Slide 1 – Title Slide

Hello and welcome to Week 1, Part 5 of EGM703: Atmospheric Correction. In this lesson, we'll learn about a few different ways that we can correct for atmospheric effects in satellite images, focusing slightly more on the thermal infrared portion of the electromagnetic spectrum.

Slide 2 – Atmospheric effects

So far this week, we've covered how electromagnetic radiation interacts with the Earth's surface – the incident radiation can either be reflected, absorbed, or transmitted by the surface. We can also have molecules emitted by the surface. The same is true for the atmosphere, of course, since the atmosphere is also made up of atoms and molecules. As a result, what we "see" or measure with the sensor is not simply the interaction with the surface – there's also a component that comes from the atmosphere. If molecules in the atmosphere absorb radiation, that decreases the radiance that we measure with the sensor (and, as a result, the temperature that we estimate). If they emit radiation, that increases the radiance that we measure with the sensor, as well as the temperature that we estimate. They can also transmit radiation, which can also change what we measure at the sensor. Together, all of these effects create a bias, or shift, in the measurement that we're making – meaning that in order to have as accurate an estimate as possible, we need to remove the atmospheric component before we estimate the surface temperature. Unfortunately, this sounds more straightforward than it is, because how the atmosphere changes our measurement varies based on the atmospheric conditions at the time of acquisition.

Slide 3 – So what does the sensor see?

This leads us to discussing what it is that the sensor is actually measuring. Because there's comparatively less incident radiation in the thermal infrared, we don't actually measure much reflected radiation from the atmosphere. Remember that scattering processes depend heavily on the size of the particle relative to the wavelength – because we're observing at wavelengths much, much longer than most atmospheric particles, we also have very little scattering in the thermal infrared. All of this means that the signal we actually record in the thermal infrared consists of: the radiation emitted by the surface, modified by atmospheric transmission (this is the thing we actually want to measure!). We also have a component that is the reflected downwelling radiation – this is radiation that is emitted by the atmosphere, or by clouds, and then reflected by the surface, and modified by transmission through the atmosphere. Finally, we also have the upwelling radiation, which is the radiation that is emitted by the atmosphere. So, we can write this equation, which just says that the signal recorded by the sensor is the sum of these three components.

Slide 4 – Radiative transfer

The theory describing how electromagnetic radiation is transmitted through a medium, like the atmosphere, is known as radiative transfer. We can write a simplified version of the radiative transfer equation like this – even though it looks slightly different, this is the same idea as what we saw on the previous slide. Here, the radiance L measured at the top of the atmosphere at a given wavelength or channel, denoted i, is equal to: the emissivity multiplied by the blackbody radiance for a given surface temperature, T_s – this is what is emitted by the surface; one minus the emissivity (remember: this is the reflectance!) multiplied by the atmospheric irradiance – this is what is emitted at the bottom of the atmosphere and reflected by the surface. Both of these components are then multiplied by the atmospheric transmittance, since they have to actually make it through the atmosphere in order to be measured by the sensor. Finally, we have the atmospheric radiance – this is the radiation emitted at the top of the atmosphere. So, the key parameters that we have to know in order to estimate the atmospheric components are: the surface emissivity, since that determines the radiance emitted by the surface; the atmospheric transmittance, which depends on the atmospheric composition – for the most part, we're concerned here with how much water vapor there is in the atmosphere, at least for the thermal infrared wavelengths; and finally, the atmospheric temperature, because this determines what is emitted by the atmosphere.

Slide 5 – Atmospheric correction

There are a few different methods that we have available to actually do these corrections; we'll cover three of them here. The first is known as the empirical line method, or ELM – this is where we have in-situ measurements of radiance or reflectance, and we use these to estimate a function for calculating the atmospherically-corrected radiance as a function of the measured radiance. The example shown here is from a paper that uses this method for visible and near-infrared wavelengths, but the basic principle is the same for thermal infrared wavelengths. While this method is relatively straightforward to implement, the main downside of this is that we actually have to have in-situ measurements of radiance that correspond to the acquisition time – this is often more easily said than done. The second method we'll touch on is a radiative transfer model – this is where we actually try to model the atmospheric conditions at acquisition time. While doing the modelling is generally more complicated than the empirical line method, find the necessary meteorological parameters can be relatively easier than in-situ measurements of radiance. There are a few software packages available that will do this kind of modelling – one of the main ones is known as MODTRAN, which you can find at the website shown here; there's also the Temperature and Emissivity Separation algorithm described in this paper linked at the end of the presentation. The main output of radiative transfer models is usually the atmospheric transmittance – the other components of the radiative transfer equation can be estimated from the atmospheric temperature at different heights.

Slide 6 – Split-window methods

The final approach that we'll cover for atmospheric correction is known as a "split-window" method. First, let's remember that the spectral radiance and spectral emissivity are both dependent on the wavelength. The same is true for the atmospheric transmittance, tau – think back to this figure from the first lesson this week. What this means is that if we have observations at two different wavelengths, or wavelength bands, then we can: estimate the atmospheric components, recover the surface brightness temperature, and estimate the emissivity – in effect, what we can set up is a linear system of equations to solve for the surface temperature. Starting from the radiative transfer equation, after we do quite a bit of math that we won't get into in this module, we end up with the result that the surface temperature T_s is a linear combination of the brightness temperature in different bands – this is one reason why sensors such as ASTER and AVHRR have multiple thermal channels – to make estimating surface temperature that much easier. If you are interested in more of the details, there some articles uploaded to blackboard and the Zotero library for this module that go into more detail about these methods.

Slide 7 – Summary

The atmosphere is something that exists, which is great for life on Earth, even if it does make remote sensing more challenging.

This is of course because a sensor above the atmosphere is measuring both ground and atmospheric components of radiance, which means that if we want to study what's happening on the Earth's surface, we have to somehow correct for the atmospheric component.

To do this, we have to either use in-situ measurements from the same point in time that our image was acquired; model the atmopsheric parameters to solve the radiative transfer equation, or use observations at multiple wavelengths. As with everything else, each of these methods has their own advantages or disadvantages, and which option we choose will depend on our application, data availability, and so on.

Slide 8 – Additional resources

Once again, you can read further about most of the concepts we have covered in this lesson in the textbooks, chapter 7.2 of Lillesand, Kiefer & Chipman, chapters 2.5, 11.2, and 11.3 of Campbell & Wynne, and Chapter 6 of Jensen. I've also included a few links to some of the articles referenced in the slides here, including these two about MODTRAN, this one about the Temperature and Emissivity Separation algorithm, and this one about the empirical line method. 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!