

Talking points for SatFC-J Module: Introduction to Microwave Remote Sensing (with a focus on passive sensing)

Slide 1: Course Title

- This module is part of the Satellite Foundational Course for JPSS

Slide 2: Module Title

- And is an Introduction to Microwave Remote Sensing (with a focus on passive sensing)

Slide 3: Learning Objectives

- This is a *general* introduction to microwave remote sensing.
- This will help put into perspective *how* microwave remote sensing complements visible and infrared observation and *why* it is important.
- We'll look briefly at properties that influence the interpretation of microwave measurements.

Slide 4: Product Preview

One of the benefits of microwave imagery is the unique products that are produced. Total Precipitable Water (TPW), Cloud Liquid Water (CLW), Rain Rate (RR). Wind Speed (WS) and SST and soil moisture information is incorporated into analysis and modeling activities. This module gives an introduction as to how this is possible.

Slide 5: Types of Microwave Instrumentation

- The instruments used in microwave remote sensing includes both imagers and sounders. Imagers are designed to gather high-resolution detail in the horizontal. Sounders are designed to capture detail in the vertical. Sounders tend to have more channels than imagers and the channels are strategically placed to measure properties at various heights in the atmosphere so that the end result is a 3-D view.

Slide 6: Types of Microwave Sensors

- Microwave sensors can be further divided into passive and active sensors.
 - The microwave energy detected by a passive sensor is a combination of radiation emitted by the atmosphere, that naturally emitted from the Earth's surface, and transmitted radiation. Passive microwave sensors include scanning radiometers for imaging.
 - The amount of *naturally* emitted microwave radiation is generally quite small, so active sensors provide their own source of radiation and the backscattered signal is measured. An example of an active sensor is the Dual-frequency Precipitation Radar (DPR) on the Global Precipitation Measurement (GPM) Mission.
 - In this module, the focus is on Passive sensors.

Slide 7: Global Coverage 2X Daily

- For a polar-orbiting satellite, a point on the earth can be imaged 12 hours apart; once during the day and the other at night; one will be a descending pass, the other an ascending pass. There is currently no microwave instrumentation in geostationary orbit. Microwave imagery can view all weather conditions (clear, non-precipitating and precipitating clouds) and hence enhance our observations and understanding of the weather. In a constellation module of this foundation course more information will be provided about the orbit and swath width of particular satellites and instruments used in microwave remote sensing.

Slide 8: Electromagnetic Spectrum

- This slide orients the microwave region (highlighted by the green dashed oval) within the electromagnetic spectrum. As shown here wavelength increases from left to right, which is what we're used to expressing in the infrared and which is to the left of the microwave region at shorter wavelengths. Radiation can also be expressed in terms of energy or frequency which is inversely proportional to wavelength. From the IR perspective, frequency is backwards and decreases from left to right.

- For historical reasons it is most common to use frequency rather than wavelength as the unit and it is often expressed in gigahertz. The frequency range most used for meteorological applications ranges from 1 to 200 GHz.
- Emitted microwave energy is less than in the infrared region of the spectrum and decreases with increasing frequency. The remote sensing of longer wavelengths requires a larger optical lens as well as a large receiving antenna. How far the sensor is from the source also contributes to the size of the lens and the antenna (think local radar versus one in polar orbit at 800 km vs one in geostationary orbit at 36000 km). This is one of the reasons why it's been challenging to get a microwave sensor on geostationary orbit. Currently microwave is only in low-earth and polar-orbiting satellites. Spatial resolution is generally coarser for microwave products than infrared products.

Slide 9: Microwave Spectrum

- This zoomed in view shows the microwave region of the spectrum with the vertical transmittance to space for a standard mid-latitude cloud-free atmosphere on the y axis. The frequency range on the x-axis goes from large to small. If the atmosphere were completely transparent to microwave energy, this graph would show a horizontal line across the top near the value "1". It shows the major absorbing regions of oxygen and water vapor that are used in atmospheric temperature and moisture profiles, and window regions where the surface can be observed.

Slide 10: Absorption Regions vs Window Regions

- Observed brightness temperatures are influenced by absorption and emission properties, transmission, and scattering. For a clear sky or one that has non-precipitating clouds, the dominant properties are absorption/emission, and transmission (as shown here above the purple line). Non-precipitating clouds are transparent in the microwave because cloud droplets (which are less than 0.1 mm radius) are much smaller than microwave wavelengths (at cm) so that scattering is negligible. However, scattering has an important role in detecting ocean surface winds and when precipitating clouds are present, such as determining precipitation type and rain rate. These processes are shown here below the purple line. More information will be presented in the modules on winds and the influence of clouds and precipitation respectively.

