

## Talking points for “GOES-R Water vapor bands”

1. Welcome to the satellite foundational course for GOES-R mini-module on IR water vapor bands, my name is Dan Bikos.
2. Learning objectives
3. This spectral plot illustrates brightness temperatures calculated at various wavelengths in the black line while the solid blue regions correspond to spectral response functions for the three ABI water vapor bands 8, 9, 10 from left to right on the plot. The water vapor bands are characterized by relatively strong absorption by water vapor in the atmosphere of energy at these wavelengths that leave the surface. The energy is then re-emitted at a higher altitude and thus colder region of the atmosphere. The red box indicates the main spectral region of the current GOES-15 water vapor band, the 3 bands available on the GOES-R ABI will allow a broader spectral region to be observed.
4. Water vapor imagery interpretation
5. The weighting function profile is variable, and depends not only on spectral width of the instrument, but also temperature, moisture, and viewing angle / distance from the subpoint. We will discuss the temperature dependence in a case study a bit later, but next we'll look at moisture and then viewing angle.
6. For clear-sky conditions, brightness temperatures vary with atmospheric moisture for the 3 ABI water vapor bands. Given the same temperature profile, in this example the standard tropical atmosphere, a much colder brightness temperature is observed with more total precipitable water. Generally speaking, the higher the TPW, the greater the cooling on the brightness temperatures since water vapor absorption occurs at a higher altitude in the troposphere.
7. This is another perspective on the weighting function profile dependence on moisture. In the left column we have the weighting function profile for the standard tropical atmospheric profile for the 3 ABI water vapor bands, and in the right column we have the weighting function profile for the US Standard atmospheric profile for the 3 ABI water vapor bands. The total precipitable water is about 3 times greater in the standard tropical profile compared to the US standard profile. As we learned on the previous slide, we would expect the weighting function profile to peak higher in altitude, thus having colder brightness temperatures for the profile with greater moisture and that is indeed what we observe. The dashed green reference line indicates the peak weighting function value for the standard tropical profile for the 3 ABI bands. Not only is the peak weighting function value higher in altitude, than the US standard profile, but the entire profile is shifted to a higher altitude and thus colder brightness temperatures.
8. Again, for clear sky conditions, the brightness temperature varies with viewing angle for the 3 ABI water vapor bands. In the plot on the right, ABI bands 7-16 dependency on viewing angle is shown, and you can see it varies between the different bands with the most sensitivity with the 9.6 micron ozone band and the least sensitivity with the 11.2 micron IR band. This would be important to know in an RGB that uses several bands, for example, since the image colors might change with view angle but the atmosphere does not. Here we are primarily interested in the 3

ABI water vapor bands which I've highlighted with a blue box in the legend and with arrows pointing to the 3 curves. All 3 ABI water vapor bands show this dependency on viewing angle, with the 7.3 micron band being the most susceptible to this effect, and the 6.2 micron band being the least (although still significant). As viewing angle increases, the brightness temperature decreases due to increased path length. Another way to view this effect is shown in the plot on the bottom. These are weighting function profiles for a standard atmosphere which varies the viewing angle between 0 and 80 degrees. These profiles are valid for the current GOES water vapor band at 6.5 microns under clear-sky conditions. As the viewing angle increases, the weighting function profile shifts to higher altitudes, therefore the brightness temperature will be colder.

