

## Slide 1 – Title Slide

Hello and welcome to Week 9, part 4 of EGM310: Interaction with the Earth's surface. In this lesson, we'll cover how electromagnetic radiation interacts with the Earth's surface, and how that affects what we "see" with remote sensing.

## Slide 2 – Some definitions

I apologize in advance for the wall of text on this page, but before we keep going I think it's important to set out some definitions for the ways that objects interact with electromagnetic radiation. Feel free to skip ahead about a minute or so in the video.

If you're still with us, let's keep going.

Radiant energy, measured in Joules, is the total amount of energy emitted by, or falling on, an object.

Radiant flux, measured in watts or Joules per second, is the energy per unit time.

Radiant intensity, measured in watts per steradian, is the radiant flux per solid angle. A solid angle is the portion of a field of view covered by an object – it's the three-dimensional extension of an angle, indicated by the cone in this diagram.

Radiance, measured in Watts per steradian per meter squared, is the flux per solid angle per area that is emitted by, or falls on, an object.

The total radiant flux emitted by, or falling onto, a surface, is either the radiant emittance or the irradiance, respectively, measured in watts per square meter.

The radiosity of an object, measured in Watts per square meter, is the total radiant flux leaving a surface – the sum of the flux that is emitted from, reflected, and transmitted by the object.

Finally, we have the spectral radiance or spectral irradiance, which is just the radiance/irradiance measured over a given wavelength band.

## Slide 3 – EMR and Earth Surface

Similar to what we discussed for the atmosphere, electromagnetic radiation interacts with the Earth's surface by either being reflected, absorbed, or transmitted. How it interacts with the surface depends on the properties of the surface, the wavelength of the light, and the angle of illumination, or incidence.

It's important to note that these are not mutually exclusive – an object can transmit some incident radiation, absorb some, and reflect the rest – or, it can completely absorb, or completely reflect, the incident radiation. In any case, the incident radiant flux,  $\Phi_i$ , is the sum of the radiant flux that is reflected, absorbed, and transmitted.

## Slide 4 – Reflection

For most of the remote sensing we'll talk about in the rest of this module, reflection is the main type of surface interaction we're interested in. This is usually what we measure with optical – that is, visible or infrared – sensors. The image to the left shows how much energy has reflected off the Earth's surface towards the satellite in the near-infrared portion of the spectrum (remember that these are wavelengths around 900 nm). In general, we can break surfaces into two idealized types based on how they reflect electromagnetic radiation: specular, or mirror-like reflectors, and diffuse, or Lambertian, reflectors.

We can also define the reflectance,  $\rho$ , of an object as the ratio of the energy reflected by the surface to the energy incident on the surface. In other words, this is the fraction of energy incident on the surface that is reflected by the object.

## Slide 5 – Specular reflectors

Specular, or mirror-like reflectors, are surfaces that are smooth relative to the wavelength of the electromagnetic radiation. Similar to a mirror, or a perfectly calm lake surface, perfect specular reflectors re-direct, or reflect, nearly all of the incident radiation in a single direction. For a perfect specular reflector, the angle of reflection, or exitance, is equal to the angle of incidence. Most surfaces are not perfect specular reflectors, however, so there may be some light scattered in other directions – in this case, most of the radiation, rather than all of the radiation, is reflected at an angle equal to the angle of incidence.

## Slide 6 – Diffuse reflectors

Diffuse reflectors are surfaces that are rough relative to the wavelength of the electromagnetic radiation. In the case of a perfect diffuse reflector, known as a Lambertian surface, the incident radiation is scattered uniformly in all directions. Similar to non-perfect specular reflectors, non-perfect diffuse reflectors have some preferential scattering at an angle equal to the angle of incidence, but more of the radiation is scattered from the surface. Because of the way that the electromagnetic radiation interacts with the surface, diffuse reflection actually tells us about the color of the surface. Some wavelengths are absorbed by the surface, and anything not absorbed is reflected by the surface. Because of this, diffuse reflection is often the most useful type of reflection for remote sensing, as it enables us to distinguish objects based on the wavelengths of reflected light.

