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Topic: Flash Floods

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Hi, my name is Jill Hardy and welcome to this lesson on flash flood meteorology.

We have a guest speaker for this lesson: Steve Martinaitis of OU CIMMS at NSSL. But if you have any questions regarding the material, please feel free to contact me, or the RAC team. Our contact information will be on the next slide.

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Lesson Objectives

- Identify the mesoscale and storm-scale variables that contribute to the flash flood potential
  - Precipitation Rate/Efficiency
  - Precipitation Duration
- Identify heavy rainfall using WSR-88D and Dual-Polarization technology

There are two main objectives with this lesson. The first is to identify the variables related to precipitation rate and duration that contribute to the flash flood potential at a meso-scale and storm-scale levels. The second objective is to identify rainfall signatures using the WSR-88D and the new dual-polarization technology.

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Defining a Flash Flood

- **Flash Flood:** A life-threatening flood that rises and falls quite rapidly.
- Occur *within six hours* of a causative event.
  - – Heavy or excessive rainfall
  - – Dam or levee failure
  - – Sudden rise in stage associated with an ice jam
  - – Rapid snow melt

To guarantee that we are all on the same page, I want to make sure we understand how a flash flood is defined. Basically, it is a life-threatening flood that occurs quite quickly, i.e., within a six hour period. Flash floods can occur from a variety of events, such as heavy rainfall, dam failures, ice jams, or rapid snow melt.

For the purpose of these lessons, we will focus on flash flood events related to heavy rainfall.

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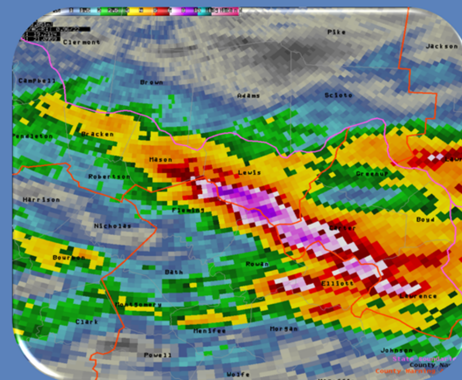
Meteorological Ingredients

Precipitation Rate



Precipitation Duration

When it comes to the meteorological aspects of flash flooding, the two most important things to consider are the precipitation rate and the precipitation duration. Let's focus on the factors that influence the rate first.

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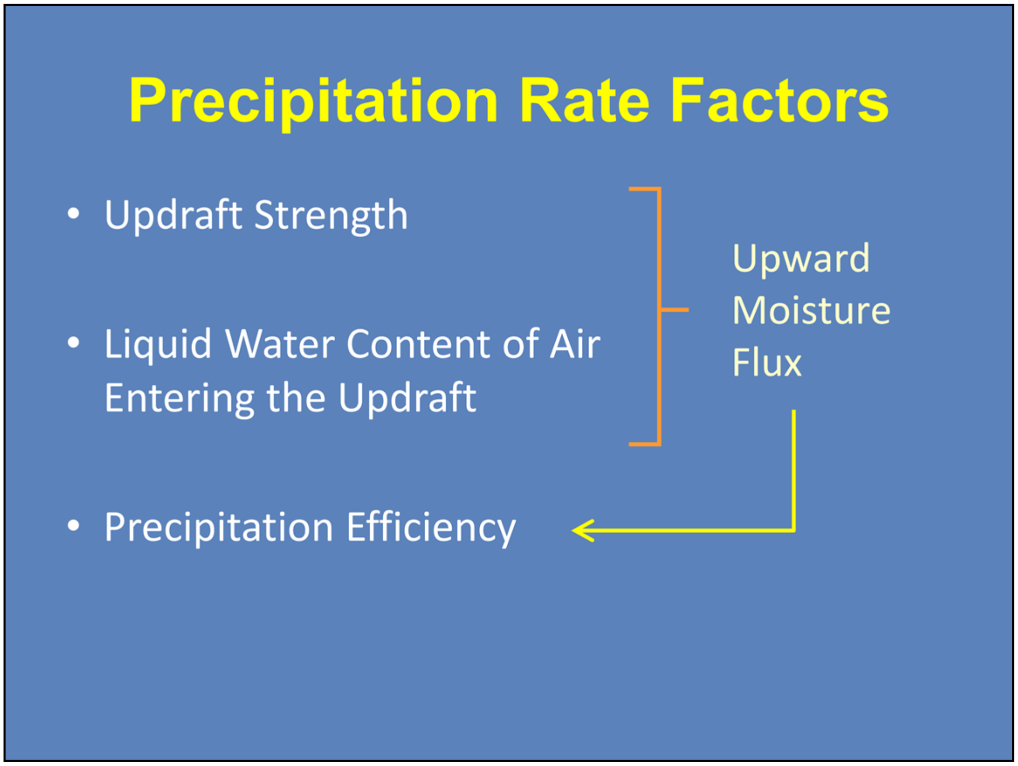

There are several factors that help determine the precipitation rate. The updraft strength and the liquid water content of the air that is entering the updraft contribute to the upward moisture flux into a storm. The percentage of that moisture flux that returns to earth as precipitation characterizes the precipitation efficiency of the storm.

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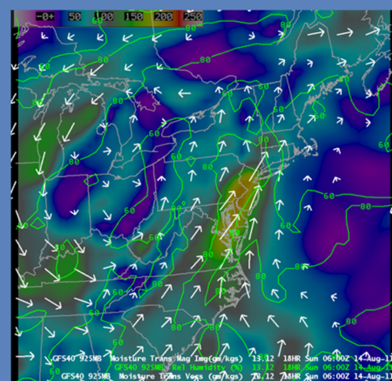
Precipitation Efficiency

- Definition: Fraction of total moisture ingested by the updraft that falls back to the ground
- Dependent upon…
  - Updraft Strength
  - Moisture Profile
  - Warm Cloud Layer
  - Cloud Seeding



As you see here on the slide, precipitation efficiency is defined as the fraction of total moisture ingested by the updraft that returns as precipitation. Precipitation efficiency cannot be quantified in real time, so you will need to examine a number of factors to infer an efficiency. These factors include the updraft strength, the vertical moisture profile of the atmosphere, the depth of the warm cloud layer, and cloud seeding.

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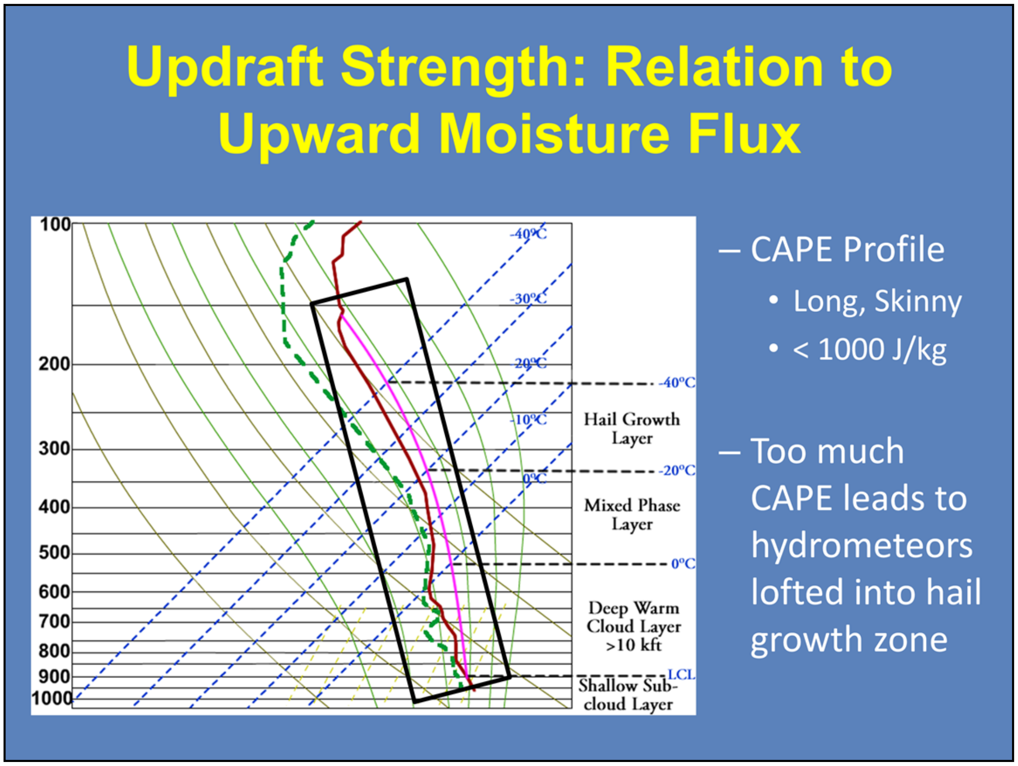
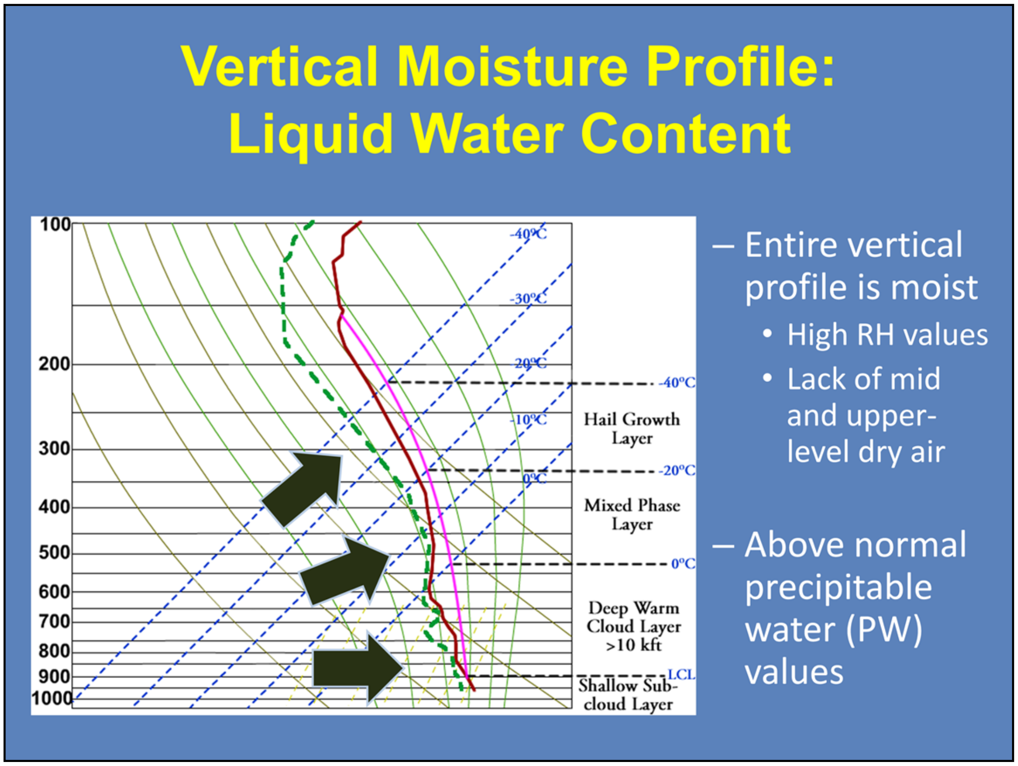


Let's start with the strength of the updraft. Shown here is the average atmospheric profile of flood and flash flood events. When considering the updraft strength of a convective storm, you would want to see a long and skinny CAPE profile. The amount of CAPE in the atmosphere should be under 1000 J/kg. Larger CAPE values will loft the hydrometeors ingested by the updraft into the hail growth zone.



Now looking at the temperature and dew point profile of this sounding, you can see that it is very moist at all levels. Notice how there is a lack of dry air at the mid and upper levels. This is important when you consider the depth of water within a column of the atmosphere if all the water were precipitated as rain, otherwise known as the precipitable water (PW) value. Seeing above normal PW values is a good indication of how moist the atmosphere is.

So how do you determine what is an above normal PW value?

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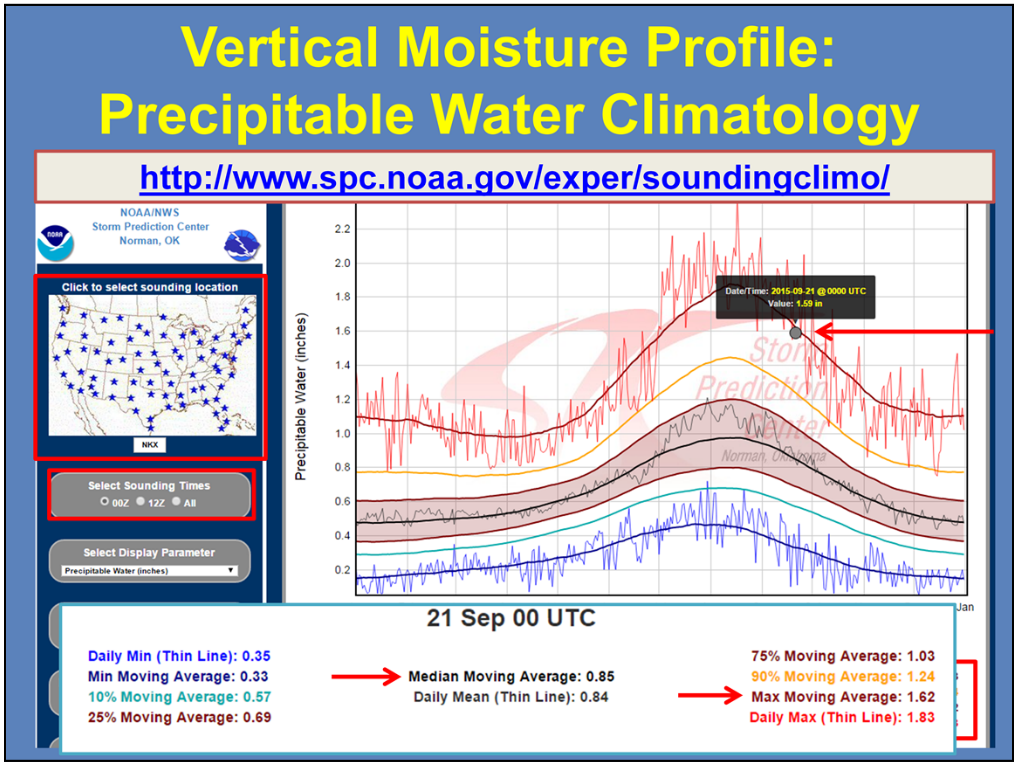


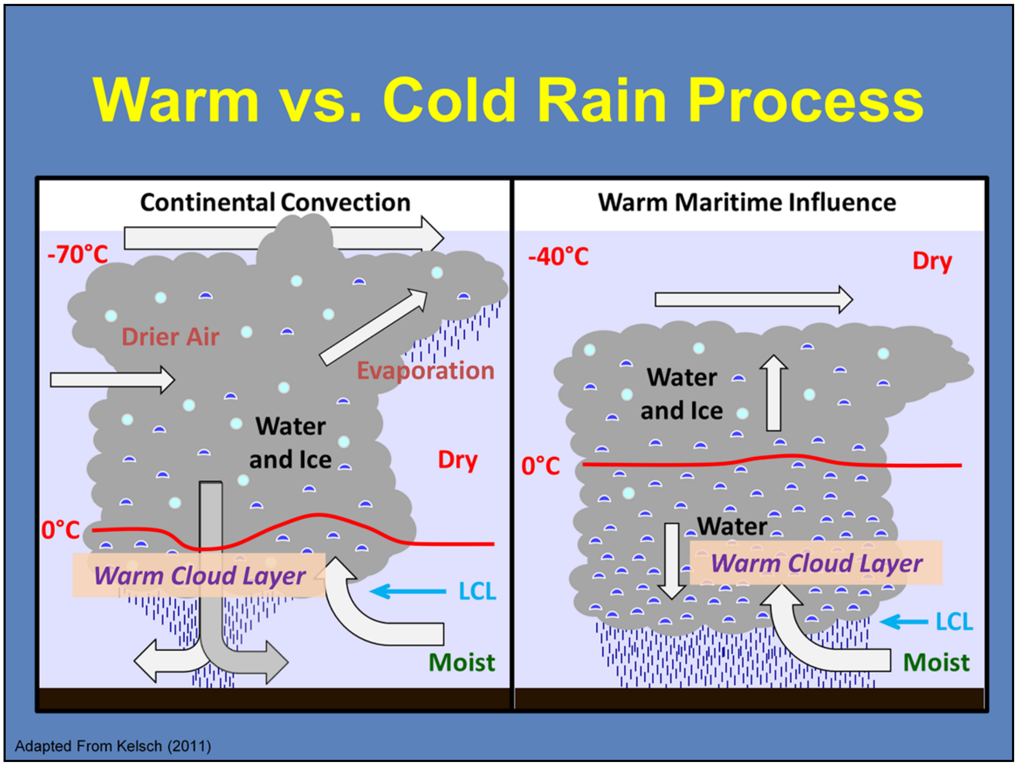
I'm going to briefly hop in here, as there's been a change since this lesson was created. Many of you may have been familiar with Matt Bunkers' Precipitable Water Climatology page. However, the SPC now hosts the point sounding climatologies, similar to the previous website.

Using the SPC site, comparing model or observed precipitable water (PW) values is quite easy. Begin by navigating to the desired sounding location, and select a sounding time. The plot now shows the daily minimum, several moving percentile averages, as well as the daily maximum for each day of the year.

Let's use this 00Z sounding climatology plot for the KNKX radar near San Diego. When I overlay the latest sounding information, we see the current value is 1.59 inches. This is near the maximum moving average of 1.62 inches for this day. Historically on this day, the median PW is 0.85 inches, so we are quite a bit higher than that.

Heavy precipitation events that lead to flooding and flash flooding have values that are above the 75th percentile and usually approach the 90th or maximum moving averages. In fact, for this example, the San Diego WFO had a flash flood watch in effect for the majority of their CWA. Use the URL to access the PW climatology page.

Alright, back to Steve!



Now that we have analyzed the CAPE and moisture profile of the atmosphere, we can see how it helps determine whether a warm rain or a cold rain process is the predominant precipitation production method. Recall that precipitation forms through collisions and coalescence within a warm rain process while deposition and the Bergeron Process (the collision of ice crystals) define a cold rain process.

Looking at convection derived from a continental airmass, you can see that the LCL is relatively high while the in-cloud freezing level is quite shallow. The vertical separation between the LCL and freezing level is defined as the warm cloud layer. This is where warm rain processes occur. However, the warm cloud layer is generally not very deep with this type of convection. Within a strong CAPE environment, hydrometeors will be lofted beyond the warm cloud layer, where they will become frozen (resulting in the formation of hail) and become subjected to evaporation due to mid and upper level dry air entrainment. This region is where the majority of the hydrometeors undergo cold rain processes.

Now focusing on the convection influenced by a warm maritime airmass, you notice that the LCLs are relatively low, and the in-cloud freezing level is much higher. Therefore, you have a greater warm cloud layer. The weak CAPE profile allows for the majority of the hydrometeors to remain below the freezing level. The moist vertical profile also helps in diminishing the effects of evaporation and dry air entrainment. Here, warm rain processes will dominate precipitation production.

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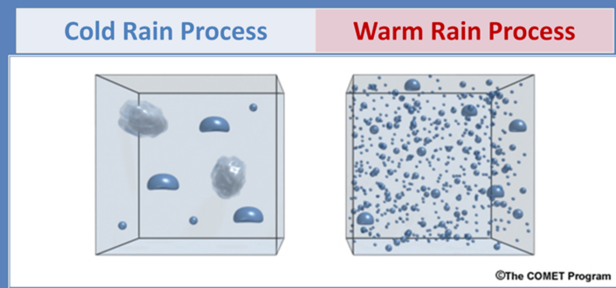
Resulting Precipitation from Warm and Cold Rain Processes



- Warm rain processes provides greater precipitation rates
- Occurs within the warm cloud layer of the storm

Comparing the resulting precipitation at the surface, you can see the dominant cold rain processes from the continental airmass yields a small quantity of rain drops that are generally large in size and can also include hail stones. The dominant warm rain processes in the maritime airmass has a substantial quantity of raindrops. So, the warm rain process results in a greater precipitation efficiency and greater precipitation rates.

In the example on the previous slide, you saw how the CAPE and moisture profiles influence the amount of hydrometeors that reside in the warm cloud layer, and thus, could undergo warm rain processes. Which leads to the next set of questions… How do we calculate the warm cloud layer? And how deep of a warm cloud layer do you need for precipitation rates that could potentially yield flooding?

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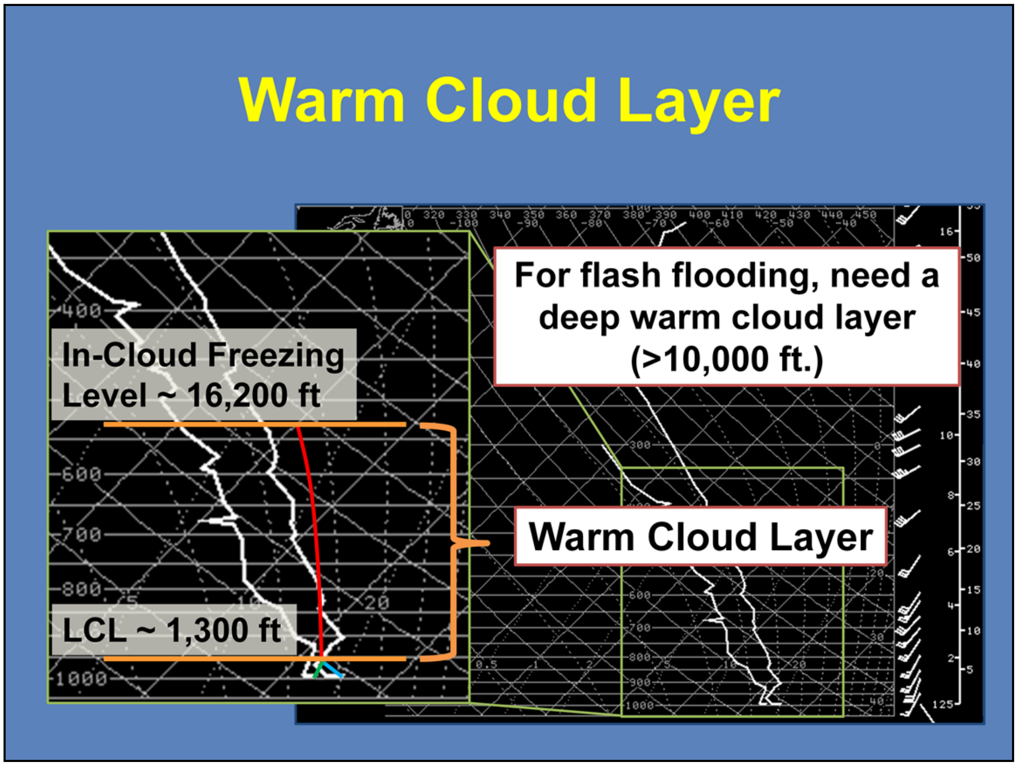

To calculate the warm cloud layer, we will use this sounding from Grey, ME during a summer-time convective event that had some flash flooding. Focusing on the lower and mid levels of the atmosphere, you would start by finding the LCL. Follow the dry adiabatic lapse rate from the surface temperature and the saturation mixing ratio from the surface dewpoint until the two lines meet. The LCL for this case is about 1,300 feet.

From the LCL, follow the moist adiabat up to the freezing level. We choose the moist adiabat because that should be "in-cloud" and also where the warm rain process (collisions and coalesence) is occurring. In this case, the freezing level is around 16,200 feet. The difference in height between the LCL and in-cloud freezing level will be our warm cloud layer. Having a *deep* warm cloud layer is very important for flash flood forecasting. A warm cloud layer over 10,000 feet is considered deep.

For this example, our warm cloud layer is approximately 14,900 feet.

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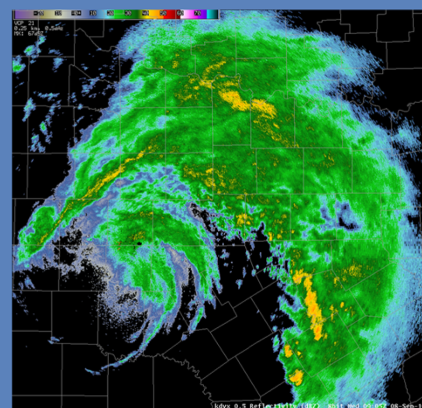
Cloud Seeding

- Definition: Jump start of precipitation product via the ingesting of hydrometeor embryos
- Inter-Storm Seeding
  - Increases upward Moisture flux
  - Increases environmental humidity



Another process that increases precipitation production is cloud seeding. We will focus on inter-cloud seeding here. This is the process where precipitation production is jump started by the updrafts ingesting hydrometeors from other storms. This will help increase the upward moisture flux and increase the local environmental humidity. In this example, an intense rain band forms with the remnants of Tropical Storm Hermine over central Texas. The combination of the tropical environment and the inter-cloud seeding enhanced rainfall production in an already efficient precipitation environment. Widespread rainfall totals of 6-10 inches were common with system.

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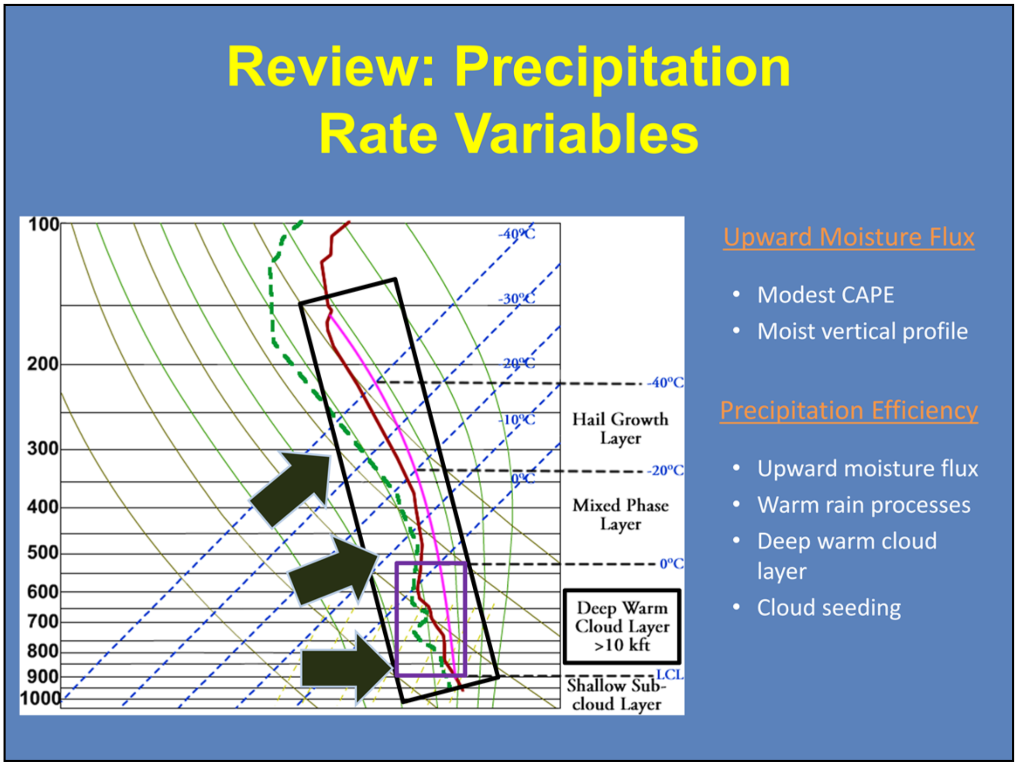

Let's quickly recap what influences the precipitation rate. First, you have to consider the variables that go into the upward moisture flux of a convective storm, such as a modest CAPE profile, generally under 1000 J/kg, and a moist vertical atmospheric profile.

The fraction of the upward moisture flux that becomes precipitation defines the precipitation efficiency of the storm. Along with the upward moisture flux, recall that warm rain processes provide greater precipitation rates. Warm rain processes occur within the warm cloud layer. Remember that for a greater flash flood potential, you would like to a deep warm cloud layer of 10,000 feet or greater. You also have to consider inter-cloud seeding to increase precipitation production.

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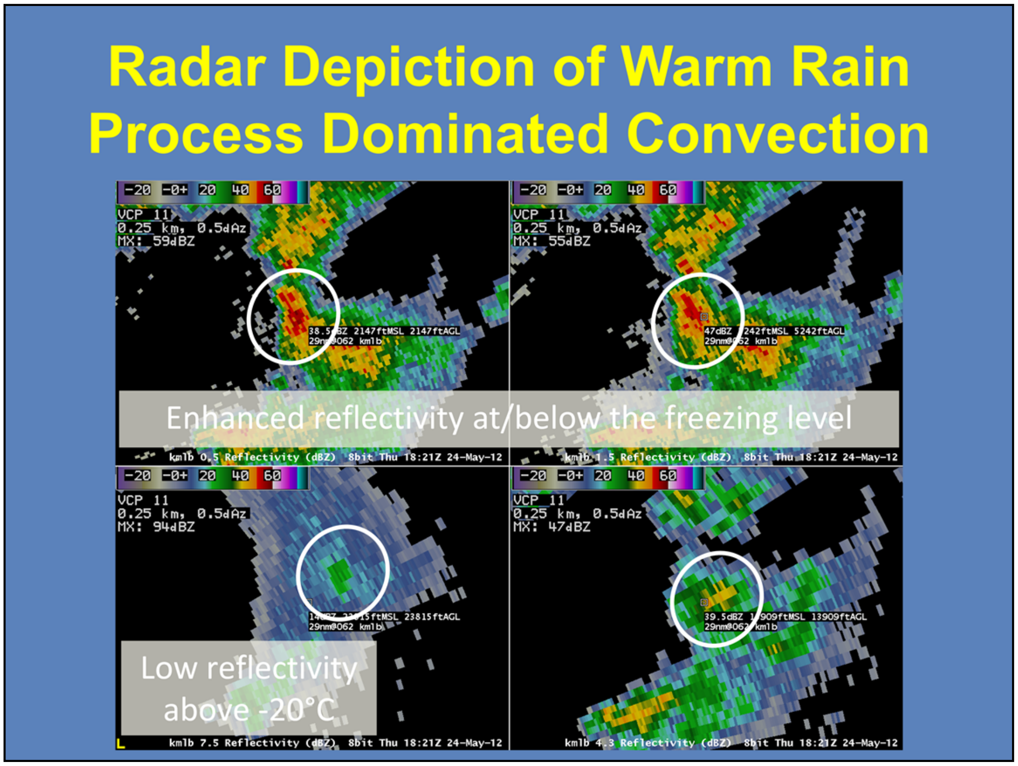
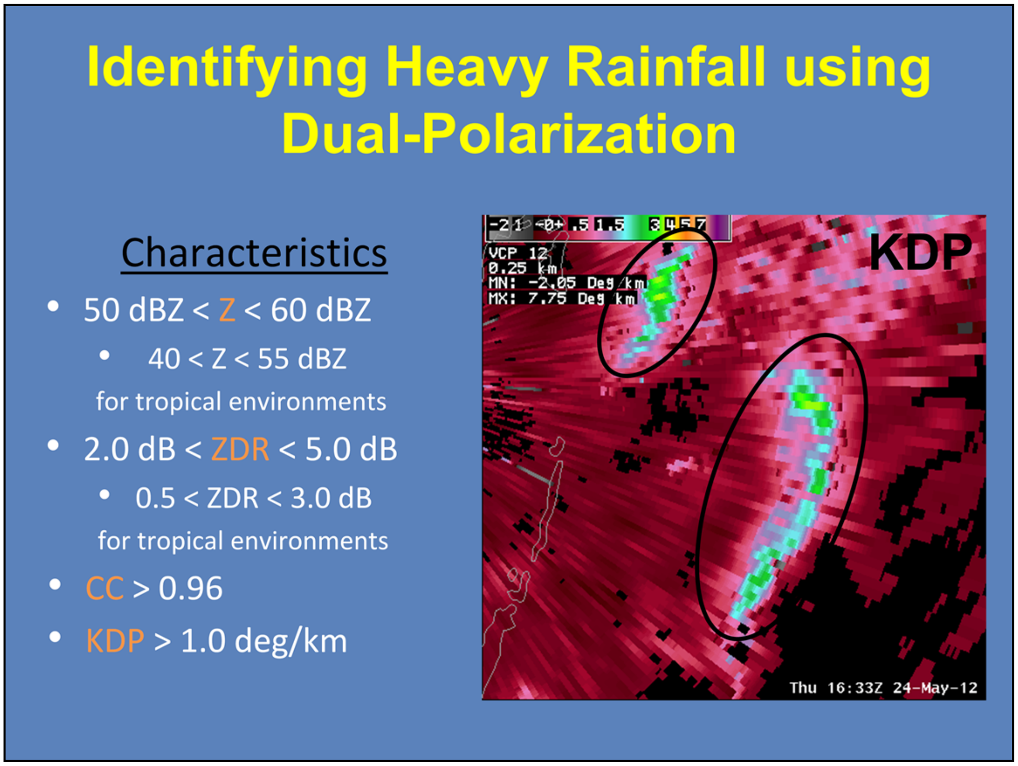


So what does convection dominated by the warm rain process look like on radar? Honestly, not much unless you know what you are looking for. The two main characteristics of convection dominated by the warm rain process are enhanced reflectivity values at or below the freezing level and low to non-existent reflectivity values above the -20°C level.

Using this example from the Melbourne, FL office, the top two images show reflectivity values between 50-60 dBZ below the freezing level. In the bottom-right panel, the 4.3° tilt scans the storm at 13,900 feet, just a few hundred feet below the freezing level. Here, there are very few pixels that meet or exceed 40 dBZ. The bottom-left panel shows the storm at the 7.5° tilt near the -20°C level. Reflectivity values here are below 25 dBZ. The storm does not exist on higher tilts.

This series of images shows what is called a low-echo centroid signature. This is where the majority of the precipitation core lies below the freezing level. The combination of this type of radar signature and a moist, slightly unstable environment should clue you in to warm rain processes being dominant here.



With the addition of dual-polarization technology, the new algorithms can help pinpoint areas of greater precipitation rates. This signature is from the Miami, FL radar and was related to a tropical disturbance that eventually became Tropical Storm Beryl.

Starting with the reflectivity (Z), you would look for areas of enhanced values, generally in the 50-60 dBZ range; 40-55 dBZ for tropical environments. Here, we are highlighting two areas of enhanced values.

Now examining the differential reflectivity (ZDR), the difference between the horizontal and vertical reflectivity factors, you would look for ZDR values between 2.0 and 5.0 dB, and 0.5-3.0 dB for tropical environments. Remember, there is a strong relationship between the raindrop size and ZDR where the greater the ZDR values, the larger the raindrop diameter. Since we are dealing with a tropical environment in this case, the ZDR values are around 1.5 dB. Combine that with the high reflectivity values, you have a lot of small rain drops here.

Moving on to the correlation coefficient (CC), you should see very high values (above 0.96). This means that the type of precipitation that is being sampled is uniform. As you can see here, the areas that had the greater reflectivity have a CC of around 0.99, meaning all the precipitation here is rain.

Finally, values of the specific differential phase (KDP) should be above 1.0 deg/km. Higher KDP values can mean larger rain drops or a larger concentration of rain drops. Since we know this is a tropical environment and the ZDR values suggest small rain drops, then this means we are dealing with a larger concentration of rain drops, and thus, greater precipitation rates.

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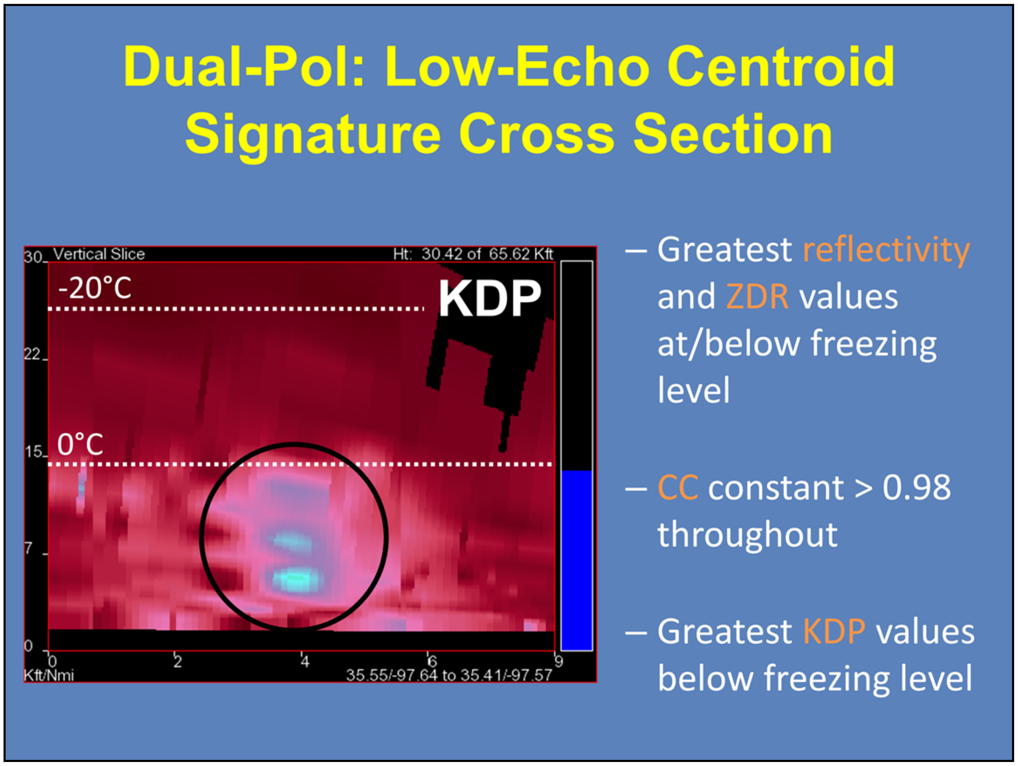


Now that you have seen what a warm rain process dominated storm looks like with base reflectivity and with the dual-pol products, we will now take a cross-section through a low-echo centroid signature. This example will look at a specific storm that was part of a system that produced significant flash flooding on the north side of Oklahoma City, OK.

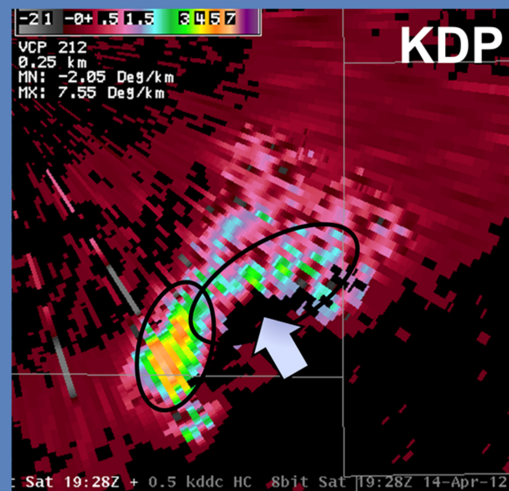
As you saw in the four panel image earlier in the presentation, most of the enhanced reflectivity values lie at or below the freezing level and low reflectivity values exist near and above the -20°C level. The greater ZDR values, which represent rain drops, also lie below the freezing level. The very low ZDR values above the freezing level can represent very small water droplets, ice crystals, and/or hail.

