Slide 1 – Title Slide

Hello and welcome to Week 1, part 1 of EGM703: Principles of Thermal Remote Sensing. In this lesson, we'll re-cover the basics of electromagnetic radiation, the main tool we use to gather information in thermal remote sensing.

Slide 2 – Week 1 Outline

In the rest of the lessons for this week, we'll cover even more principles of thermal remote sensing, thermal properties of objects, how to convert radiance to temperature, atmospheric correction, and finally applications of thermal remote sensing.

Slide 3 – Light (Electromagnetic Radiation)

As you should hopefully remember from previous modules on remote sensing, the light that we see is a type of electromagnetic radiation. For most remote sensing, we use electromagnetic radiation to observe things. But, how should we think about, or picture, light (or electromagnetic radiation)? Please note that in this lesson, I'm going to be using light and electromagnetic radiation interchangeably – we'll learn why that is a bit later.

Over time, physicists developed two main theories for how light behaved – the particle model, and the wave model – based on different phenomena or properties they observed. So, is light a particle, or is it a wave?

The table to the right here lists some of the different phenomena that scientists have observed, and indicates which of the two models can be used to explain each one. Both models can explain reflection and refraction, but only the wave model can explain the properties of interference, diffraction, and polarization. But, the wave model can't explain the photoelectric effect (see the additional resources at the end of this lesson), whereas the particle model can. So, the answer to the question "is light a particle or a wave?" is "it depends." The reason why is well outside of the scope of this course, but if you're interested there are more links at the end of the presentation (or in the description below) that go a bit deeper into the topic.

Slide 4 – The Wave Model

Electromagnetic radiation is a self-propagating wave. By "self-propagating" we mean that, unlike water waves or sound waves, electromagnetic waves travel through space without any external influence. As the name suggests, electromagnetic waves have both an electric component and a magnetic component. One of the major lessons of 19th-century physics is that a changing electric field induces a magnetic field, and vice-versa – this is the principle behind, among other things, induction stovetops and electric motors.

So an electromagnetic wave moving through space has both an electric and a magnetic component, usually denoted E and B, respectively. The electric component is moving and oscillating in one plane –

in this example, the xz-plane, while the magnetic component moves and oscillates in a plane at a 90-degree angle – in this example, the xy-plane.

Like any other wave, an electromagnetic wave has different attributes, or properties. It propagates at a certain speed, usually denoted ‘c’. In a vacuum, the speed of light is about $3\ 10^{8}$ m s^{-1}. In other materials, such as Earth’s atmosphere, it drops by about 90 km/s – about .03% slower. We can also define the wavelength of an electromagnetic wave as the distance between one full cycle – this can be measured between successive peaks as shown here, or between successive ‘troughs’, or the distance between points where the electric component is 0. Another important property is the frequency, usually denoted f, of the wave – this is the amount of time it takes to go through a single cycle. The wavelength and frequency are both related to the speed of the wave according to this equation here: the speed of the wave is just the wavelength times the frequency.

Other properties of electromagnetic waves include the phase, or the fraction of a cycle. As you might have guessed, this is usually defined between 0 and 2π, or 0 and 360 degrees. Finally, there’s the amplitude, which is the height of the peak or the depth of the trough, and this is associated with the brightness or intensity of the light. The table here lists the different components, and their respective units. There is more to cover about the wave model, and we will return to this in Week 3 when we look at microwave remote sensing.

Slide 5 – The particle model

Remember that I said light can behave as both a particle and a wave. We’ve seen how we can describe light as a wave, and now we’ll take a look at the particle model. In this model, light is a particle, called a photon, that has a particular energy Q. Another of the big discoveries of 19^{th} and early 20^{th} century physics is that objects (that is, atoms), can only absorb and emit energy in discrete units, called quanta, or photons. And if you’re wondering, yes – this is where we get the term “quantum mechanics.”

The amount of energy, then, that a photon has is directly related to its frequency by a constant known as Planck’s constant. Using what we know about the relationship between the frequency and wavelength of light, we can re-write this using the equation on the bottom of the slide here, with the table showing the units of the different variables on this slide.

Slide 6 – Implications

So, the energy contained in a photon is inversely proportional to its wavelength. Or, put another way, longer wavelengths mean lower frequencies mean lower energy. And, conversely, shorter wavelengths mean higher frequencies mean higher energy. For remote sensing, this also means that longer wavelengths are harder to detect – we need more photons at lower energies to strike our sensor in order to register a signal, compared to higher-energy photons. This is a fact that we will keep coming back to as we look more at thermal remote sensing – it is one of the reasons why, for example, we don’t see high-resolution thermal sensors.

Slide 7 – Blackbody radiation

All matter that has a temperature above 0 Kelvin (-273.15 degrees Celsius) emits electromagnetic radiation. The amount of radiation that is emitted, also called the radiant emittance, strongly depends on the temperature.

