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 suscepitable 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 illustrates water vapor bands that are available on the current GOES satellite imager and sounder instruments and compares that with what will be available on the GOES-R ABI instrument. The water vapor band on the imager instrument for the current GOES satellites is centered at 6.5 microns with a resolution at nadir of 4 km. The sounder instrument on the current GOES satellites has 3 water vapor bands as shown here, however the resolution is only about 10 km. On the GOES-R ABI instrument, there will be 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 see's 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 improve considerably on the ABI water vapor channels relative to the current 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 will be a significant improvement over what is currently available on the GOES Imager and Sounder instruments.
10. The weighting function profile provides a clear indication of what layer the instrument see's. 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 see's, 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 ABI water vapor channels along with the current GOES water vapor channel at 6.55 microns for comparison. The current GOES 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 current GOES water vapor channel. The 3 water vapor channels on the GOES-R 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 current GOES water vapor single 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 currently shows real-time weighting functions at each sounding site for the current GOES bands. 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 see's. 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 see's the temperature at cloud top. Once GOES-R data is flowing to field offices this page will be updated to show the realtime weighting function profiles for GOES-R bands.
12. We'll introduce the 3 water vapor channels by comparing the 3 water vapor channels from Himawari, since the instrument is very similar to the ABI on GOES-R. Throughout this lesson, we'll be using the 11-bit rainbow color table. In this example from the western Pacific, a strong cyclone with a well-defined dry slot appears readily in all 3 channels. 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. Also note the brightness temperatures are generally colder further north, this is due to the greater viewing angle at high latitudes we discussed earlier. The dry slot is not as well defined in some regions, one useful application of the 6.2 micron channel is the relative depth of subsidence. In this example of a strong developing cyclone the subsidence associated with the dry slot shows up in all 3 channels, however for weaker systems it may not be as noticeable in the upper level water vapor channel. Recall from the weighting function profiles shown earlier that the 6.5 micron channel on the current GOES lies in between the GOES-R 6.2 and 7.0 micron channels. The best practice is to use them in tandem to get a better 3-dimensional perspective of features you're accustomed to analyzing in the water channel such as troughs, ridges, jet streams, shortwaves etc. 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.
13. Let's compare the current GOES-15 water vapor channel with one of the water vapor channels from Himawari near Hawaii. Unfortunately, we cannot make a direct comparison since there is not a 6.5 micron channel on Himawari, so we choose 7.0 microns which will have slightly warmer brightness temperatures since the weighting function peaks lower in altitude. Another

complicating issue for direct comparison is that this is close to the limb for Himawari, particularly for the eastern edge of this scene, this is not so much of an issue with the GOES perspective. The resolution of the imagery degrades whenever you get close to the limb. Despite these issues, a comparison shows the improved resolution of the Himawari imagery, particularly in the vicinity of the convective clouds. This improvement in resolution will also be apparent in GOES-R over the current GOES satellites. 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 7.4 micron band and the Himawari 7.3 micron band in the same color table. In this comparison the wavelengths between the two channels are quite close, however we still have the issue of Himawari being near the limb, thus at reduced resolution, particularly the eastern edge of the scene. In this comparison, the improvements are obvious since the resolution of Himawari is 2 km and the GOES Sounder is about 10 km, this improvement will be comparable for GOES-R as well.
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. When presented with an image such as this, it may be tempting to interpret point A as "moist" and point B as "dry". Remember to interpret this imagery as the net temperature of the layer the sensor is seeing. In this 6.2 micron image, note the brightness temperature is 22 degrees C colder at point A compared to point B.
16. Moving down in altitude, we analyze the 7.0 micron mid level water vapor band. Note the large difference in brightness temperatures between these locations. Keep in mind clear sky conditions exist at both points so we are not observing cloud top temperatures.
17. Moving further down in altitude with the 7.3 micron band. The difference in brightness temperatures between the 2 points is about 25 degrees.
18. Now we analyze soundings at points A and B to gain a better understanding. Is it really more moist at point A than point B? Absolutely not, the TPW at point B in the tropics is much greater than point A in the Arctic. In fact, the mixing ratio is comparable between the 2 soundings for the layer where the 6.2 and 7.0 micron channels typically have peak weighting function values. Therefore, the majority of the variation between these points 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 point A is at high latitude, where the weighting function would peak higher in altitude (and therefore colder).
19. In our previous example, we considered clear sky conditions for our points however what if there are optically thick clouds? The weighting function profile is only valid for clear sky conditions. When optically thick clouds are present, the brightness temperatures are at cloud top since this is where the instrument see's. In this example from the SIFT software, we place the cursor over an optically thick cloud. The brightness temperature for all 3 water vapor bands

are nearly the same for this point over optically thick clouds. You can make use of this fact to determine if optically thick clouds exist over a region of interest.

