Slide 1 – Title Slide

Hello and welcome to Week 1, Part 4 of EGM703: Converting Radiance to Temperature. In this lesson, we'll cover how we convert what the sensor actually measures, radiance, into what we want to measure or observe, which is temperature. We'll also talk about a few common satellite missions that we can use for our own thermal remote sensing applications.

Slide 2 – What is temperature, anyway?

In this lesson, we're going to cover how to go from radiance to temperature – but first, we need to be sure we're clear about what we mean by temperature. From previous lessons, remember that: all substances are made up of atoms or molecules, when we are above absolute zero, those atoms or molecules have some kind of vibrational motion; as a result of that motion, they also emit, or radiate, energy. Temperature, then, is a measure of the average energy contained in those atoms or molecules. If an object has a high temperature, it contains more energy in the form of heat. This isn't the end of the story, though. We can think of an object's kinetic temperature as its "true" temperature – this is the temperature that you measure if your thermometer is in contact with the substance – for example, when you stick a thermometer under your tongue. The radiant temperature, on the other hand, is what we actually measure with remote sensing. As you might have guessed by the fact that we're making this distinction, there is a difference between these two things, as we'll see.

Slide 3 – Radiance values

In order to estimate temperature from a satellite image, the image values need to be converted from digital numbers, or DN, to radiance. To do this, the sensor, and the images, have to be calibrated. This is normally done in one of two ways: internally to the sensor, normally using an onboard blackbody with a known radiance and temperature, or externally, using objects with known radiances in the image itself. For Landsat images like we'll be using in this week's practical, the calibration is performed by the USGS – all we have to do is take the rescaling values provided in the metadata and plug them into the equation shown here. In general, the calibration routine for most satellite images takes the form of a linear rescaling based on the minimum/maximum radiance recorded by the sensor, like the one shown here. Most sensors will have information available about the calibration procedure, and most modern sensors now provide the calibration values so that you can rescale the images yourself.

Slide 4 – Planck's law of blackbody radiation

Once we have radiance, we can use Planck's law of blackbody radiation to estimate the radiant temperature. We've seen this equation before, but this form of the equation gives us the spectral radiance as a function of wavelength and temperature. The constants here are: h, Planck's constant; k, the Boltzmann constant; and c, the speed of light in a vacuum. The units for each of the variables are shown here in the table on the side – note that because this is the spectral radiance, the units are Watts per steradian per cubic meter, since we're essentially dividing the radiance by the wavelength, which has units of meters. What this also tells us is that if we can measure radiance, we can calculate the radiant temperature by inverting this equation for temperature – we'll see what this looks like on the next slide. Remember again that most objects or materials are not perfect blackbodies, meaning they have an emissivity less than 1 – we'll need to take this into account in order to calculate surface temperature.

Slide 5 – Brightness temperature

When we invert Planck's law, we end up with an expression to calculate brightness temperature – this is the temperature that we would measure if all of the objects in our image were ideal blackbodies. Remember from the previous slide that h, c, and k are all constants – for a given sensor, so is the wavelength. This means that we can simplify this slightly to the following form, where K_2 is equal to h times c divided by k times lambda, and K1 is equal to 2 times h times c squared, divided by lambda to the fifth power. For Landsat images, the USGS gives the sensor-specific values of K_2 and K_1, which you will see in this week's practical.

Slide 6 – Emissivity correction

Remember, this is all assuming that we are observing blackbodies. Unfortunately, the world is not so simple as that, and we have to somehow correct the brightness temperature to account for this fact, in order to estimate the surface temperature. In this equation, we see that we calculate the surface temperature as a function of the brightness temperature and the emissivity of the surface. Of course, this approach neglects the atmospheric component of the spectral radiance, or assumes that it's already been accounted for – in the next lesson, we'll look at some ways that we can do this.