9. This slide compares water vapor bands from the pre-GOES-R era to that of the GOES-R era. The water vapor band on the imager instrument for the pre-GOES-R satellites is centered at 6.5 microns with a resolution at nadir of 4 km. The sounder instrument on the pre-GOES-R era satellites has 3 water vapor bands as shown here, however the resolution is only about 10 km. On the GOES-R series ABI instrument, there are 3 water vapor channels. Band 8 is centered at 6.19 microns, band 9 at 6.95 microns, and band 10 at 7.34 microns. The motivation in having 3 water vapor channels is to provide a better 3-dimensional view of the atmosphere. Prefix nicknames have been given to each channel (upper, mid and lower) to correspond to the layer of atmosphere it sees relative to each of the other bands. For example, the full name of the 6.95 micron band is the mid-level tropospheric water vapor band. The spatial resolution of each water vapor band is 2 km and the temporal resolution will be 5 minutes over CONUS (or even 1-minute in mesoscale sectors). In addition, the signal to noise ratio will be considerably better on the ABI water vapor channels relative to the pre-GOES-R era imager and sounder instruments. This factor in combination with the improved spatial resolution and bit depth mean that smaller scale features are more likely to be real and not artifacts due to noise. The ABI water vapor bands are a significant improvement over pre-GOES-R era Imager and Sounder instruments.
10. The weighting function profile provides a clear indication of what layer the instrument sees. There are 2 important aspects of a weighting function profile, the peak and the range in the vertical. The peak refers to the maximum weighting function value which occurs at a given altitude, or pressure level. This represents the altitude where the majority of the signal in the layer is seen by the instrument. The range in the vertical refers to the layer in which the instrument sees, you may also visualize the relative contribution within that layer. In our example, these are the weighting function profiles for a standard atmosphere under clear sky conditions for the 3 GOES-R era ABI water vapor channels along with the pre-GOES-R era water vapor channel at 6.55 microns for comparison. The pre-GOES-R era water vapor weighting function profile, indicated in the black dashed line, shows a peak at 359 mb, however the range in the vertical shows there is a contribution above and below that level. Notice that the contributions drop off to near zero below about 850 mb, which is why surface features typically do not show up in the pre-GOES-R era water vapor channel. The 3 water vapor channels on the GOES-R series have different weighting function profiles which explains their nicknames of upper, mid and lower. Analyzing these 3 bands provide a 3-dimensional perspective compared to the single pre-GOES-R era water vapor band. The 7.34 micron band offers new capabilities

when you consider the weighting function profile at low-levels down to the surface. Notice that it does include contributions all the way to the surface, and it will most of the time generally speaking. That means features you are used to analyzing in the IR band such as fronts, diurnal temperature swings of the ground, low-level clouds, and so forth may be seen in addition to higher-level features you're used to viewing in the water vapor imagery such as shortwaves/jet streaks and so forth. Be sure to take time to analyze this exciting new band and the broad range of features you'll be able to readily identify, keeping in mind the 3-dimensional perspective of looking at all 3 channels in tandem.

11. We've learned that the weighting function profile is important to understand how to interpret the imagery, and also that the weighting function varies. The web-page listed below shows real-time weighting functions at each sounding site for bands in the GOES-R series. Simply click on the sounding site of interest and the weighting function profiles for the various bands will appear so that you may understand what layer the instrument sees. Keep in mind, these weighting function calculations are based on clear sky conditions only. For example, under thick clouds the brightness temperature among the various channels will be the same since it sees the temperature at cloud top.
12. We'll introduce the 3 water vapor channels in the GOES-R series here and apply the default color table in AWIPS which is `ramsdwv_12bit`. This example includes Hurricane Michael as well as a strong trough over the central US. From this point forward we'll round off the wavelengths for each band so we will refer to the 6.2, 7.0 and 7.3 micron bands. In the 6.2 micron or upper level water vapor band, brightness temperatures are generally colder in clear skies than those in the other 2 bands. This makes sense since the weighting function peaks at a higher altitude than the other 2 bands. Recall from the weighting function profiles shown earlier that the water vapor band from the pre-GOES-R era is at 6.5 microns which lies in between the GOES-R era 6.2 and 7.0 micron channels. In the 7.3 micron band, brightness temperatures are generally warmer than the other 2 channels since the weighting function peaks at a lower altitude. Be sure to utilize the 4 panel display in AWIPS when viewing water vapor imagery. You can efficiently view all 3 water vapor channels in tandem to analyze troughs, ridges, shortwaves, jet streaks etc. in the layer that the channel sees. As you gain experience in looking at the 3 water vapor channels of in the GOES-R era, you'll develop skill at analyzing a 3-dimensional perspective of the atmosphere somewhat analogous to looking at multiple tilts of radar products to gain a better 3-dimensional perspective of a thunderstorm for example.
13. Let's compare the pre-GOES-R era GOES-15 water vapor channel with the GOES-16 7.0 micron mid-level water vapor band. Unfortunately, we cannot make a direct comparison since there is not a 6.5 micron channel on the GOES-R series, so we choose 7.0 microns which will have slightly warmer brightness temperatures since the weighting function peaks lower in altitude. A comparison shows the improved resolution of the GOES-16 imagery. The improvement in spatial and temporal resolution will greatly enhance your ability to identify features in the imagery.
14. Along the same lines as the previous slide, we make a comparison between the GOES Sounder 7.0 micron band on GOES-15 with the GOES-17 7.0 micron mid-level water vapor band. In this

comparison the wavelengths between the two channels are quite close. The improvement in spatial resolution is obvious since the resolution of GOES-17 is 2 km and the old GOES Sounder is about 10 km.

