

## **Slide 1 – Title Slide**

Hello and welcome to Week 10, part 3 of EGM310: Passive Sensors.

## **Slide 2 – Recall**

In the previous lesson, we learned that remote sensing typically involves measuring electromagnetic radiation – in order to measure electromagnetic radiation, we need a source of electromagnetic radiation. The previous lesson covered sensors where the source of electromagnetic radiation is the sensor itself – active sensors. In this lesson, we'll learn about sensors that record energy that has been reflected by the sun, or emitted by the earth surface – called passive sensors.

## **Slide 3 – Emitted radiation**

Recall from last week's lessons that the energy emitted by an object depends on the wavelength we're observing, and its temperature,  $T$ . On Earth, where most surfaces have relatively low temperatures (typically below a few hundred Kelvin), this means that the amount of energy emitted is relatively low, and so it is also more difficult to detect – more energy needs to strike the sensor in order to be registered, which also means that the sensor footprint is quite large, and the spatial resolution of the sensor is quite low. At lower temperatures and longer wavelengths, the difference in emitted energy by an object is more due to the object's physical properties, rather than the temperature. You can see this on the graph, where the difference in radiance at 106 nm (1 mm, corresponding to the beginning of the microwave portion of the electromagnetic spectrum) is much smaller than it is at 104 nm (in the thermal infrared). Two common applications for measuring emitted radiation are for measurements of soil moisture – the amount of radiation emitted by soil has a strong dependence on its moisture content – and for measuring sea ice concentration. Similar to soil moisture, the formation of sea ice on the surface of the ocean has a strong impact on the energy emitted by the surface, which we can measure with passive microwave radiometers.

## **Slide 4 – Visible and Infrared (optical) sensors**

The next type of passive sensor that we'll learn about are what are called optical, or visible and infrared, sensors. These are the types of sensors that we'll spend the rest of the semester working with, as they produce images that feel very familiar to us, unlike sensors that record microwave radiation. Visible and infrared sensors are also known as optical sensors because they work on a principle similar to cameras – they focus and collect incoming radiation using a lens or a rotating mirror. They then split the signal into its component wavelengths, recording the signal on a detector array. There are two main types of optical sensors that we'll discuss here, which have different scanning geometries – that is, the way they record images is different.

## Slide 5 – Optical-mechanical (whiskbroom) sensors

The first of these two types of sensors are what are known as optical-mechanical, or whiskbroom, sensors. These sensors use a rotating mirror, which scans lines perpendicular to the motion of the satellite – ‘sweeping’ along like a whiskbroom. The sensor scans across like this, rotating back to the start as the satellite moves along. Inside of the sensor, the signal is reflected off the rotating mirror, where it is split by the sensor into different wavelengths and then recorded on a detector array. The detector array works similarly to the camera in your cell phone – incoming light strikes a sensor chip, which creates an electrical signal that is then recorded. The good thing about optical-mechanical sensors are that because the signal is scanned, we can get by with fewer detectors – we don’t need enough detectors to cover the whole field of view of the sensor. To give you an idea, the first Landsat sensor, the Landsat 1-5 Multispectral Scanner, only had 24 detectors (6 detectors for each of 4 wavelength bands). The Landsat thematic mapper had a total of 100 detectors - 16 detectors for each of 6 bands in the visible and near/shortwave infrared, plus 4 detectors for thermal infrared wavelengths. Landsat 7 ETM+ had 136 detectors – 96 detectors for the same visible and near/shortwave infrared wavelengths as TM, plus 4 extra detectors in the thermal infrared and 32 detectors for the panchromatic band. In all, not very many detectors needed, which helps cut down on costs. Fewer detectors also means fewer detectors that we have to calibrate – something that we’ll discuss more in the next lesson. Unfortunately, optical-mechanical sensors also require us to have moving parts in space, which isn’t always easy to work with. Space is not a nice place for an instrument, and moving parts have a tendency to break. Because of the way they record, the image geometry is also significantly more complicated, which can be difficult to work with. Finally, because the sensor only has a very small amount of time to “observe” each small area on the ground, the signal recorded is weaker, which can mean noisier, less sharp images.

## Slide 6 – Linear array (pushbroom) sensors

The second of these two types of sensors are what are known as linear array, or pushbroom, sensors. This name comes from the fact that the sensor is basically “pushed” along the orbit by the satellite, sampling perpendicular to the motion of the satellite. These sensors consist of an array of detectors that are located on the “focal plane” of the sensor, similar to how a camera functions. The good thing about pushbroom sensors is that they don’t have moving parts, at least within the sensor itself. Space is not a very nice place for an instrument, and the fewer moving parts the better – more on this in a minute. They also mean that the detector has longer to record – because the signal is not being scanned over the field of view, each of the detectors “sees” an area on the ground, which means the signal being recorded is stronger, and the images are sharper. It also means a simpler image construction – we’re basically reading the image as if we’re scanning along the satellite path. The bad news is, we need a lot more detectors than for optical-mechanical sensors, which very quickly gets expensive. Landsat 8 Operational Land Imager, the most recent Landsat instrument, has a total of 7000 detectors per band, for each of 11 bands. Compare that to the 136 detectors used for its predecessor. The Advanced Spaceborne Thermal Emission Radiometer (ASTER) has a total of 5000 detectors per band for each of 15 bands – and it was built back when these detectors were significantly more expensive than they are

today. More detectors also means we have more detectors to calibrate, which can become difficult to work with over time, as the detector arrays degrade.

## **Slide 7 – Moving parts are not ideal**

But, not having moving parts is a big advantage that pushbroom sensors have. The image on the left here is a Landsat 7 image acquired in 2001 or 2002 – it looks very nice – we can clearly see the mountains and glaciers here on the coast of Alaska. The middle diagram shows how the Landsat 7 scan-line corrector, or SLC, works. As the satellite moves along its orbit, the scanner is actually observing a different location when it returns to one side of the scan or the other – causing a gap in the image. The SLC is meant to correct for this, by compensating for the forward movement, making sure that each successive scan starts where the previous one left off. In May 2003, the SLC instrument failed, meaning that the scanner was no longer compensating for the forward movement of the satellite. As a result, Landsat 7 images acquired after May 2003 have these black stripes in them, which start slightly away from the middle of the scene and get bigger towards the edges of the scene. Unfortunately, this means that there are large gaps present in these images, as they represent areas where the sensor didn't actually scan. For some applications, you can “fill in” the gaps using other images, but this doesn't necessarily help in all cases.

## **Slide 8 – Summary**

In this lesson, we learned about how passive sensors rely on external energy sources, such as the sun or energy emitted by the Earth's surface.

We also learned that visible and infrared (also known as optical) sensors typically come in two main types – the first, optical-mechanical scanners, act like a “whiskbroom” sweeping perpendicular to the motion of the satellite. The second, linear array or “pushbroom” scanners, push a line of detectors along the satellite track. Each of these sensors have their advantages, but one main lesson to keep in mind is that moving parts in space are not ideal.

## **Slide 9 – Additional Resources**

Once again, you can read more about the concepts we've covered in this lesson in the textbooks, Chapter 4 of Lillesand, Kiefer & Chipman; and Chapter 6 of Campbell & Wynne. You can also read more in the online Remote Sensing Tutorials from Natural Resources Canada. I've also included a link to a lecture from a professor at The University of Colorado at Boulder, that covers some of the different climate applications of passive microwave remote sensing. It's not too long, only about 10 minutes or so, and it goes into more detail about one of the really powerful remote sensing tools that is perhaps less well-covered than others. 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!