# Slide 1 – Title Slide

Hello and welcome to Week 1, Part 6 of EGM703: Applications of Thermal Remote Sensing. In this lesson, we'll look at a few different example applications of thermal remote sensing.

# Slide 2 – (Some) Applications of TRS

I mentioned that we'll look at some of the applications of thermal remote sensing here – obviously this is only a small subset of the different applications that we can find, but I've tried to find what I think is an interesting balance of different disciplines and approaches here. We'll start by looking at a few different examples from Volcanology, before looking at Urban Heat Islands, global wildfire monitoring, and sea surface temperature.

# Slide 3 – Volcanology: Hot spot detection

The first volcanology application we'll cover here is hot spot detection. A hot spot is defined as a pixel, or group of pixels, that are significantly brighter (i.e., hotter) than the surrounding pixels. The example here, taken from a 2004 paper by Pieri and Abrams, illustrates this nicely. In these thermal band images, we can see clearly that most of the volcano is dark, meaning lower temperatures – except for a few exceptionally bright pixels that we can see here near the summit of the volcano. In night-time images like these, hot spots tend to stand out even more, because of the diurnal cycles that we covered earlier this week. On volcanoes, hotspots can be indicative of increased activity – for example, active fumaroles, or places where hot volcanic gases vent into the atmosphere; they can also indicate crater lakes, or active lava flows. The examples shown here are from Chiliques Volcano, Chile, which started to show increased thermal activity in 2002, possibly indicative of increased activity before an eruption; as of now, at least, the volcano is still dormant.

# Slide 4 – Volcanology: lava flows

On the previous slide, I mentioned active lava flows – these are, of course normally incredibly hot, usually in excess of around 400 Kelvin. At higher temperatures, there is significant emission in the shortwave infrared, as well as the thermal infrared – this is something that can help us with atmospheric correction, since it gives us an additional "window" to use to estimate the atmospheric components of the radiance measured at the sensor. In the example shown here, from a paper by Harris et al., they used repeat Landsat ETM+ images to help map lava flows at a volcano in Guatemala called Santiaguito. Repeat thermal images can also help to estimate cooling rates, which helps us understand how these flows are changing over time.

# Slide 5 – Volcanology: $SO_2$ concentration

In addition to lava, volcanoes also emit gases, such as sulfur dioxide, or $SO_2$. We can see two examples here from the Pieri and Abrams paper – the first is a false-color thermal infrared composite that shows a sulfur dioxide plume in purple; the second is an image that shows an estimate of how much sulfur dioxide is present in the plume. For most life forms, sulfur dioxide can be quite hazardous to breathe, and it might also be indicative of increased activity and the potential for eruptions, so it's something that volcanologists often try to monitor. How much absorption (or emission) there is in a plume is heavily tied to the concentration of sulfur dioxide and other gases, which means that with observations from multiple thermal infrared bands, we can actually estimate these concentrations and monitor them over time, especially using sensors such as MODIS, which acquire images on an almost daily basis. The example shown here, from a 2004 paper by Watson et al., shows the estimated sulfur dioxide concentration during an eruption of Mount Cleveland, Alaska, in 2001.

## Slide 6 – Urban Heat Islands

Switching topics slightly, another major application of thermal remote sensing is in studying urban heat islands. Urban, or built-up, areas tend to be hotter than surrounding rural, or not built-up, areas. This is in part because impervious surfaces such as concrete or asphalt tend to be much better at absorbing or holding heat – if you've ever walked across a car park in the middle of the afternoon on a hot summer day, you have no doubt noticed this effect. In contrast, natural or vegetated surfaces tend to be better at regulating heat and keeping temperatures lower. The figure here comes from a 2021 paper by Benz and Burney, which looked at the variation in urban heat island effects in the United States. It shows the difference in daytime temperature during extreme heat events for urban census tracts versus rural census tracts in the same region – we can see that, in general, the darkest areas corresponding to the largest change in temperature are located in built-up areas. Because urban areas are not all the same, however, there can be significant variation, even in the same city. What this paper showed is that in the United States, there was a significant correlation between the most extreme urban heat islands and the race and economic class of the people that live there. In general, the poorest areas, or those areas with the highest number of minority residents, tended to be much hotter than more wealthy areas, or areas with a larger share of white residents. This has significant consequences for public health, ...

