

## Slide 1 – Title Slide

Hello and welcome to Week 9, part 3 of EGM310: Interaction with the Atmosphere. In this lesson, we'll learn about how electromagnetic radiation interacts with the Earth's atmosphere, and how that affects what we "see" with remote sensing.

## Slide 2 – The Atmosphere

As you may or may not know, the Earth has an atmosphere. It warms the Earth's surface (sometimes too much), modulates the temperature between day and night, enables liquid water to exist on the surface, and absorbs ultraviolet radiation. In short, it helps us live on this planet.

For satellite remote sensing, the atmosphere sits between the sensor and the target – the thing we want to observe. In order for us to make our observations, electromagnetic radiation has to go through the atmosphere, which means that it has to interact with the atmosphere.

This interaction can take one of four forms – either the electromagnetic radiation is refracted, meaning it appears to be bent as it enters the atmosphere; it can be scattered in random directions; it can be reflected back into space, or it can be absorbed and potentially re-emitted.

## Slide 3 – Refraction

Remember that as a wave passes from one medium to another, the speed may change depending on the relative properties of the two media. For light traveling through air, this means that the temperature, air pressure, humidity or vapor pressure, and wavelength of light all play a role. The speed change changes the travel time for the light, which causes an apparent displacement of the object. You can easily see this by looking at a straw in a glass of water, for example.

The relationship between the angle of incidence and the angle of refraction is described Snell's law, which you can see [here](#). The amount of displacement is described by the refraction index, which is calculated as the ratio of the speed of light in a vacuum,  $c_0$ , to the speed of light in the medium. The amount of refraction also depends on the angle of incidence, measured from the vertical as shown [here](#). Larger incidence angles cause more refraction, and vice-versa. Think about how the shape of the sun appears distorted as it sets, or the way mirages look – the wavy pattern that we see happens as a result of refraction due to the atmosphere. The maximum amount of refraction we observe is about a meter, so the impact is limited outside of high-resolution images.

## Slide 4 – Scattering

Scattering is the diffusion of electromagnetic radiation in unpredictable, or random, directions. For smaller particles, this can take the form of absorption and re-emission of electromagnetic radiation, but for larger particles this can be physical scattering of electromagnetic radiation – think pool balls, or bowling pins.

Depending on the size of the particle, there are three main types of scattering. Rayleigh scattering is caused by particles with a diameter  $d$  that's around  $1/10$ th of the wavelength – usually atmospheric molecules such as oxygen or nitrogen. Mie scattering is caused by particles that are between  $1/10$ th and 10 times the wavelength – this is usually things like dust or smoke particles, or even smaller water droplets. Non-selective scattering occurs with particles that are bigger than about 10 times the wavelength of the electromagnetic radiation – it's called non-selective because it scatters all wavelengths equally. This is caused by large water droplets or ice crystals, usually in the form of clouds.

## **Slide 5 – Rayleigh scattering**

Rayleigh scattering occurs when the particle is much smaller than the wavelength. It depends on the refraction index – remember that this depends on the density of the substance. For air, this also means the temperature, air pressure, and water content. The amount of Rayleigh scattering also strongly depends on the wavelength of the light. In fact, the amount of scattering is proportional to  $1$  over the wavelength to the fourth power – this means that blue light at about 400 nm scatters about 5 times more than red light at about 700 nm. This is why the sky appears blue to us during the day – blue light is scattered from all portions of the sky. Rayleigh scattering is also partly why the sky appears red or orange during a sunset. Near the horizon, the sun's light travels through more of the atmosphere – as a result, shorter wavelengths are more preferentially scattered away from the observer, and so the light that we see has longer wavelengths.

## **Slide 6 – Mie Scattering**

For slightly larger particles, Mie scattering is the dominant scattering mechanism. Mie scattering is stronger than Rayleigh scattering, in that less light passes through. The amount of scattering depends less on wavelength – rather than  $1$  over  $\lambda$  to the fourth, it's only  $1$  over  $\lambda$ . Mie scattering is caused mostly by smoke, pollution, or dust particles in the atmosphere. I'm sure you've seen images from the different wildfires in California, Australia, or Siberia over the past year – the darkened, orange sky you can see in these photos is a result of Mie scattering. Dust storms, like this one blowing off the coast of Africa, can have a similar effect. Mie scattering can also be caused by smaller water droplets in the atmosphere.