The CC values are constant throughout the vertical profiles with them ranging from 0.98 to 0.995. The values closer to 0.98 (the darker purple shading with a slight orange tint) represent all rain with slightly larger drop sizes. Finally, the greater KDP values exist below the freezing level, showing where the greatest concentration of rain drops are occurring.

Dual-Pol: Identifying Heavy Rainfall with Supercells

Characteristics

- Z > 55 dBZ
  - Hail/Rain mixture
- ZDR can be anything
- CC < 0.96
- KDP > 1.0 deg/km
  - Normally most extreme
  - KDP not shown when CC < 0.90



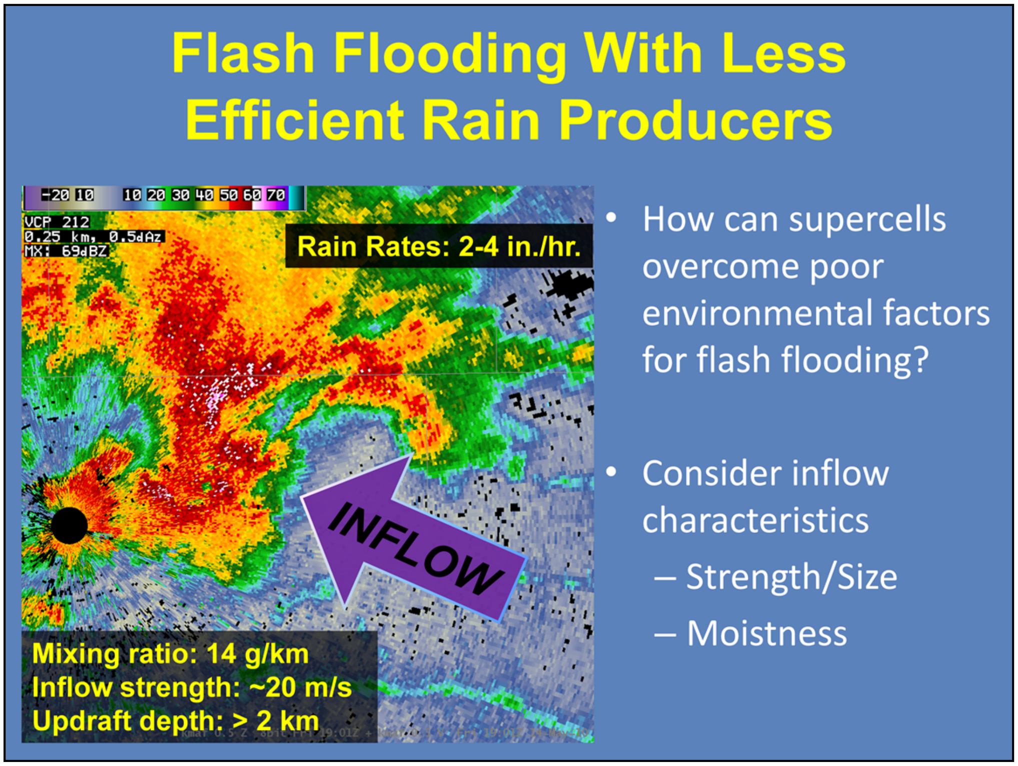
Since we have looked at what an efficient rainfall producer would look like with radar, let's take a look at what an inefficient storm would look like in dual-pol. For this example, we will use a supercell viewed from the Dodge City, KS office during the April 14, 2012 outbreak. Supercells can produce heavy rainfall, but you would need to examine the characteristics and motion of the storm to determine its flash flood potential.

Starting again with reflectivity (Z), you would look for areas that are greater than 55 dBZ. Here, we have highlighted two separate areas within this supercell. These areas of enhanced values are probably areas of hail/rain mixture.

Now starting with the dual-pol products and differential reflectivity (ZDR), it should be noted that the ZDR values can be anything because of hail contamination. Severe hail can bring ZDR values to near 0 dB while water coated hail can have values up to 6 dB.

Since we are dealing with non-uniform precipitation types, correlation coefficient values will be below 0.96 in areas of rain/hail mix. Here, we see values ranging between 0.9 and 0.95, with some lower values within the forward flank downdraft. Now overlaying the hydrometeor classification algorithm (HCA), you can see where the radar is seeing the hail/rain mixtures in red.

Finally, looking at the specific differential phase, you would see values greater than 1.0 deg/km here, and you do in both of the highlighted areas. Some of the more extreme values, like the area of 4.0-7.0 deg/km near the rear flank downdraft, are where the greatest rainfall rates are occurring, but some values could be a result of water coated hail. It is important to note that KDP values will not display in areas of CC less than 0.90.

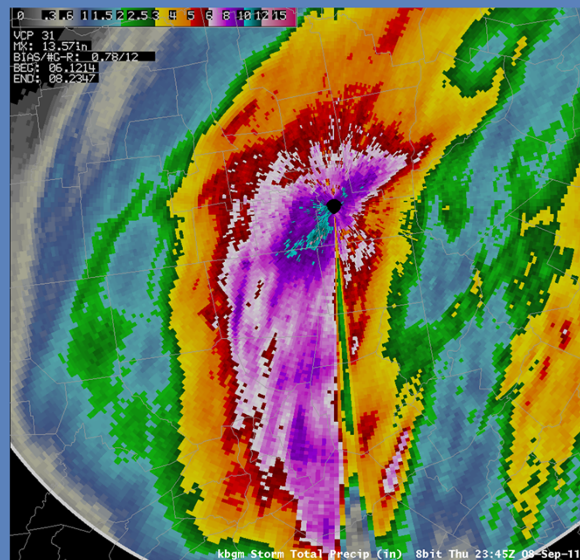


The key to high precipitation rates with supercells is understanding why supercells are such a threat despite poor precipitation efficiencies and at times swift movement. You just saw the dual-polarization characteristics of a supercell. However, there are some environmental factors to consider. In this case, we will focus on how much air it is ingesting and how moist is the inflow. Looking at this high-precipitation (HP) supercell near Midland, TX, this storm is in an environment where the profile is moist up to 700-mb and is considerably dry above it (The warm cloud layer is about 9,000 ft.). So, this storm is undergoing processes such as dry air entrainment and evaporation.

However, the storm has a very strong, moist updraft with it. It is ingesting very moist air (mixing ratio of 14 g/kg) at about 20 m/s. The updraft is wide and has a vertical depth of over 2 km. So, even though this supercell existed in an environment characterized by dry air above 700 mb, the storm produced rain rates of 2-4 inches per hour and fatal flash floods in the city of Midland. This shows that the factors that give HP and classic supercells a lower precipitation efficiency can be balanced by large values of moisture inflow and why supercells can produce high rain rates and flash flooding.

Precipitation Duration Factors

- Residence time of precipitation over a location
  - Rainfall Area
  - Storm Motion
  - Boundaries
  - Training Storms



Now that we have examined the meteorological variables that influence the precipitation rate, let's examine the other meteorological factor that can influence the flash flood potential: precipitation duration.

When we talk about duration, we are talking about the residence time of precipitation over a location. There are a number of things that affect the duration of rain over a specific area, such as rainfall area, storm motion, slow moving boundaries, and training storms. We will look at each one to see how they can increase precipitation duration.

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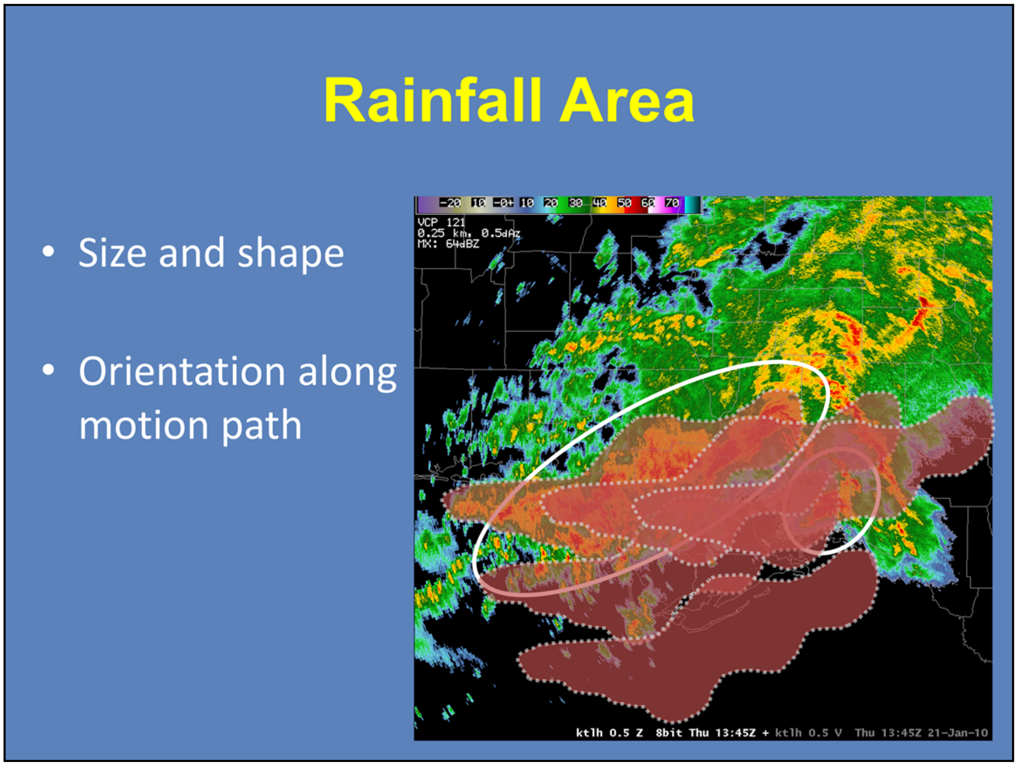

The first thing to look at is the size and shape of the precipitation area. Using the Tallahassee, FL radar, you can see a supercell southeast of the radar. Supercells and pulse storms are small in size, and depending on movement, will generally have a small residence time over one location. Linear convection, like the complex to the west, cover a much greater area. Therefore, the residence time of rainfall over a specific point is increased.

One thing to look at is the orientation of the precipitation area with respect to the motion path. Let's assume that this convection highlighted here is moving towards the south at a constant speed of 40 mph. If we were to assume that the width of the area is approximately 20 miles, then the residence time of the moderate to heavy rain is about 30 minutes.

Now let's assume that this linear complex is moving to the east at 40 mph. If we were to assume that the length of the area is about 120 miles, then the residence time over this area is closer to three hours. With this event back in January 2010, the complex was moving towards the east and produced 4-7 inches of rain around the Tallahassee area.

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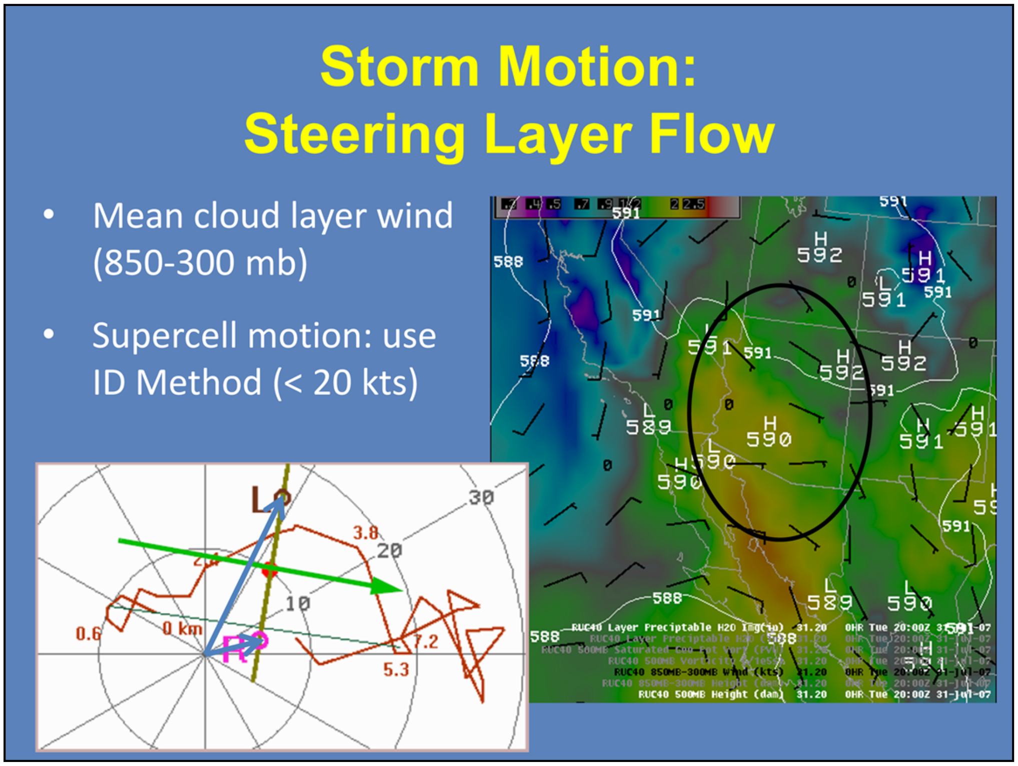
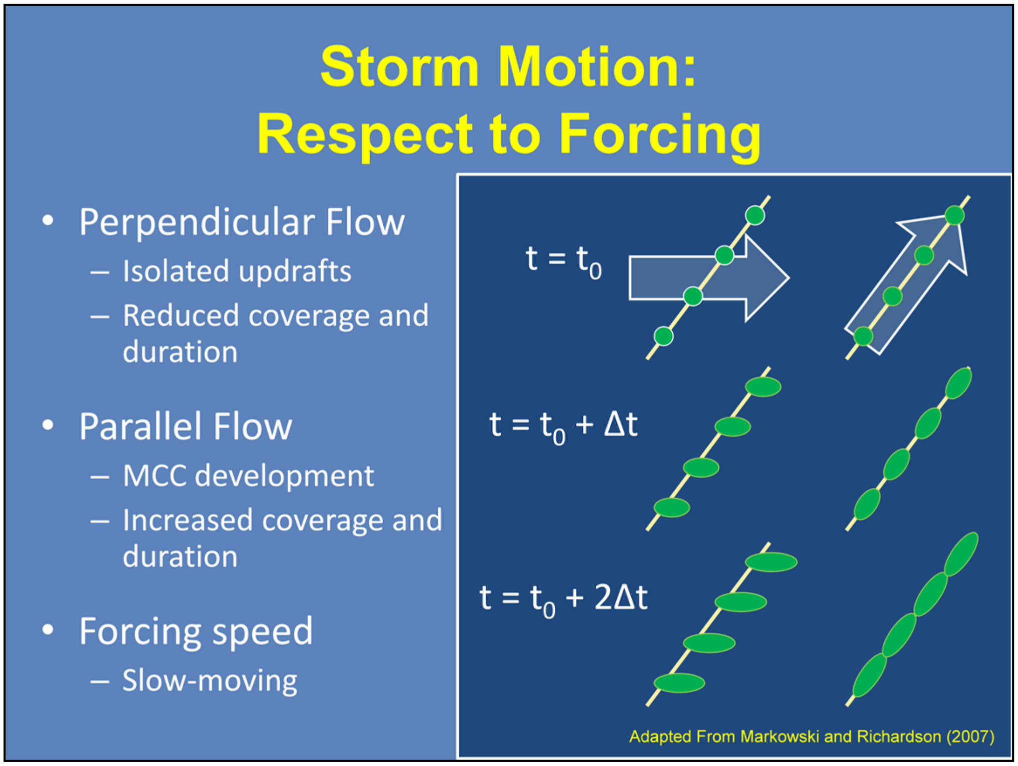


Storm motion is a significant factor when it comes to precipitation residence time over an area. Obviously, slower storm motions lead to longer durations. But what would you look for to determine storm motion?

One factor to look at is the steering layer flow. You can use your volume browser in AWIPS to view the mean wind between 850 and 300 mb. Using the example over Arizona, you can see that the 850-300 mb winds over the state is generally from east to west at 5 kts. Very slow moving storms in this area did produce fatal flash floods in the Tuscon CWA.

For supercells, you can use the Internal Dynamics (ID) Method to calculate the motion of right and left moving supercells. A storm motion of under 20 kts is preferred. In the example shown here, you can see that right moving supercells with this hodograph would be moving just north of due east at about 5 kts. Recall how to use the ID Method with hodograph in the lesson on Supercell Dynamics and Motion.



Forcing mechanisms play an integral role in the development and motion of convection. A forcing mechanism can range from fronts to outflow boundaries to topographic features. How storms form and move along a boundary can determine whether you have isolated updrafts or consolidated line segments and mesoscale convective complexes (MCCs).

Recall the work of Markowski and Richardson. Flow that is perpendicular to the forcing will lead to isolated updrafts, which in turn will have reduced areal precipitation coverage and smaller precipitation durations. Flow that is more parallel to the forcing will lead to linear convective formation. This will increase precipitation coverage and duration. Slow moving or quasi-stationary forcing mechanisms are best for increased precipitation residence time over an area.

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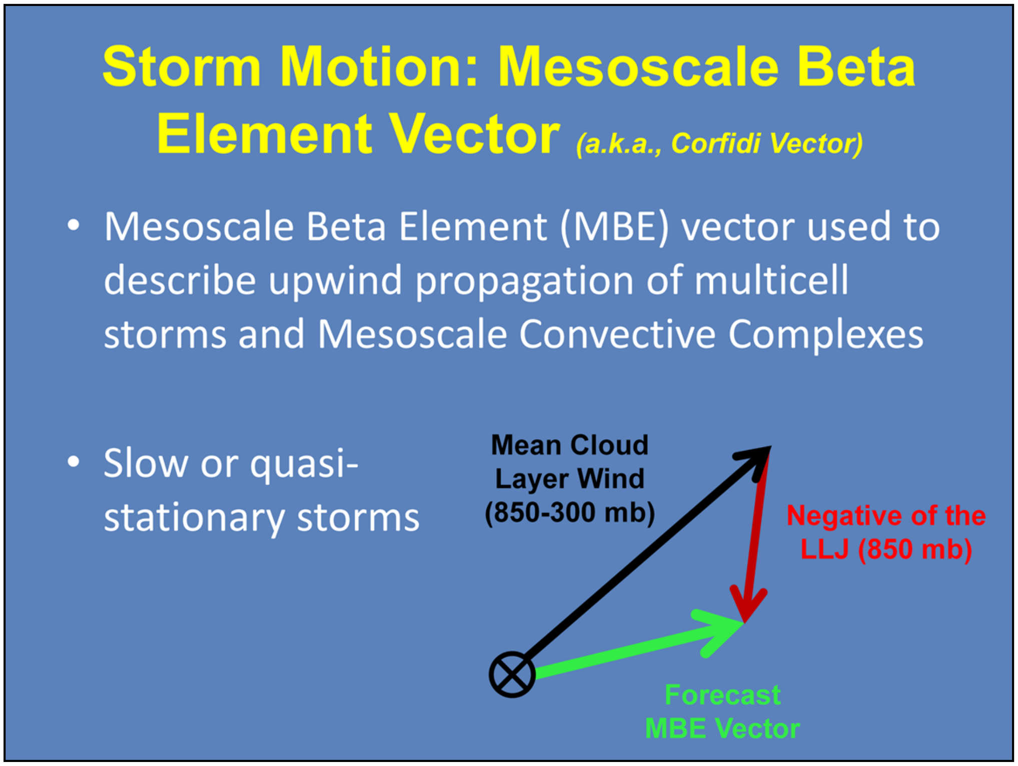

When dealing with multicell storms and mesoscale convective complexes (MCCs), the Mesoscale Beta Element (MBE) vector can help describe the upwind propagation of multicells and MCCs. Recall from the lesson on Multicell Motion that the MBE vector is calculated from taking the mean cloud layer wind and adding the negative of the low-level jet (850 mb flow depending on the depth of the inflow layer). Small MBE vectors means that if there is upwind propagation, then the complex will be slow moving or even quasi-stationary.

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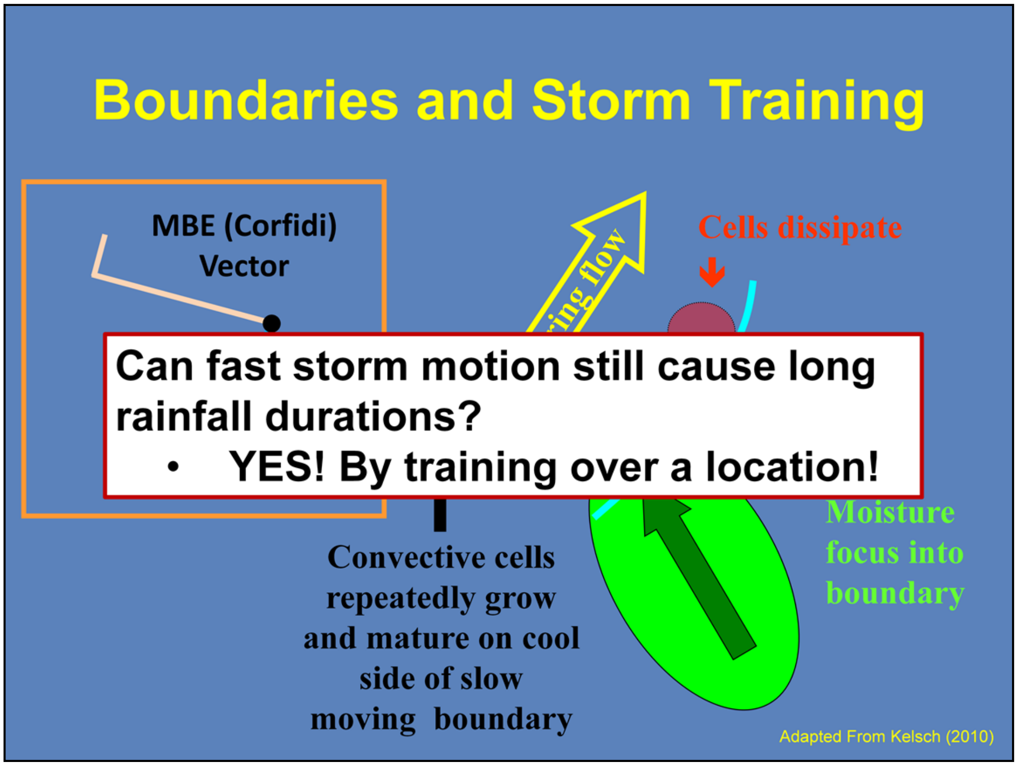

So far, we have talked about slow storm motions. What if storm motions are relatively fast? Can we still get large durations of rainfall? The answer is definitely yes.

If storms are training over the same location, it is easy to get the adequate duration for flash flooding to occur. One way is to have storms continuously propagate along a slow moving boundary. In this diagram, you have a SW-NE oriented boundary with an area of focused moisture transport. With enough lift and instability, convective cells will develop, move along the boundary, and dissipate. This cycle will continue so long as the boundary motion, moisture, instability, and trigger remain constant.

If you were to examine the vectors of this case, the mean flow parallels the boundary with expected storm motion of 25 kts. The MBE Vector shows that with backbuilding storms (upwind propagation), this system will move to the east at about 5 kts. This will allow for ample precipitation duration for flash flooding.

Example: Training Storms along a Quasi-Stationary Boundary

- See web video

Web Object

Address:
http://www.wdtb.noaa.gov/courses/rac/severe/objects/FWSradarLoop/

Here is an example of training storms that led to significant flash flooding. In this case from the Dallas/Fort Worth office, a series of storms train over the northern part of Texas near the Red River. This loop shows 5 ½ hours of radar data from KFWS. The star on the map shows the relative area of maximum focus and continuous development. Note how the storms train over the same area until a substantial cold pool develops for forward propagation.

Click next to advance to the analysis of this event when you are done viewing this loop.

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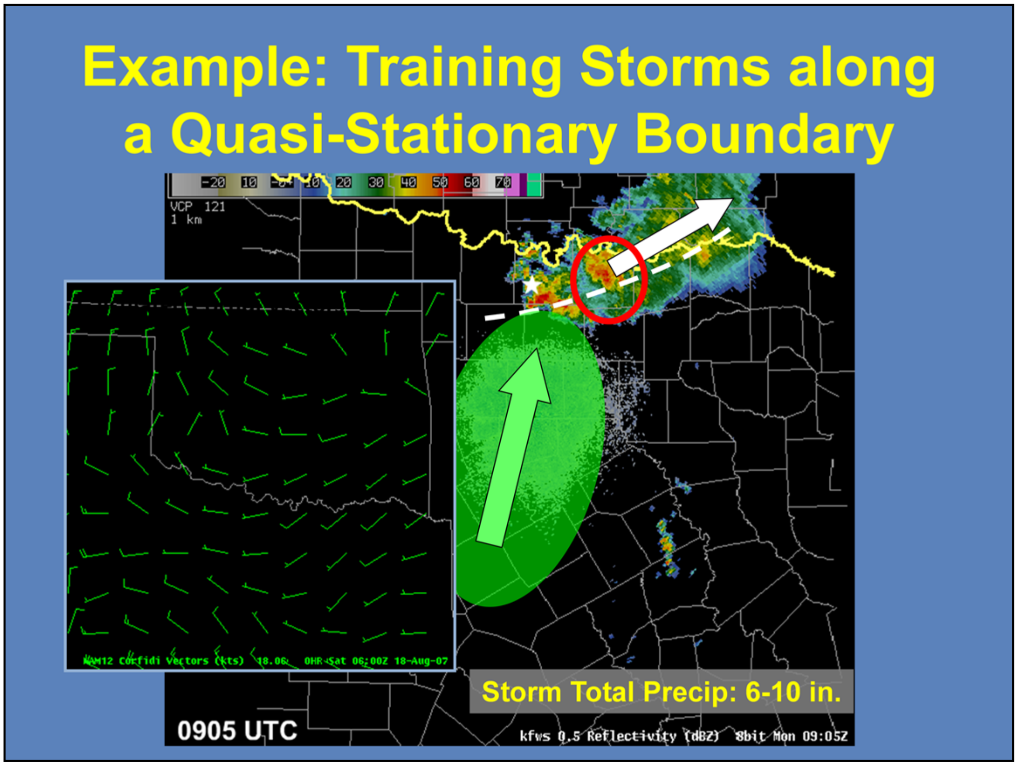

This event was created from a remnant mid-level circulation and boundary where a small vorticity maximum around the southern periphery is providing focus along the axis of forcing. The 1200 UTC sounding from Dallas/Fort Worth showed a very moist southerly 850 mb winds at 35 kts. You saw that storms initiated along the boundary where the forcing was maximized and then moved off to the ENE. However, the area of storms barely moved over a four hour time period. As you see here in the MBE, or Corfidi, Vectors, overall forecasted motion of the system is around 5 kts.

During this event, some areas received over four inches of rain in less than two hours, and storm total precipitation of 6-10 inches. There were six fatalities from these flash floods. Grayson County, which is circled in red here, had approximately 450 water rescues from vehicles and homes. There were hundreds of other water rescues in the surrounding counties.

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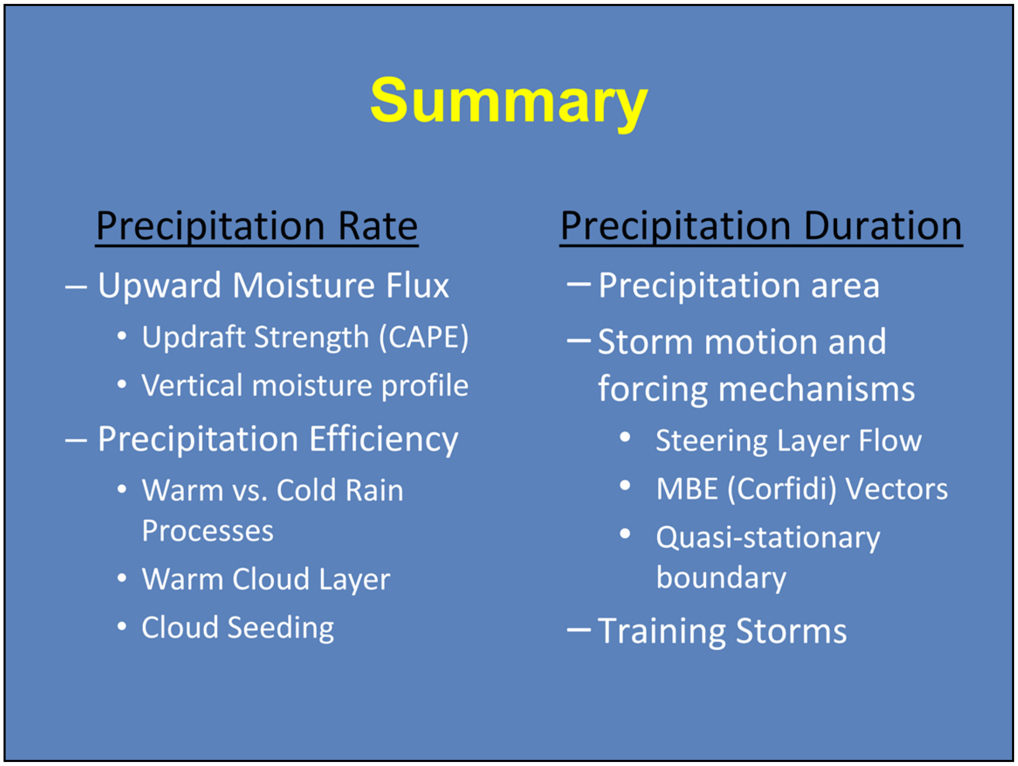

In summary, you saw that there were two primary meteorological factors regarding rainfall and flash flooding. With precipitation rate, you saw how the strength of the updraft and the overall vertical moisture profile played a role in the upward moisture flux into a storm. The fraction of that that is returned as precipitation is defined as the precipitation efficiency of a storm. This is dependent upon the type of rain processes that are dominant, the depth of the warm cloud layer, and cloud seeding.

With precipitation duration, you have to consider the area and motion of the precipitation. Understanding storm motion and forcing characteristics, such as flow parallel to boundaries, weak steering layer flow, backbuilding complexes via slow MBE vectors, and slow or quasi-stationary boundaries, can help provide longer duration periods. Analyzing the mesoscale environment can help you determine the potential for training storms if storm motions are relatively fast.

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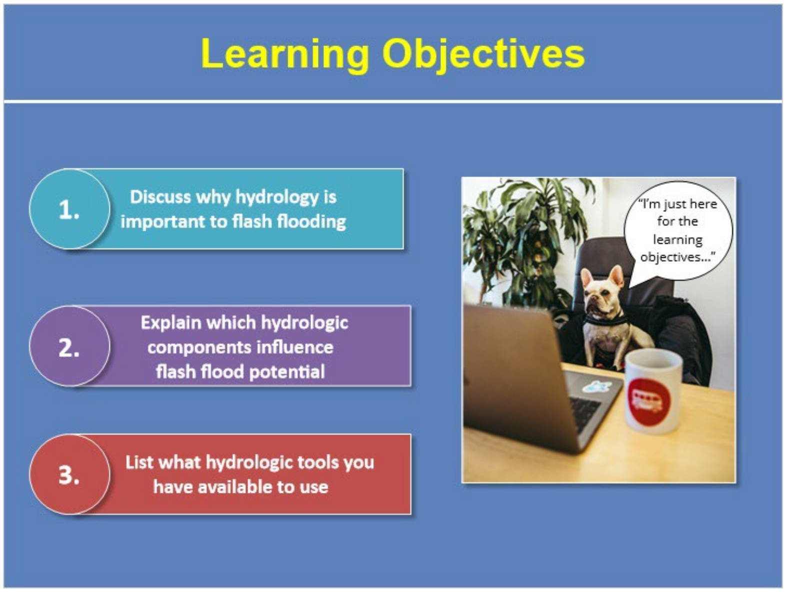
Flash Flood Hydrology

Introduction

Notes:

Welcome to this lesson over flash flood hydrology! In the module titled “Flash Flood Meteorology”, we discussed the meteorological side of flash flooding, but today we are going to talk about the other side that is equally just as important - that is the hydrological side.

Learning Objectives



Notes:

So what are you expected to learn today? After completing this module, you should be able to discuss why hydrology is important to flash flooding. Next, you'll need to explain which hydrologic components influence flash flood potential. And lastly, you need to be able to list what hydrologic tools you have at your disposal to aid in diagnosing the hydrologic side of flash flooding.

Game Time!

Notes:

Okay, before we dive in, let's play a quick game to get you ready! Below are snapshots from scenes in three different movies - the iconic Singing in the Rain scene, Pride Rock under the reign of Scar in Lion King, and Isengard under attack from Lord of the Rings, the Two Towers. In each of these scenes, there is some aspect of hydrology on display, but only one of them has hydrology playing a MAJOR role in causing flash flooding and ultimately affecting the outcome of the movie plot. Your job is to guess which scene where you think hydrology played a MAJOR role in affecting the plot outcome. Once you've made your selection, click next to submit your answer!

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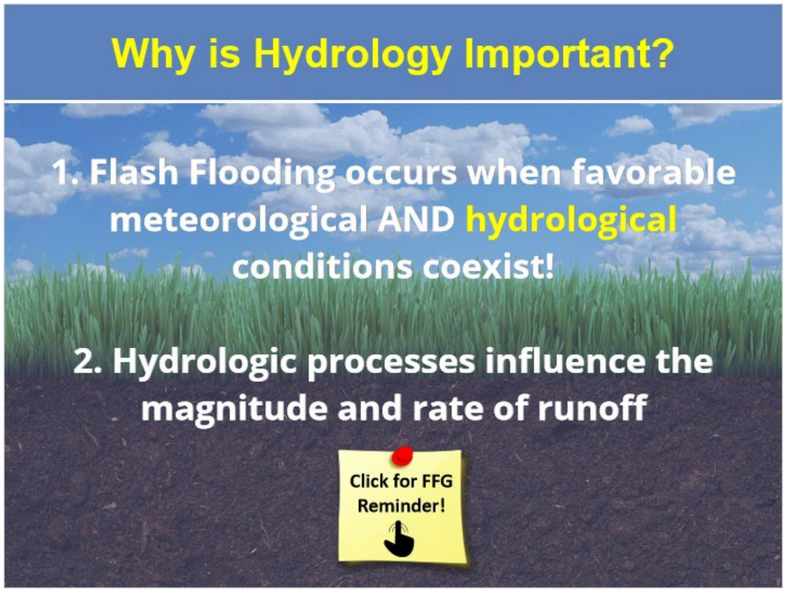
Why is Hydrology Important?



Notes:

Okay, I know you are probably curious to see what the answer is but before we get to that, we need to spend some time talking about how hydrology influences flash flood potential. Remember from the "Flash Flood Meteorology" module that heavy precipitation results when rainfall rates are high over the same geographic region for a long period of time. However, what you need to know is that not all heavy rainfall results in flash flooding! This is because flash flooding occurs when the favorable meteorological AND hydrological conditions coexist. In other words, precipitation amounts may be considerably high, but flash flooding may not occur due to hydrological factors not being favorable.

Next, hydrologic processes are important to account for because they influence the magnitude and intensity of runoff associated with flash flooding. So if you want to properly account for runoff potential, you've got to consider the hydrology.

Now, before we go any further, throughout the remainder of this module, we will be referring to Flash Flood Guidance off and on so if you need a quick overview or reminder on what it is and how it works, feel free to click here. If you don't need a refresher, go ahead and just click "next."

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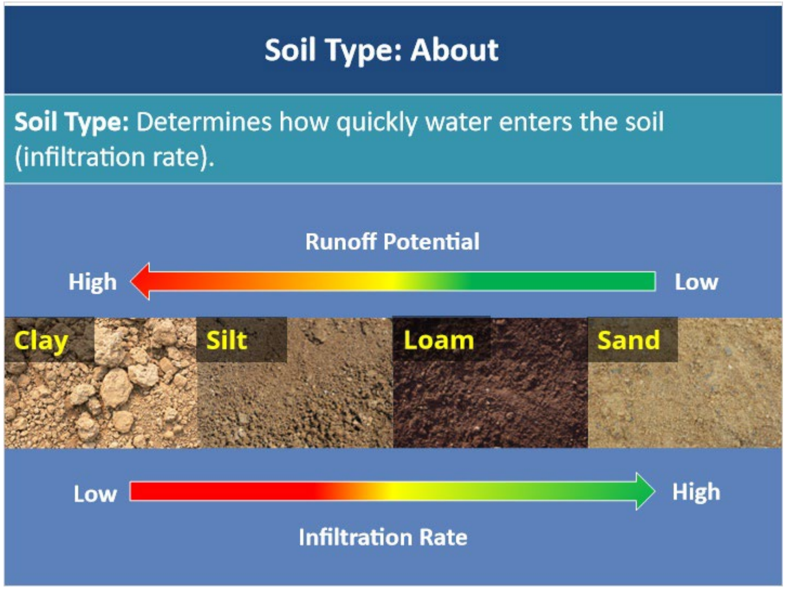
Soil Type: About



Notes:

The first hydrologic factor that influences flash flood potential is the soil type. The type of soil is important because it determines how quickly water enters the soil, referred to as infiltration rate. A low infiltration rate means that the soil is not able to absorb water quickly and as a result, runoff will occur much faster. Of the common soil types, clay has the lowest infiltration rate followed by silt meaning that these soil types have a high runoff potential. In contrast, soil types such as loam and sand have a high infiltration rate, meaning that they are able to absorb and process water at a high rate so the potential for surface runoff is lower. So the type of soil in your CWA is actually important to be aware of as it can either help to enhance or reduce runoff potential!