For an idealized object, called a blackbody, that perfectly absorbs and re-emits all of the energy that falls on it, the radiant emittance is directly proportional to its temperature raised to the fourth power – this first equation here is known as the Stefan-Boltzmann law. So, relatively small increases in temperature lead to large increases in radiant emittance. In reality, most objects aren't perfect blackbodies – intstead, they emit some fraction of the electromagnetic radiation that blackbodies do. We can measure how well an object approximates a perfect blackbody via its emissivity, which is defined as the ratio of its emittance to that of a blackbody with the same temperature. And again, the table here shows the different units for the variables shown on the slide.

Slide 8 – Blackbody radiation

So, starting to put all of this together, we see that objects with higher temperature have higher energy; and, the electromagnetic radiation they emit will have a higher frequency, or a shorter wavelength. This also means that the "color" of electromagnetic radiation that an object emits changes as well.

The plot here shows how an object's radiance (amount of energy emitted) varies with both wavelength and temperature. Note that this is a semi-logarithmic plot – the steps on the y-axis represent an increase of 1000, while the steps on the x-axis go from 100, to 1000, to 10000, and so on.

Cooler objects, shown as darker lines on the plot, have lower overall radiance – and the wavelengths they emit most at are much longer. As we increase in temperature, we also increase the overall radiance – the peak gets higher and higher – and we shift the peak of the curve toward lower wavelengths.

In space, our sun appears mostly white because it emits fairly evenly across the wavelengths that we can see with our eyes, though our atmosphere changes this slightly. Wood fires with a temperature of around 1500 K appear mostly reddish-orange to our eyes, while the human body at ~300K doesn't really emit at all in the wavelengths our eyes can see.

We can calculate the dominant wavelength that an object emits (i.e., the color of its maximum radiance) using something called Wien's displacement law – I think we've had plenty of equations already in this lesson, so that's one for you to look up later.

Slide 9 – Electromagnetic spectrum

As we have seen, electromagnetic radiation comes in a large range of possible wavelengths or frequencies, which we call the electromagnetic spectrum.

We can somewhat arbitrarily divide the spectrum into regions of wavelengths with "similar enough" properties. As you can see here, the light that we can see with our eyes, known as visible light or visible EMR, makes up a very small portion of the electromagnetic spectrum, with wavelengths between about

400 and 700 nanometers. Just below visible light we have ultraviolet light, with wavelengths between about 10 and 400 nanometers. Above the visible spectrum we have infrared light, followed by microwaves and then radio waves, which can have wavelengths over several kilometers in length. Each of these different regions has its own properties that we can use to study different things.

Slide 10 – Thermal Infrared

As shown on the previous slide, the thermal infrared roughly covers the portion of the electromagnetic spectrum between 3000-35000 nm (or 3-35 μm). Within this region of the electromagnetic spectrum, there are three “atmospheric windows.” An atmospheric window is a region where the atmospheric transmission, or the percentage of radiation that the atmosphere lets through, is rather high, which usually means that satellites can actually observe these wavelengths. The first of these windows, from 3000-5000 nm, overlaps with reflected solar radiation. There are some sensors that record in this range, and we’ll cover those a bit later this week. The second window, from 17000-25000 nm, is not typically used for remote sensing – this is partly because longer wavelengths are harder to detect, but also because this window has a lot of absorption bands – areas where the atmospheric is essentially opaque to radiation. Finally, we have the window between 8000-14000 nm. This is the one we most commonly use for thermal remote sensing, because aside from the ozone absorption band at about 9600 nm, atmospheric transmission is generally uniformly high in this region. This region also overlaps nicely with the peak of Earth’s emitted radiation – meaning that we can use this region to estimate the temperature of the Earth’s surface.

Slide 11 - Summary

As we’ve seen, electromagnetic radiation, or light, has properties of both a wave and a particle, which is only a small part of what makes our universe such a strange and wonderful place.

The energy of electromagnetic radiation depends on its wavelength or frequency – higher wavelengths/lower frequencies mean less energy, and vice-versa.

All objects with a temperature over absolute zero (0K) emit electromagnetic radiation, the amount of which and color of which depends on the temperature.

Finally, we can think of electromagnetic radiation as existing on a spectrum of wavelengths or frequencies, and divide these up depending on their properties. The thermal infrared, which we will be covering this week, is usually considered to be the region between 3000 and 35000 nm (roughly).

When we are doing thermal remote sensing, especially from satellites, we typically use the region between 8000-14000 nm, because this represents both a strong atmospheric window, and the peak of Earth’s emitted radiation.

Slide 12 – Additional resources

You can read more about the topics we’ve discussed here in the two textbooks – Lillesand, Kiefer & Chipman, Chapters 1 and 4.8 – 4.11, or Cambpell & Wynne, Chapters 2 and 9. Or, read more about it from the Natural Resources Canada Remote Sensing Tutorials. I’ve also included links that cover some of extra topics we didn’t get into, like the photoelectric effect and “the ultraviolet catastrophe”, which goes into some more details about blackbody radiation and the history of its study. 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!