## **Slide 7 – Non-selective scattering**

Non-selective scattering occurs when the particle is much larger than the wavelength. It does not depend on the wavelength – hence the name “non-selective” – but rather, all wavelengths are scattered equally. It's primarily caused by large water droplets, ice crystals, or larger dust particles in the atmosphere. The classic example of non-selective scattering is clouds. As you can see in these satellite images acquired in four different wavelengths, the clouds are visible in each of the images, all with similar levels of brightness. From the ground, clouds normally appear white to gray, again owing to the relatively even scattering across wavelengths. Another classic example of non-selective scattering is fog – the dull gray color of fog is caused by even scattering of relatively low levels of light.

## Slide 8 – Effects of scattering

One main result of atmospheric scattering is that shadows in satellite images aren't completely dark – scattering causes light to be re-directed into the view of the sensor. In these mountains here, we can still see the surface that's obscured by shadow. Scattering also causes what's known as atmospheric perspective – objects farther away appear to have different colors and brightness. It is also part of the reason why we don't normally use ultraviolet radiation in remote sensing – at shorter wavelengths, the atmosphere itself appears brighter, and so most sensors will record that brightness rather than the brightness of the scene. Because scattering re-directs radiation from outside of the view of the sensor, it also decreases the spatial detail recorded, and it decreases the contrast of the scene – bright objects appear less bright, while dark objects appear brighter than they otherwise are.

## Slide 9 – Reflection

When it comes to the atmosphere, reflection takes one of two forms. It can either refer to absorption and then re-emission of electromagnetic radiation, or it can refer to physical scattering of electromagnetic radiation by particles in the atmosphere that directs the electromagnetic radiation back towards the sensor. In general, most atmospheric reflection is caused by clouds – you can see the example here of this image of hurricane Katrina acquired in August 2005.

## Slide 10 – Absorption

That brings us to the last form of interaction between electromagnetic radiation and the atmosphere, absorption. Whether or not electromagnetic radiation is absorbed depends on the wavelength and the kind of molecule doing the absorbing. This diagram here shows the amount of atmospheric absorption that occurs as a function of both wavelength and the kind of molecule. We see, for example, that oxygen and ozone ( $O_2$  and  $O_3$ ) absorb most all incoming radiation in the ultraviolet portion of the spectrum, as well as another strong peak in the infrared portion of the spectrum. Fortunately for our purposes, the atmosphere is fairly transparent – meaning very little absorption – in the visible portion of the spectrum. In the infrared and ultraviolet portions of the spectrum, though, we see near-total absorption of incoming electromagnetic radiation, with some thin “windows” where electromagnetic radiation isn't absorbed.

## Slide 11 – Absorption bands/windows

When designing sensors, we try to take advantage of these windows as much as possible. This figure shows the wavelength bands for a number of different satellite sensors – we'll talk more about these next week. Unlike on the previous slide, this slide shows how much electromagnetic radiation passes through the atmosphere, rather than how much is absorbed – and most of the bands acquire in wavelengths where the atmosphere is fairly transparent. More recently, some sensors such as Landsat 8 Operational Land Imager (OLI) or Sentinel-2 Multispectral Imager (MSI) have also included bands to acquire in regions where the atmosphere is opaque, with the goal of studying or detecting clouds.

## **Slide 12 – Absorption bands/windows**

Further out, we can see that in the microwave region of the electromagnetic spectrum, the atmosphere is mostly transparent. This is one big advantage that microwave remote sensing has over visible/infrared remote sensing – with microwave remote sensing, we can make observations largely independent of weather. We'll talk more about this next week when we get into the different kinds of satellite sensors.

## **Slide 13 – Summary**

In this lesson, we've discussed how the atmosphere is great for life on Earth, even if it makes remote sensing more difficult.

Incoming electromagnetic radiation interacts with the atmosphere in four different ways, depending on the properties of the electromagnetic radiation and the atmosphere. Each of these types of interactions have different implications for remote sensing.

Finally, we design satellite sensors to make use of the “windows” in the atmosphere where electromagnetic radiation is not absorbed by the atmosphere.

## **Slide 14 – Additional resources**

You can read more about the topics we've discussed here in the two textbooks – Lillesand, Kiefer & Chipman, Chapter 1, or Campbell & Wynne, Chapter 2. Or, read more about it from the Natural Resources Canada Remote Sensing Tutorials. I've also included a link to a video that answers questions like “why is the sky blue?” in a bit more detail than we've covered here. That's all for this lesson – I hope you found it interesting, and if you have any questions, please don't hesitate to e-mail me or post in the discussion forum on blackboard. Bye!