15. When interpreting water vapor imagery it's important to understand that variations in water vapor are not the only reason you see variability in the water vapor imagery. There is also a dependency on temperature, which is what we will demonstrate with this example. Consider the AWIPS cursor readout over Miami, Florida. This is within a region of obvious warm brightness temperatures in all 3 GOES-16 water vapor bands. It may be tempting to consider this region as dry compared to other regions with much cooler brightness temperatures. Remember to interpret this imagery as the net temperature of the moisture in the layer the sensor is seeing, in the 7.0 micron band for example, the brightness temperature is about -12 degrees Celsius. Next, we'll compare this point with a location much further north in Canada where much cooler brightness temperatures exist, but keep in mind the TPW from the Miami sounding is 1.77 inches and the 700-500 mb layer precipitable water is observed at 0.1 inches, and that comes from microwave instruments on board polar orbiting satellites as seen in the advected layer precipitable water product.
16. We've moved our cursor readout in AWIPS to Maniwaki, Quebec since this region is characterized by much cooler brightness temperatures than Miami. For that reason, it may be tempting to think of this as a more moist airmass compared to Miami, but is it? Our Total Precipitable Water is 0.35", considerably less than that at Miami where it was 1.77". However, note the 700-500 mb layer Precipitable water is 0.1", the same value we observed at Miami.
17. Recall our interpretation of water vapor imagery is the net temperature of the moisture in the layer the sensor is seeing, and where it is seeing is defined by the weighting function profile. Here is the weighting function profile for the 3 water vapor bands for Miami on the left and Maniwaki on the right computed from the available soundings valid for clear sky conditions. This plot defines the relatively broad layer that the sensor sees, and also informs you of where the peak contribution in the vertical exists, in this case it is slightly higher at Maniwaki as you might expect due to increased path length at a higher latitude due to the viewing angle dependence we discussed earlier.
18. Here is a cross section from the 00 hour forecast of the GFS that spans from Miami to Maniwaki. I am showing the observed brightness temperatures from the cursor readout in AWIPS along with the specific and relative humidities at those levels. The most important point is that brightness temperatures are considerably cooler at Maniwaki compared to Miami. Is it really more moist at Maniwaki than at Miami? No, not as a measure of absolute moisture. In fact the specific humidity values are comparable at the level of the brightness temperatures being observed at both locations. Where we do see variability is in the relative humidity, which exists due to the much colder brightness temperatures at Maniwaki compared to Miami. The majority of the variation between these sites can be explained by the large temperature difference. Remember that water vapor channels are essentially an IR channel. The brightness temperature is a function of the absolute quantity of the absorbing molecule (in this case, water vapor), and the temperature of the tropospheric layer where that moisture resides. Recall there is some

contribution to viewing angle as well since Maniwaki is at higher latitude, where the weighting function would peak higher in altitude (and therefore colder).

