Slide 1 – Title Slide

Hello and welcome to Week 4, Part 5 of EGM703: Applications of Passive Microwave Remote Sensing. In this lesson, we'll learn about different scientific applications of passive microwave remote sensing.

Slide 2 – Applications of Passive Microwaves

We'll look at examples of how passive microwave remote sensing can be used to study soil moisture, sea surface temperature and salinity, sea ice, and different types of snow studies. As always, these are not the only applications out there, but rather a small selection.

Slide 3 – Emitted (passive) microwaves

Before we jump right in, we should talk a little bit about emitted, or passive, microwaves, and how we measure these. We can divide instruments that measure passive microwave radiation into two main varieties: the first, sounding radiometers, are primarily used to study atmospheric properties. The second, imaging radiometers, operate a bit more like what we are used to – the antenna moves in order to create a two-dimensional "image" of the radiation emitted from a given area. Remember that the radiation emitted by an object is typically very low at longer wavelengths – this means that the signal received tends to be very weak. Because the amount of radiation measured by the sensor is related to the size of the antenna (like real-aperture radar!), we typically need to have an impossibly large antenna to get high-resolution images – as we a result, we're typically talking about ground sampling distances on the order of a few kilometers. A few recent examples of passive radiometers are the advanced microwave scanning radiometer 2, or AMSR-2. This instrument rotates its antenna across an angle of 122 degrees as it moves, across a swath of 1450 km. The second example we'll look at is the soil moisture active/passive satellite, which used a combination of a SAR instrument to measure reflectance (which helps us work out the emissivity, remember), and a scanning radiometer to measure the emitted radiation. The antenna for this instrument rotated in a full circle as it orbited, covering a 1000 km-wide swath. We'll see a few examples of what the data collected by these sensors was used for as we move on in this lesson.

Slide 4 – Soil moisture

The amount of radiation emitted from soil has a very strong dependence on the soil moisture content. To see why, consider that the real part of the dielectric constant for dry soil, ε_r', is about 3.5, while for water it's over 20 times that, at about 80. You can see in the graphs here how this varies for different soil moisture percentages – the graph on the left show the real part of the dielectric constant, while the one on the right shows the imaginary part. From this, we can also see that the penetration depth for soil will also depend on the moisture content – wet or saturated soil has a lower penetration depth than dry soil. The emissivity for saturated soil at about 5 GHz (C-band microwaves) is about 0.6, while for dry soil it's above 0.9. Other things we do have to keep in mind for estimates of soil moisture are vegetation cover, the penetration depth, as mentioned before, and the different sensor parameters, including the frequency/wavelength, the viewing angle, and the polarization – all of these have an impact on what the sensor actually measures, and whether we can effectively estimate the soil moisture content from those measurements.

Slide 5 – Sea surface temperature and salinity

Like for other surfaces, the radiation emitted by the ocean surface is dependent on the physical properties of the ocean, such as the temperature; it also depends on the chemical properties, such as the salinity. From the graph on the left here, we can see how the derivative of measured brightness temperature with respect to sea surface salinity (SSS) varies as a function of both frequency and viewing angle. The vertical red line here highlights the 1.4-1.427 GHz band, which is protected for Radio Astronomy – at these frequencies, we don't have to worry as much about interference from other transmitters. On the right, we can see how the relationship between brightness temperature and salinity changes with the sea surface temperature – in order to accurately estimate the sea surface salinity, we need to know the sea surface temperature. Similar to many of the other applications we've discussed over the course of this module, other things that we have to keep in mind are things like reflected radiation, atmospheric effects, ionospheric effects, and surface roughness, all of which can change the amount of radiation recorded by the sensor. Two example satellites/sensors that we can use to estimate sea surface salinity are the soil moisture and ocean salinity satellite, or SMOS, operated by ESA and launched in 2009; another is one we've seen already, the soil moisture active/passive mission, which operated in 2015.

Slide 6 – Sea ice monitoring

In general, ice crystals emit more energy than liquid water does at microwave wavelengths. This means that we can use emitted microwave radiation to differentiate between open ocean and sea ice; using techniques similar to spectral unmixing, we can also estimate the concentration of ice in a given pixel. And, with enough years of data, we can also look at trends in ice extent over time – we've been using passive microwaves to study sea ice extents and concentrations from space since about 1978. Another thing that we can use passive microwaves to do is to estimate the "age" of sea ice – as sea ice survives a summer melt season, its physical and chemical properties change. This so-called "multiyear" ice contains less brine, as it has been effectively flushed out during the melt season; it also has more air pockets, and it tends to be stiffer/stronger than first-year ice. All of these images come from the National Snow and Ice Data Center, or NSIDC, which keeps records of the extent, concentration, and age of sea ice in both the Arctic and Antarctic measured using passive microwave remote sensing and other techniques.

Slide 7 – Snow depth mapping

Snow crystals help to scatter emitted radiation, which means that deep snow tends to have a lower brightness temperature due to the increased number of scatterers, at least when compared to shallow snowpacks. Using the measured radiation emitted by the ground surface, we can estimate the depth of the snowpack over time, as illustrated here. This map, from a 2008 study by Che et al., shows the distribution of the average winter snow-depth in China over 1978-2006, based on data from two microwave radiometers, the scanning multichannel microwave radiometer, or SMMR, and the Special Sensor Microwave/Imager, or SSM/I. To accurately map snow depths using these methods, we need to consider the snow conditions – for example, the grain size and density, which will also affect the brightness temperature measured by the sensor. As always in microwave remote sensing, the presence of liquid water also has a strong impact – wet snow emits very differently from dry snow, and as a result it is more difficult to estimate snow depth using the emitted microwave radiation. We also need to consider vegetation cover, as this will also have an impact on the brightness temperature measured by the sensor. Finally, we have to consider precipitation, which shows a similar scattering signature to snow in certain frequency bands.

Slide 8 – Snow melt mapping

As snow melts, its emissivity changes – dry snow behaves more as a volumetric scatterer, while wet snow behaves more like a surface scatterer, with an emissivity that very nearly approaches 1. While we can't use this to map snow depths, we can use this to map melt extents, as illustrated here for the Greenland Ice Sheet. Using SSM/I data, this 1995 study by Abdalati and Steffen shows the annual melt extent on Greenland for 1998-1991. The emitted radiation measured by the sensor also depends on the polarization – by comparing the signal in different bands at different polarizations and taking a threshold value, we can map when melt has occurred for a given location, as illustrated by the graph here showing the normalized difference between the brightness temperature in the horizontally-polarized 19 GHz channel and the brightness temperature in the vertically-polarized 37 GHz channel of the sensor. From the plot, we see how the onset of melt in the two years when a research camp was established, and how this lines up with where the normalized difference goes above the chosen threshold value of -0.025.

Slide 9 – Summary

In this lesson, we've discussed how we have two main flavors of passive microwave systems: imaging radiometers and sounding radiometers. Sounding radiometers are primarily used for measuring atmospheric properties, while imaging radiometers are used for a number of different purposes.

Because the levels of radiation emitted at microwave wavelengths are very low, these sensors tend to have a low spatial resolution.

Despite this, there are a number of important climate applications of passive microwave remote sensing, including soil moisture, sea surface properties, sea ice, and more.

Slide 10 – 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!