Slide 11: Window View of Surface Features

- This and the next 3 slides show example microwave channel imagery. The channels are from the Advanced Technology Microwave Sounder (ATMS) on the Suomi National Polar-orbiting Partnership satellite and are also available from NOAA-20. This is the 31.4 GHz window channel. For interpretation of what is shown here, it is important to note that land emissivity is variable with a high mean value around 0.95 and ocean water emissivity is more consistent but with a low value around 0.5. The ocean emissivity in particular makes detection and measurement of atmospheric phenomena far easier over ocean than land due to the high contrast between the relatively cold background of the low-emissivity ocean surface and warmer emission from falling rain. In this view of the surface, notice the temperature range from 150 to 300 degrees Kelvin and where those values are located. Do these make sense? From a normal IR perspective, no. For a surface of 300K, and an emissivity of 0.95, the sensor observed temperature would be 285 (288.6K/15.5C) – which is within the ballpark of what we are seeing over the land surfaces. For a surface of 300K, and an emissivity of 0.5, the sensor observed temperature would be 150K/-123C – which is within the ballpark of what we are seeing for the coldest temperatures over the ocean. The warm green blob over the ocean is Hurricane Maria.

Slide 12: "Dirty" Window View

- From the same ATMS (Advanced Technology Microwave Sounder) swath, this is the 88 GHz channel with the same color bar as the previous slide. Recall from the mid-latitude microwave spectrum graph shown in slide 9, transmittance at this frequency is 0.8 due to "contamination" by water vapor. Notice there are no very cold "blue" values. There is moisture above the surface which is absorbing and reemitting at a warmer temperature. Over the ocean, what we saw as cold/clear blue regions in the previous image are now warmer so this channel can be readily compared with the previous channel to derive a moisture component. The eye and bands of Hurricane Maria are more easily discernable to the east of the

Bahamas. There are differences between the precipitating clouds, the non-precipitating clouds and the clear moisture laden regions causing them to stand out. We don't see this distinction over land surfaces because the high emissivity of the surface essentially overwhelms the cloud signal.

Slide 13: Water Vapor Absorption

- This band at 183 GHz from ATMS for the same swath and having the same color bar as the previous slide is in the water vapor absorption region and is generally insensitive to surface emissivity. If we took off the map, we could not readily distinguish between land and water areas. In a general sense, this is similar to the water vapor channels in the infrared (~6.0 to 7.5 μm region). Because of sensitivities to precipitating and non-precipitating clouds and moisture regions, we can discern eye and bands from Hurricane Maria.

Slide 14: Oxygen Absorption

- For comparison, here is another image from ATMS on S-NPP for the 57.3 GHz channel covering the same area and having the same color table as the previous 3 slides. This is in the oxygen absorption region and corresponds to the upper troposphere around 300 mb. You notice that it would be very difficult to discern that there is a tropical cyclone. In the next module on absorption, there will be a brief overview on obtaining moisture and temperature profiles with the oxygen and water vapor channels.

Slide 15: Products: Vertical Profiles

- Microwave information can also be displayed in vertical profiles. Here is an example of humidity profiles derived from the Advanced Technology Microwave Sounder (ATMS) on S-NPP. This graph also shows that this information can be merged with the Cross-track Infrared Sounder (CrIS), another instrument on S-NPP, to obtain a more detailed humidity profile representation. The vertical profile information is an output of the NOAA Unique Combined Atmospheric Processing System (NUCAPS) which is already in AWIPS and will be discussed in an applications module.

Slide 16: Assimilation into Numerical Models

- An often overlooked but important use of microwave data is the assimilation into numerical weather prediction models. The graph shows the percent improvement from 1981 to 2017 for the 500 hPa geopotential height anomaly correlation for various forecast ranges. Before 2001, there was a large spread between the Northern and Southern hemisphere forecasts. The AMSU-A instrument was launched in 1998 on NOAA-15, and it and successor instruments closed the gap between NH and SH performance. This is mainly due to channels from 50-55 GHz which are sensitive to the atmospheric temperature profile (and thus the 500 mb height), in both clear sky and clouds.

Slide 17: Microwave Advantages and Limitations

- To summarize, let's review the advantages and limitations of microwave sensing. The major advantage of microwave remote sensing is its use even in the presence of clouds. Microwave is sensitive to important phenomena such as precipitation type and rate, ocean surface winds, sea ice presence, and soil moisture that are not readily obtainable with visible and IR measurements. The last two advantages listed here attest to the microwave ability to enhance temperature and moisture profile information, particularly over the ocean.
- Drawbacks to the microwave band for remote sensing are that the longer wavelengths limit the spatial resolution, the variations in land emissivity complicate interpretation, and the observations are not as frequent as from a geostationary satellite.
- Follow on modules will build on many of these topics further, introducing current microwave sensors in orbit and example imagery highlighting the product applications.

Slide 18: Resources