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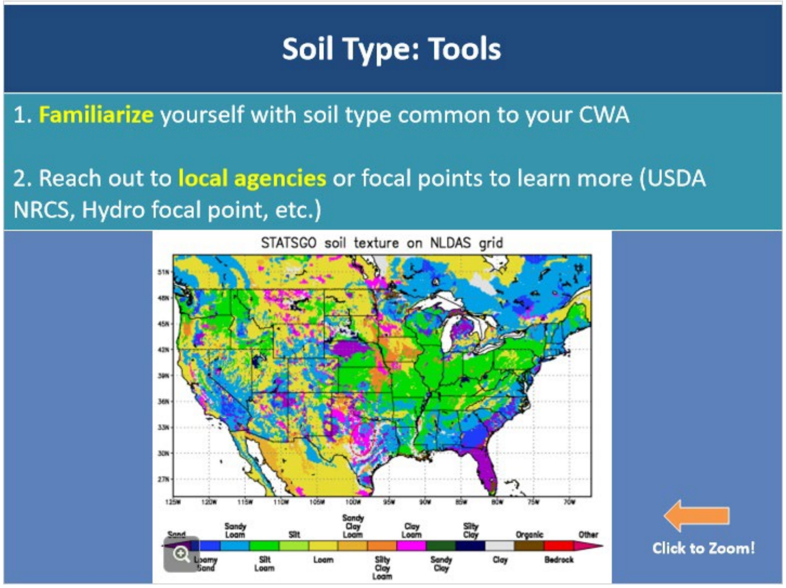
Soil Type: Tools

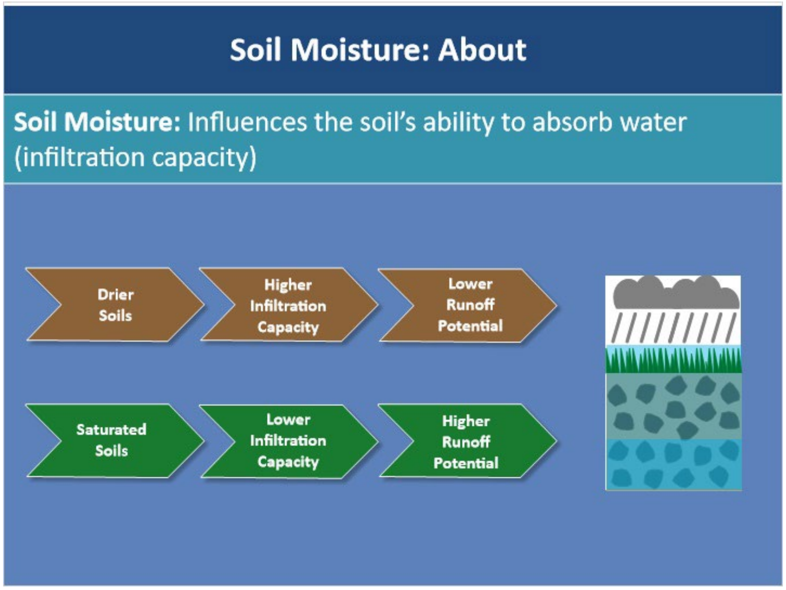


Notes:

As for what tools are available to help you in this area, the first is to familiarize yourself with the soil type that is most common in your CWA. Take a look at the figure here that shows the distribution of soil types across the U.S. Remember how a portion of central Texas is often referred to as “flash flood alley?” Well, one of the many reasons that region is especially susceptible to flash flooding is due to widespread clay soils there that have low infiltration rates, meaning that surface runoff occurs much faster. Knowing the soil type that is most common across your CWA can help you be aware of what areas absorb and process less water and will be at a higher risk for rapid surface runoff. This figure is included in the “Resources” tab so feel free download it and take note of your CWA’s common soil types.

Another optional tool is to reach out to your local agriculture agencies, such as the USDA Natural Resources Conservation Service, to get more detailed and specific info and maps about soil types in your area. Your hydro focal point can also help point you in the right direction as well.

Soil Moisture: About



Notes:

The next soil characteristic to pay attention to is the soil moisture - is the soil dry or saturated? Soil moisture matters because it affects the soil's ability to absorb water, or its infiltration capacity. For example, soil that is saturated due to recent rainfall has a low infiltration capacity, meaning that it is not able to accept any more moisture and any precipitation falling at the surface will very quickly become surface runoff. In contrast, soils that are dry have a high infiltration capacity and are able to take in moisture, resulting in less surface runoff. It's important for you to be aware of what areas have recently received high amounts of rainfall, as this means that the soil's infiltration capacity there may be used up and flash flooding can occur very easily.

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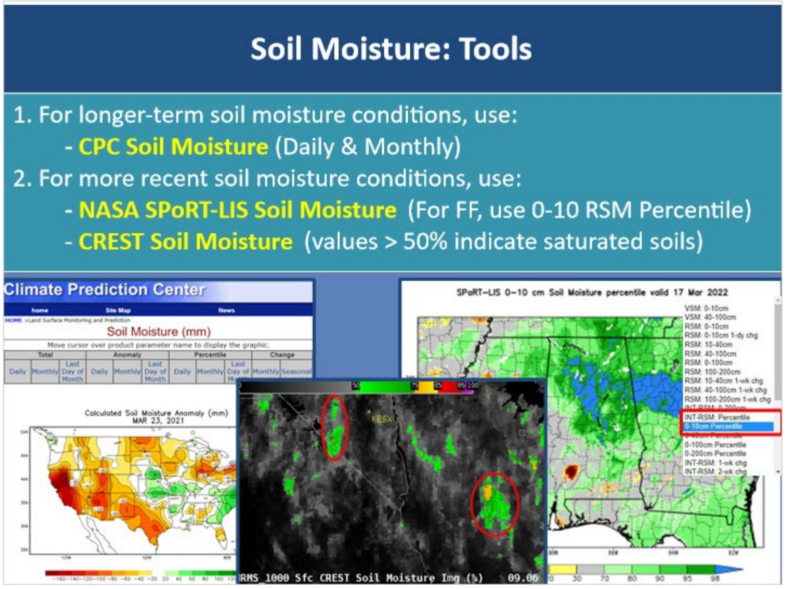
Soil Moisture: Tools



Notes:

So what tools do you have at your disposal to help identify saturated soils? For longer-term soil moisture conditions, check out the Climate Prediction Center's Soil Moisture webpage to quickly get a feel for what your soil moisture conditions are like on monthly and daily timescales.

For a more recent snapshot of soil moisture through varying soil depths, NASA SPoRT has a plethora of available products that are updated every 6 hours and have a 3 km spatial resolution. For flash flood applications, we recommend using the 0-10 cm relative soil moisture percentile product as it is based on climatology and takes into account soil type and saturation.

And lastly, for a finer temporal resolution product, check out the CREST Soil Moisture product as it updates every 10 minutes. Due to its quick update time, you can use CREST soil moisture to spot potential problem areas, especially if you have more storms coming upstream. We here at WDTD recommend paying attention to areas of greater than 50% soil moisture to identify areas primed for flash flooding. These locations have less capacity for extra moisture, and thus, will react quickly if more rainfall occurs. If you want to learn more about this product in specific, please refer to the WDTD FLASH products course where it'll be covered in more detail.

Website links to both the CPC and NASA SPoRT soil moisture products are included in the Resources tab so feel free to check those out.

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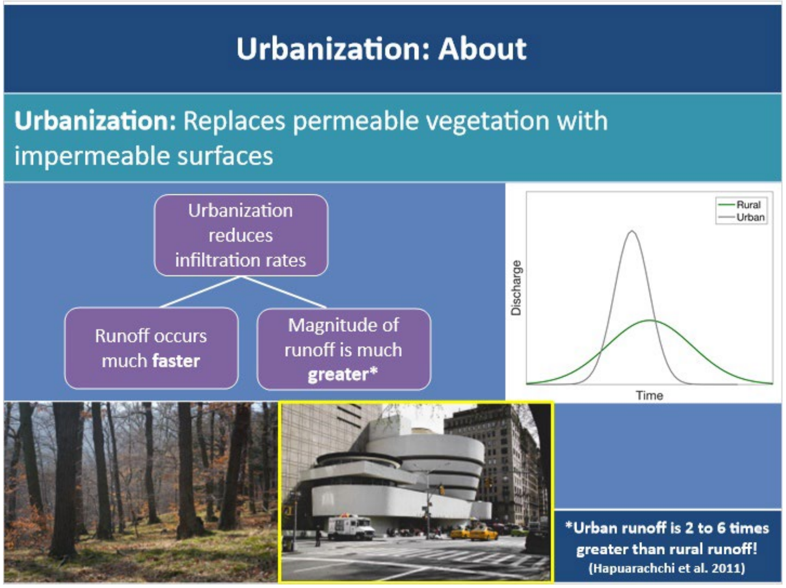
Urbanization: About



Notes:

Now that we've talked about how soil characteristics affect flash flood potential, let's take a look at which land surface characteristics are important to consider beginning with urbanization. So how does urbanization influence flash flood potential? Urbanization essentially replaces natural permeable vegetation surfaces with impermeable surfaces, such as sidewalks, buildings, and concrete. This is a problem because impervious surfaces are very poor absorbers of water compared to vegetation. For example, when heavy precipitation falls on vegetation and soil, some of that rainfall is partially absorbed. However, when rainfall occurs over urban areas and falls on roofs and sidewalks, rainfall cannot infiltrate those surfaces and is directly converted to runoff! In other words, urbanization reduces infiltration rates and allows runoff to occur much faster over urban areas than non-urban areas.

Not only does runoff occur much faster over urbanized areas, but the magnitude of that runoff is much greater. Think about the picture shown here - storm sewers, roads, roofs, and stream channelization culverts all force runoff to occur more quickly and at a much greater magnitude due to the combination of all of these! The figure to the right illustrates this. Peak discharge for urban areas occurs much earlier and faster compared to rural areas. Additionally, the magnitude of discharge for urban areas is also much greater than rural areas. To give you an idea, studies have found that urban runoff is two to six times greater over urban areas compared to rural areas! So the important thing to remember is that urbanized areas greatly increase the potential for flash flooding!

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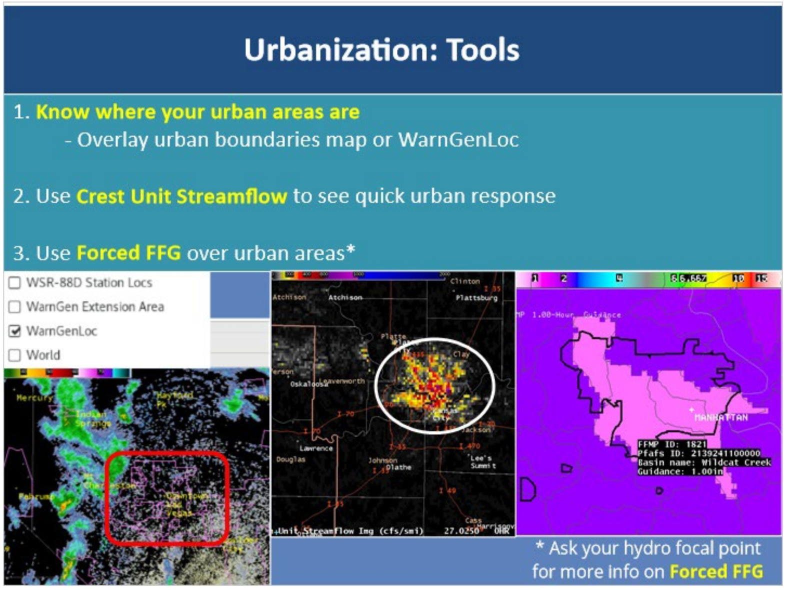
Urbanization: Tools



Notes:

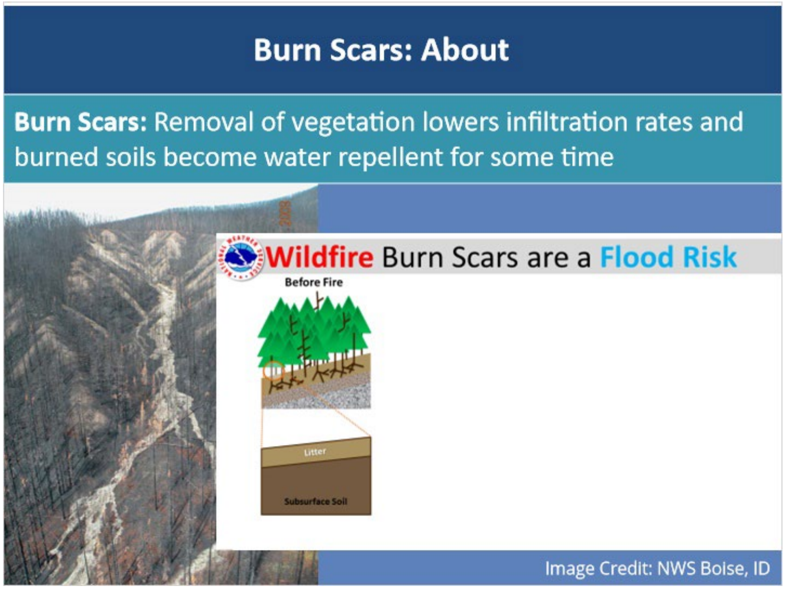
So what are some tools that you can use to properly anticipate the urban flash flood threat? One of the first and most important tools you have at your disposal is to KNOW where your urban areas are as these will typically be the first to go in terms of flash flooding. Oftentimes it may only take an inch of rain in an hour to start causing havoc over metro areas. One way to help draw your attention to those areas is to overlay an urban boundaries map on your flash flood bundles. If you don't have a local map for this, don't worry! WarnGenLoc is a default AWIPS map of all the WarnGen city locations. When either of these maps are overlaid, it will highlight your urban bounds and can help you remember where your most vulnerable urban areas are.

Next, CREST Unit Streamflow is an excellent hydrologic tool over urban areas because it includes an imperviousness parameter. This parameter helps the model react more quickly to rainfall in urban areas since it recognizes the higher runoff potential. To learn more about the applications of this product, please refer to the 'FLASH Best Practices' module.

Lastly, you can use the forced FFG tool to set flash flood guidance to be a certain value over your urban areas. For example, if you know that one of your cities typically begins to flash flood anytime you get more than 1 inch of rain in an hour in that basin, you can manually set or force your 1-hour FFG to be 1-inch over that area. Feel free to talk to your hydro focal point to learn more about this option.

Using all these tools together can help you remember to not forget the serious risk that urbanization poses to enhancing the flash flood potential.

Burn Scars: About



Notes:

Another land surface characteristic that presents an enhanced flash flood risk is areas that have recently been burned by wildfires, known as burn scars. The issue with wildfires lies in the aftermath effects on the land surface. Vegetation that normally acts to intercept and delay water entering the soil is removed during wildfires so burn scar areas have a much lower infiltration rate. Additionally, soils that have been burned by wildfires are extremely water repellent, and are equivalent to a slab of concrete. To make matters worse, soils remain hydrophobic for some time after the wildfire - in some cases, up to 2 years after!

To further illustrate the post-wildfire effects on flash flood potential, take a look at the schematic shown here. Here are typical conditions before the wildfire where, at the top of the soil, you have a layer of organic material referred to as litter, which is essentially any leaves or materials that have fallen from trees or vegetation. Beneath the layer of litter, you have the subsurface soil which varies according to geographic region. During a wildfire, vegetation and the layer of litter is burned and transformed into a water repellent compound which condenses on top of the cooler soil layer below. Ash and burned soil prevent the soil beneath from absorbing water. As such after a wildfire, the soil is not able to absorb any water during periods of heavy rain and essentially acts as a slab of concrete. Rapid surface runoff and flooding results over burn scar areas and in some cases, mud and debris flow may result from the leftover burned debris and ash.

Burn scars are some of the scariest flash flood threat areas because even moderate rainfall rates can see rapid, deadly impacts due to these land surface characteristics.

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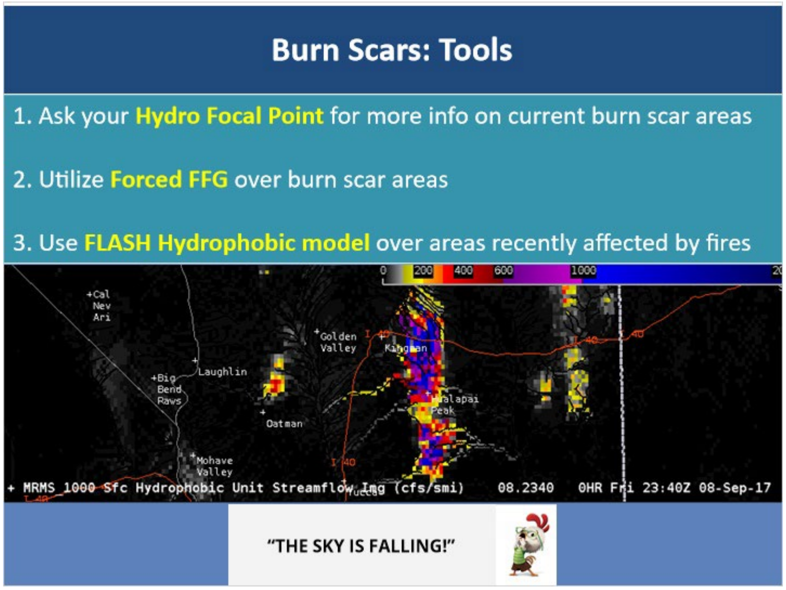
Burn Scars: Tools



Notes:

The first tool for dealing with burn scars is to be in contact with your hydro focal point about any areas in your CWA that have been recently affected by wildfires. You should become familiar with the location, impact areas, and rainfall thresholds for each burn scar.

Next, as we mentioned for urban areas, you can use Forced FFG over your burn scar areas to manually set the amount of rainfall needed over a certain amount of time for flash flooding. In many cases, it only takes half an inch of rain in an hour over burn scar areas to start causing serious problems. Making sure you use forced flash flood guidance over these areas to properly reflect that will help you not miss some of the most vulnerable areas.

Lastly, the FLASH product suite has a hydrophobic model that you can make use of over burn scar areas. The hydrophobic model essentially converts any rain that falls directly to runoff so it will often have an end of the world appearance. However, for newer burn scars where hydrophobic soil is prevalent, this model's output can be fairly realistic and can help quickly identify threat areas.

For more details about burn scar flash flooding, we have an entire lesson devoted to operational best practices and tools specific to this topic and the link is included in the "Resources" tab.

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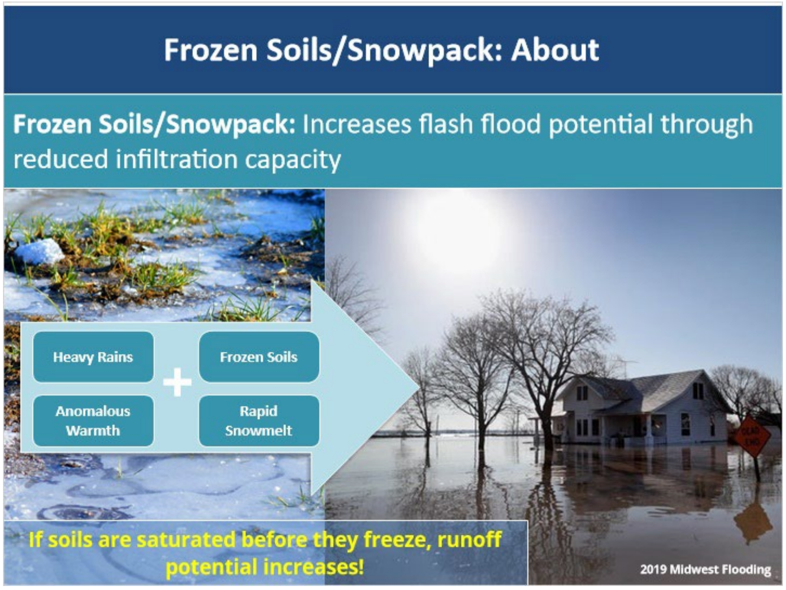
Frozen Soils/Snowpack: About



Notes:

While more a result of season, frozen soils and snowpack are the last land surface characteristics I want to mention. Frozen soils have a reduced infiltration capacity which can enhance runoff. The runoff potential is even higher too if the soils were saturated before the soil froze. This is often the case if you have an anomalously wet fall but then all those saturated soils freeze during the winter months.

Likewise, heavy rain falling on snowpack has nowhere to percolate and can also help to melt the snowpack, especially if the snowpack is already near the melting point. While rain on snow events are more often associated with longer term flooding events, that can be an antecedent condition for flash flooding later on.

A memorable example of this sort of situation was the historic Midwest floods of 2019. Heavy rains coupled with anomalously warm temperatures lead to rapid snowmelt and because the soils underneath were still frozen, they were not able to absorb any of this excess moisture, leading to historic runoff and flooding over the region.

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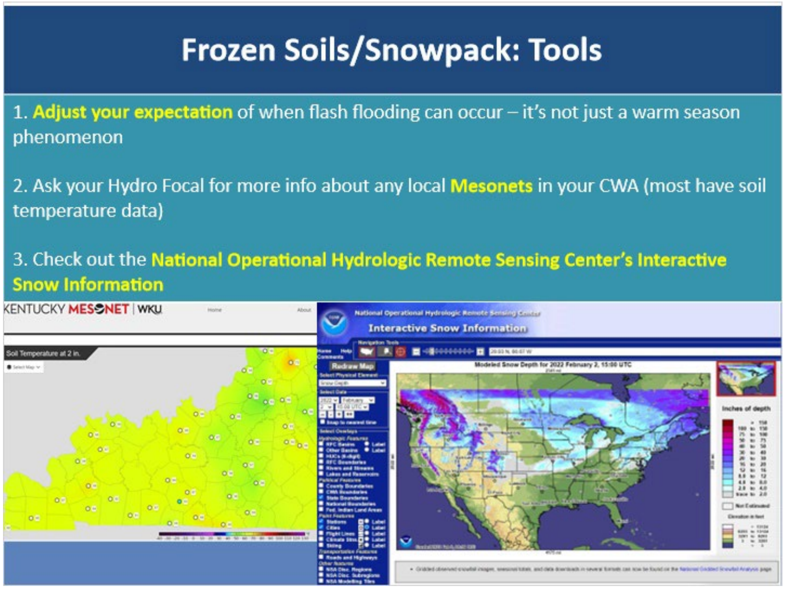
Frozen Soils/Snowpack: Tools



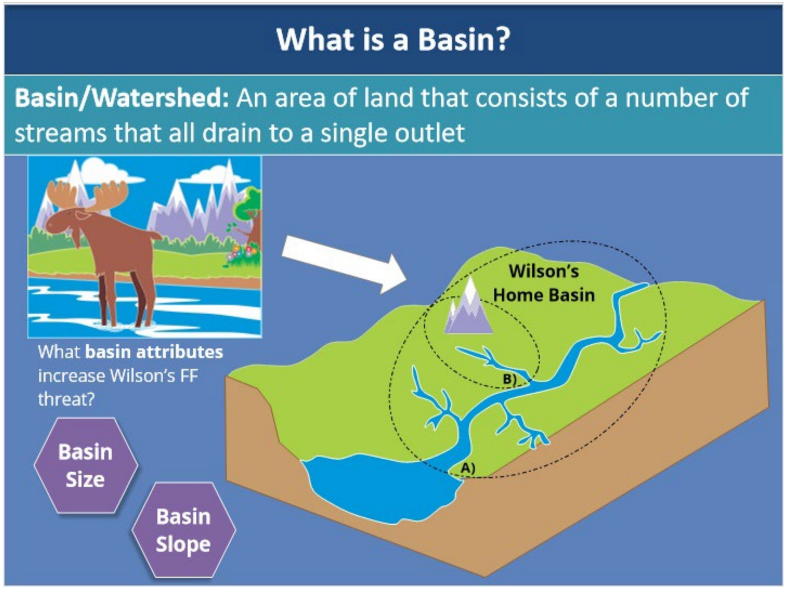
Notes:

So how can you be equipped to handle these sorts of situations? The first and most important tool is for you to mentally adjust your expectations of when you think flash flooding can occur. If you view flash flooding as just a warm season phenomenon, these sorts of events will catch you off guard. It's important to remember that flash flooding can happen even during the winter months!

Next, it's important to have a general feel for what your soil temperatures are like if you have a setup that is suggestive of flash flooding. While there unfortunately isn't a nationwide soil temperature monitoring system, be sure to check with your hydro focal point if you have any local Mesonets in your CWA at your disposal as these most often have soil temperature readily available for you to use.

Lastly, the National Operational Hydrologic Remote Sensing Center has a plethora of snow related observations, products, and datasets readily available and the website link is included in the "Resources" tab in case you are interested.

What is a Basin?



Notes:

Okay, before we delve further into discussing basin attributes, we first need to understand what a basin or watershed even is! Let's say Wilson the Moose lives in this lush green land area shown here that consists of multiple streams that run into a main river. Eventually, the main river drains to a single outlet, referred to as Point "A" shown here. A basin is simply the area of land that consists of all the streams that drain to a single outlet. Now, basins can be further divided into smaller basins as shown by the dashed line. The letter "B" now marks the outlet point for this smaller basin where Wilson spends a majority of the time. So, what basin characteristics here can increase Wilson's flash flood threat? In general, there are two - basin size and basin slope.

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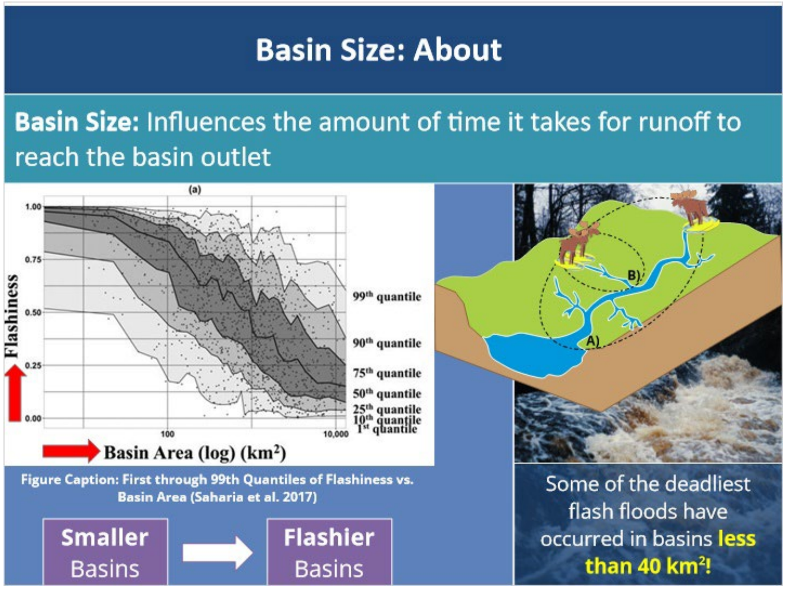
Basin Size: About



Notes:

Okay, let's talk about the influence of basin size by taking a look at this figure from a study in 2017 that examined how various climatological and geomorphological variables affect flash flood severity across the U.S. Here we have basin area on the x-axis plotted against flash flood severity, referred to as flashiness, on the y-axis. What this study found was the smaller the basin, the greater the potential for fast and extreme runoff to generate flash flooding. In other words, smaller basins are more prone to flash flooding than larger basins.

Why is this the case? When basins are smaller in size, like Wilson's home basin, runoff reaches the outlet point much quicker due to having less distance to travel downstream. As a result, the rate of discharge at the outlet point will be much greater and that basin will flash flood more quickly. In contrast, runoff in larger basins has a longer distance to travel and takes longer to reach the outlet point. While basins can range in size from as small as 5 km^2 to as large as 1000 km^2 or even larger, some of the deadliest flash floods in history have occurred in basins less than 40 km^2. So, it's very important to pay attention to where your smaller and therefore, more vulnerable basins are.

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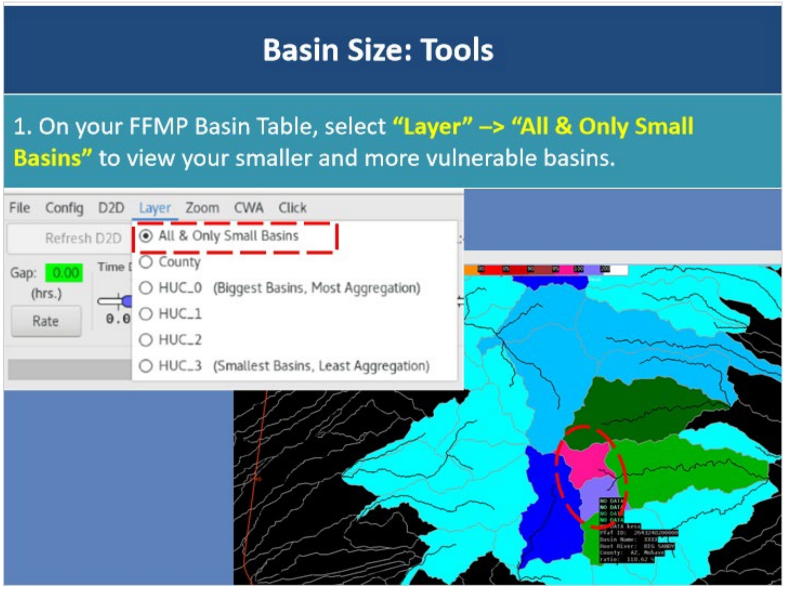
Basin Size: Tools



Notes:

As for what tools you have at your disposal, this is where FFMP comes in as a great tool to help you mentally keep track of where your smaller basins are! To view basins in FFMP, be sure to change your "Layer" view to be "All and Only Small Basins." When you select this display option, it will allow you to visually keep track of your smaller and therefore more vulnerable basins as shown in this image here.

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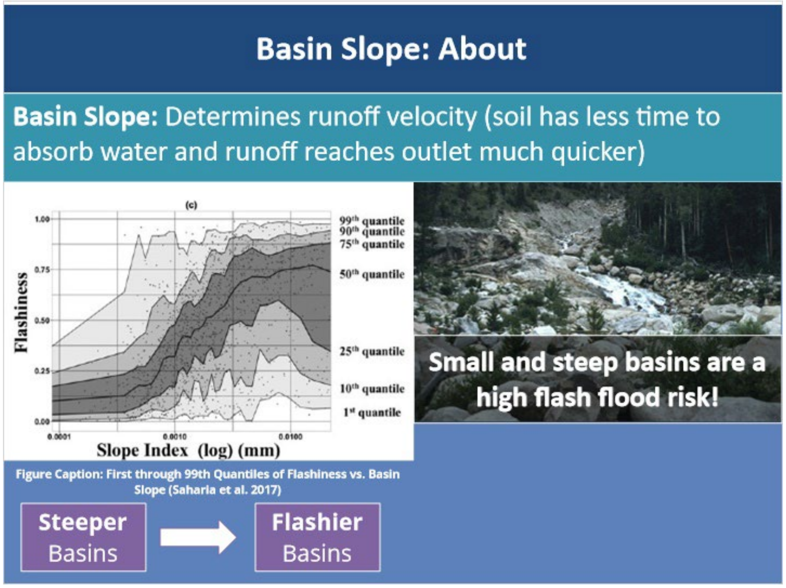
Basin Slope: About



Notes:

The next basin characteristic that can affect flash flood potential is the actual slope of the basin, where slope is defined as the measured change in elevation along the main stream channel. As before, the study we previously mentioned also looked at basin slope and the results were as you'd expect - the steeper the topography of the basin, the more flash flood prone it is. Basins with steep slopes result in higher velocity runoff such that the soil has less time to absorb water. Runoff will then reach stream channels and the basin outlet much quicker, resulting in an increase in runoff rate and magnitude!

Interestingly, the study found both basin slope and basin area are equally important contributors as to how flashy a basin was. So, the overall takeaway is that small, steep basins are at a much higher risk for flash flooding than larger, flat basins.

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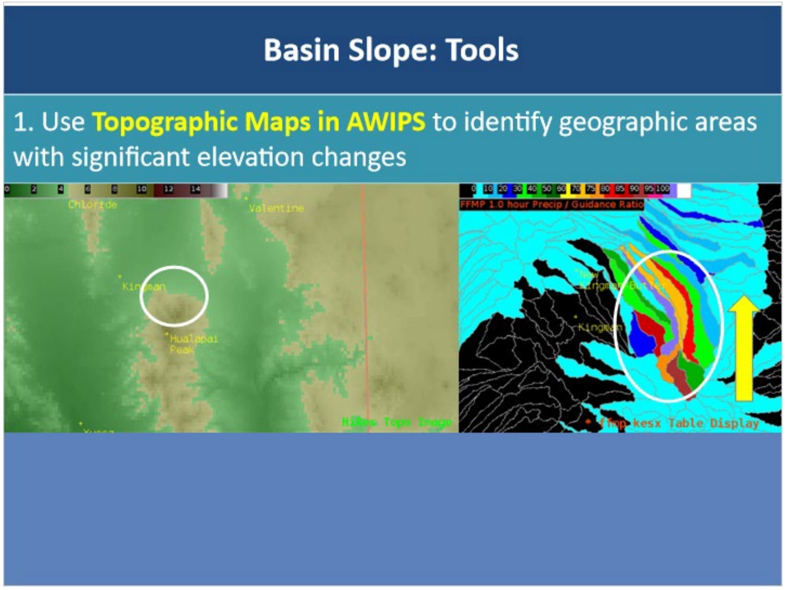
Basin Slope: Tools



Notes:

Since FFMP does not display slope information for individual basins, the best tool you have at your disposal is to rely on topographic maps in AWIPS to identify geographic areas with significant elevation changes in your CWA. You can use that knowledge in tandem with the FFMP basin display to help you identify small steep basins that are particularly at risk for flash flooding. In this example, notice the series of long, thin basins. These basins are on a mountainside that has eroded in such a way that there are channels flowing down it. This is a prime example of flashy basins that are small and very steep.

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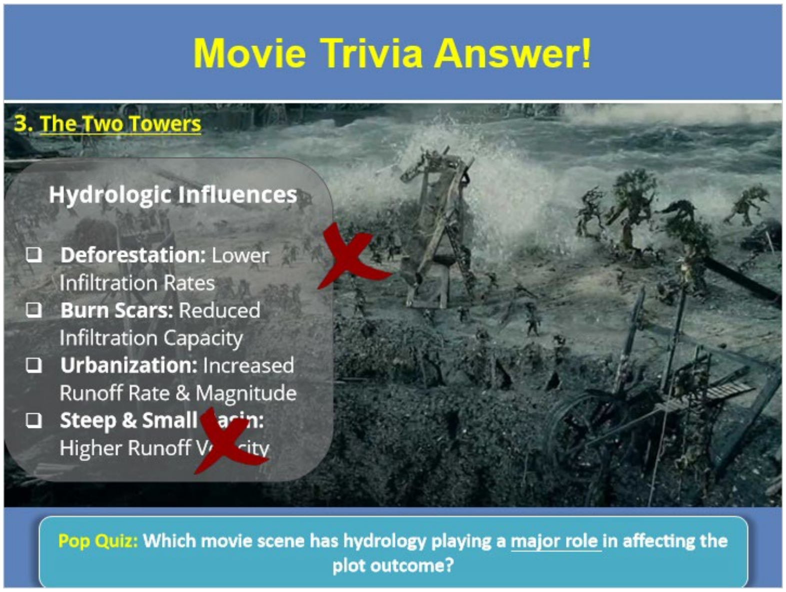
Applied Example



Notes:

Now that you have a solid framework for understanding what hydrologic factors affect flash flooding, let's return to our movie trivia question at the beginning of this module. Remember that we wanted to know which of these movie scenes illustrated where hydrology played a MAJOR role in causing flash flooding and ultimately affecting the outcome of the movie plot. Ready for the answer? If you chose the Isengard scene from Lord of the Rings, the Two Towers, you're correct!

In this iconic scene, hydrology actually played a major role if you think about it! Recent removal of vegetation and deforestation across Isengard acted to reduce infiltration rates drastically. Burn scars across the region from burning of vegetation resulted in water repellent soils and reduced infiltration capacity. Recent expansion of impermeable urban surfaces for evil purposes resulted in increased runoff rate and magnitude! Lastly, Isengard is located within a very steep basin which further increases the flash flood threat. Putting all of these factors together, it's no surprise that severe flash flooding occurred when Treebeard and his fellow colleagues broke the dam upstream! One could say that hydrology played a major role here at the turn of the tide for the battle of middle earth.

While urbanization definitely increased the flash flood potential in the ironic Singing in the Rain scene, Bing Crosby wrapped up his solo before things got to flash flood emergency level so that one is out. Lion King didn't quite make the cut because the drought and resulting widespread dry soils brought on by Mufasa's reign actually helped to absorb all the rain that fell upon Simba's return, preventing widespread flash flooding and allowing for a smooth-ish transition of power between the two. Okay, now that I've hopefully got your attention, let's summarize everything we've learned so that you can be prepared for the final quiz!

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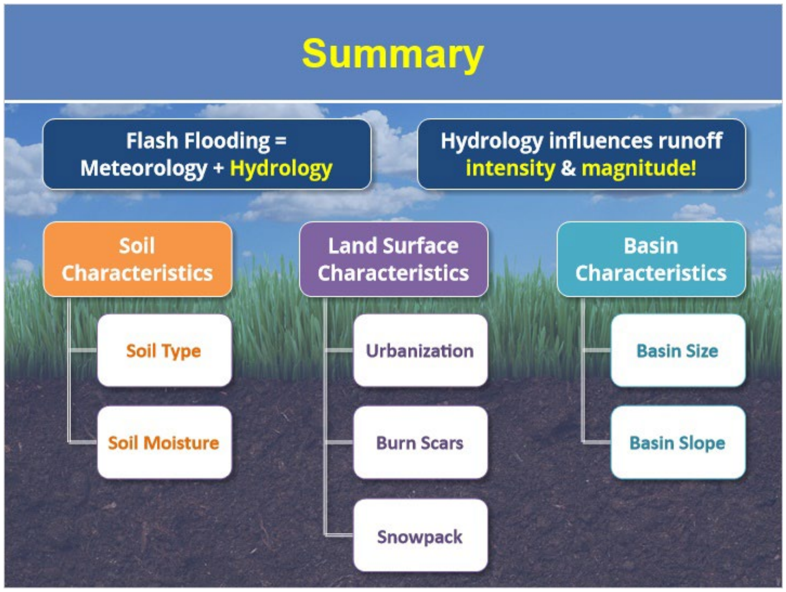
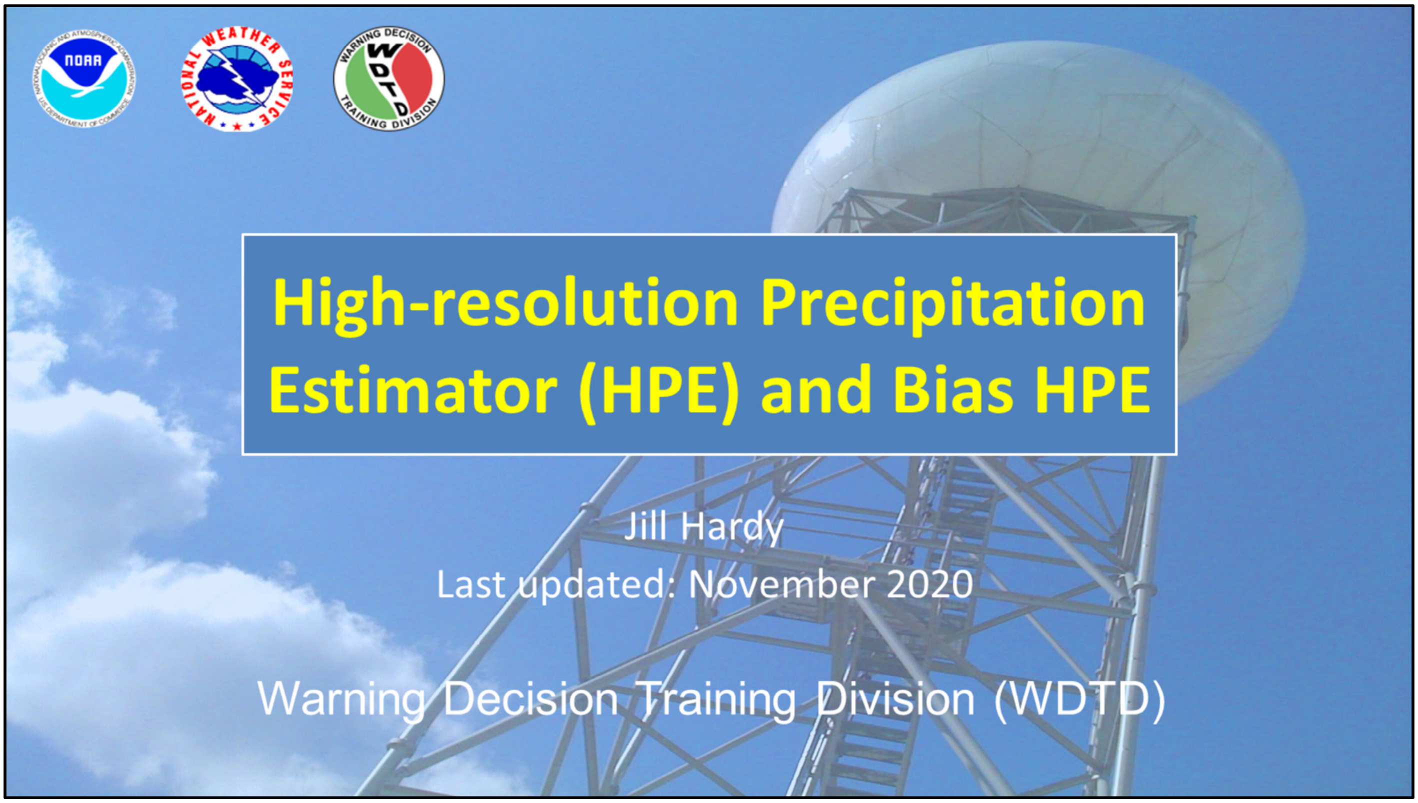
Summary



Notes:

Alright, let's quickly recap everything we've learned so far. Firstly, remember that flash flooding occurs when both meteorological AND hydrological conditions are favorable! Next, hydrology plays a major role in determining the intensity and magnitude of surface runoff! So, if you want to do flash flooding right, you've got to consider the hydrological side! As to what hydrologic factors impact flash flood potential, we focused on three different areas. Firstly, soil characteristics such as soil type and soil moisture impact how quickly water can enter the soil and how much water the soil can hold. Next, it's important for you to mentally be aware of certain land surface characteristics, such as urbanization, burn scars, and snowpack, as all three of these increase the intensity and magnitude of surface runoff! Lastly, be sure to pay attention to basin size and slope, with smaller more steep basins presenting a heightened flash flood risk. We also talked about several tools you can use in AWIPS and beyond to help you account for these hydrologic factors.