## Slide 7 – Bidirectional Reflectance Distribution Function

Most surfaces lie somewhere between the idealized surface types of specular reflectors and diffuse reflectors. And, in fact, whether surfaces behave more like specular or more like diffuse reflectors normally depends on the viewing angle. For example, in this image, you can see the arrow pointing to water on the ocean. Notice how bright it appears – this is because the sensor (in this case, a camera) is picking up a strong reflection of the sun's light off of the water surface. When the camera moves to its next position, the same area appears dark – the reflection from the surface is no longer pointing directly at the sensor. One way that we can describe or assess this tendency of a surface's reflectance is

something called the bidirectional reflectance distribution function, or BRDF. The BRDF is a mathematical description of how the reflectance varies for combinations of illumination and reflection angles at a given wavelength. Given the BRDF of a surface, we can estimate its albedo – the ratio of the radiosity, or total radiant flux leaving a surface, to the irradiance, or total radiant flux onto a surface. Albedo is an important concept for climate, as it in part helps to determine the energy balance of Earth's surface. In order to estimate the BRDF and the albedo, we need multiple viewing angles of the surface. This last image here is of the satellite Terra, and it demonstrates how a sensor called the Multi-angle Imaging SpectroRadiometer, or MISR, works. MISR has nine different cameras, each acquiring images at different angles. With measurements like this, we can work out the BRDF and albedo for objects and surfaces all over the Earth.

## **Slide 8 – Absorption & Transmission**

Any energy that isn't reflected by a surface has to be either absorbed or emitted by the surface. We covered this a bit with diffuse reflectors – the properties of the surface determine how electromagnetic radiation is absorbed, and at what wavelengths. For example, leaves on healthy, chlorophyll-producing plants absorb light in the red and blue visible wavelengths, leaving mostly green light to be reflected – as a result, most plants appear green to our eyes. We can also see absorption and transmission in action with the color of water. At the shore of the lake here, water is mostly clear. As the depth increases, though, we see a shift in color to green and then dark blue. Water molecules preferentially absorb longer wavelengths like red light, so the light that gets scattered back toward the sensor is at shorter wavelengths. As the water gets deeper, more of the light is absorbed, and so the water appears darker and darker – less of it is reflected back. Scattering by suspended sediments and other particles in the water also plays a role – because most of the light that is transmitted into the water column is preferentially shorter wavelengths, the light scattered back appears more green and blue, depending again on the depth.

## **Slide 9 – Summary**

In this lesson, we have discussed how electromagnetic radiation that makes it through the atmosphere interacts with Earth's surface – it is either reflected, absorbed, or transmitted, but these are not mutually exclusive interactions.

Most of what we measure with remote sensing is reflection – this is radiation that is re-directed by an object towards the sensor, where it is then recorded. The amount of radiation reflected depends on the wavelength of the radiation, the illumination angle, viewing angle of the sensor, and the properties of the surface itself – we can use the radiation that is reflected to study the surface.

Of all of the different processes we have discussed today, the most useful for remote sensing is generally diffuse radiation, as this tells us something about the spectral properties of the surface.

## **Slide 10 – Additional resources**

Once again, you can read further about most of the concepts we have covered in this lesson in the textbooks, chapter 1 of Lillesand, Kiefer & Chipman, and chapter 2 of Campbell & Wynne. You can also read further in the Natural Resources Canada Remote Sensing Tutorials, linked here. Finally, I've included some links to a few different videos that go into some more detail about absorption, reflection, and transmission – you can find the links on the slides, or in the description below. That's all for this lesson – I hope you found it interesting, and you have any questions, please don't hesitate to e-mail me or post in the discussion forum on blackboard. Bye!