## Slide 7 – Urban Heat Islands

A 2019 review paper on urban heat islands found that since 2005, the number of studies of urban heat islands has positively exploded, especially for cities in Asia, with an increase of only a few papers published between 1972-2000, to over 200 published between 2010 and 2018. The marjority of these studies use freely-available data, including Landsat images from a variety of sensors; or MODIS images, which partly explains the massive increase. In general, these studies have broadly agreed on what controls the distribution of urban heat islands – as we mentioned on the previous slide, this is broadly related to factors such as impervious surface area, albedo, and vegetation cover, but also landscape cover and climate. Based on this review, the main limitations for studies of urban heat islands are that the measured surface temperature is not directly comparable to the air temperature, which means that direct validation can be more difficult; in addition, cloud-free images are often difficult to find, which can bias results; there are also issues related to resolution – for example, MODIS images are acquired more frequently than Landsat images – every 1-2 days compared to 8-16 days – but at a much lower spatial resolution of 1 km, compared to roughly 100 meters.

## Slide 8 – Wildfire monitoring

Another big application of thermal remote sensing is in monitoring and studying wildfires. For an actively burning wildfire, the radiance at approximately 4 µm is much higher than the radiance at approximately 11 µm. Remember that from Wien's displacement law, the wavelength of peak radiance is inversely related to the temperature – for a wildfire burning at several hundred Kelvin, the radiance emitted at 4 µm is going to be much brighter than the approximate "background" temperature of 300 K, especially because we're often talking about sensors with a resolution of several hundred meters to over a kilometer. As we've mentioned before, MODIS, the moderate resolution imaging spectrometer, acquires images every 1-2 days, depending on the location, and it also has multiple bands in both the "mid" infrared around 4-5 µm, as well as in the thermal infrared, around 10-11 µm. This means that we can use MODIS, as well as the fact that fires have much brighter radiance in the mid-infrared compared to the thermal infrared, to study global wildfire dynamics, as was done in this 2006 study by Giglio et al. By dynamics, I mean factors such as the duration and timing of the wildfire season in a given area, as well as the intensity. With observations that stretch back over two decades at this point, we can also study these factors over longer time periods, and see how they are changing in the face of climate change.

## Slide 9 – Sea Surface Temperature

The final application that we'll cover is sea surface temperature. The first observations of sea surface temperature from space were made in 1967, One thing to keep in mind, however, is what exactly we're measuring when we say "sea surface temperature". What we measure with a satellite is usually the so-called "skin" temperature – this is the temperature emitted by the surface at a depth of approximately 10 µm for the wavelengths typically used. Depending on ocean conditions, though, this can vary significantly from the water temperature at even 1 mm depth, so we need to be mindful of this when interpreting the satellite observations. The first global observations of sea surface depth were made by 1972, but it wasn't until 1979 that we had satellite sensors with channels at different wavelengths that enabled us to use the split-window atmospheric correction methods that we discussed in the previous lesson. The main sensors that are used for observations of global sea surface temperature are: AVHRR, which has observations available from 1978 to the present (though only 1979 using multiple bands); the (advanced) Along-Track Scanning Radiometer, with observations from 1991 to the present; MODIS, 2000 to the present; the Visible Infrared Imaging Radiometer Suite, which succeeded AVHRR, available from 2011 to the present; and the most recent addition, the Sea and Land Surface Temperature Radiometer on-board the Sentinel-3 series of satellites, first launched in 2016. For smaller-scale or higher-resolution studies, other sensors that we have covered, such as ASTER or the various Landsat sensors, are also quite useful.

## Slide 10 – Summary

In this lesson, we've looked at a few different applications of thermal remote sensing. As we've seen, there are a number of different applications across a number of different fields; importantly, thermal remote sensing is not limited to applications that deal directly with land surface temperature! For example, we looked at how thermal remote sensing can be used to estimate volcanic plume composition, to help in monitoring volcanoes; other applications, which we'll look into a bit more next week, include mineral identification. Of course, there are many examples of applications that do deal directly with land surface temperature.

## Slide 11 – Additional resources

As always, I've included links to the different articles referenced in this presentation here – they're also available on the slide notes, and you can find PDF versions of the articles on Blackboard or in the Zotero library. I've also added a few additional papers to the Zotero library that weren't covered here, so feel free to browse those as well. 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!