Okay, it's time to shine and show how much you've learned through acing the upcoming quiz! When you're ready to take the quiz, go ahead and click "next."

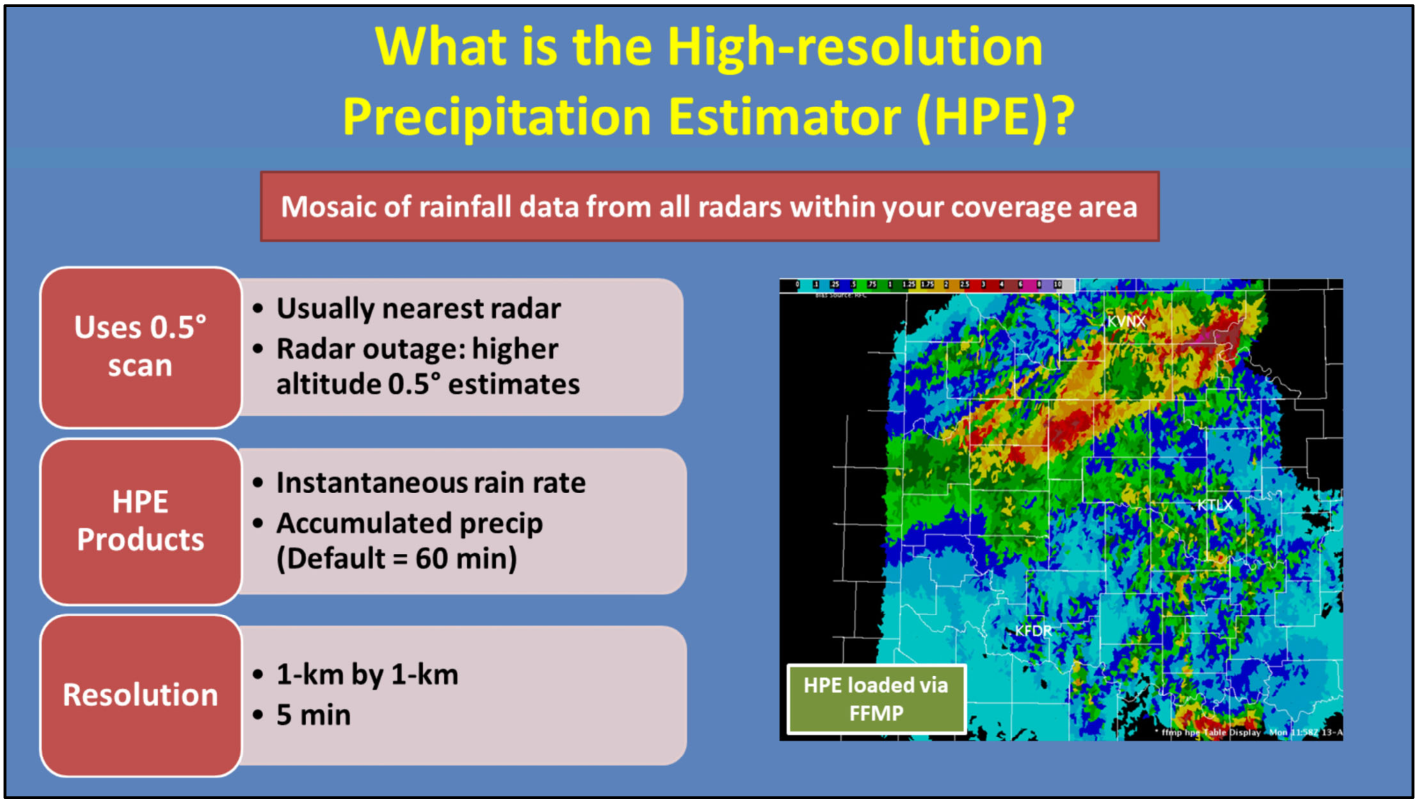


Hi, my name is Jill Hardy and welcome to this lesson on the High-Resolution Precipitation Estimator (or HPE) and Bias HPE products. Let’s jump right in!

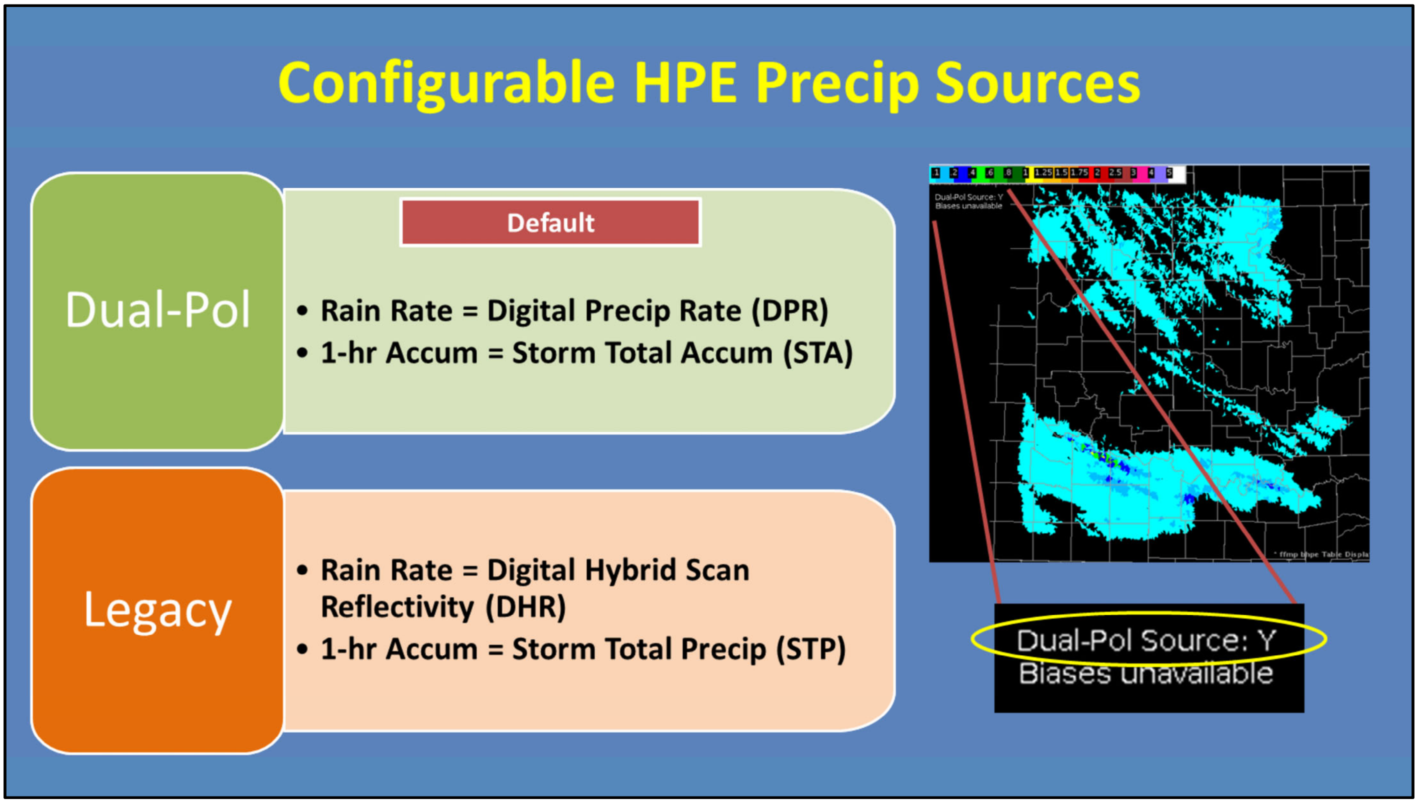
Learning Objectives

- By the end of this lesson, you will be able to:
  - Define what are the HPE, Bias HPE, and HPN products
  - Identify the default precipitation source for HPE and Bias HPE
  - Identify the default bias source for Bias HPE
  - Interpret HPE and Bias HPE text overlays
  - Identify how to determine areas of higher confidence in HPE/Bias HPE precipitation estimates

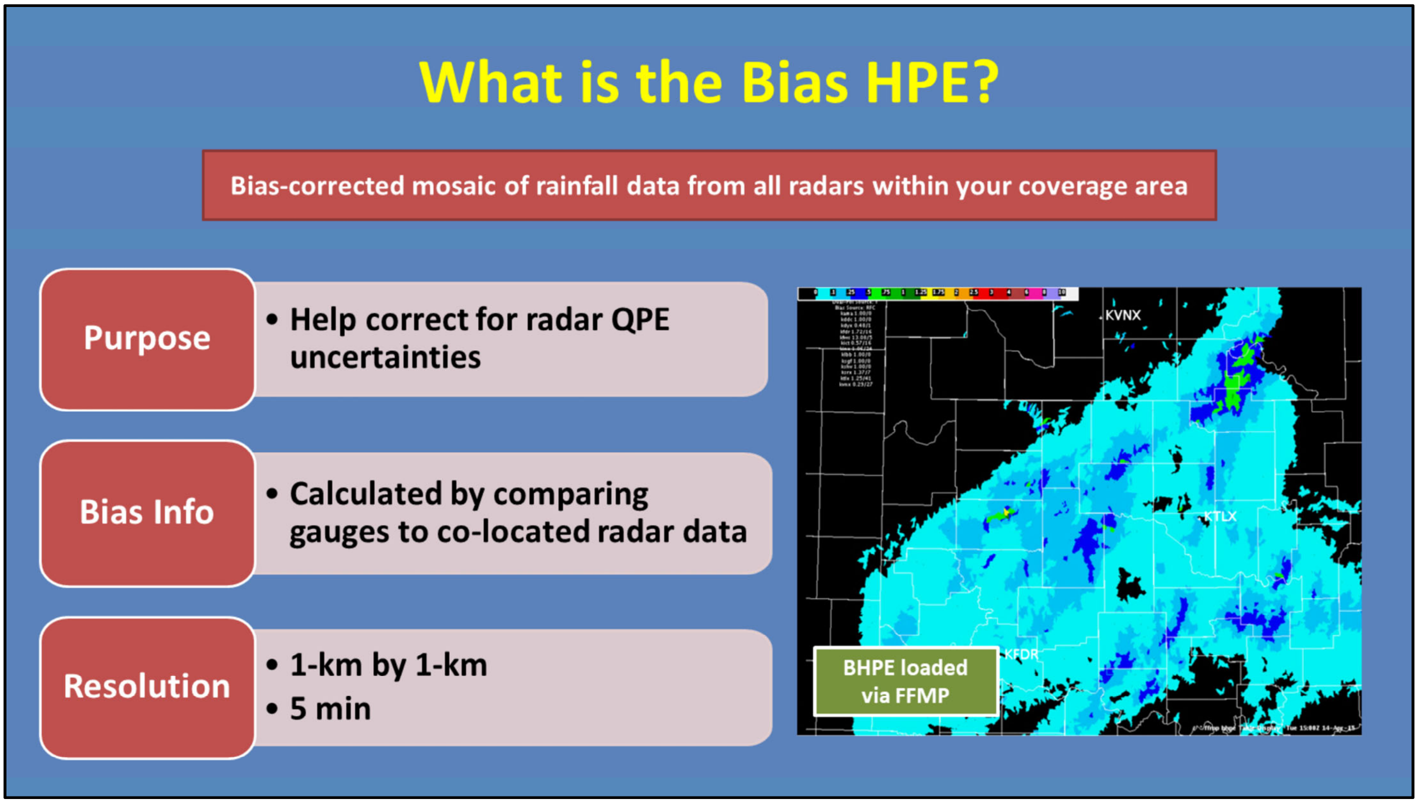
Here are the learning objectives for this lesson. When you have finished reading them, please move onto the next slide.



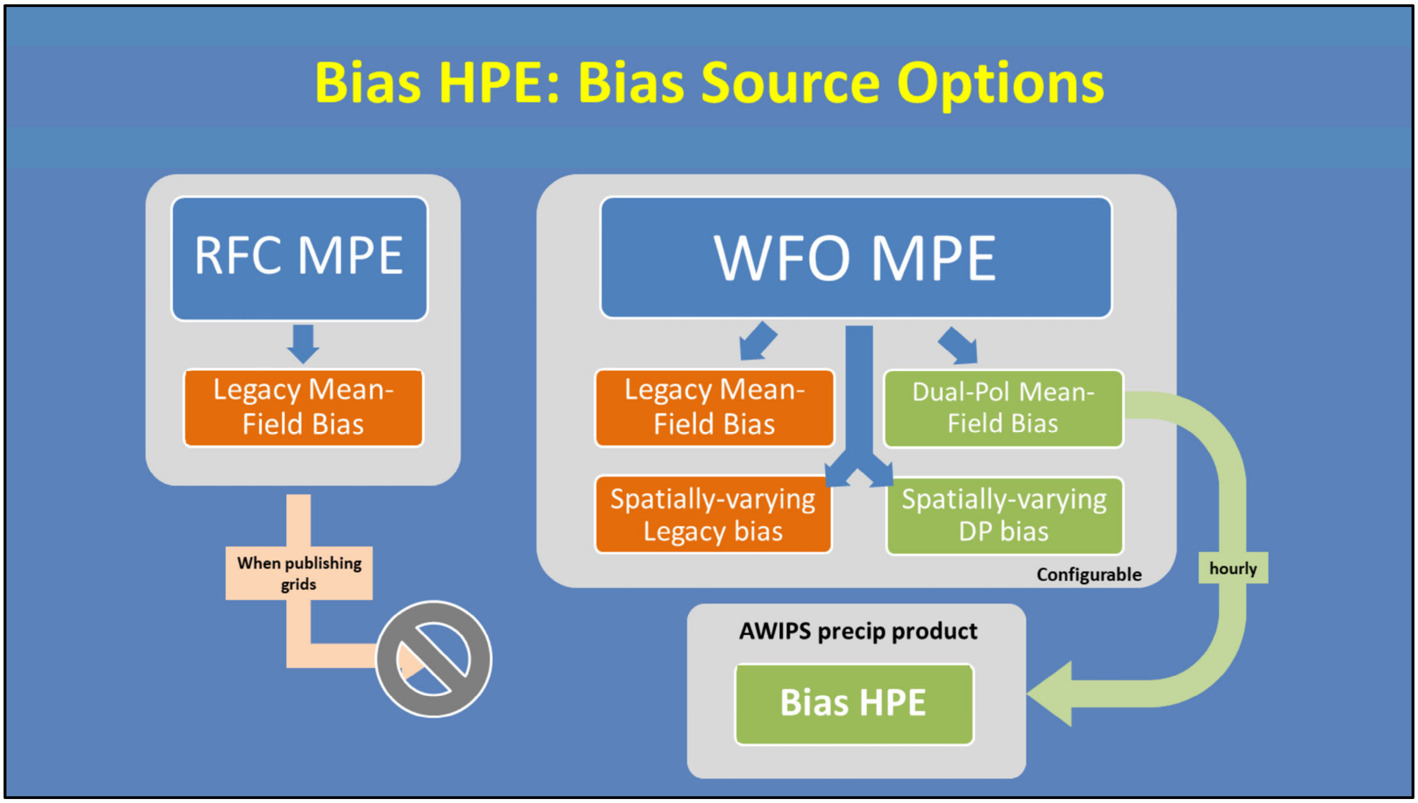
--The High-Resolution Precipitation Estimator (or HPE) is a mosaic of rainfall data from all radars within your coverage area.
--The mosaic is created using the lowest altitude scan, which is usually the nearest radar. However, when a radar is down, the mosaic will employ neighboring radars which will result in higher altitude estimates.
--The two available HPE products are the instantaneous rain rate field and the accumulated precipitation field.
--A one-hour accumulation is the default in HPE, but this value can be altered with help from your hydro focal point.
--These products update every 5 minutes. However, the one-hour product needs at least an hour's worth of data before it begins updating every 5 min.
--HPE will stop collecting data once every contributing radar has not received rainfall within the last 20 min.



--Dual-Pol or Legacy can be configured by your hydro focal point to create the HPE and Bias HPE mosaics, with Dual-Pol being the default.
--For either precip source, the rain rate product is populated using the respective rate product and the 1-hour accumulation product is created using the storm total product.
--The image below shows an example of the HPE legend in FFMP. And you can see which precip source is being used. Here, it is Dual-Pol. If the source were changed to one of the Legacy products, the letter "N" would be displayed instead.



--Bias HPE is the same as HPE, except that a bias correction is made to the precip estimates, meant to help correct for radar uncertainties.
--In short, the bias is calculated by comparing rain gauge information with co-located radar data. This process is detailed in the lesson "Interpreting QPE Bias Information in AWIPS".
--Both products have the same resolution.

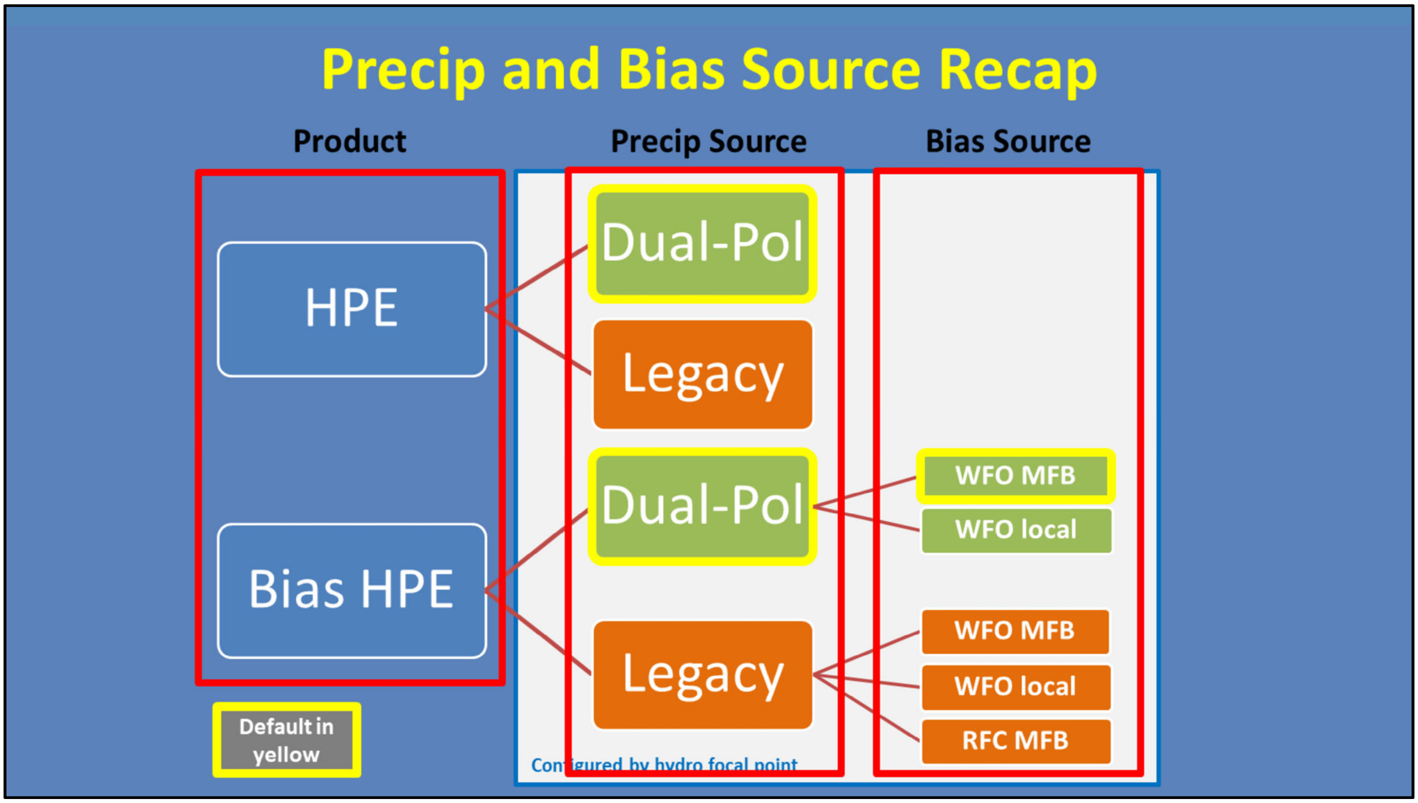


So where is the bias information computed? MPE, or Multi-sensor Precip Estimator, is an AWIPS application used to generate and QC various precip estimates, including gauge-corrected estimates.

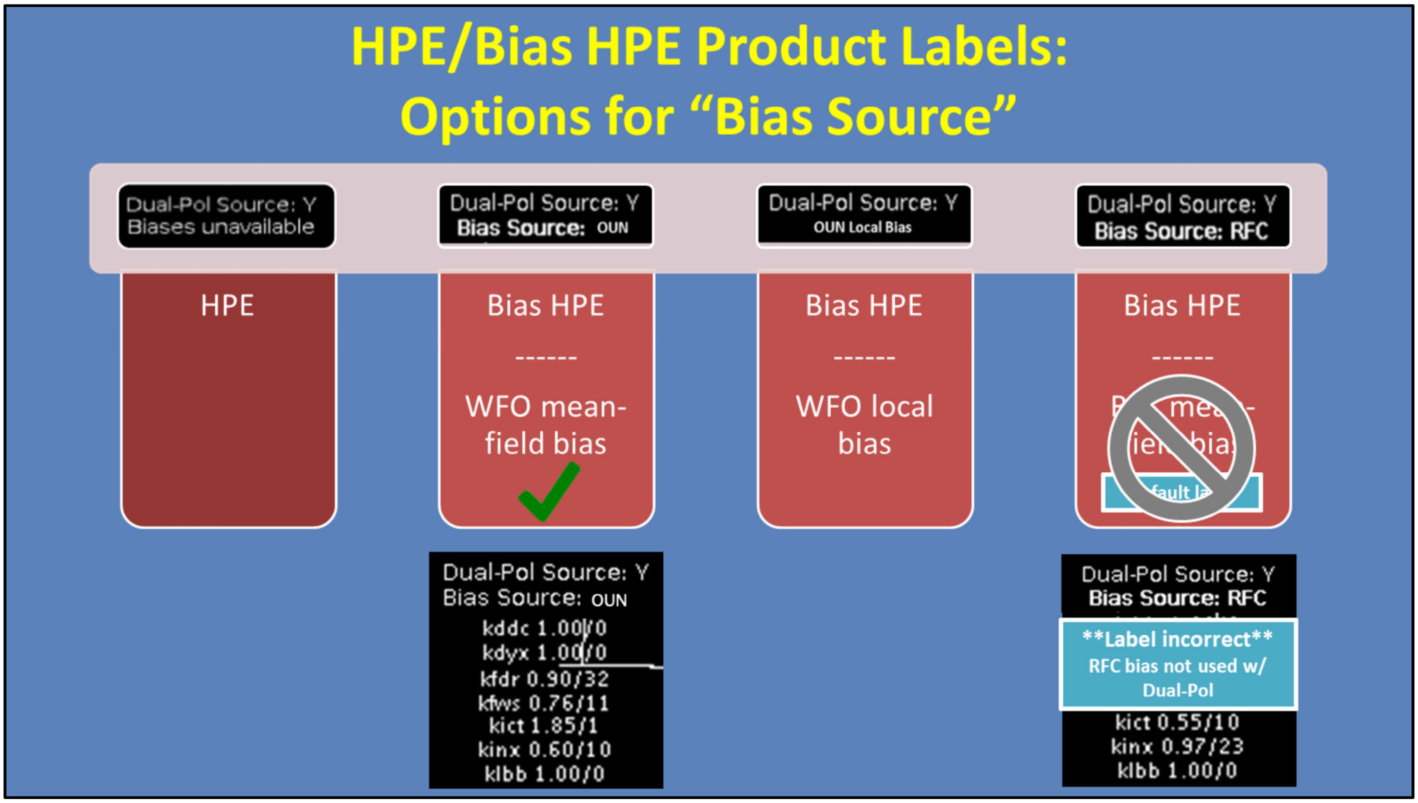
Your WFO MPE generates both Legacy and Dual-Pol mean-field biases for each radar, as well as spatially-varying bias grids of each. The mean-field bias options apply one bias factor across each radar's effective coverage area. While the spatially-varying options apply different bias values across the domain based on nearby gauge observations.

Every hour, these biases are sent from the MPE to be used to create the Bias HPE product, amongst other things. Right now, the default is for the Dual-Pol mean-field bias to be used within Bias HPE, but this is configurable. See the VLab reference documentation for more details on this.

The RFCs also have an MPE that creates Legacy mean-field biases that are transmitted to WFOs based on when they publish their QPE grids. However, some RFCs have not been maintaining the code required to transmit the biases. Regardless, since Dual-Pol is now the default for Bias HPE, this doesn't impact the product. It primarily impacts which Legacy mean-field bias factors are displayed in the Legacy precip products.



It can be a little confusing to keep track of all of the options between precip sources and bias sources. So here is a little flow chart to help summarize what is available.
--So you, as the forecaster, will have the option of choosing between HPE or Bias HPE to load into FFMP, depending on if you want a bias applied to the mosaic field. From there, the precip source will either be Dual-Pol or Legacy. Dual-Pol is the default, and likely what's configured at most offices. If you choose Bias HPE, then one of two bias sources will be applied to the mosaic: either the WFO mean-field bias or the WFO local bias. Here, WFO MFB is the default.
--All of these choices are configurable by your local hydro focal point, with instructions on the VLab.



Okay, so let's talk about how this bias information is displayed in the HPE and Bias HPE product labels.

First off, since HPE doesn't have any biases applied, its Bias Source label simply says "none". Easy enough.

Now for Bias HPE, the label changes based on which bias source is configured.
--If the bias source is the WFO MFB, then the three-letter identifier is given (in this example, OUN), and the mean-field bias info is listed for each radar.
--Next, if the bias source is the WFO's spatially-varying bias, then it will say the WFO's identifier, followed by "Local Bias" and nothing will appear underneath. If you recall from the earlier slide, this is because this option does not offer a uniform bias for each radar, so there's nothing to list out.
--Finally, there's the RFC MFB. This is actually the default bias source *label* for Bias HPE. However this is misleading because the RFC bias is not used with the Dual Pol precip source. We have a workaround to fix this on our VLab reference page.

To summarize, Dual Pol is the default precip source for all products, and is labeled correctly. For Bias HPE, the WFO MFB is *generally* used for the bias source, even though the default label may incorrectly say it's the RFC MFB.

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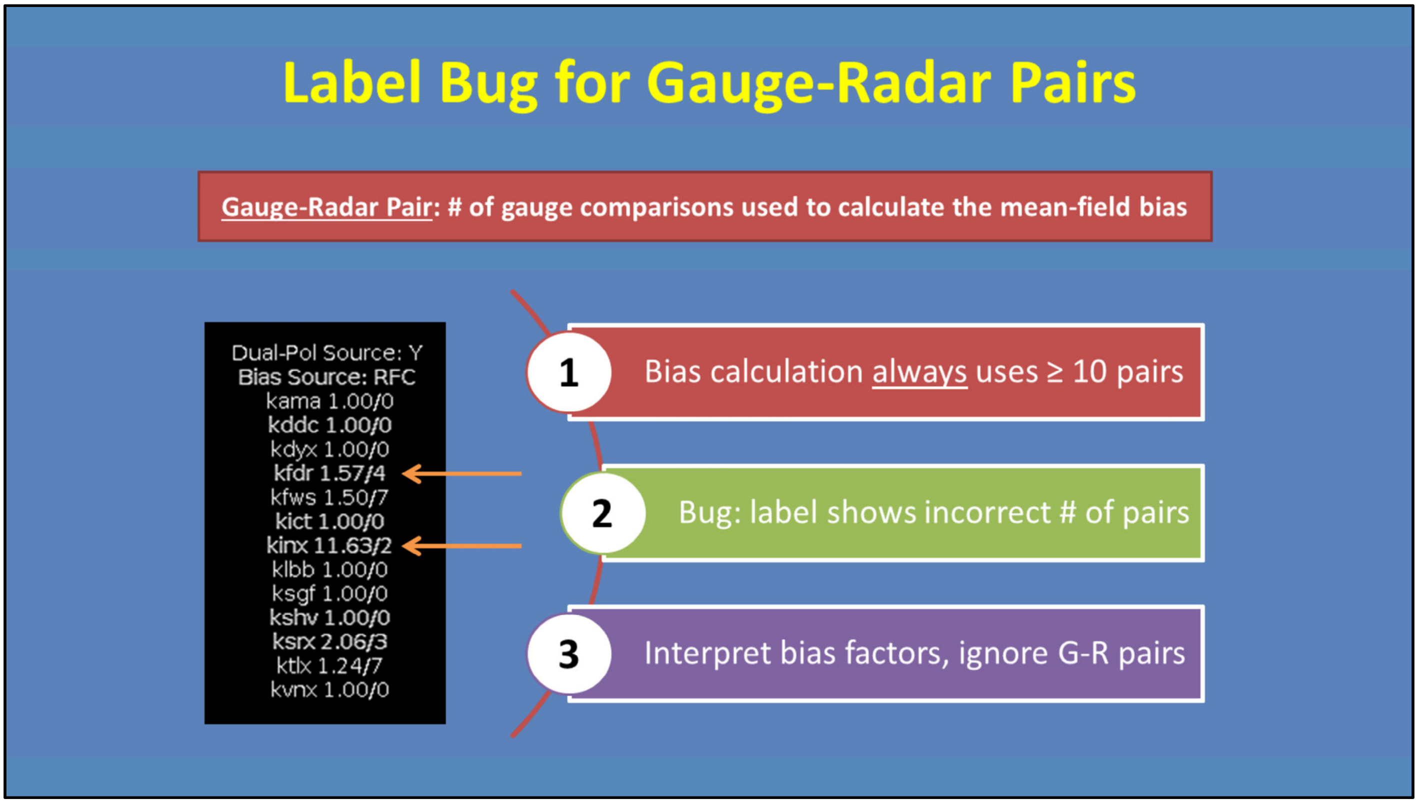

You will learn more in the lesson "Interpreting QPE Bias Information in AWIPS", but briefly, the number next to the mean-field bias factor is the number of gauge-radar pairs used to calculate each radar's mean-field bias. The more gauge comparisons used, theoretically, the more reliable the bias factor should be.

Mean-field biases are *always* calculated using at least 10 pairs. However, there is currently a bug where the label will sometimes say there's less than 10 pairs, as shown here.

The key takeaway is simple...you can interpret your bias factors knowing that they were calculated with the correct number of pairs. Simply ignore the gauge-radar pair number as it can sometimes be wrong.

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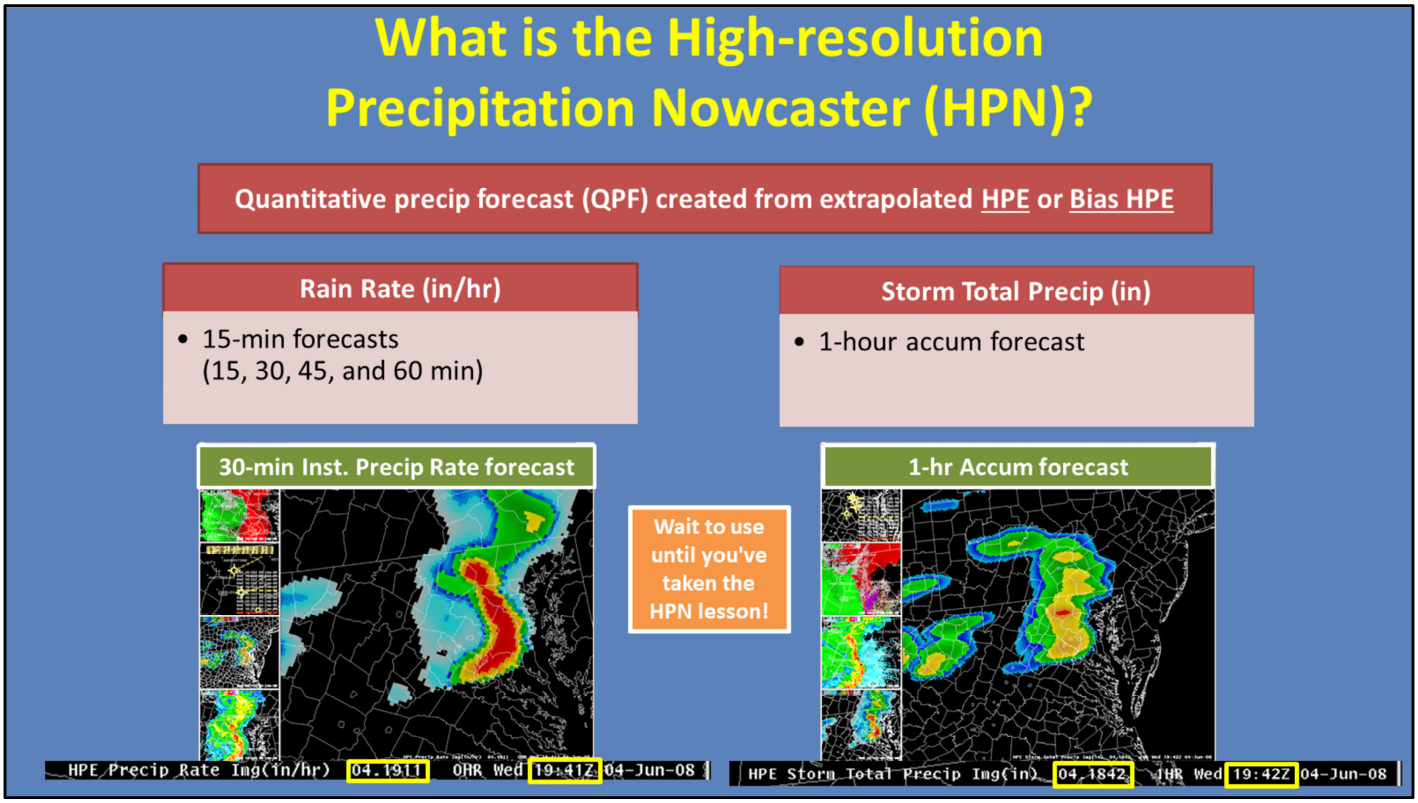

HPE also has a QPF component called the High-Resolution Precipitation Nowcaster (or HPN). This product uses its own feature tracking to extrapolate precipitation forecasts from an HPE or Bias HPE rain rate input. Therefore, the Dual-Pol default carries over into these HPN forecast products, as well.

--The output is QPFs up to one hour in the future. For the rain rate products, four 15-min forecasts are created (at 15, 30, 45, and 60 minutes out). For the accumulated product, the rain rate products can be summed to create a single one-hour forecast.

--HPN products have a slightly lower spatial resolution, at 4km.

--Below is an example of each type of output from the Volume Browser. On the left, is a 30-min forecast of instantaneous precipitation rate for HPE. You can see the current time is 1911 and the product is valid at 1941. On the right is a one-hour accumulation, with the current time being 1842 and the forecast time as 1942.

--Both of these examples are forecasts of HPE, but remember, you can also look at forecasts of Bias HPE, as well.

--Due to the advanced nature of how this product is created, we recommend you wait to use it until you have taken the HPN lesson.