Slide 7 – Advanced Very High Resolution Radiometer (AVHRR)

Now, we'll shift focus slightly to look at a few of the satellitle sensors that we might use to estimate surface temperature. The first of these is the Advanced Very High Resolution Radiometer, or AVHRR. AVHRR was first launched in 1978 aboard the TIROS-N satellite. AVHRR operates in two different modes: the first is local area coverage, or LAC – this operates at approximately 1.1 x 1.1 km resolution; the second is global area coverage, or GAC, which operates at approximately 1.1 x 4 km resolution. AVHRR comes in two different versions that have either 4 or 5 bands; the first version acquires in thermal infrared wavelengths between 10.5 and 11.5 µm. The second version has two thermal infrared bands, with Band 4 acquiring at wavelengths between 10.3 and 11.3 µm, and Band 5 between 11.5 and 12.5 µm. AVHRR is still in operation on a few different satellites, though the sensor design has since been succeeded by the Visible Infrared Imaging Radiometer Suite, or VIIRS. To download AVHRR data, head over to earthdata.usgs.gov. You'll need to open a free account to access the data, if you don't already have one.

Slide 8 – The Landsat program

We’ve worked with Landsat data before, but I thought it might be worth it to revisit the thermal infrared bands specifically. The first Landsat sensor to feature a thermal band was the Thematic Mapper, carried on both Landsat 4 and 5. The temporal coverage for these images ranges from 1982 to 2011, though the temporal resolution is often extremely variable. Band 6 of TM acquired in the thermal infrared between 10.4 and 12.5 µm, at 120 m spatial resolution. At this point, I would like to once again remind you that spatial resolution and pixel size are not the same thing – when you download Landsat data, the thermal bands have been re-sampled to 30 meters, to match the other bands. The next Landsat sensor to carry a thermal sensor was the enhanced thematic mapper plus, carried on the Landsat 7 satellite. The temporal coverage for these images starts in 1999 and is still ongoing, though Landsat 7 is rapidly approaching the end of its mission. Like TM band 6, ETM+ band 6 covers wavelengths from 10.4 to 12.5 µm, though with a spatial resolution of 60 m (resampled to 30 m). After that, we have the Thermal Infrared Sensor, or TIRS, carried aboard the Landsat 8 satellite. These images cover 2013 and are still ongoing, with two thermal infrared bands: band 10, from 10.6 to 11.19 µm; and band 11, from 11.5 to 12.51 µm. Each of these bands have a spatial resolution of 100 m, resampled to 30 m pixel size. And, coming very soon, we will hopefully have a Landsat 9, which has a launch planned for no later than 23 September 2021! This satellite will carry an upgraded version of the Landsat 8 sensors, with data hopefully starting to be acquired before the end of 2021. You can get Landsat data by heading to earthexplorer.usgs.gov – as with earthdata.nasa.gov, you’ll need to sign up for a free account.

Slide 9 – ASTER

The last sensor we’ll look at today is ASTER, Advanced Spaceborne Thermal Emission and Reflection Radiometer, carried aboard NASA’s Terra satellite. ASTER started acquiring data since 2000, and as of 2021 it is still acquiring, with the end of the mission planned for September 2023. ASTER has 5 bands in the thermal infrared, which makes it especially useful for studying surface temperature and emissivity. ASTER TIR bands have a 90 m spatial resolution, so a comparable spatial resolution to Landsat 8 TIRS scenes. NASA also provide Level-2 data, including both atmospherically and emissivity-corrected surface temperature, as well as emissivity products. All of these data are available at earthdata.nasa.gov.

Slide 10 – Summary

As we’ve seen, in the thermal infrared, satellites measure the radiance emitted by Earth’s surface.

Once we have calibrated these measurements, we can calculate the brightness temperature of the Earth’s surface using the measured radiance and by inverting Planck’s law for blackbody radiation.

In order to calculate the land surface temperature, though, we need to know the emissivity of the surface. We should also correct for atmospheric effects, which we will discuss more in the next lesson.

We also looked at a few different sensors that provide thermal infrared data – these are, of course, not the only options, and we’ll see a few more examples over the next couple of lessons.

Slide 11 – Additional resources

Once again, you can read further about most of the concepts we have covered in this lesson in the textbooks, chapter 4.11 of Lillesand, Kiefer & Chipman. I’ve provided links to more information about AVHRR and the Landsat Calibration/Validation procedure here, as well as links to a couple of papers that cover estimating surface temperature from thermal infrared images – for even more examples, please see the Zotero Group Library for this module. 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!