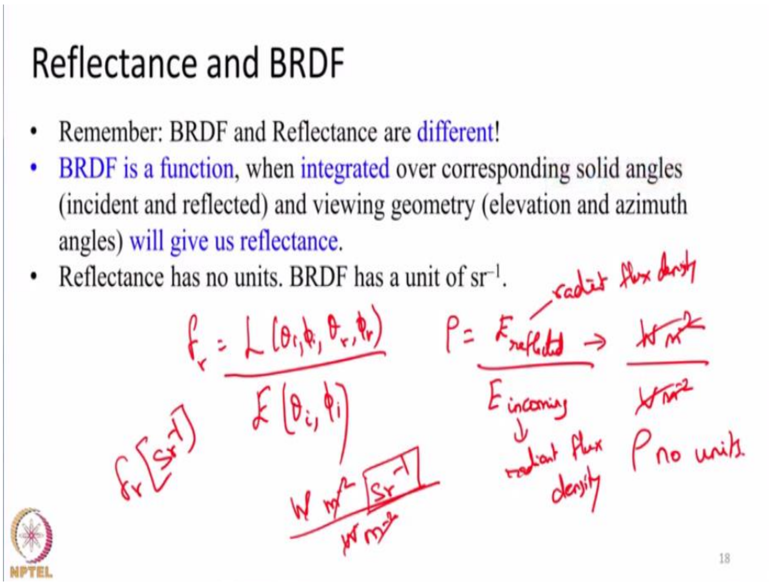

Reflectance is refined as $E_{reflected}/E_{incoming}$. So, both the terms are radiant flux density. Essentially both the units are watt/meter^2 units. They cancel of each other and reflectance has no units. Now, we look at the definition of BRDF. BRDF is defined as radiance in a given direction divided by irradiance from a given direction.

So, if we look at this radiance has a unit of watt/meter^2/steradian. Please refer back to the previous slides where we defined radiometric quantities watt/meter^2/solid angle. So, watt/meter^2/steradian is its units. E has units of watt/meter^2. These will cancel out and BRDF will have a unit of per steradian. So, this is the unit of BRDF.

So, conceptually speaking, BRDF is a function which we integrate over the angles of our observation, which angle are we observing with which θ_i and ϕ_i with which θ_r and ϕ_r are we observing. If we integrate BRDF over these angle combinations, we will get reflectance. So, BRDF is a function which is like the maximum limit in which we can go and see about an object of interest.

So, this is the finest derivative of an object like a single point an object. So, it is a concept of integration and differentiation. You have one point you integrate or a function defined over one point. So, you integrate it over an area you get the surface area. That is the process of integration.

You integrate it over like the different solid angles over which you work that will give you reflectance. So, reflectance has no units. BRDF has a unit of per steradian, sr^{-1}. And BRDF is a intrinsic property of a surface. And we need to integrate it in order for us to get reflectance. Whereas reflectance, we can measure it basically. So, reflectance denotes how much energy came out.

So, it is kind of we can measure. And the purpose of BRDF is to convert other various directionalities over which we measure and take them to different quantities. BRDF helps us to understand in detail about how object will look if we look from different angles. If we supply energy from different angles or if we look from different angles, how an object will look. BRDF will help us to understand that and model that.

We are not going very much in detail about conversion of different reflectance quantities and all. But just for your understanding I defined all these quantities. So, if you come across such quantities, albedo, directional hemispherical reflectance, bi-hemispherical reflectance, BRDF and so on, in various papers you read or demos in textbooks you read, you should be remembering or you should be knowing what is what.

That is the purpose of telling this. So, in summary, in this particular lecture, we have discussed, what reflectance is, what albedo is, how albedo is classified further such as white sky albedo and black sky albedo. And also we defined one more important property call BRDF, bidirectional reflectance distribution function. With this we end this lecture.
Thank you very much.