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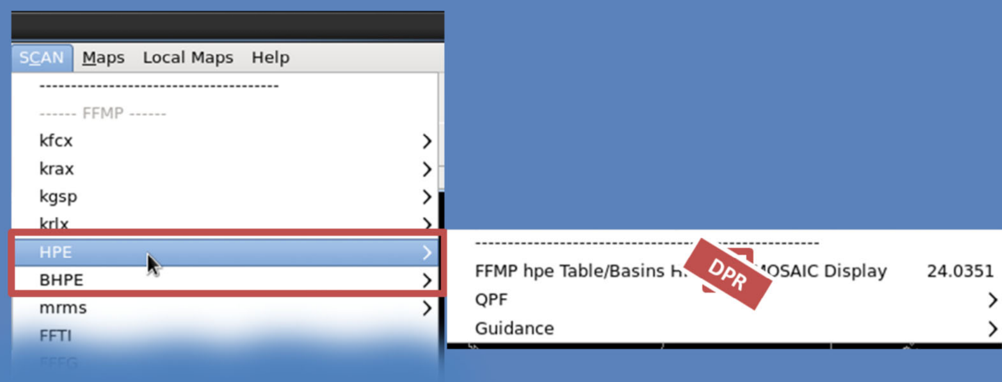
Loading HPE/BHPE in FFMP

1. SCAN --> Under "FFMP" --> HPE or BHPE
2. FFMP hpe Table/Basins

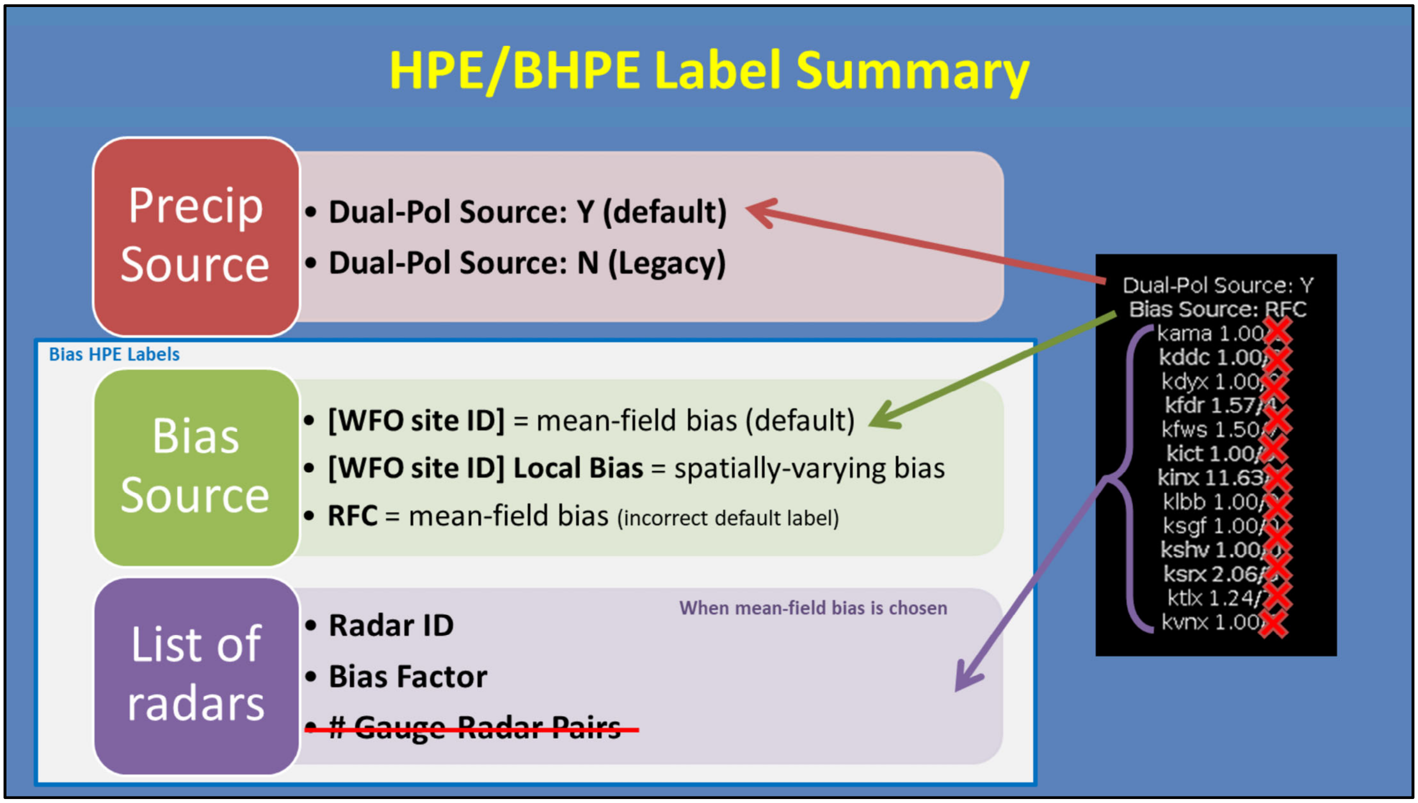


--HPE was designed to make it easier to view multiple radars in one mosaic. This is especially useful in FFMP because you can load just one HPE mosaic, instead of multiple FFMPs for different radars.

--As a reminder, to load HPE via FFMP, go to the SCAN menu and click the HPE (or Bias HPE) sub-menu. From there, open the FFMP Table/Basins display.

--Remember that the default HPE source is Dual-Pol, though the label incorrectly says "DHR". To be correct, it should read "DPR".

--If you are interested in how to load these products, as well as the HPN grids, via the Volume Browser, please refer to the VLab reference material.



--Here is a summary of how to read the label information for HPE and Bias HPE.
--The first line specifies the precipitation source. If it says “Dual-Pol: Y”, then Dual-Pol is being used. This is the default. If it is an “N”, then Legacy is used.
--The second line specifies the bias source. There are three options here: If it is the WFO's mean-field bias, then it will state the WFO's three-letter identifier. This is the actual default. If it is the local spatially-varying bias, then it will specify the WFO’s three-letter identifier with “Local Bias”. If the RFC mean-field bias is used, then it is says "RFC". Currently, the default label incorrectly says "RFC" when it is generally using the WFO mean-field bias.
--Finally, if one of the mean-field bias sources is configured, then the bias information for each radar is listed.

Remember, that the gauge-radar pair info can be labeled incorrectly, so simply ignore these values.

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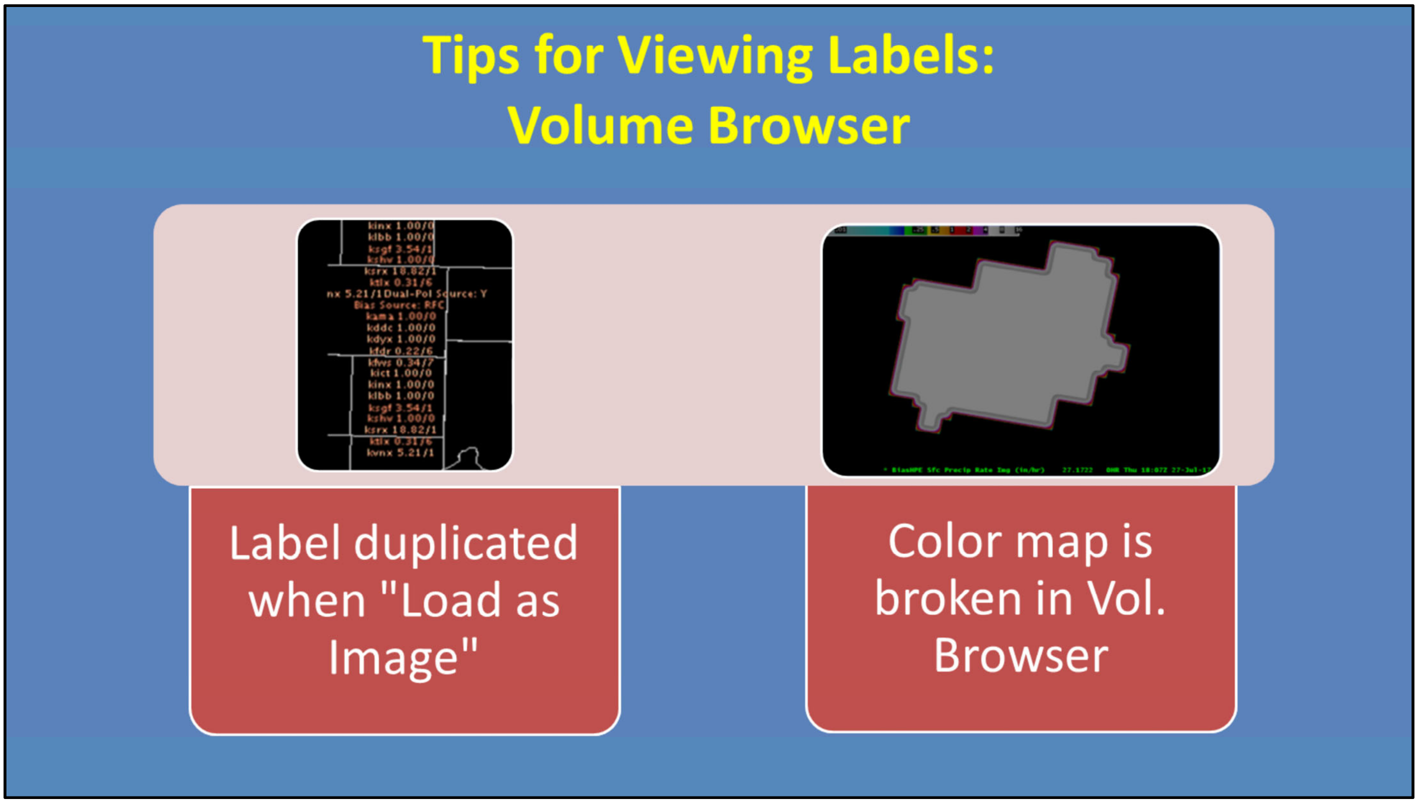

--There are a few things to be aware of when viewing HPE and Bias HPE.
--When viewing in the Volume Browser, the label gets duplicated when you "Load as Image". This can make it a little difficult to read, but none of the text is overlapping, so the important information is still visible.
--Also note that the color map is broken in the Volume Browser display for most localizations (for both HPE and Bias HPE). But we have a fix for this problem on the VLab.

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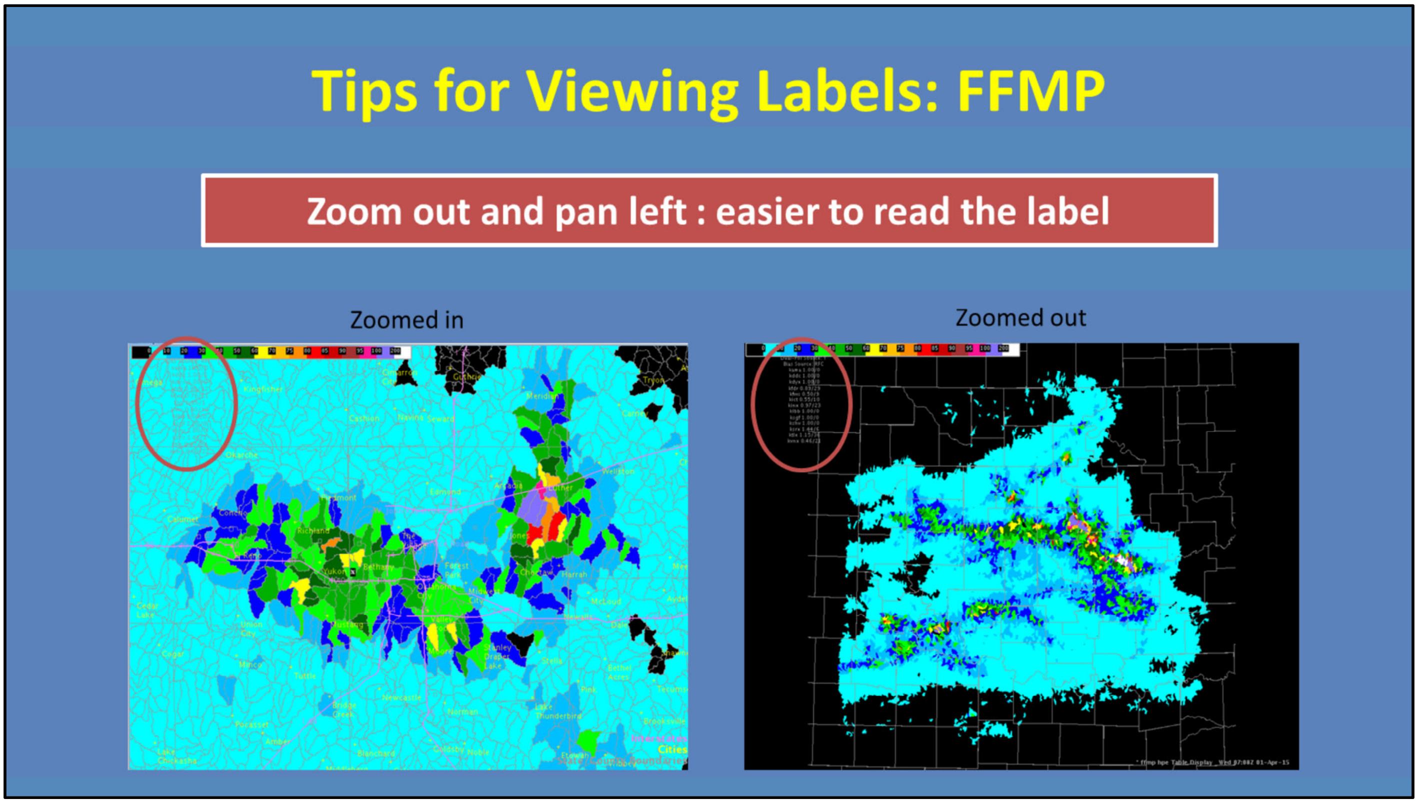

--When viewing in FFMP, make sure to zoom out and pan to the left border in order to better read the label. When zoomed in, the label may be obscured by the basin fill. But if you zoom out, you can move it to a blank area to read easier.

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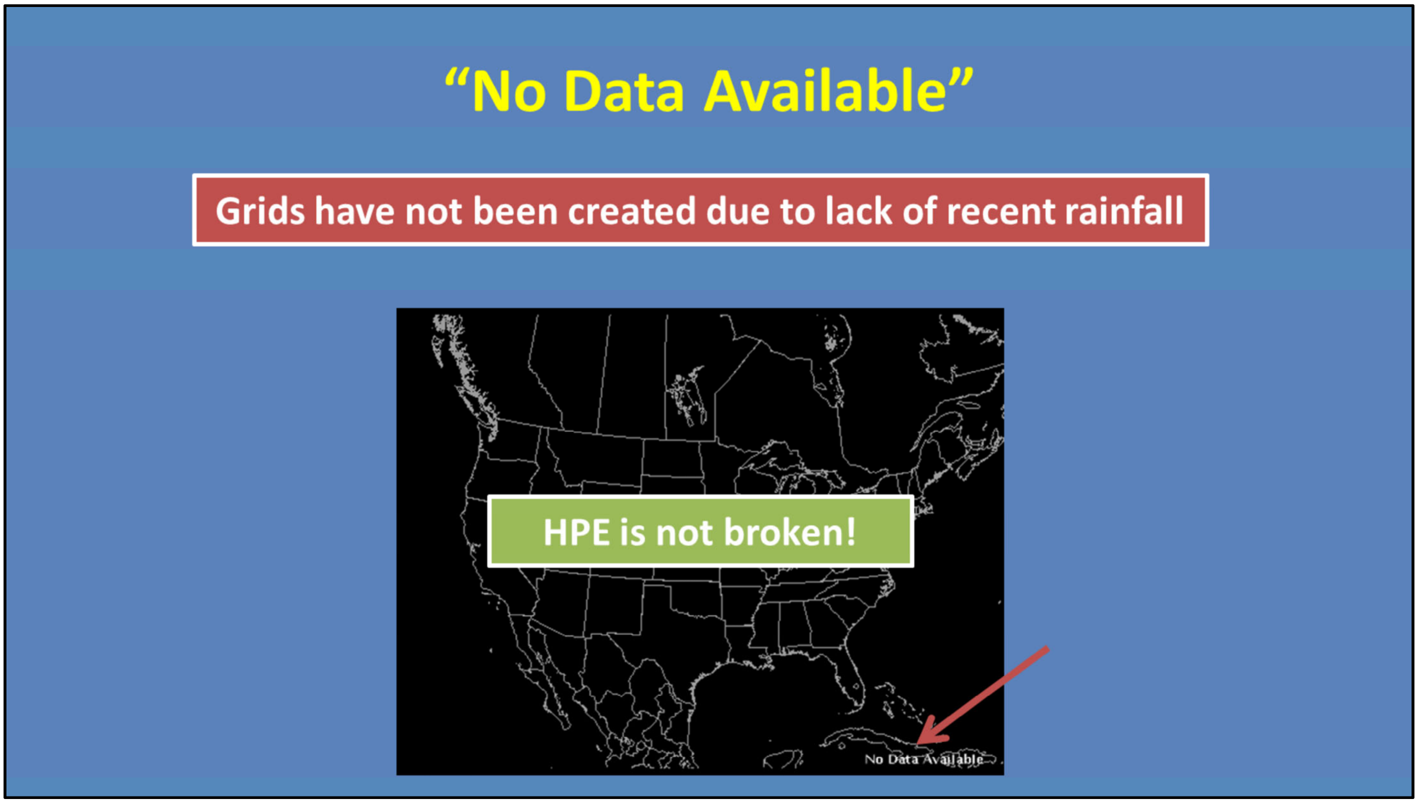

If you try to open HPE or Bias HPE when there has been no rainfall in your domain, you will get a blank pane with "No Data Available" in the bottom-right. This does not mean that HPE is broken! It simply means that the grids have not been created due to the fact that there has not been any recent rainfall. Just wait until the next rainfall occurs in the domain, and try opening again.

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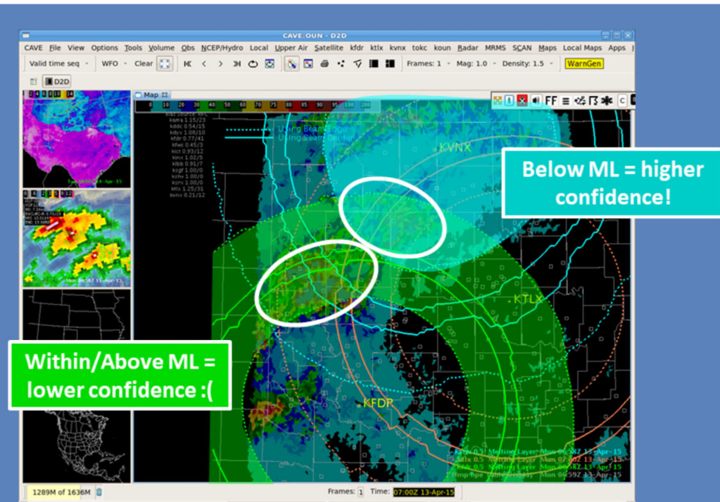
Mosaic Caveats:
Identify the Melting Layer

Have higher confidence in estimates below the melting layer



There are some caveats to using any Dual-Pol mosaic, like HPE and Bias HPE.
--For one, identify the melting layer by using the low-level melting layer overlay. Have higher confidence in estimates below the melting layer. Within and above the melting layer, your estimates are going to change, and they won't be as good. This is due to the HCA assigning mixed phase or ice classifications at these heights, and thus, the Z-R relationships are being matched to those precip types, even if they are liquid when hitting the ground.
--Here is an image of HPE. Let's consider the circled areas that may be experiencing flash flooding. By overlaying the melting layers for the three nearby radars, you can see the northeastern circled area is closest to the most northern radar, or the one with the blue ML circles. These values are located below the ML, so you can have higher confidence in them. However, the area to the southwest is within the ML circles for both radars. Thus, this area has more uncertainty.

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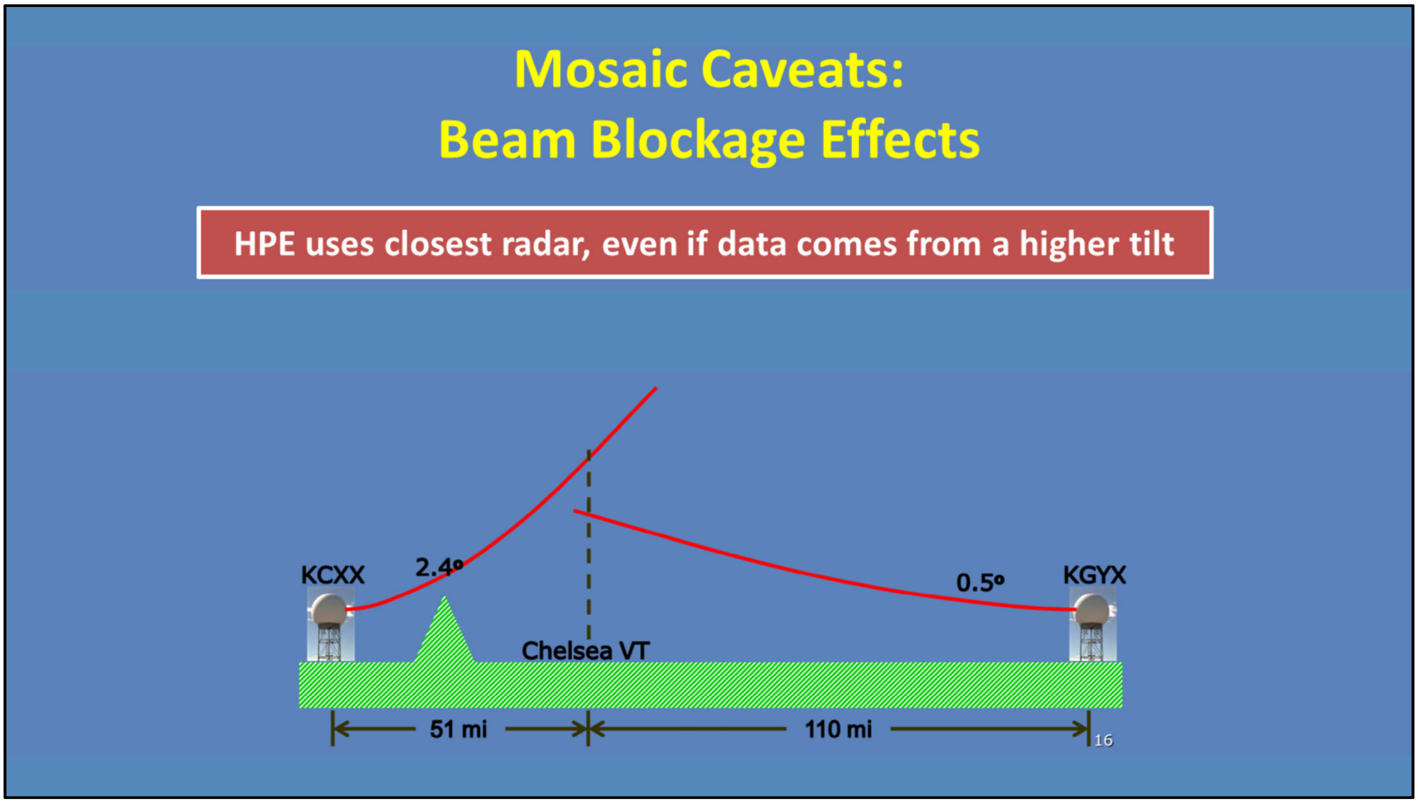
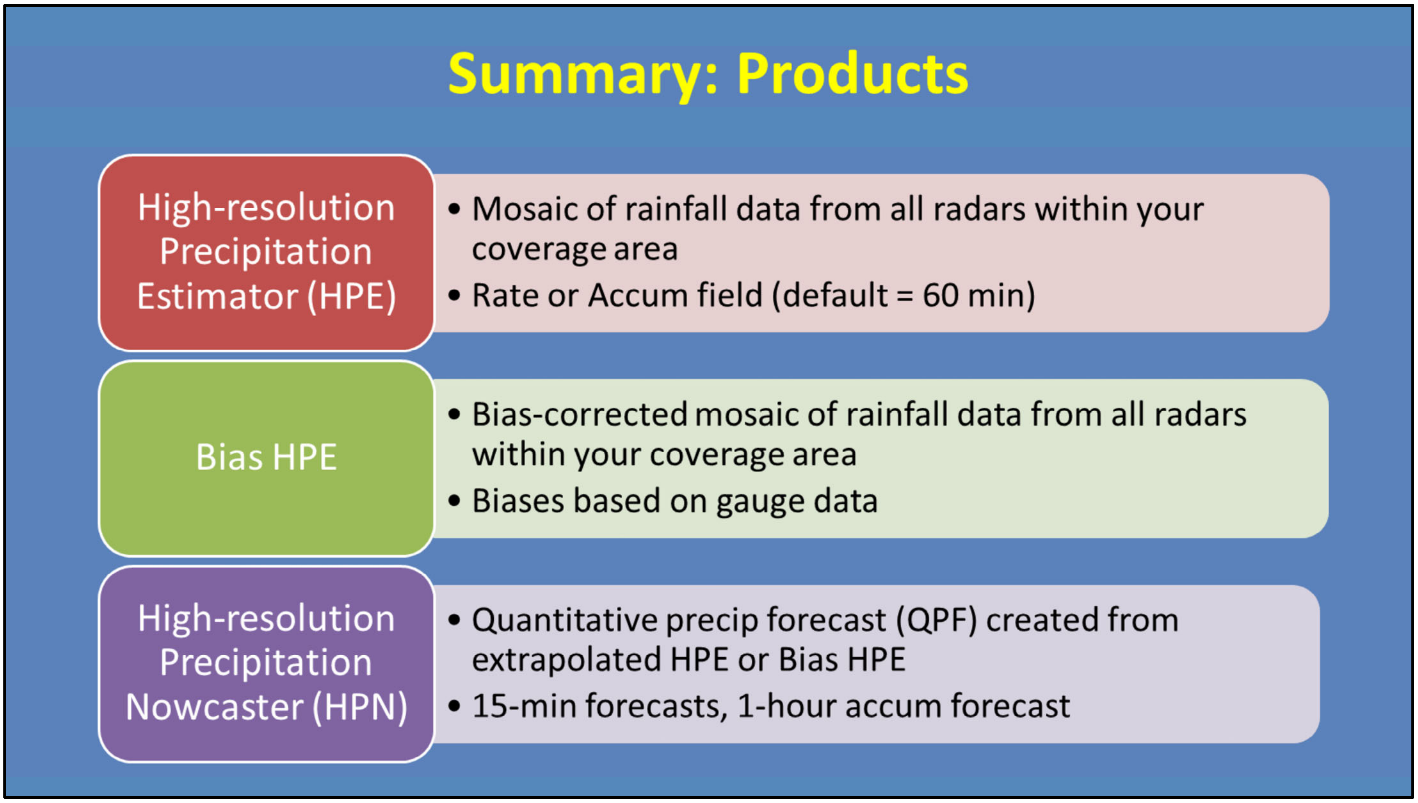


Secondly, watch for artifacts in areas of beam blockage. In this example, HPE only knows that KCXX is the closer of the two radars, so it uses the KCXX precip estimates at the given point. However, we see its precip estimates are coming from the 2.4 deg tilt. KGYX actually has the lower altitude estimate at this grid point. So how do we fix this?

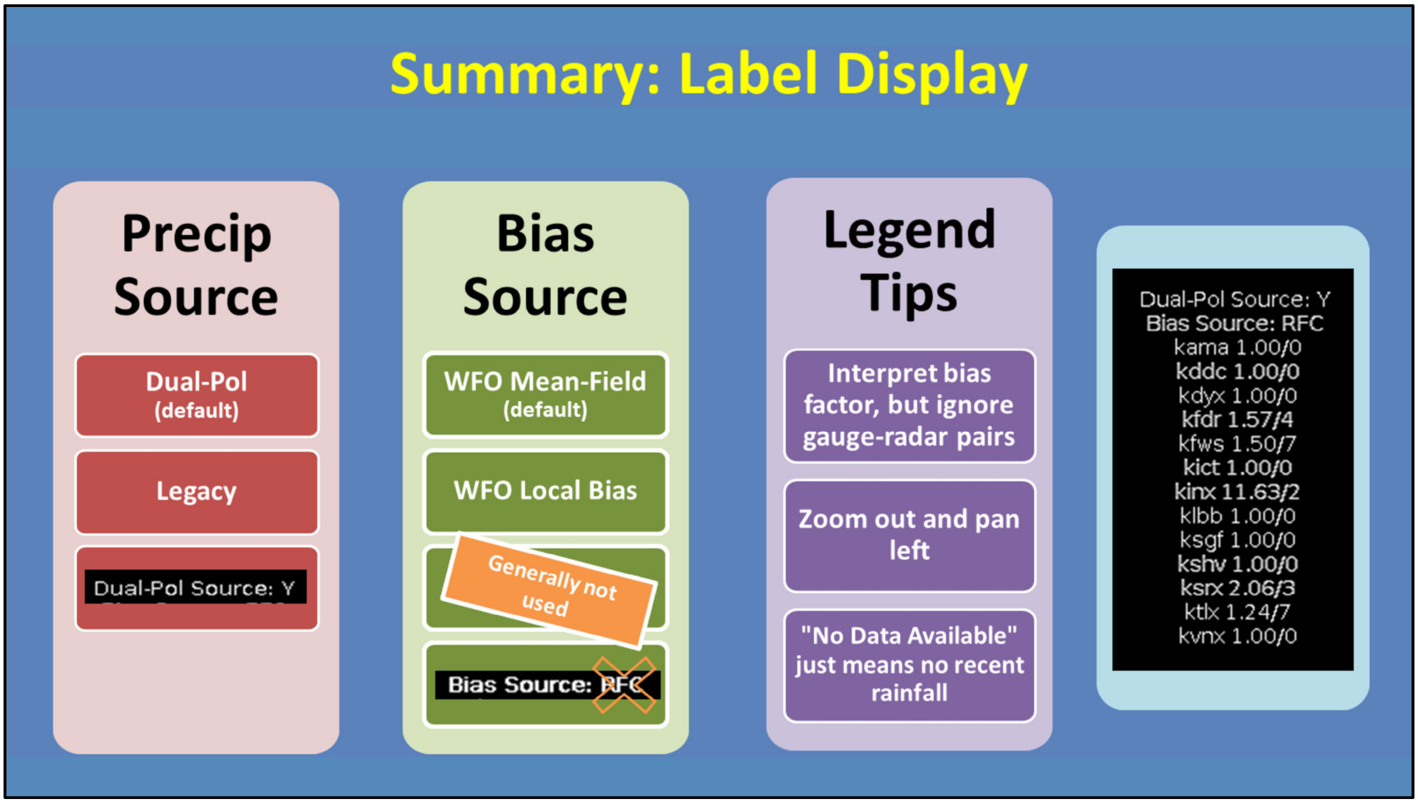
Well, you can force HPE to use the farther radar with what's called a misbin file. For more information on this topic, please see the Resources tab for a presentation from Greg Hanson.



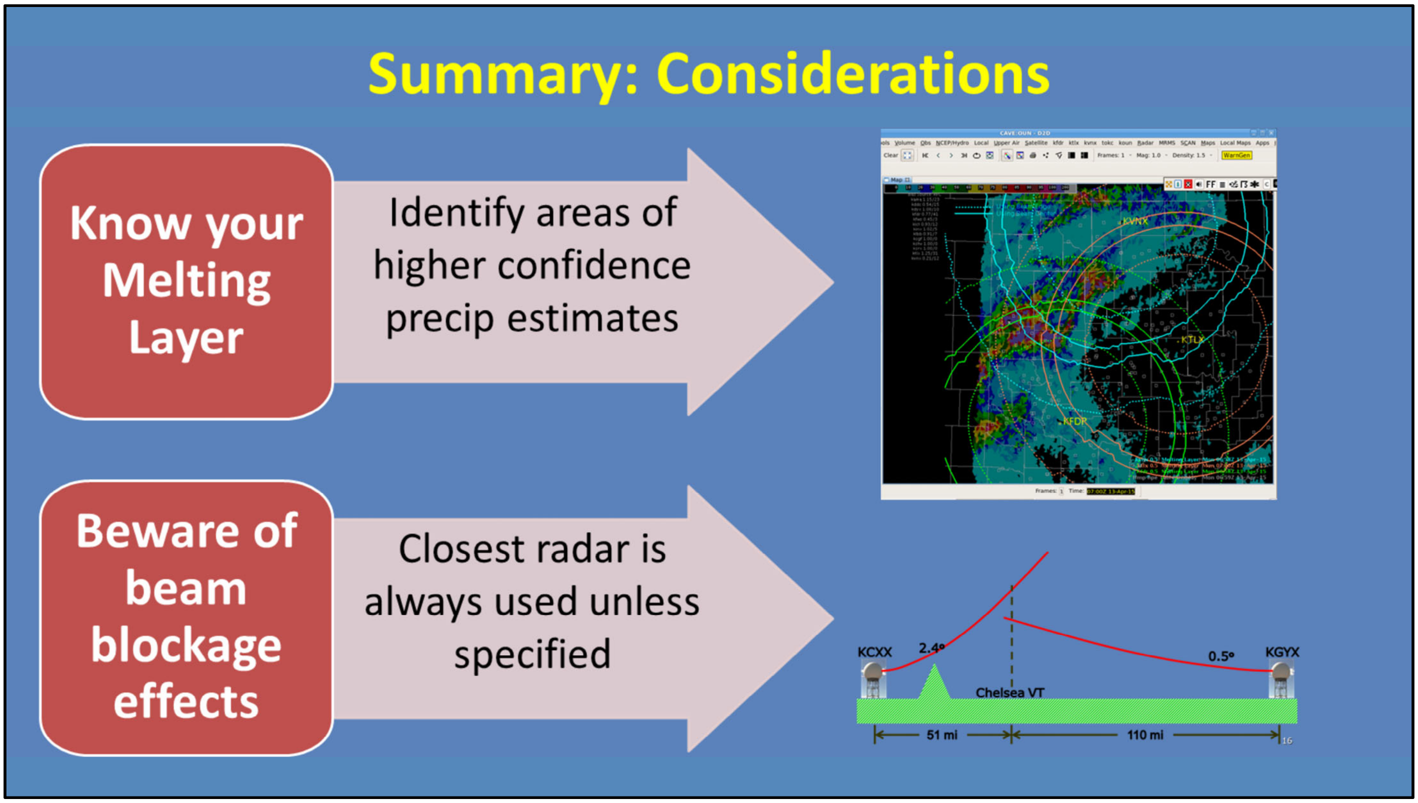
So let's quickly summarize the products we discussed in this lesson.

1. The High Resolution Precipitation Estimator (or HPE) is a gridded rainfall mosaic, based on single radar sources. It can be created as an instantaneous rain rate or accumulation field, with the default accumulation being one hour.
2. The next product is the Bias HPE. This is similar to HPE, except that biases have been applied to the radar estimates to correct for uncertainties. These biases are calculated using available gauge data.
3. Finally, there is the High Resolution Precipitation Nowcaster (or HPN). This product is an extrapolated QPF, based on either the HPE or Bias HPE product. The forecast is available for 15-minute intervals up to one hour, or for a single one hour accumulation.

All three of these products update every 5 minutes.



The labels for HPE and Bias HPE can be used to interpret valuable information about the products.
--For one, you can see which precip source is being used, either Dual-Pol or Legacy, with Dual-Pol as the default.
--For Bias HPE, you can also determine the bias source. The default is the WFO mean-field bias, but you can also use your WFO local bias. Keep in mind, if your label says RFC (and you're using Dual-Pol), it's incorrect because the RFCs do not send Dual-Pol mean-field biases.
--Remember that you can interpret the bias factors from the legend, but ignore the gauge-radar pair information.
--In FFMP, you can view the legends easier by zooming out and panning to the edge.
--Also, if you see a blank pane and “No Data Available” when loading in FFMP, it means there hasn’t been enough recent precip for the HPE grids to be calculated. Simply try loading again once rainfall has occurred in the area.



Finally, there are some important considerations to better apply HPE and Bias HPE.
--First, you should overlay the low-altitude melting layer algorithm to identify areas of higher confidence precip estimates.
--Also, beware of beam blockage in complex terrain, as it may affect the QPE estimates.

This is the end of this lesson. When you are ready, please move onto the next slide to take the quiz and receive credit on the LMS.

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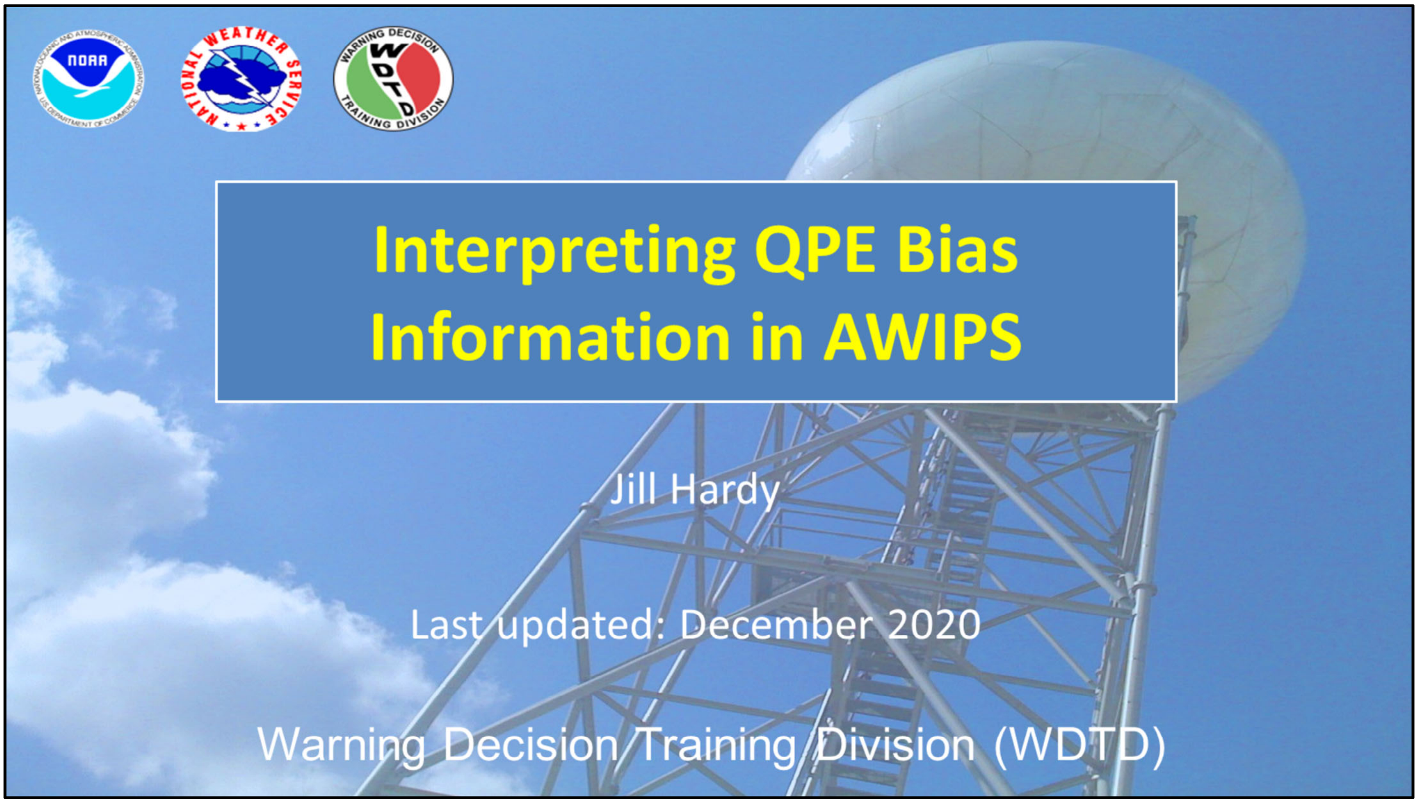

Hi, my name is Jill Hardy and welcome to this lesson on how to interpret QPE bias information in AWIPS.

Learning Objectives

- By the end of this lesson, you will be able to:
  - Determine the bias option(s) for each precip source
  - Define a mean-field bias
  - Interpret a mean-field bias from a product legend
  - Identify times when you should be cautious of interpreting mean-field bias information
  - Identify ways to view mean-field biases in AWIPS
  - Identify when mean-field biases are applied
  - Interpret MRMS bias information

Here are the learning objectives for this lesson. We will cover everything you need to know about what the biases are, how to interpret them, and a little on the application.