19. Next we'll consider an example with multiple clouds heights to analyze which water vapor bands can detect clouds at different heights. This is a case of rapid cyclogenesis off the east coast as viewed in GOES-16 water vapor bands and the visible band at 0.64 microns in the lower right. The visible band shows the relatively shallow clouds just east of the circulation center, while much higher level clouds can be observed over New England with a uniform cirrus appearance at cloud top. When optically thick clouds are present, such what we observed over New England for this case, brightness temperatures will be nearly the same across all 3 bands. This is why the weighting function profile is only valid for clear sky conditions. Now look over the region where shallow clouds exist east of the circulation center. These clouds are shallow enough to only be seen with bands that have a weighting function that sees far enough down into the atmosphere to observe these clouds. For example, in the 7.3 micron band we observe many more low-level clouds compared to the 6.2 micron band. This is because the weighting function profile at 6.2 microns isn't low enough in altitude to detect the low-level clouds. Note the band in the middle at 7.0 microns does begin to detect some of the low-level clouds, but the majority do are not detected. This can be useful information in determining the areal extent of clouds that are more vertically developed. Always keep in mind the layer the instrument sees as we detailed in the discussion on weighting function profiles. Also recall that for optically thick clouds the brightness temperature will be the cloud top temperature across all 3 water vapor bands since that is where the sensor see's.
20. The 7.3 micron band has a number of applications such as cold fronts aloft and elevated mixed layer identification that we'll discuss in more detail in the convective section of this course. For now, we'll discuss the importance of the 7.3 micron band in detection of sulfur dioxide during volcanic eruptions. The 7.3 micron band is the only ABI water vapor band capable of detecting sulfur dioxide. The animation shows the 7.3 micron water vapor band from GOES-16 along with the SO<sub>2</sub> RGB for the Sierra Negra volcanic eruption in Ecuador of June 2018. Often times a RGB product will show more information than a single band alone may show. This topic will be discussed in more detail later in the module on volcanic ash detection.
21. Here is a 4 panel display of the 3 water vapor bands along with the IR band at 10.3 microns for a dryline in the Texas panhandle. The loop spans from the afternoon hours into the evening hours after sunset, therefore we expect the IR band to readily show the change in temperatures on either side of the dryline. During daytime hours, temperatures are warmer on the dry side of the dryline and cooler on the moist side, however after sunset that temperature regime reverses. Later in the loop, you can easily see the dryline moving westward with warmer temperatures on the moist (or eastern) side while temperatures on the dry (or western) side are cooler. Now study the 3 water vapor bands, can you detect the dryline in these bands? I'll give you some time to study the animation to help answer this question.
22. To understand why you see the dryline in some bands and not others, it's best to look at the weighting function profile. Recall that we're looking at the net temperature of the moisture in a layer that the sensor sees, the layer it sees is variable and can be assessed by the weighting function profile. The IR band at 10.3 microns obviously sees down the surface which is verified

in the brown line for this weighting function profile based on the nearest observed sounding. The 7.3 micron water vapor band (shown in the pink line) sees the lowest layer in the atmosphere which is why we're able to detect the dryline in this band much more readily compared to the other 2 water vapor bands. The mid water vapor band at 6.9 microns (shown in the blue line) had subtle indications of the dryline, however the 6.2 micron band (shown in the green line) had only extremely subtle indications of the dryline which makes sense since the weighting function profile is the highest in altitude of the 3 water vapor bands on the ABI.

23. Remember that for any set of ABI bands, in this training module water vapor bands, there are qualitative and quantitative applications. We've looked at a variety of qualitative applications in this training module by learning about imagery interpretation. Examples of quantitative applications include derived products and assimilation into NWP models. The ABI baseline products are derived products that make quantitative use of various bands. In later training modules, you will learn about these ABI baseline products. In this table, we can see the list of all ABI baseline products and the ABI bands that go into producing them. I've highlighted in the red box the 3 water vapor channels to give you an appreciation for the various products that make use of these bands. For example, if you're looking at derived motion winds, understand that data from the water vapor bands are being used in the product. Finally, some bands may be used by needed "upstream" products, such as the cloud mask.
24. In summary, the GOES-R series offers 3 water vapor channels at greater spatial and temporal resolution compared to what was available in the pre-GOES-R era. Be sure to utilize the 3 water vapor channels in tandem to provide a 3-dimensional perspective of the atmosphere. The 6.2 and 7.0 micron channels see slightly lower and higher in altitude respectively compared to the pre-GOES-R water vapor channel at 6.5 microns. Keep in mind the layer that you are seeing when analyzing familiar features like troughs, ridges, jet streaks, shortwaves etc. The 7.3 micron channel offers a new perspective since it sees lower down into the atmosphere where you can see low-level features such as fronts, outflow boundaries, low-level clouds in combination with mid and upper level features you're experienced with seeing in pre-GOES-R era water vapor imagery. Finally, always be aware of the layer that the sensor sees by making use of the weighting function profile information that was discussed.