20. Let's make use of the SIFT software to illustrate identification of lower level clouds between the 3 water vapor channels. We make use of a case from Himawari as a proxy to GOES-R. We will start with the 7.0 micron mid level water vapor channel as being representative of a band that is similar to the current GOES water vapor channel at 6.5 microns. The dry slot of an intensifying cyclone shows up as green in the rainbow color table with the bottom end of the comma cloud at the top of the image and higher level colder cloud tops in purple and blue to the east and southeast. South of the comma cloud, there is strong cold advection taking place where low-level cumulus develops due to the steep lapse rates over the relatively warm ocean surface. In the current GOES water vapor band at 6.5 microns these are detectable, but much more subtle compared to the IR band at 10.7 microns due to the weighting function peaking mostly above where they exist. This is true in the Himawari 7.0 micron imagery as well. In the example shown, we highlight an area in purple over the field of lower level clouds south of the comma head where we can produce a histogram of brightness temperatures within that region. As you may expect, the histogram shows brightness temperatures with some variability because you're including some lower-level clouds mixed in with clear regions higher in altitude and thus colder. 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 since that is where the sensor see's.
21. Now we switch to 6.2 microns, recall the weighting function is higher in altitude. Can we detect the lower level clouds we saw at 7.0 microns? No, because the weighting function profile is above where the lower level clouds exist, only the higher level clouds can be readily seen. The histogram for the same region of interest shows much less spread in the brightness temperatures compared to the 7.0 micron channel, in fact most of the values lie between -31 and -34 degrees Celsius. This is another illustration of how the weighting function profile provides expectations of what can and cannot be seen for a given band.
22. At 7.3 microns, the lower level clouds are readily seen. This makes since since the weighting function profile is sufficiently low in altitude so that low-level clouds can be observed. Note the high variability in the brightness temperatures across the region of interest, this makes sense because we are seeing cloud tops as well as clear sky in between clouds for the layer that the sensor see's. This example reinforces the notion that the water vapor channels provide the net temperature of a layer that the sensor see's.
23. 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 later in this course. Chris Gitro has done a lot of work on making use of the GOES sounder 7.4 micron band, identification of these features in the 7.3 micron band on the GOES-R ABI will be much easier due to the higher spatial and temporal resolution of the imagery.
24. The 7.3 micron band will be on the only ABI water vapor band capable of detecting sulfur dioxide associated with volcanic ash. The animation shows the 3 water vapor channels from Himawari for the Pavlof volcanic eruption in the Aleutian islands. The left panel, which displays the 7.3 micron band shows the volcanic ash plume the most clearly. All 3 of the water vapor

bands show the cloud plume, but only the 7.3 micron band shows a contribution from sulfur dioxide. This topic will be discussed in more detail later in the module on volcanic ash detection.

25. Be sure to utilize the 4 panel display in AWIPS when viewing water vapor imagery with GOES-R. 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 see's. In this 4-panel display, the lower right displays the 10.4 micron band, but it's really a wildcard, select whatever you wish to go along with the 3 water vapor bands, this easily could be a baseline product such as mid-level moisture, cloud type, or a wind field from the automated motion vectors. As you gain experience in looking at the 3 water vapor channels of GOES-R, 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.
26. 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 learning 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.
27. In summary, GOES-R will offer 3 water vapor channels at greater spatial and temporal resolution compared to the current GOES water vapor channel. 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 current GOES water vapor channel. 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 will offer a new perspective since it see's 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 used to seeing in the current GOES water vapor imagery. Finally, always be aware of the layer that the sensor see's by making use of the weighting function profile information that was discussed.