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Default Available AWIPS Precip Sources

More on QPE sources: "Choosing Your Precip Sources"

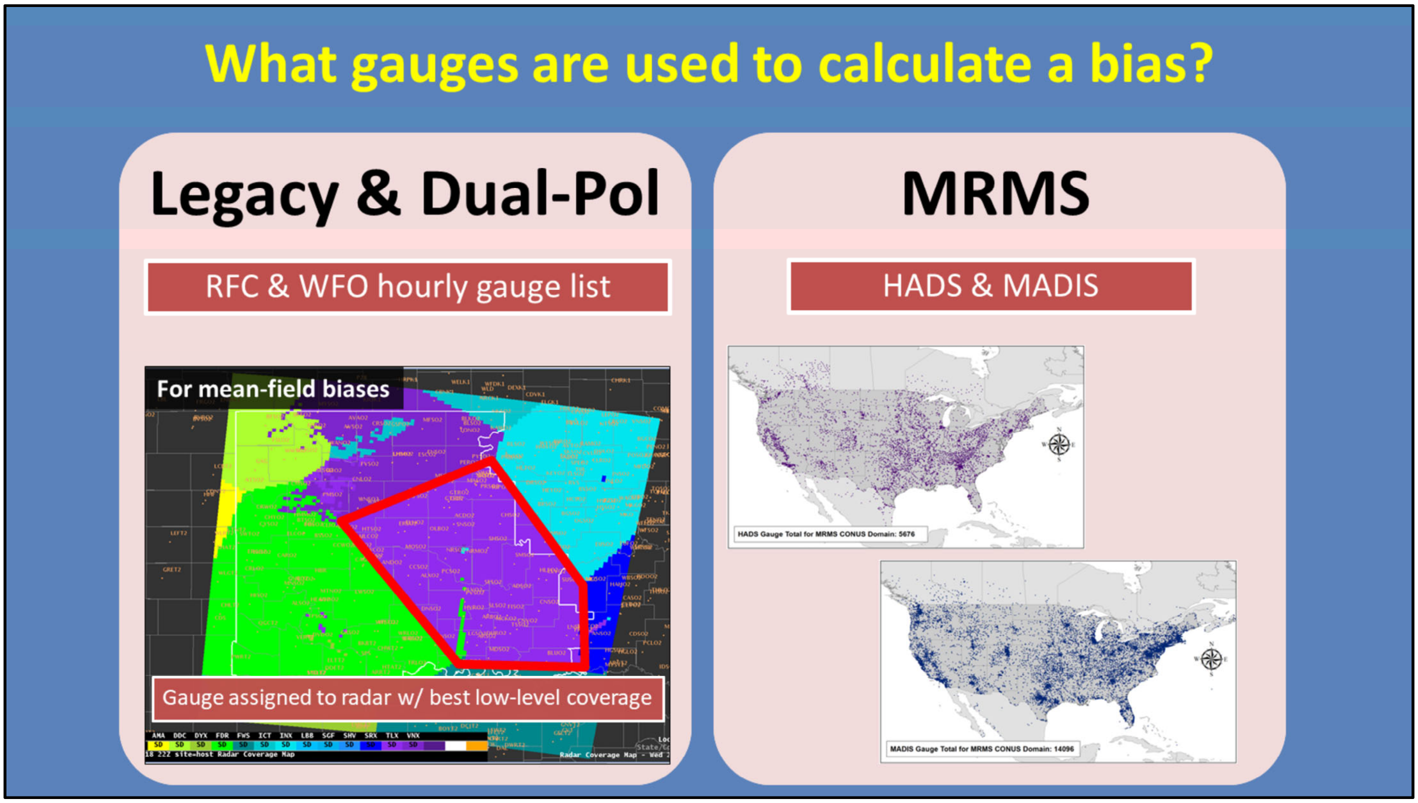
QPE Source	Z-Rs	Bias Option
Legacy	**Single Z-R** (set at RPG)	**Mean-field**
		~~**Spatially-varying**~~ (not commonly used)
Dual-Pol	**Spatially-varying** (based on precip type)	**Mean-field**
		Spatially-varying (available in Bias HPE; weighted based on distance from gauges)
MRMS	**Spatially-varying** (based on precip type)	**Spatially-varying** (weighted based on distance from gauges)

Before we dig into the guts of interpreting biases, let's talk about the three available precip sources in AWIPS for which biases can be computed.

These precip sources are Legacy, Dual-Pol, and MRMS. To learn more on how to determine which source is best in any given situation, please see the "Choosing Your Precip Sources" lesson.

But for the purposes of this lesson, we're going to focus on how the default bias options are computed for each one.
--Legacy QPEs are computed using one Z-R relationship across the whole radar umbrella, set at the RPG. Its default bias option is what's called a "mean-field bias". As the name implies, this is one averaged value that can be applied across the radar field.
--Moving onto Dual-Pol, it's calculated using spatially-varying Z-R relationships based on precip type at each pixel. The mean-field bias is an option, but having a single number for a whole radar umbrella doesn't allow for bias differences in different precip types. The spatially-varying bias allows for biases to change across the radar umbrella, but it requires a higher density gauge network to be useful.
--Finally, MRMS is a QPE mosaic that also has spatially-varying Z-Rs based on precip type. And it, too, has implemented spatially-varying logic in the bias-corrected product.

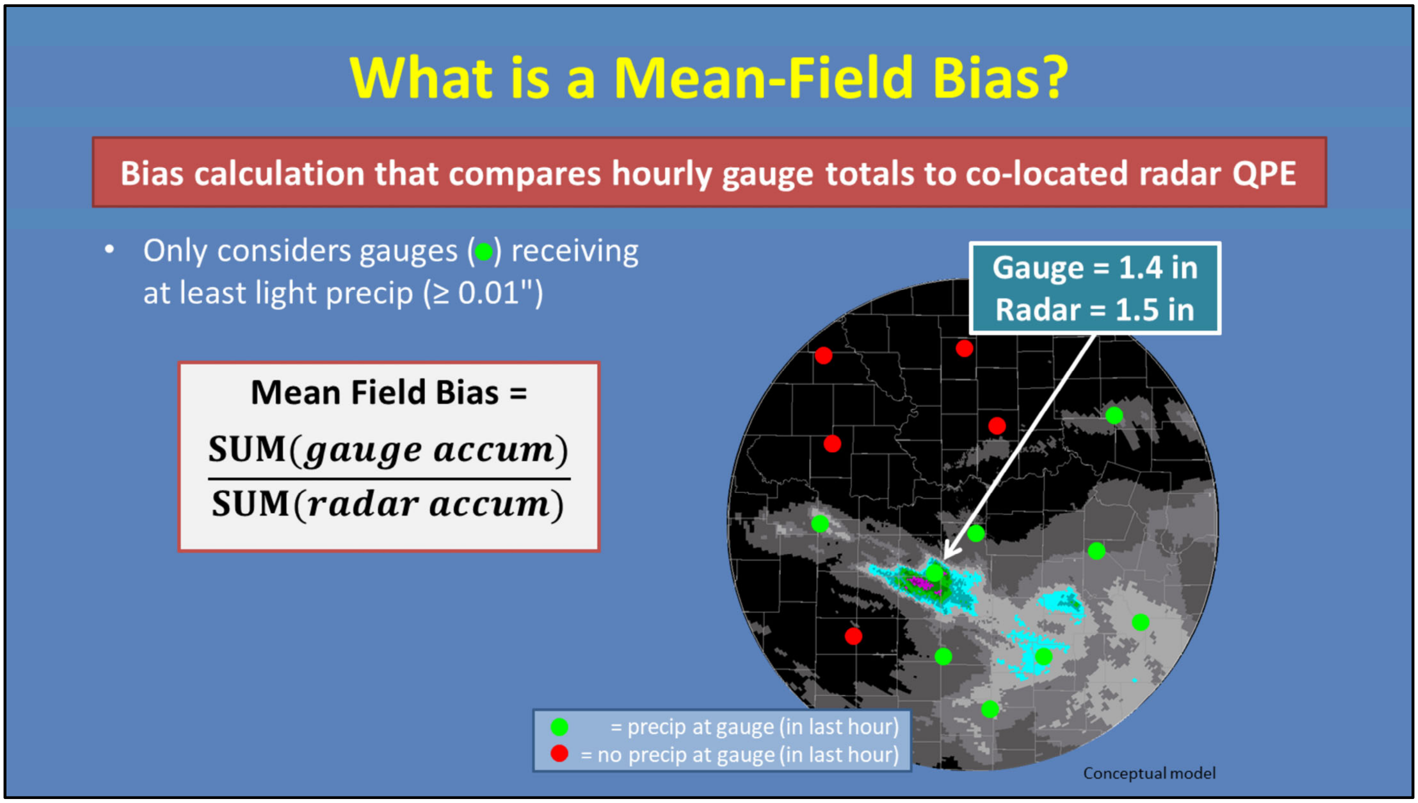
Knowing this, the rest of the lesson is going to describe the two bias options, where to find them, and how to interpret them for each precip source. Let's get to it!



The idea of a bias correction inherently relies on observations that calibrate the radar estimates. So the first question to ask is: "Well, what gauges are even used to calculate a bias?"

For Legacy and Dual-Pol, a list hourly gauges is maintained at both the RFCs and WFOs. RFCs tend to better QC their list, so when possible, their information is used. When calculating each radar's mean-field bias, the hourly gauges are assigned to the radar with the best low-level coverage. Here is an MPE display showing the low-level radar coverage for WFO Norman, with hourly gauges overlaid. So, for example, any gauge that falls within a light purple gridpoint will be used to calculate the mean-field bias for KTLX. To learn more about viewing the gauge info in the MPE perspective, visit the VLab references.

For MRMS, the gauge networks frequently update and improve. Currently, MRMS uses a combination of the HADS and MADIS networks. To learn more, please visit our MRMS Hydro Products course.

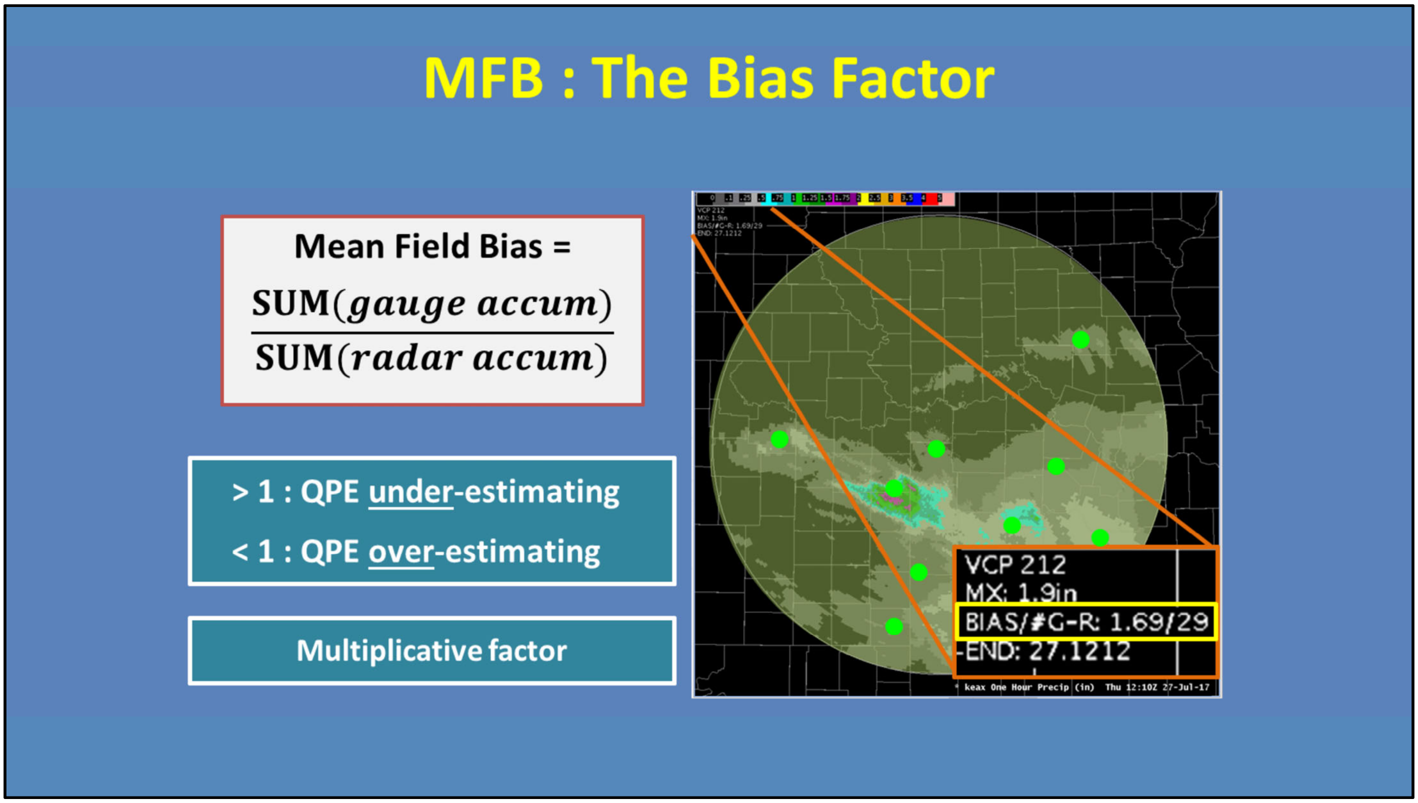


Okay, let's start off by defining what a mean-field bias is. It is a bias calculation that compares hourly gauge totals to co-located radar QPE. Its purpose is to help the forecaster interpret whether the radar estimates are running higher or lower compared to gauge observations.

Consider this radar umbrella, showing Legacy one-hour precip totals. Remember that this is NOT the coverage map used in the calculation, that's the MPE grid shown on the previous slide. But for the sake of simplicity, I will continue using radar examples like these throughout the lesson. So getting back...Each dot represents a gauge location, with green gauges getting precip in the last hour and red gauges not. The mean-field bias calculation only considers gauges receiving at least light precip, so only the green dots.

Let's focus in on one gauge. The one-hour total at this gauge was 1.4 inches. The co-located radar QPE value was 1.5 inches during the same accumulation period. This is called a gauge-radar pair. And at this location, the Legacy QPE was slightly higher than the observation.

So the mean-field bias calculation is this: It takes the sum of all the gauge accumulations in the hour (so the totals at each green dot), and divides it by the sum of all the radar QPE accumulations at those locations. We'll discuss what that means on the next slide.



When viewing mean-field bias information in AWIPS, it will be displayed in one of a few ways. The first is in the upper-left corner of your Legacy one-hour and storm-total precip products, as shown in this image. We will talk about the other ones later.

There are always two pieces of information given in the bias display: the bias factor itself, and the number of gauge-radar pairs. First, let's discuss the bias factor.

The bias factor is the result of the calculation shown on the previous slide, and duplicated here. If all the gauges together have a higher total than radar estimates at those locations, the bias will be greater than 1, and the precip source is under-estimating. If the gauges have less than radar, then the bias is less than 1, and the precip source is over-estimating. For example, in this image, the bias factor is 1.69. Therefore, the precip source is under-estimating.

It is a multiplicative factor. So even though, in reality, the bias is calculated over a smaller domain than shown here, it is meant to be multiplied across the entire radar umbrella. So here, the algorithm recommends multiplying the QPEs by 1.69 to bring them up to where they should be. By default, the bias factor is not applied at the RPG, just given in these Legacy precip legends for reference.

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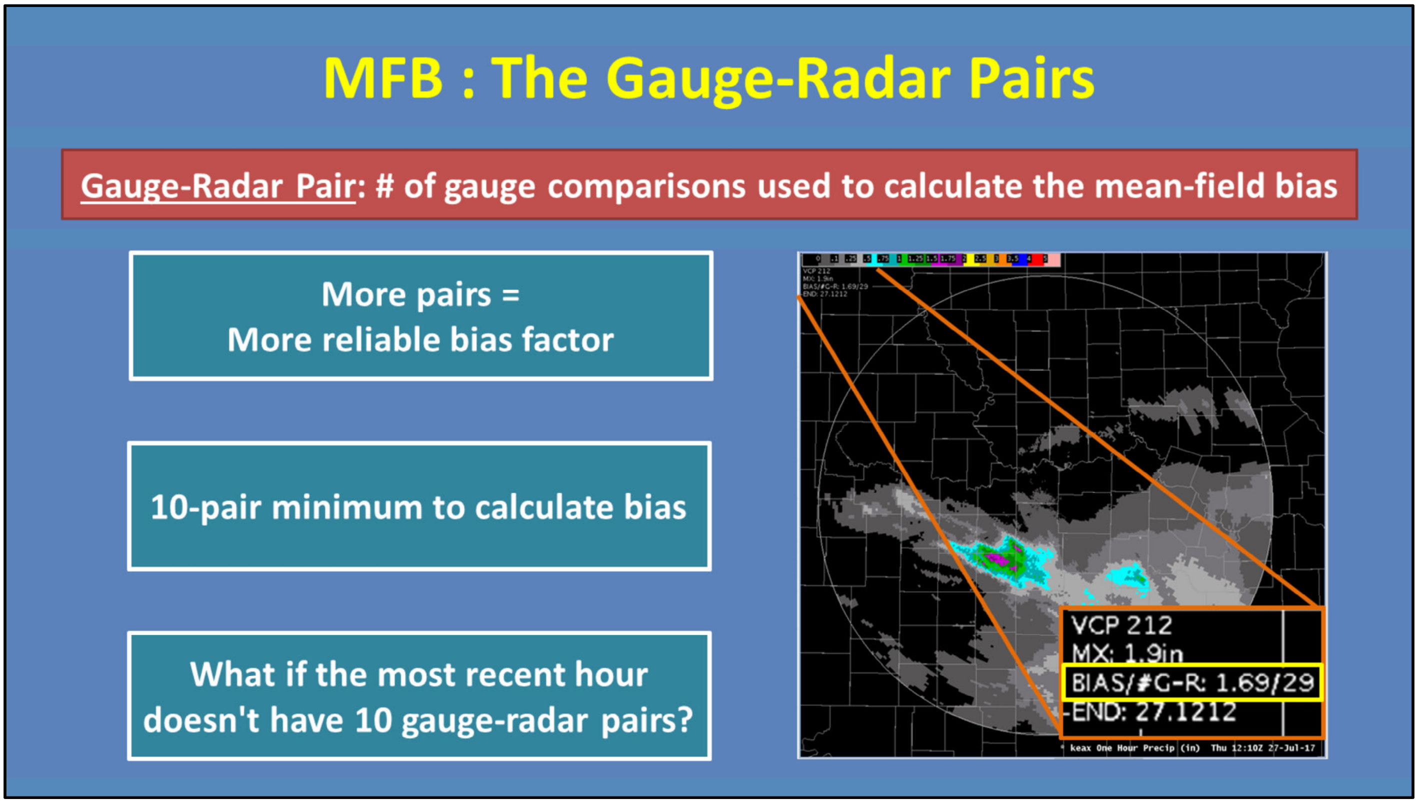
Let's practice interpreting the bias factor with some questions on the next slide.



The second component is the number of gauge-radar pairs used to calculate the bias. This is provided in order to add confidence to the bias factor. The more pairs used, theoretically, the more reliable the bias should be. In this example, there were 29 gauge-radar pairs used to get the 1.69 bias factor.

In order to calculate the bias, there is a minimum of 10 gauge-radar pairs needed. But what happens when the most recent one-hour of rainfall doesn't hit enough gauges?

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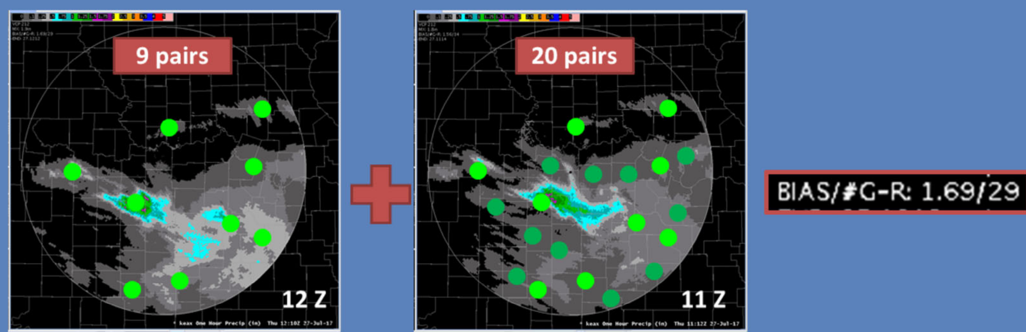
Gauge-Radar Pair Information

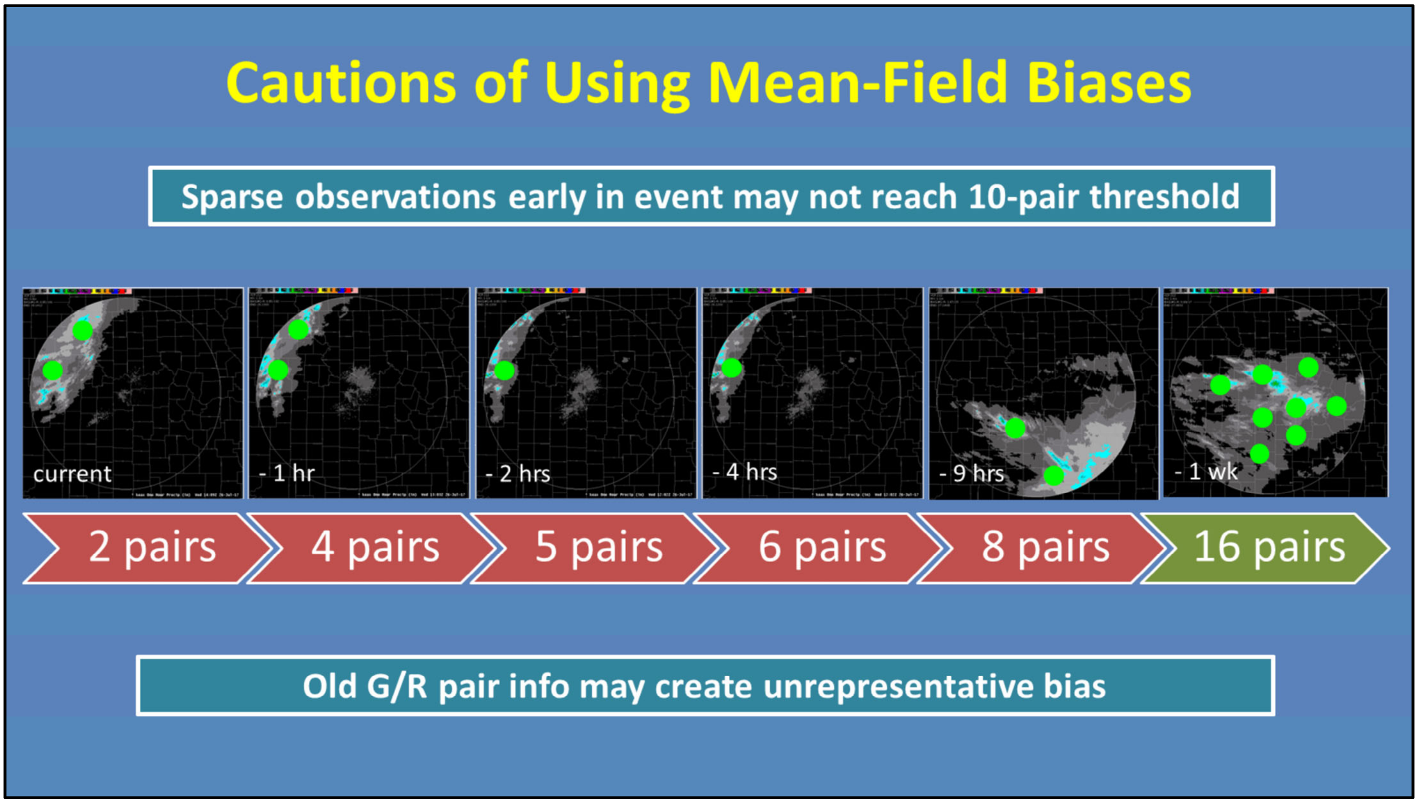
≥ 10 pairs in latest hour	Use current hour's bias
< 10 pairs in latest hour	Increase time window until reach 10 pairs*

*Latest 2 hrs, 3 hrs, 5 hrs, 10 hrs, 1 week, 1 month, 3 months, lifetime



So, if there are 10 or more G/R pairs with accumulations in the latest hour, then the current hour's bias factor is used. But if there are less than 10 G/R pairs in the latest hour, then the algorithm increases the time window to collect more gauge information. If it reaches 10 or more gauges in the latest two hours, it creates a bias factor. If it is not reached by then, it will look at the latest 3 hours, and so on...even potentially very far in the past.

Let's consider our example. In the current hour, there are only 9 gauges that received precip. That's not enough to calculate a bias factor. So the algorithm looks back an hour ago, to 11Z, and finds that 20 gauges hit during that hour, including some of the same ones. It can now use all of these pairs (from both hours!) to create the bias. Hence why there are 29 pairs in the display.



A caution of this method is if you are early in an event, you may not have a lot of recent rainfall to trigger gauge accumulations. Therefore, the algorithm may be looking VERY far back in time to reach the 10 G/R pair threshold. Take, for instance, this example. Since the rainfall is just moving into the radar's umbrella, the most recent several hours don't have enough gauge hits to calculate a bias. There are only 6 total pairs in the latest 5 hours. Only until the algorithm looks back to one week ago, did it get over that 10 pair threshold.

At this point, half of your gauge information is quite old. And old G/R pair info may not be representative of the current event, thus creating an unrepresentative bias.

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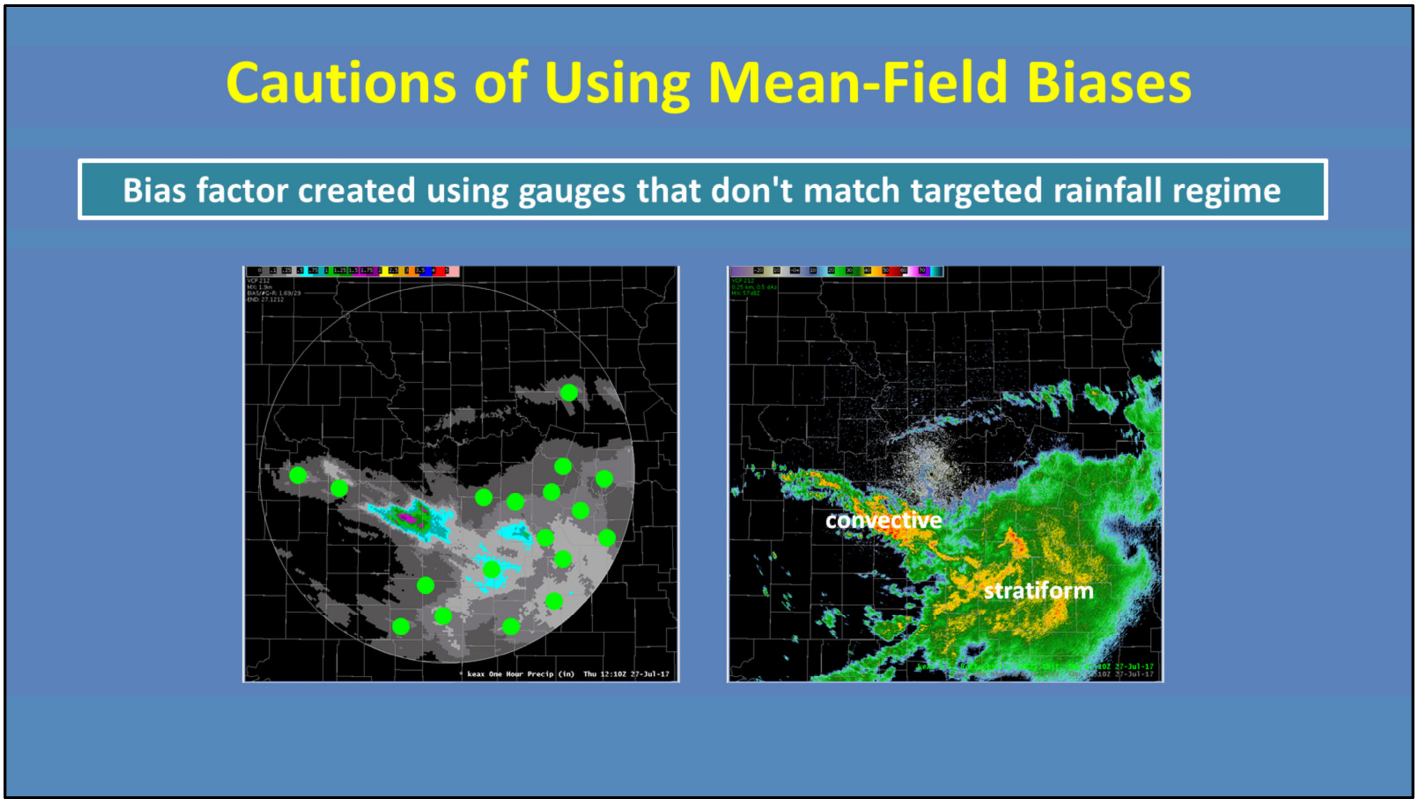
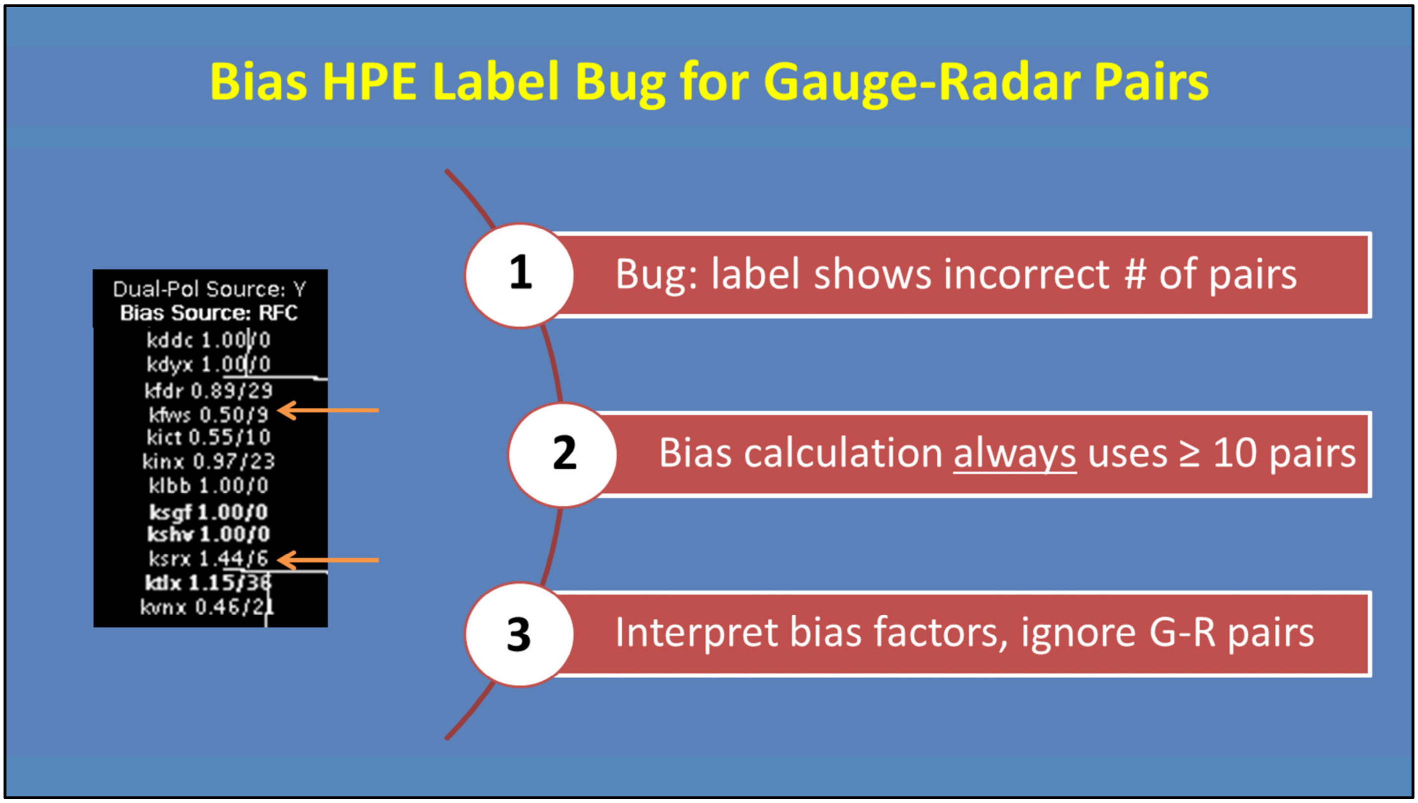


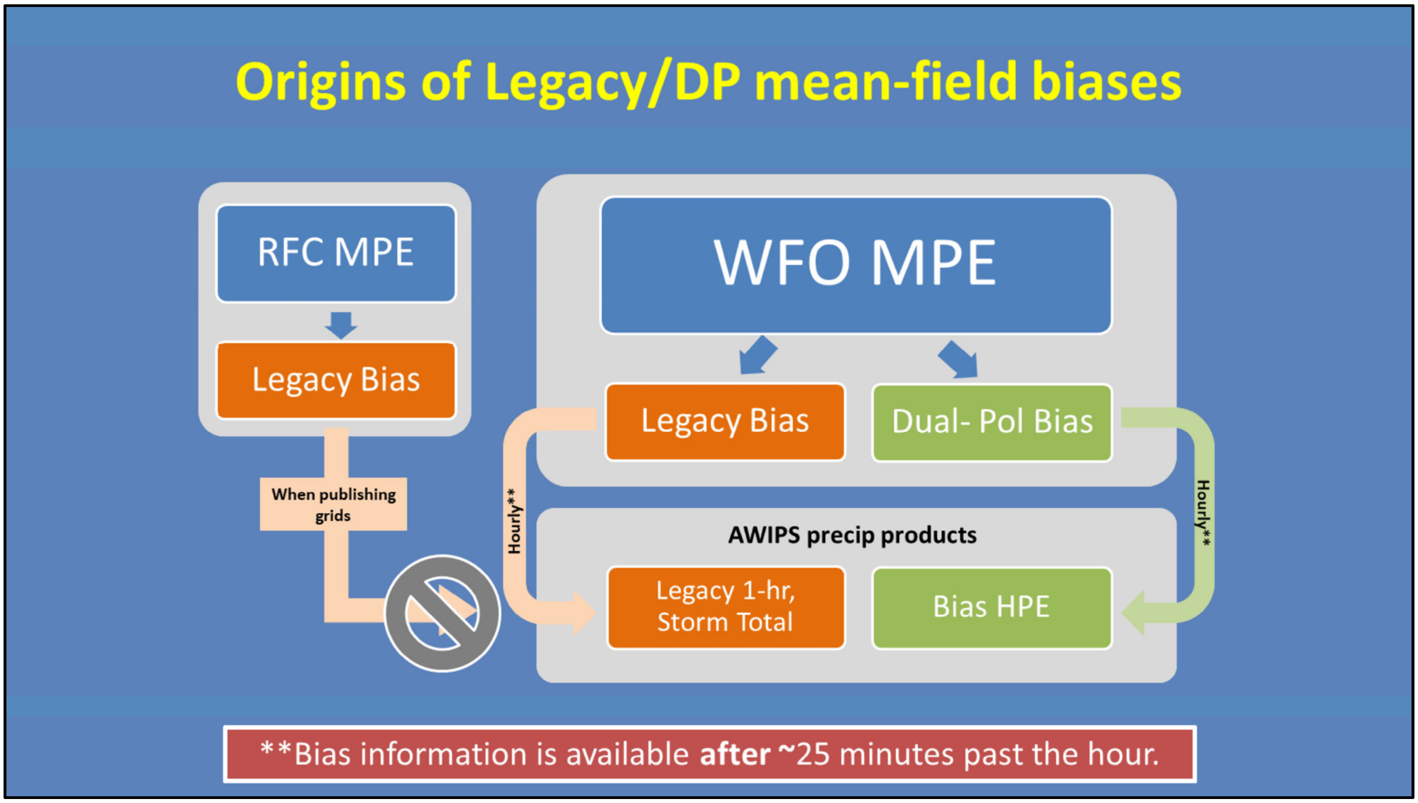
Another caution is that the bias factor could be created using most, if not all, gauges that don't match your targeted rainfall regime.

In our example, it may be more important to properly bias correct the convective area, since it's creating the highest rainfall totals. However, maybe the stratiform region is where all the gauge hits are for that hour. And what if those very light totals create a bias factor that is unrepresentative of the convective region? Would you necessarily want to apply it there? Unfortunately, you don't get that choice. That's where the term "mean field" comes into play.



Before I move on, I should mention there's currently a bug in the Bias HPE label related to the gauge-radar pairs.

Mean-field biases are *always* calculated using at least 10 pairs. However, the label will sometimes say there's less than 10 pairs, as shown here. The key takeaway is simple...you can interpret your bias factors knowing that they were calculated with the correct number of pairs. Simply ignore the gauge-radar pair number in Bias HPE as it can sometimes be wrong.



So where is the mean-field bias information computed? MPE, or Multi-sensor Precip Estimator, is an AWIPS application used to generate and QC various precip estimates, including gauge-corrected estimates.

Your WFO MPE generates both Legacy and Dual-Pol bias information, and then disseminates it hourly to your Legacy precip legends, and Dual-Pol Bias HPE. More on this in the next slide.

The RFCs also have an MPE used for their daily tasks, including the creation of just Legacy bias information. These Legacy biases are supposed to be sent when the RFCs publish the grids, but currently, some RFCs do not have MPE configured to send these out.

Theoretically, the RFC biases are thought to be better since RFCs are QC'ing their precip and gauge data constantly. So once the RFCs are configured to send biases to the WFOs, these RFC biases will take precedence over the WFO Legacy biases.

Also, it's important to know that your new bias information will NOT appear until after about 25 minutes past the hour. This is due to known latencies in gauge data collection.

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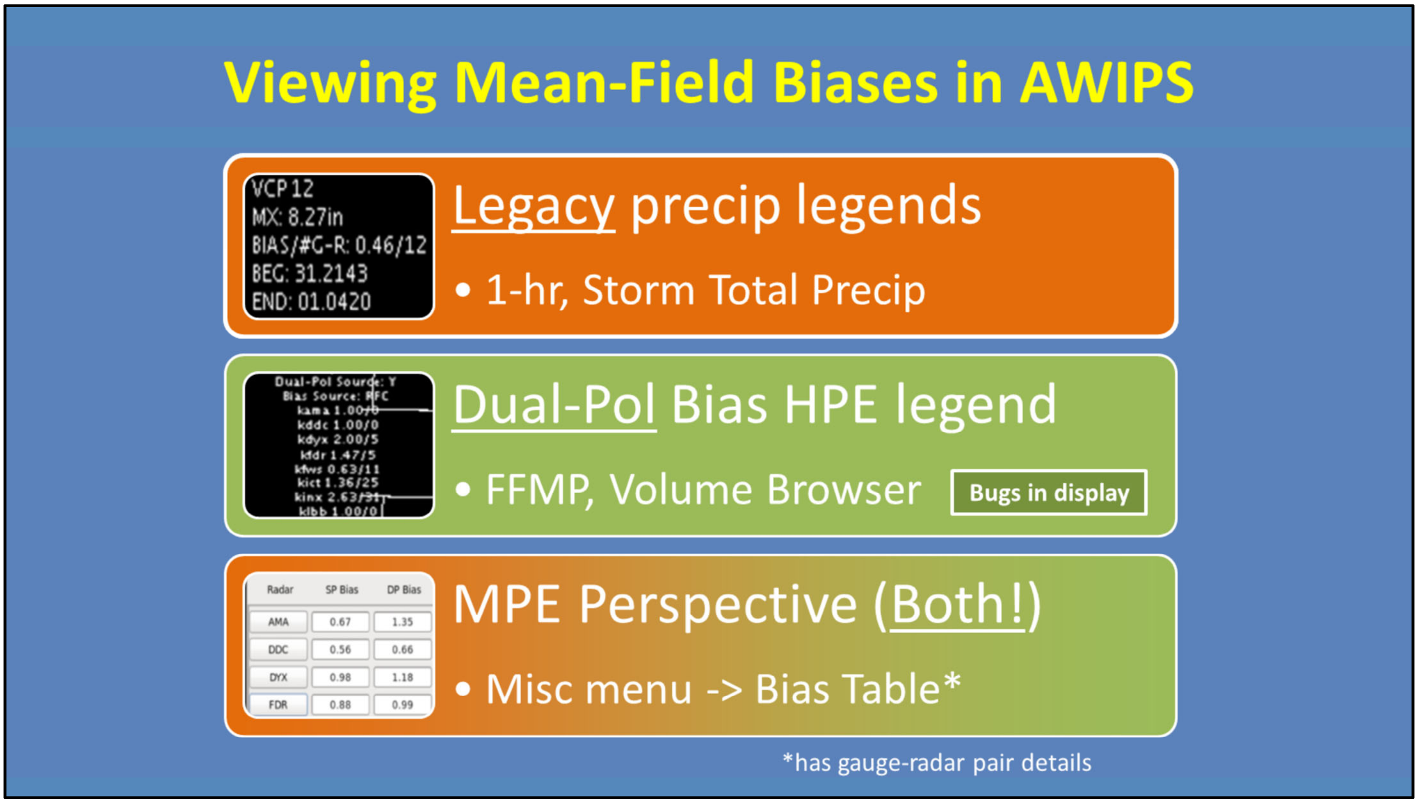
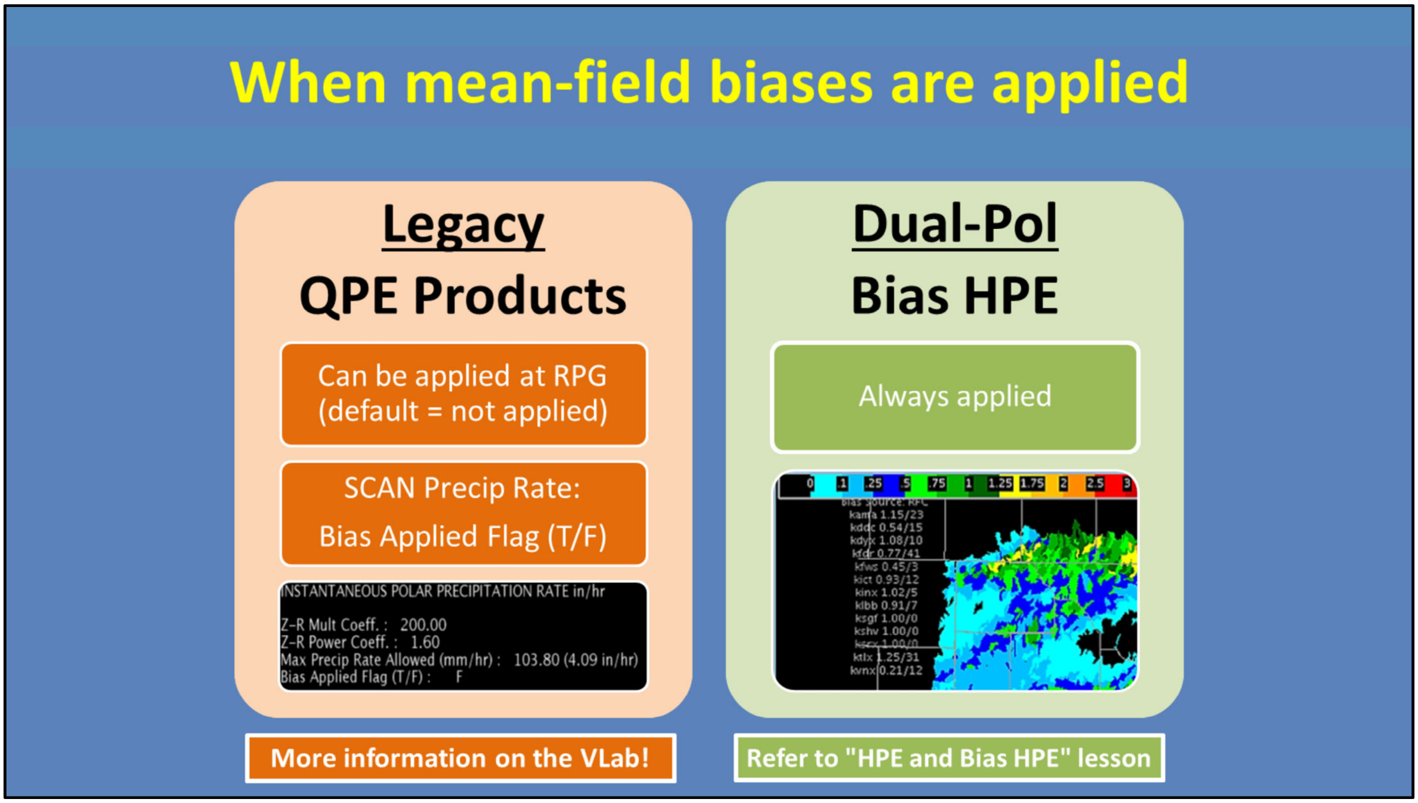


As diagramed on the previous slide, there are three ways to view mean-field bias information in AWIPS.

--For Legacy mean-field biases, look at the Legacy precip legends, as has been our focus throughout the lesson.
--For Dual-Pol mean-field biases, there's the Bias HPE product legend. This is a mosaic QPE product, and thus has Dual-Pol bias info for each radar contributing to the mosaic. It is an FFMP precip source, but is also accessed through the Volume Browser. However, there are some bugs in the display, as mentioned earlier.
--Finally, MPE has its own perspective in AWIPS, and there's a table forecasters can access with the bias info for both Legacy and Dual-Pol for all your radars, as well as details for the gauge-radar pairs. We don't expect you to go here during warning ops, but if you're interested in finding out how old your gauge-radar pairs are, this is where you'll find it. For more information on how to access this table, please see the supplemental slide at the end of this lesson.



Even though there are several ways to *view* mean-field biases in AWIPS, there are only a couple places to apply them.

For Legacy precip estimates, the Legacy bias can be applied at the RPG, but the default is that it is not applied. To simply check whether it currently is or isn't, open the SCAN Precip Rate product for the radar of interest, and look at the legend shown here. The "Bias Applied Flag" will be false if it is not applied (the default), or true if it is. For more information on how to configure this flag to be viewable in the SCAN product and how to identify if the bias has been applied at the RPG, see the reference material on the VLab.

The other option is to use the Bias HPE product. This mosaicked Dual-Pol QPE product automatically applies each radar's Dual-Pol mean-field bias factor to the pixels within its coverage. There are more details on this product in the lesson "HPE and Bias HPE".

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Dual-Pol Spatially-Varying Bias

QPE Source	Z-Rs	Bias Option
Legacy	**Single Z-R** (set at RPG)	**Mean-field** ~~**Spatially-varying**~~ (not commonly used)
Dual-Pol	**Spatially-varying** (based on precip type)	**Mean-field** **Spatially-varying** (available in Bias HPE; weighted based on distance from gauges)
MRMS	**Spatially-varying** (based on precip type)	**Spatially-varying** (weighted based on distance from gauges)

Until now, we've covered details related to mean-field bias options for Legacy and Dual-Pol. Before we jump into the MRMS biases, I wanted to briefly mention that Bias HPE also has the capability to apply a Dual-Pol spatially-varying bias instead of a mean-field bias. This requires a token change by your hydro focal point. I will save the details for the "HPE and Bias HPE" lesson, as well as the VLab reference material.

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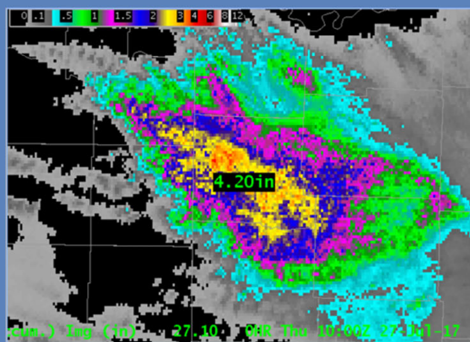
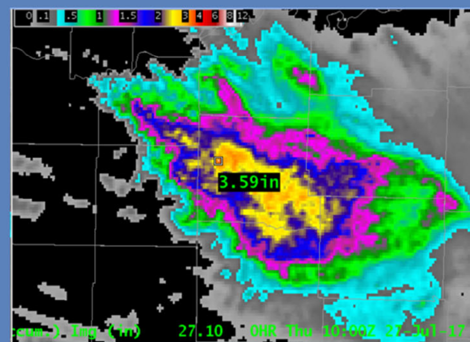
MRMS Bias Interpretation

Radar Only QPE	Multi-Sensor QPE
• Raw QPE output • 2-min update	• Includes radar, gauge, model data • Spatially-varying bias correction • Hourly update (w/ 60+ min delay)



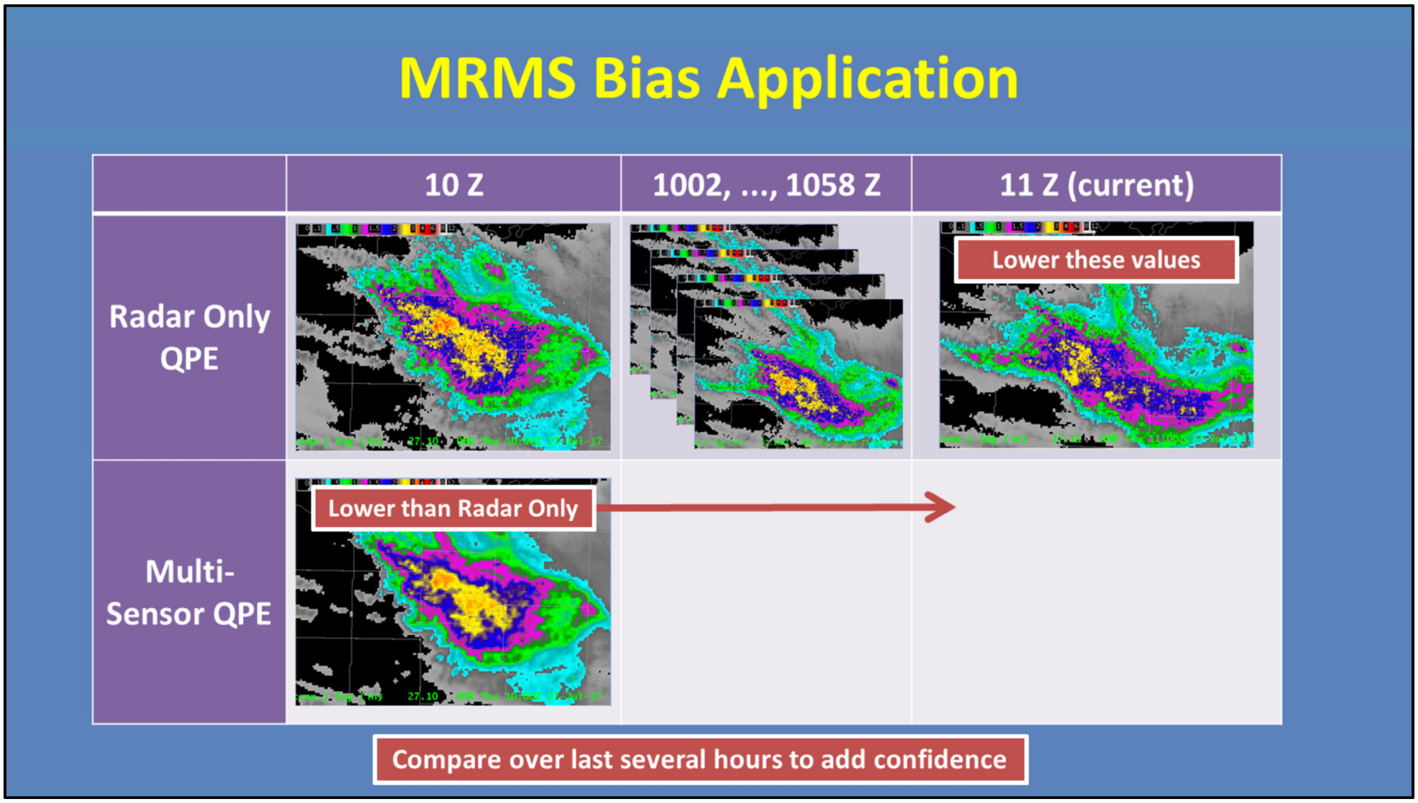


Alright, let's switch gears to the MRMS bias interpretation, which is luckily much more straight forward.

To do it, you need to compare two products side-by-side. The first is the "Radar Only" product which tells you MRMS's raw QPE output, updated in real-time. The second is the "Multi-Sensor QPE" product. This product leverages radar, gauge and model data for enhanced precip estimation. In most locations, it starts with the Radar Only QPE and then applies a spatially-varying bias correction based on gauges. Since it relies on gauges, this product is only created once every hour, and currently has a delay of at least 60 minutes. To learn more, please visit the MRMS Products Course.

Load the products side-by-side in a 4-panel layout. Make sure they're time-matched based on the *multi-sensor* product. When clicking through frames, this will force the Radar Only product to match the multi-sensor's hourly update.

In this example, we see from sampling that the multi-sensor product pulled down the extreme values, meaning there was a gauge in that area that had totals less than what the Radar Only QPE estimated. In other areas, where there are no gauges, the values remain unchanged.



So how would I apply this in operations? Well, let's say current time is 11Z. Because of the gauge delay, the most recent bias-corrected product available is from 10Z. So I do the time-matched comparison at 10Z, sample out some values, and find that the gauges have been pulling down some of the raw radar estimates.

An hour's worth of Radar Only data has come in since this comparison time. So looking at my current Radar Only data at 11Z, I would mentally want to lower these values a bit, knowing what I analyzed from the previous hour.

Additionally, I would do this comparison over the last several hours to get a quick sense of whether there's a pattern. If there is, I have more confidence when extrapolating the current 11Z Radar Only values.

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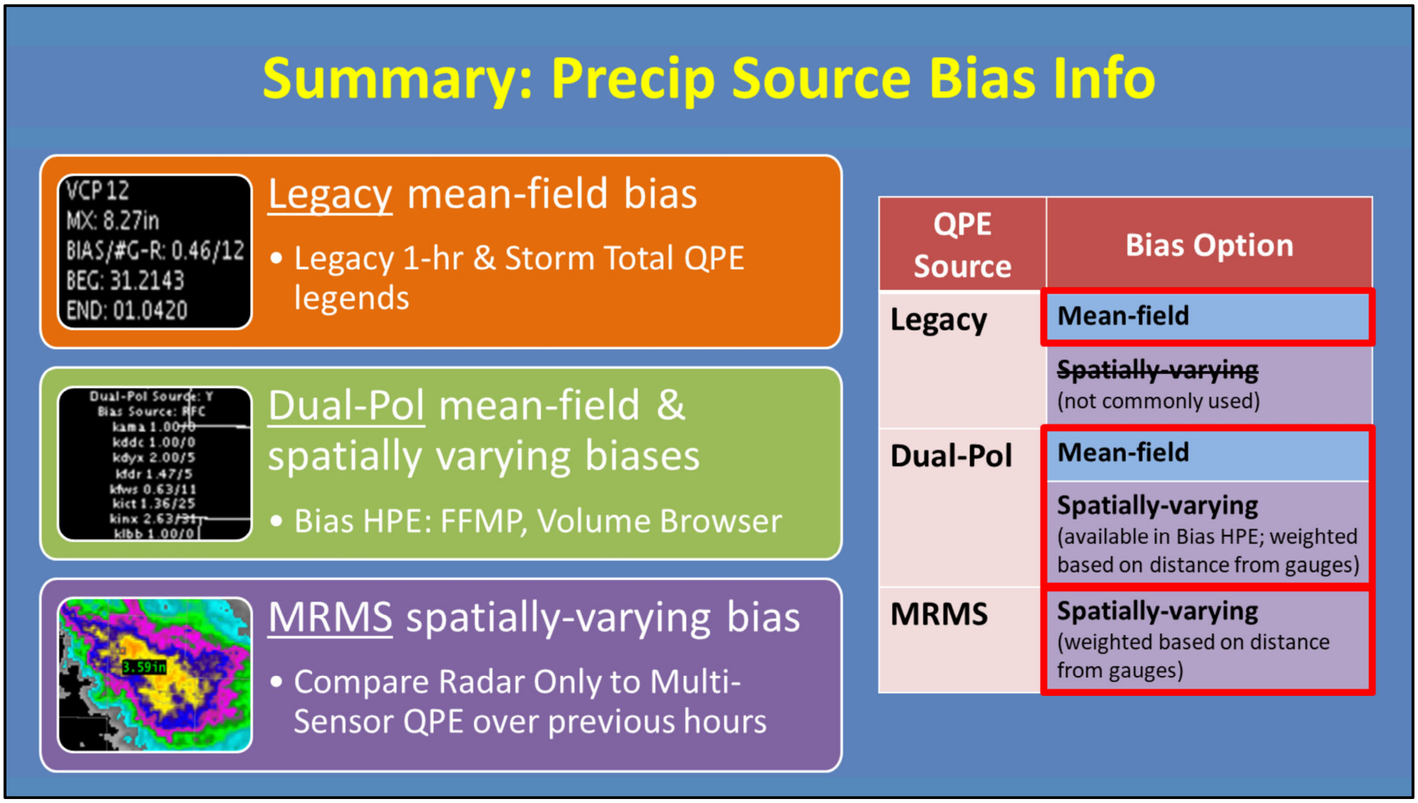
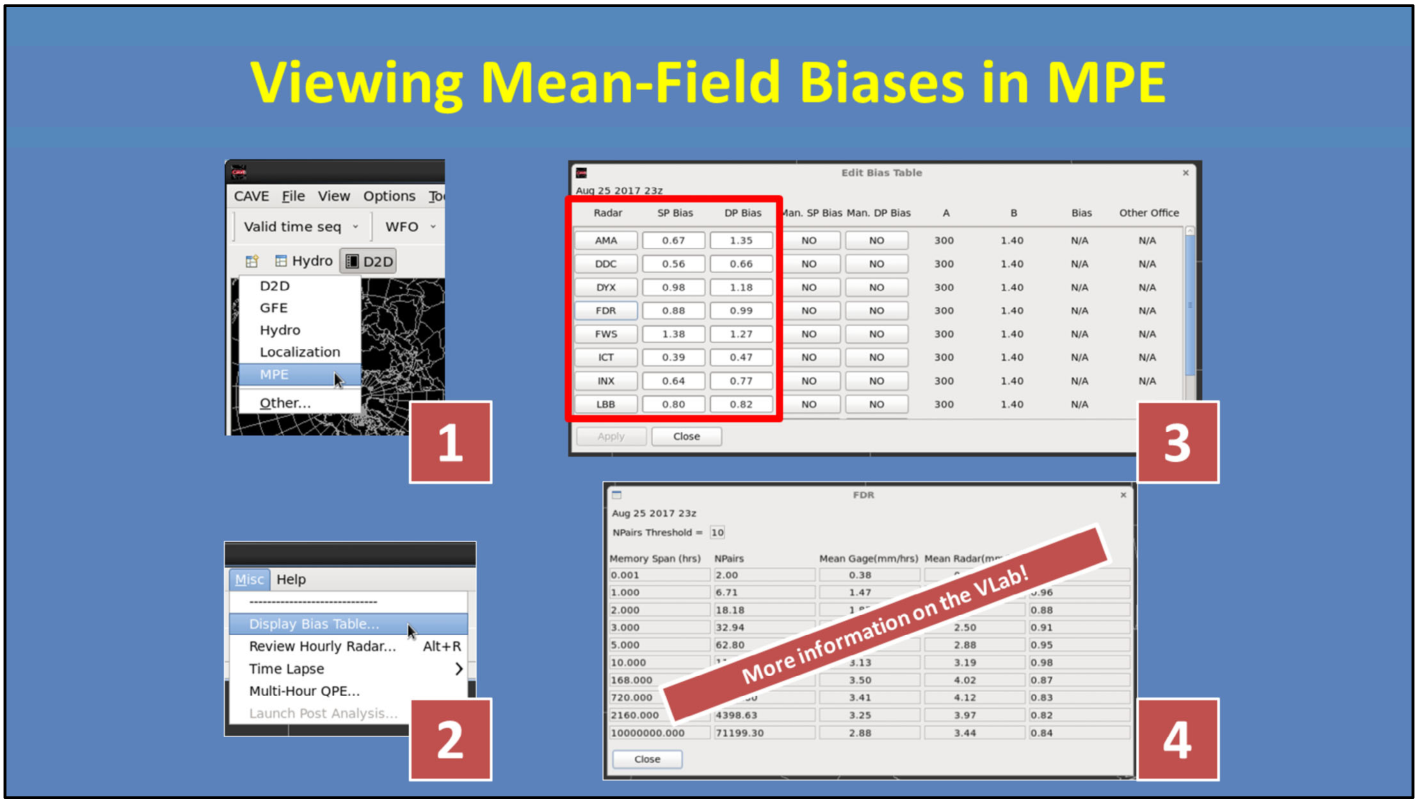


I know I threw a lot at you in this lesson, so here's a quick summary on where to look for each precip source's bias information.

For Legacy mean-field biases, simply look at the Legacy one-hour and storm-total QPE product legends.
For Dual-Pol mean-field biases and spatially-varying biases, use the Bias HPE product (either in FFMP or from the Volume Browser).
Finally, for MRMS spatially-varying biases, compare your Radar Only QPE to the bias-corrected QPE over the last several hours.



Here is your supplemental slide about viewing mean-field biases in MPE.

First, open the MPE perspective in CAVE. Once in MPE, navigate to the Miscellaneous menu, and click on the "Display Bias Table".

From this table, you will find all of the bias factors for both Legacy and Dual-Pol. Notice that each of the radar names is a clickable button.

If you clicked on one of these, you'll open a new sub-table with information about the gauge-radar pairs for that radar. Details on how to interpret that table are located at the VLab page in the Resources tab.

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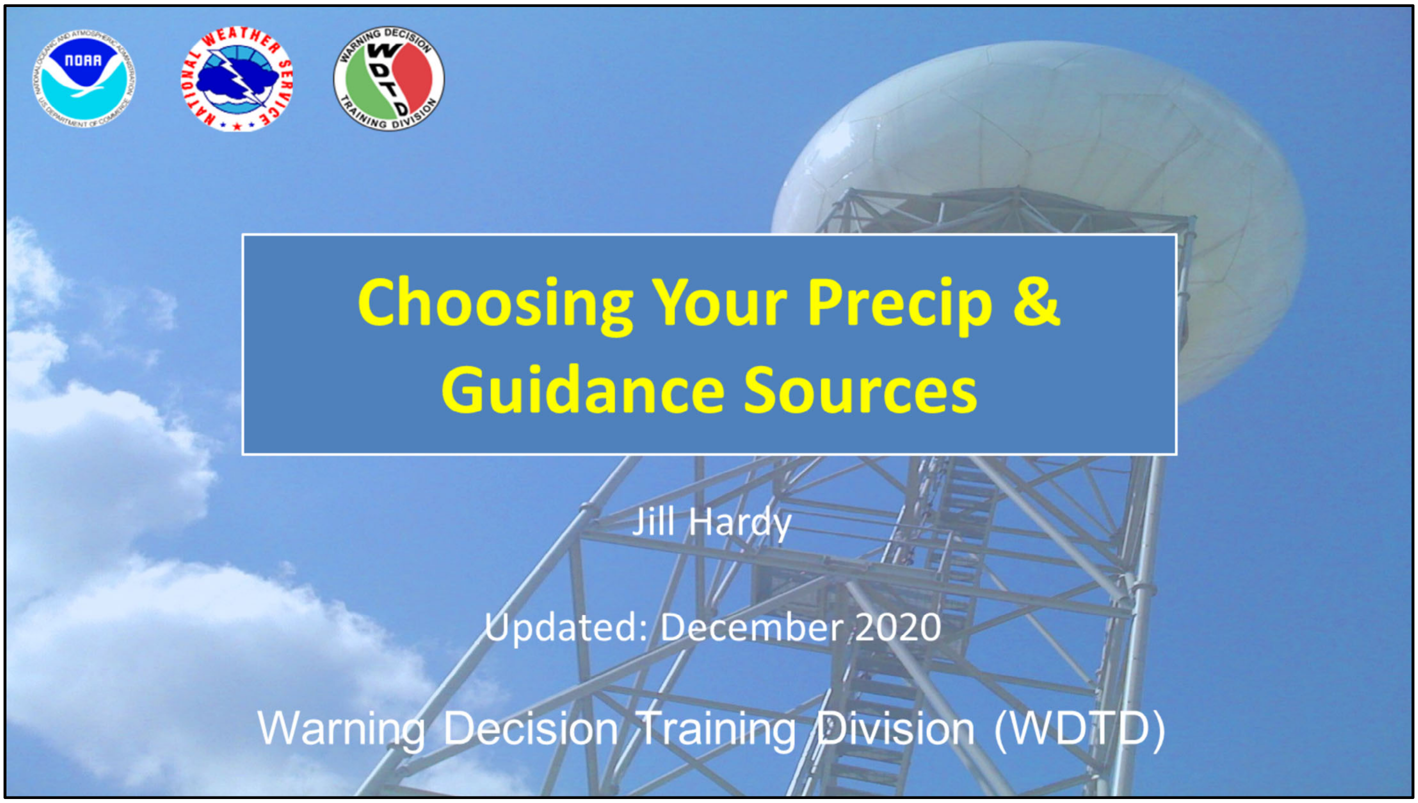

Hi, my name is Jill Hardy and welcome to this lesson on how to best choose your precip and guidance sources during the flash flood warning decision-making process.

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Learning Objectives

- By the end of this lesson, you will be able to:
  - Identify basic approach to flash flood decision making
  - Identify characteristics of the five precipitation sources in AWIPS
  - Identify how hail impacts QPEs
  - Compare QPE to surface observations
  - Identify best practices when comparing QPEs to observations
  - Identify advantages of using FFMP for QPE-to-FFG comparison
  - Identify a FLASH product useful for assessing runoff
  - Identify caveats associated with QPE and FFG

Here are the learning objectives for this lesson. When you have finished reading them, please continue to the next slide.

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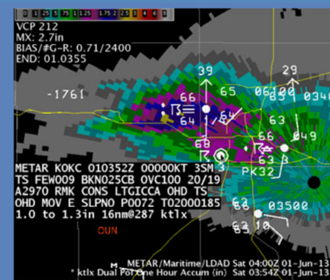
Flash Flooding: It Takes Two

Atmosphere:

How much rain has fallen, and when did it fall?

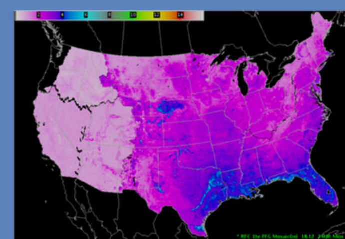
- **Determine the best QPE source by comparing to surface obs and reports**



Ground:

Will runoff cause flash flooding?

- **Use local hydrologic knowledge and RFC guidance**
- **Assess runoff threat via FLASH**



When considering a flash flood threat, there's really two questions to ask yourself. The first covers the atmosphere: “How much rain has fallen and when did it fall?”. To do this, you will need to identify the best QPE source. This is best done by comparing to surface observations and reports when you have them. But when you don’t, we have some other general guidance.

Next, consider the ground response. Ask yourself: "Will the runoff cause flash flooding?" Typically this starts with your local hydrologic knowledge and is supplemented with River Forecast Center (RFC) Flash Flood Guidance. Additionally, you can assess the runoff threat using FLASH data.

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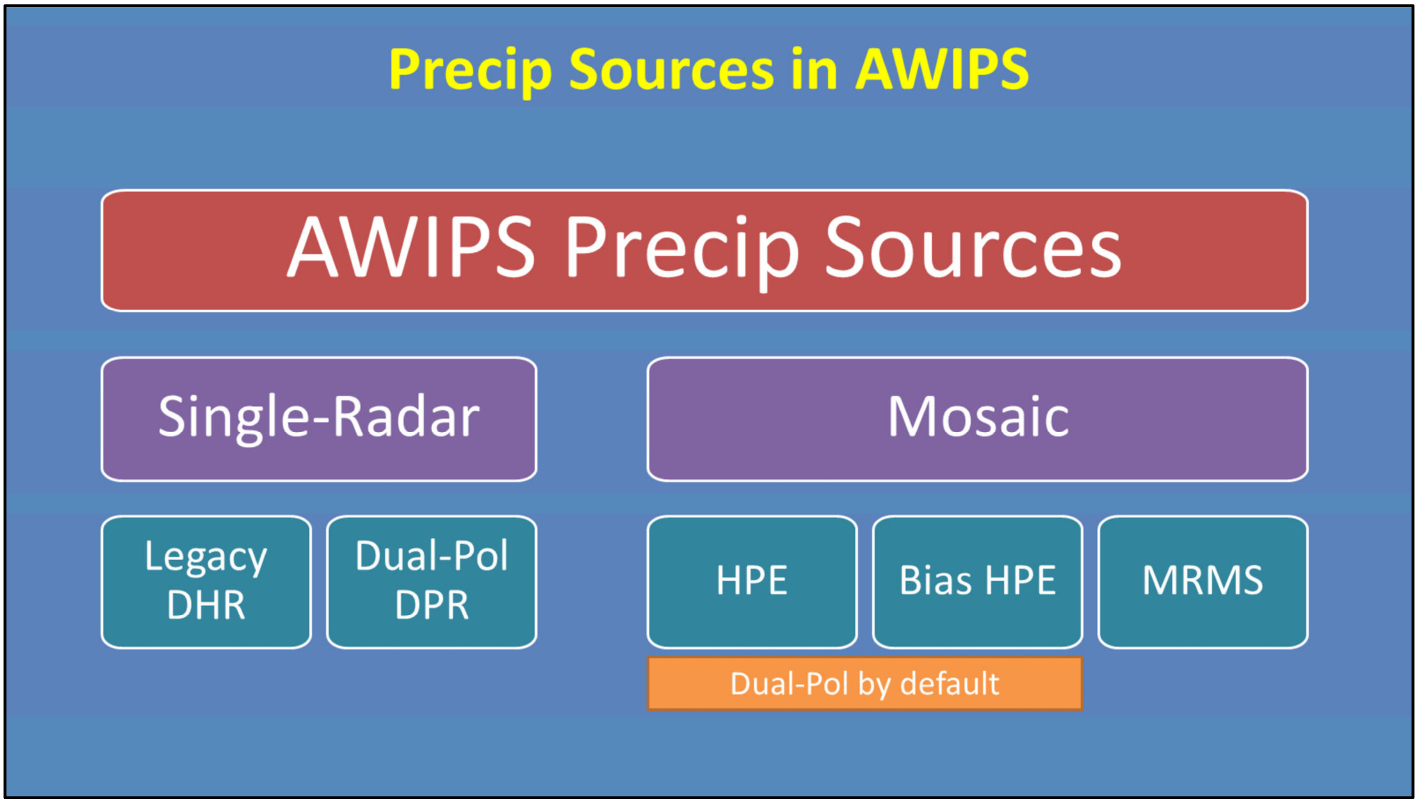

AWIPS has 5 precip sources available to choose from. For single-radar sources, there is the Legacy DHR and the Dual-Pol DPR. For mosaics, there's HPE and Bias HPE, as well as MRMS. Remember that HPE and Bias HPE are simply Dual-Pol mosaics by default, so they're not really "new" sources per se. But they do differ from the single-radar product in some regards. So let's look at a detailed comparison of all of these on the next slide.

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Precip Sources in AWIPS

	Coverage	Dual-Pol?	Bias corrected?	Resolution	Accumulation products outside of FFMP	Z-Rs
Legacy DHR	Single-radar	No	No (default, configurable at RPG)	1 km x 1 deg 3-6 min	1-, 3-, STP (and user-selectable)	Single Z-R (set at RPG)
Dual-Pol DPR	Single-radar	Yes	No	0.25 km x 1 deg 3-6 min	1-, 3-, STA (and user-selectable)	Spatially-varying (based on HHC)
HPE	Mosaic	Yes	No	1 km x 1 km 5 min	1-hr (harder to access from Vol. Browser & SCAN)	Spatially-varying (inherited from DPR for each radar)
Bias HPE	Mosaic	Yes	Yes (mean-field bias is default, configurable)	1 km x 1 km 5 min	1-hr (harder to access from Vol. Browser & SCAN)	Spatially-varying (inherited from DPR for each radar)
MRMS radar-only	Mosaic	Yes (as of Oct 2020)	No (Multi-Sensor QPEs only update hourly)	1 km x 1 km 2 min	1-hr (All other accum update hourly)	Spatially-varying (based on melting layer & SPT)

There are many factors to consider when choosing a precip source to use during an event, specifically early on before you have many observations.

1. For one, consider the coverage area. The mosaics are good when you have multiple radars because you only have to open one grid or FFMP.
2. Next, is it Dual-Pol? Both HPE products default to using Dual-Pol precip sources. And as of October 2020, MRMS also includes Dual-Pol variables in its calculation.
3. Do you want biases applied? Only Bias HPE has biases applied by default. However, DHR has the option available at the RPG. Note that MRMS does have bias-corrected products, but they are only updated at the top of the hour.
4. How do the resolutions compare? The single-radar DPR product has the best spatial resolution at 250 m by 1 deg. This is useful for events that are close to the radar. However, MRMS has the best temporal resolution, at 2 minutes. This is useful for convective events with high rain rates.
5. Consider what accumulation products are available outside of FFMP. The single radar sources offer 3-hour and storm total accumulations. Additionally, they offer the ability to do one-time requests of user-selectable accumulations. On the other hand, the HPE products only produce 1-hour accumulations by default and are not as easy to access to compare with the other sources. And, MRMS only produces the 1-hour accumulation every two minutes, with all of the other accumulations updated hourly.

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6. Finally, how are rain rate relationships managed? DHR only has one Z-R used over the whole radar domain. Every other source uses spatially-varying Z-R relationships based on precip type.

Choosing Initial Precip Sources

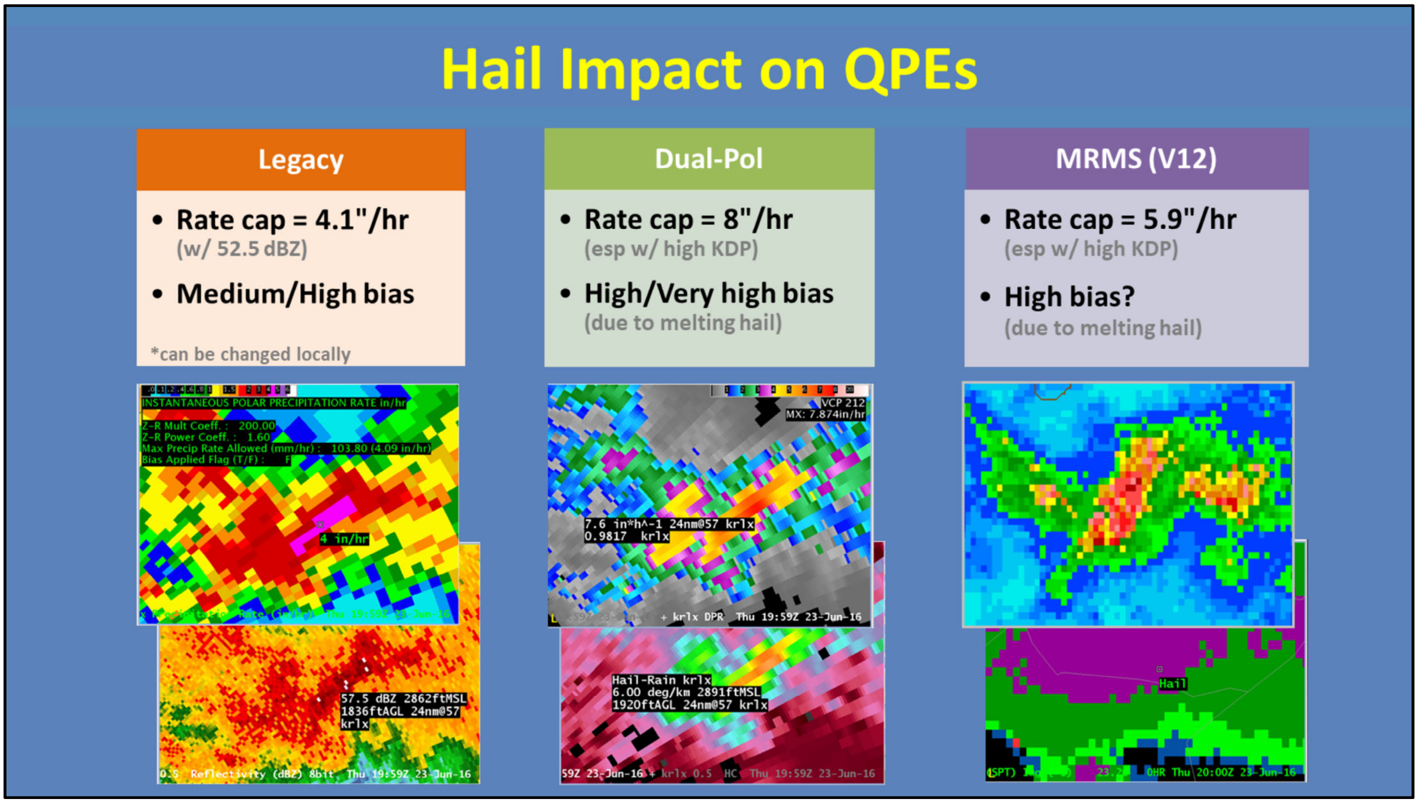
	Coverage	Dual-Pol?	Bias corrected?	Resolution	Accumulation products outside of FFMP	Z-Rs
Legacy DHR	Single-radar	No	No (default, configurable at RPG)	1 km x 1 deg 3-6 min	1-, 3-, STP (and user-selectable)	Single Z-R (set at RPG)
Dual-Pol DPR Recommended outside of FFMP	Single-radar	Yes	No	0.25 km x 1 deg 3-6 min	1-, 3-, STA (and user-selectable)	Spatially-varying (based on HHC)
HPE Recommended in FFMP	Mosaic	Yes	No	1 km x 1 km 5 min	1-hr (harder to access from Vol. Browser & SCAN)	Spatially-varying (inherited from DPR for each radar)
Bias HPE	Mosaic	Yes	Yes (mean-field bias is default, configurable)	1 km x 1 km 5 min	1-hr (harder to access from Vol. Browser & SCAN)	Spatially-varying (inherited from DPR for each radar)
MRMS radar-only	Mosaic	Yes (as of Oct 2020)	No (Multi-Sensor QPEs only update hourly)	1 km x 1 km 2 min	1-hr (All other accum update hourly)	Spatially-varying (based on melting layer & SPT)

So now, which precip source should you use? Really, the answer is any and all of them! It simply depends on which source seems to be capturing the nature of your current precip event. Here are some tips for where to start, especially without any observations to compare.

Remember, the choice comes down to the three overall precip sources: Legacy, Dual-Pol, and MRMS.

Generally speaking, Dual-Pol and MRMS are going to be your starting points because they incorporate Dual-Pol variables into their Z-R relationships, as well as allowing the Z-Rs to vary pixel-by-pixel, which is meant to better capture the true nature of the precip occurring throughout the domain. The two sources do these calculations differently, so it's good to always look at both.

Dual-Pol then has 3 options. When you want to interrogate Dual-Pol QPE outside of FFMP, I recommend the single-radar DPR because of its high spatial and temporal resolution, as well as the additional accumulations available. But when it comes to using Dual-Pol in FFMP, I generally recommend getting into the habit of using the HPE product. Since FFMP basin-averages the QPEs, there is no resolution advantage anymore. And it’s much easier to open one FFMP mosaic than jumping between different radars. Only use Bias HPE when you trust the biases and want them automatically applied to all estimates. Keeping in mind that the labels are buggy, so *only* use it once you've taken our lesson and know how to work around this problem.



In addition to the factors discussed on the previous slides, I need to mention the effects that hail can have on the QPEs. In general, hail can cause high biases for any precip source due to its enhanced reflectivities caused by it violating the Rayleigh scattering principle. So there have been adjustments made to each algorithm to try to account for it.

--For Legacy, there is a rain rate cap of 4.1 inches/hour. This is an adaptable parameter at the RPG, but recommended not to be changed. If you simply want to know your rate cap, look at the Instantaneous Precip Rate product legend, as shown here, which is loaded from the SCAN menu. Because of Legacy's low resolution, even this 4 inch/hour cap can cause high biases because it is so blocky.

--For Dual-Pol, the rate cap is 8 inches/hour. This mostly occurs when melting hail fools the radar to thinking it's very large raindrops and gets assigned very high KDP values, as shown in the bottom image. Since Dual-Pol uses a KDP-based rain rate relationship for the hail-rain class, this allows for higher rates to occur, as seen in the top image. If these rates occur over more than a couple volume scans, it can create very high-biased estimates.

--Finally, as of Fall 2020, MRMS switched to Version 12 and updated much of their QPE algorithms. The MRMS rate cap is 5.9 inches/hour in areas that may include hail. There is a higher cap for pure rain areas. In hail regions, MRMS also relies on KDP, so it is also susceptible to the melting hail problem. Compared to previous versions of MRMS, these changes have improved its low bias problem in the warm season. But compared to Dual-Pol and Legacy, it is yet to be determined where it falls. My assumption is that it will lie between the other two sources in areas of melting hail.

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R(A) in Dual Pol & MRMS

Used in areas of pure rain, specifically:

- Light to moderate pure rain
- Below the melting layer

RAC Principles of Radar
"The Dual-Pol QPE Algorithm"

MRMS
"Hydro Products Overview"
"MRMS QPE Radar-based Products"
(more in-depth)

Location with respect to ML	Rain Rate Relationship	Rain Rate Cap	Applications
Below melting layer	R(A)	7.9 in/hr	Pure rain (i.e. no ice, hail)
	R(KDP)	5.9 in/hr	Areas of potential hail & heavy rain
	Max{ R(A), $Z = 75*R^{2.0}$ }	varies	Very light or sporadic rain
Within/Above melting layer	Z-R relationships defined in V11.5	varies	Based on Surface Precip Type

In Fall 2020, both Dual-Pol and MRMS QPE algorithms were upgraded to include the use of specific attenuation in rain rate calculations. R(A) is only used in areas of pure rain, specifically in light to moderate rain below the melting layer.
As part of RAC, you should have already taken lessons that cover this topic for each Dual Pol and MRMS. If you're taking this outside of RAC, please refer to these lessons for more details on the advantages of using specific attenuation in rain rate calculations.

But I just wanted to take a moment to recognize this change and that it could impact how you interpret Dual-Pol and MRMS in those regions. For instance, MRMS increases it's rain rate cap to 7.9 in/hr when using R(A).

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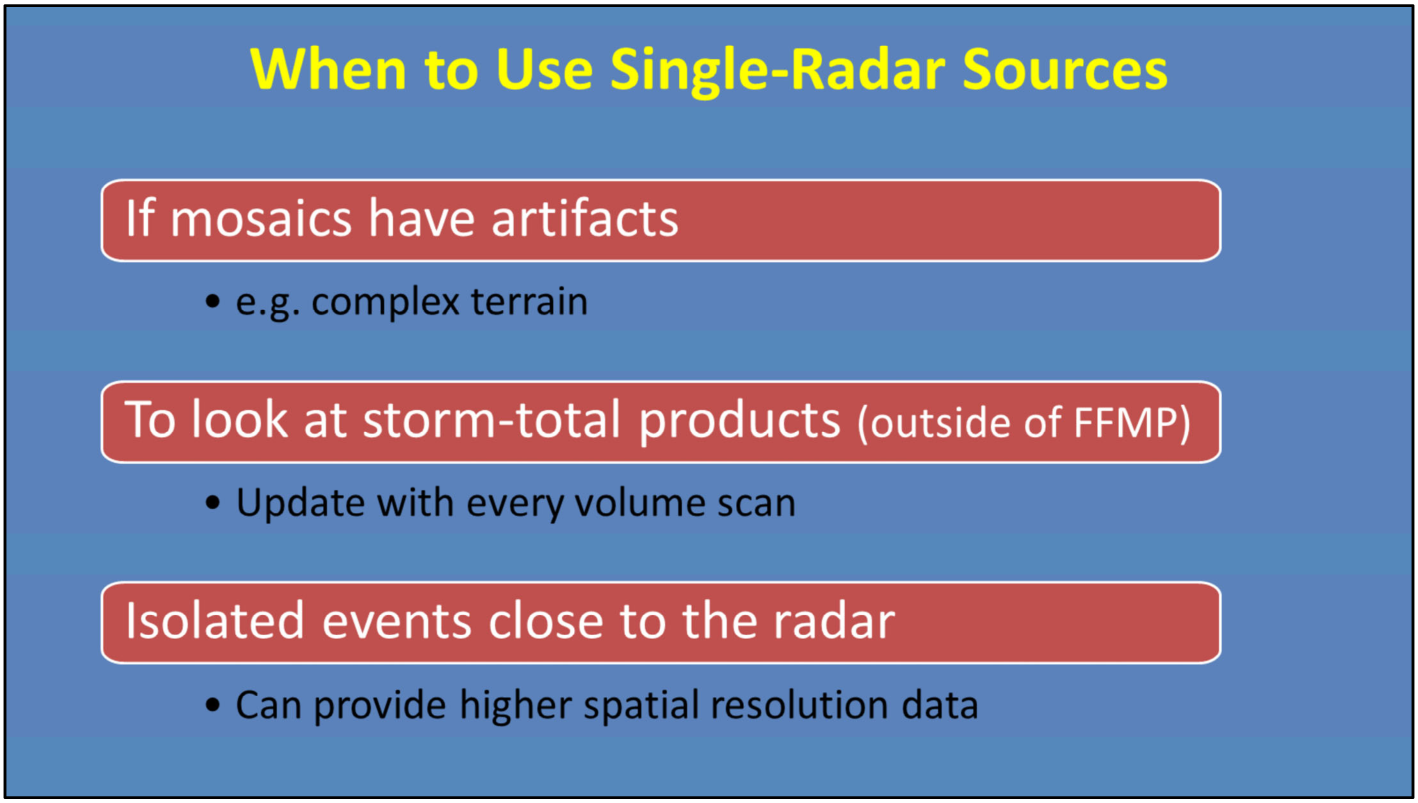
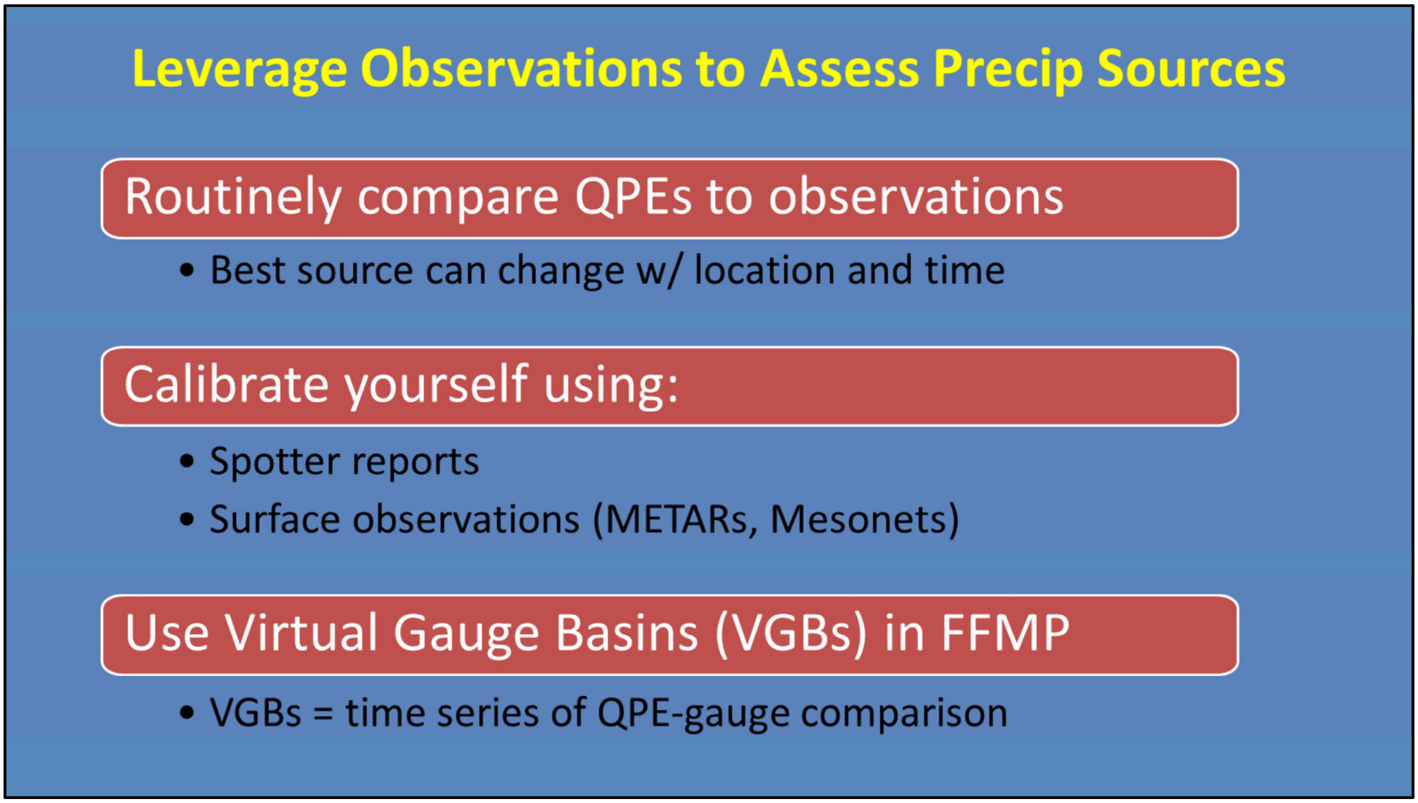


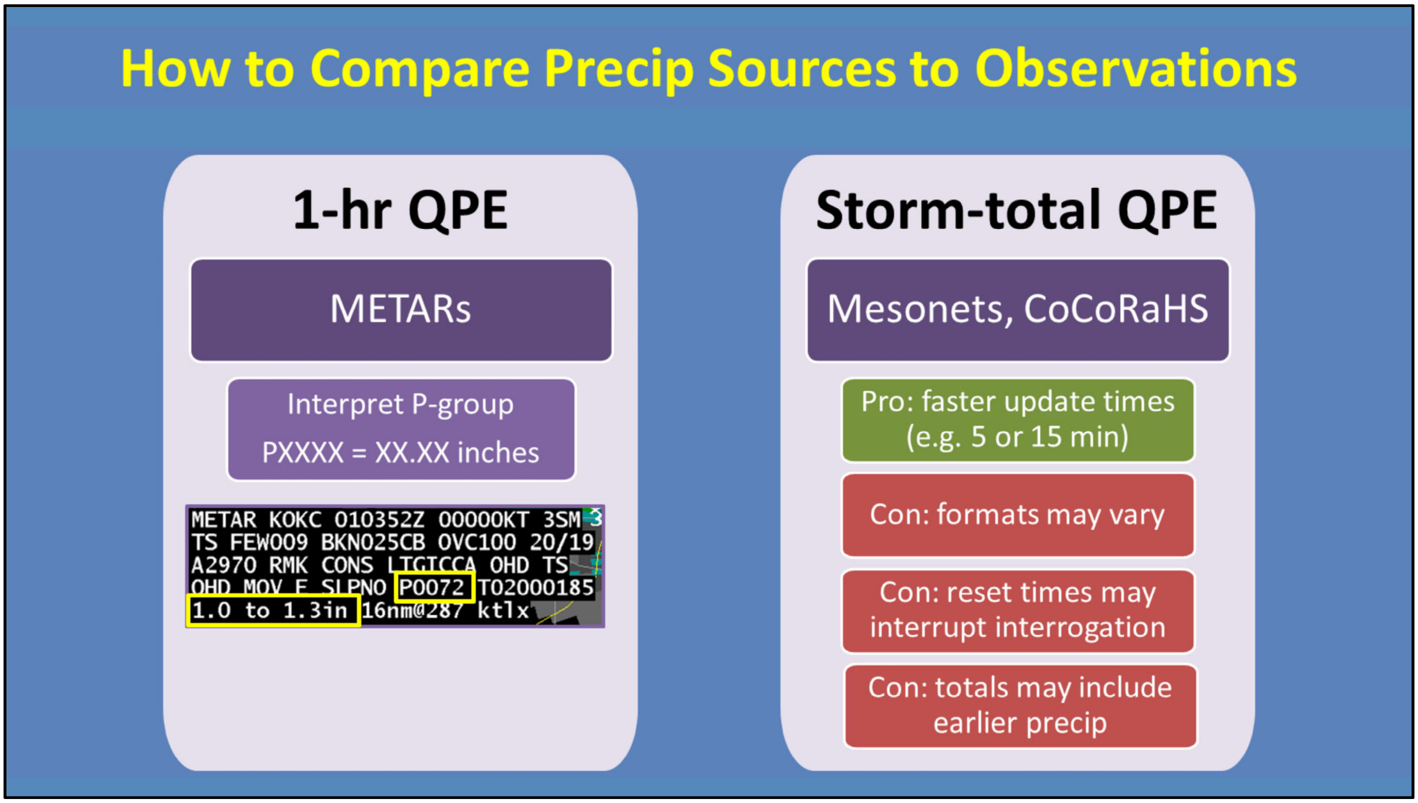
While generally it may seem that mosaicked products are preferred for their spatial coverage, there are times when using the single-radar products can be advantageous. They are good choices if the mosaics have artifacts, like when multiple radars are covering complex terrain. When you want to look at storm-total products that update with every volume scan. Or if there is an isolated storm close to a radar, which may provide better spatial resolution data.



The best way to truly know which source is doing the best at any given time is to routinely compare them to observations throughout the event. It is not unusual for the optimal precip source to change across your CWA and with time.

This includes calibrating yourself using spotter reports, as well as sampling surface observations, such as METARs, Mesonets, and CoCoRaHS. We'll discuss this on the next slide.

Additionally, the Virtual Gauge Basins (or VGBs) feature in FFMP is also a convenient way to compare a QPE source to observations. This process is a little more involved, so refer to the lesson in WOC Flash Flood to learn more.



Comparing each one of your precip sources to trusted gauges is the most robust method for determining how they are doing for that event.

Compare one-hour totals to METARs, since METARs report hourly. To find the precip total, look for the P-group. The 4 digits correspond to rainfall in inches, using this conversion. Here is an example. We see the METAR reported 0.72 inches, while the 1-hour radar QPE estimates 1.0 to 1.3 inches. This shows that this particular precip source is overestimating by a quarter to half an inch. You can use this information to self-calibrate what you're seeing from the QPEs.

For storm total QPEs, compare to local Mesonet and CoCoRaHS stations, if you've got them, since they report 24-hour running totals, which is the best proxy for comparing to the storm-total estimates. These networks can be useful because they have faster update times compared to METARs which is nice during a high-rate event. But keep in mind that the format of the data may vary between networks. Also, the networks can reset at different times, which may interrupt your interrogation of the data. For instance, if the network resets at 00Z, you could be in the middle of an event when the totals zero out. So you may need to do some on-the-fly calculations if this happens. Additionally, because they are 24-hour totals, they could include precip from the previous day that's not useful during your current analysis. A best practice early in an event is to check some of these observations to see your starting values.

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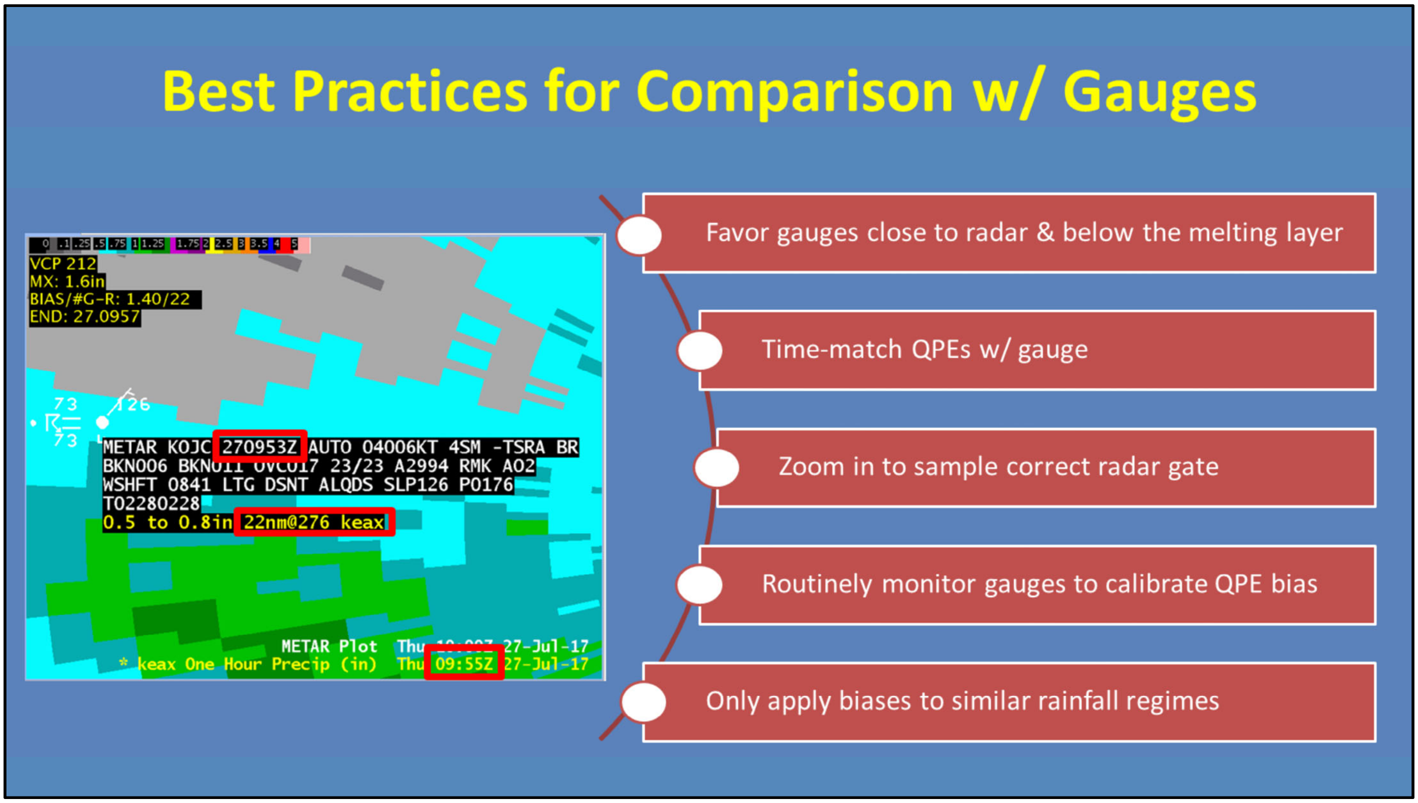
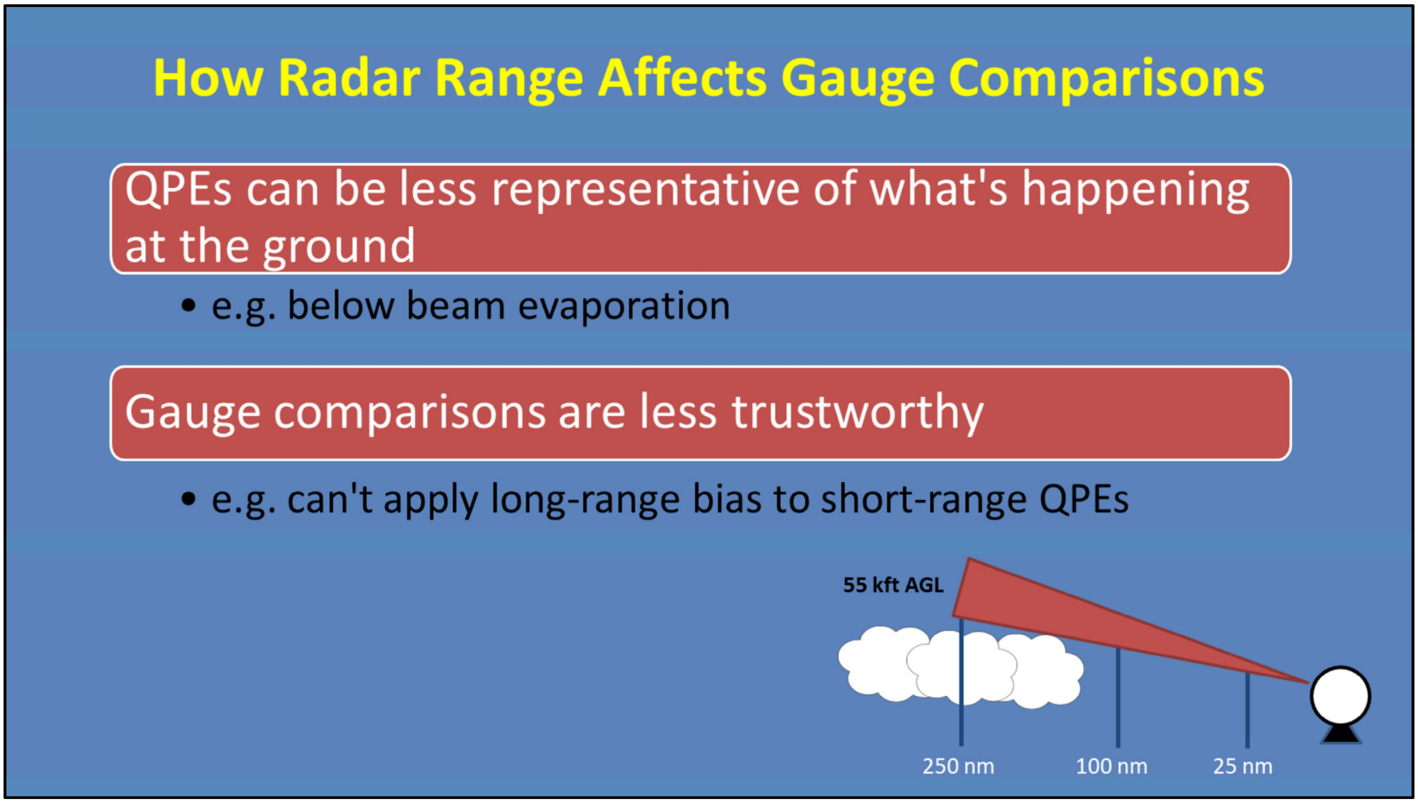
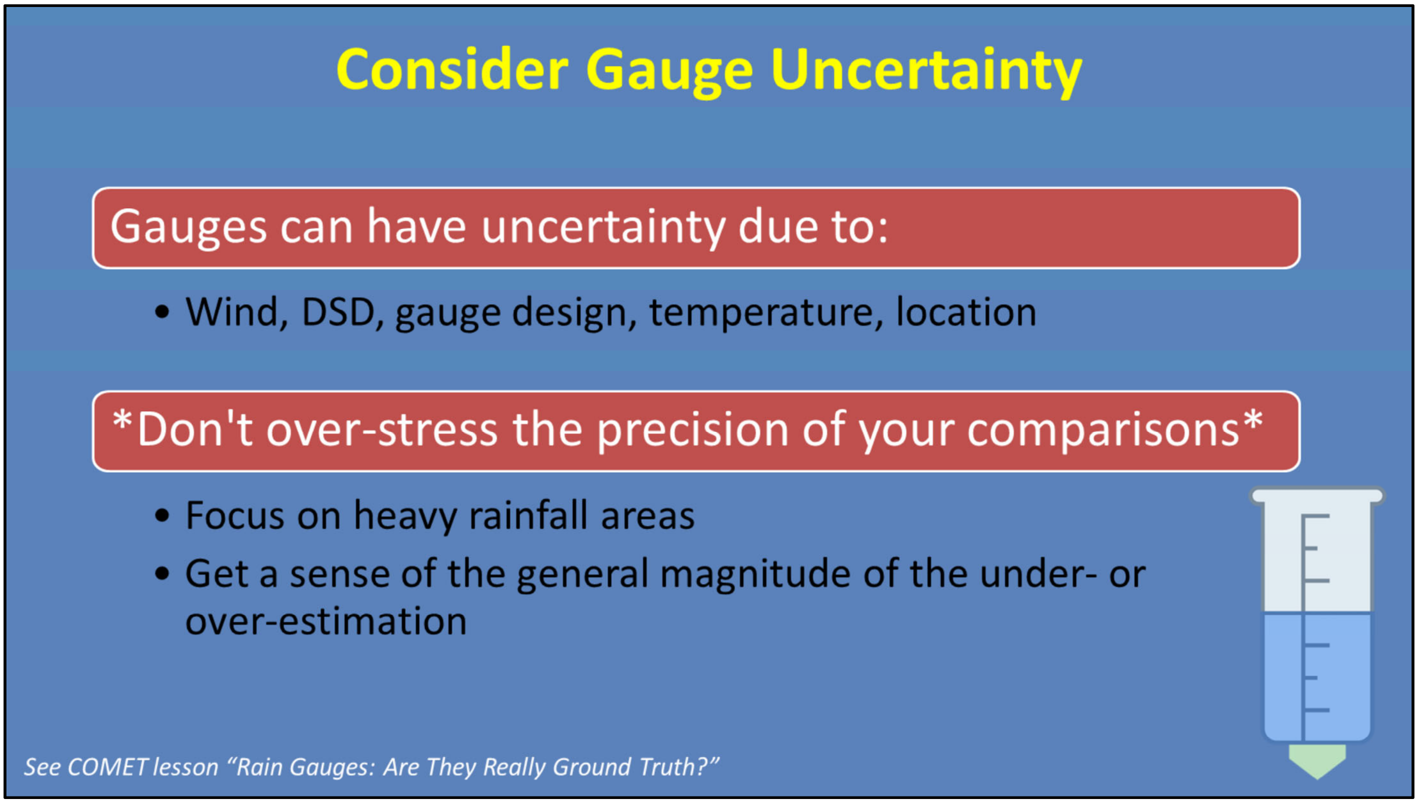


Here are some best practices when doing a comparison with a gauge:
--For one, put more weight in gauges that are closer to the radar since the QPEs will be sampling lower in the atmosphere. Similarly, favor gauges that are below the melting layer. In this example, the gauge is 22 nautical miles away, which is good.
--Next, don't forget to time-match your QPE display with your gauge observations. Here, the METAR sent it's one-hour total at 0953, so I set the Legacy QPE display as close as possible which was 0955.
--Also, don't forget to zoom all the way in when you do these comparisons, to ensure you've got the right radar gate.
--Routinely monitor your gauges to calibrate your QPE bias. This could be every hour for METARs or checking in more frequently with Mesonets.
--Finally, only apply your biases to similar rainfall regimes. Don't expect a bias that you calculated in a convective core to necessarily hold true in a stratiform region of the storm.



We recommend that you focus on doing these surface obs comparisons at closer ranges because, at long ranges, there are two things to think about:

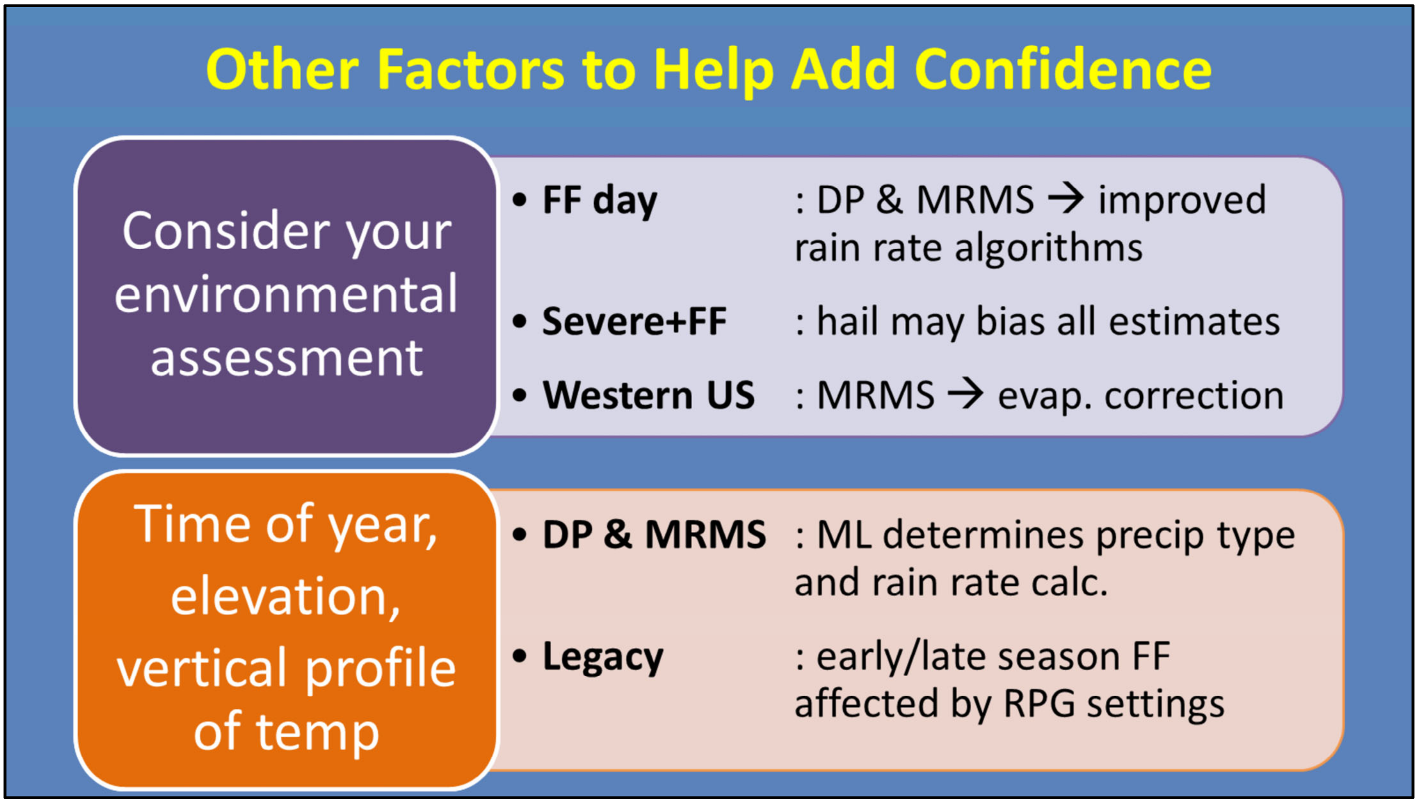
1) For one, precip estimates can be a lot less representative of what's happening at low levels. Consider the depiction below, where a radar estimate at 250 miles away could be sampling as high as 55 kft above ground level.
2) Because of this, it makes comparisons with ground observations less trustworthy. In this example, you are over-shooting the precip at long ranges. So you wouldn't want to apply that long-range information to radar data at short range because they are sampling different parts of the atmosphere.



A quick note: Just as we know there's uncertainty with radar estimates of rainfall, there is also uncertainty with gauge estimates of rainfall. This is outside the scope of this lesson, but keep it in mind when doing your comparisons. Gauges can underestimate due to factors like wind, drop size distribution in storms, the mechanisms of the gauge itself, temperature, and location of the gauge.

From the COMET module "Rain Gauges: Are They Really Ground Truth?", it's within reason to see anywhere from 10-25% variation of gauge totals, simply due to the factors listed above.

So the takeaway here is this: Don't dive too deep into the precision of your QPE-to-gauge comparisons. Focus on areas receiving heavy rainfall to do your comparisons, since these areas will have the highest impact on flash flooding. Yes, some of the variation can be attributed to uncertainties, but getting the general magnitude of whether you're off by let's say 0.25-0.5 inches or 1.0-2.0 inches is useful in your decision-making.



With all of this, I want to take a moment to step back and say: The whole purpose of picking the “best” precip source for each event is so you can have the most confidence in your precip estimates as you make decisions. It’s important that you make an informed decision, and not just “what worked last time”.

But I also recognize that there will be many, many times when you won’t have ground observations or reports to help you calibrate. And when that happens, it’s okay to lean on other tools in your toolbox and rules of thumb.

For example, consider your environmental assessment. If it’s a pure flash flood day with lots of warm rain processes, lean into Dual-Pol and MRMS because of their improved rain rate algorithms. If it’s a severe plus flash flooding day, recognize you may have melting hail that high biases all your estimates. Out West, MRMS now has an evaporation correction that could improve precip estimates in drier climates.

Take into account time of year, elevation and other factors that may affect your vertical profile of temperature. Dual-Pol and MRMS rely heavily on the height of the melting layer to determine precip type and rain rate calculations. Lower heights mean less pure rain classifications which means lower estimates. We’ve also seen Legacy affected by early spring flash flooding because the RPG is still set to a cool season Z-R. This caused low biasing that rendered Legacy useless in an early severe event.

Moral of the story: Don’t panic about getting it “right” as much as understanding the pros and cons of each source. That way you won’t be surprised by signals you see in operations.

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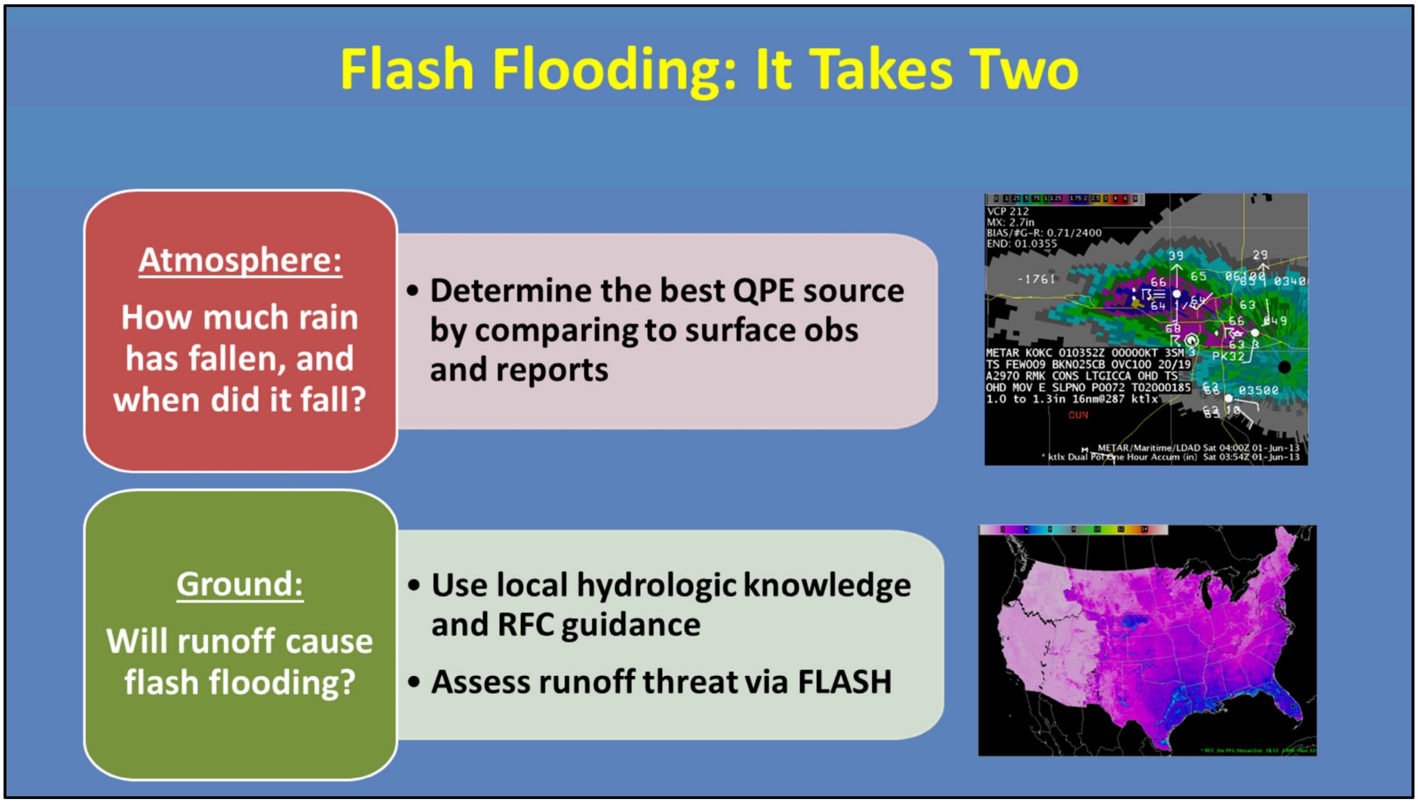
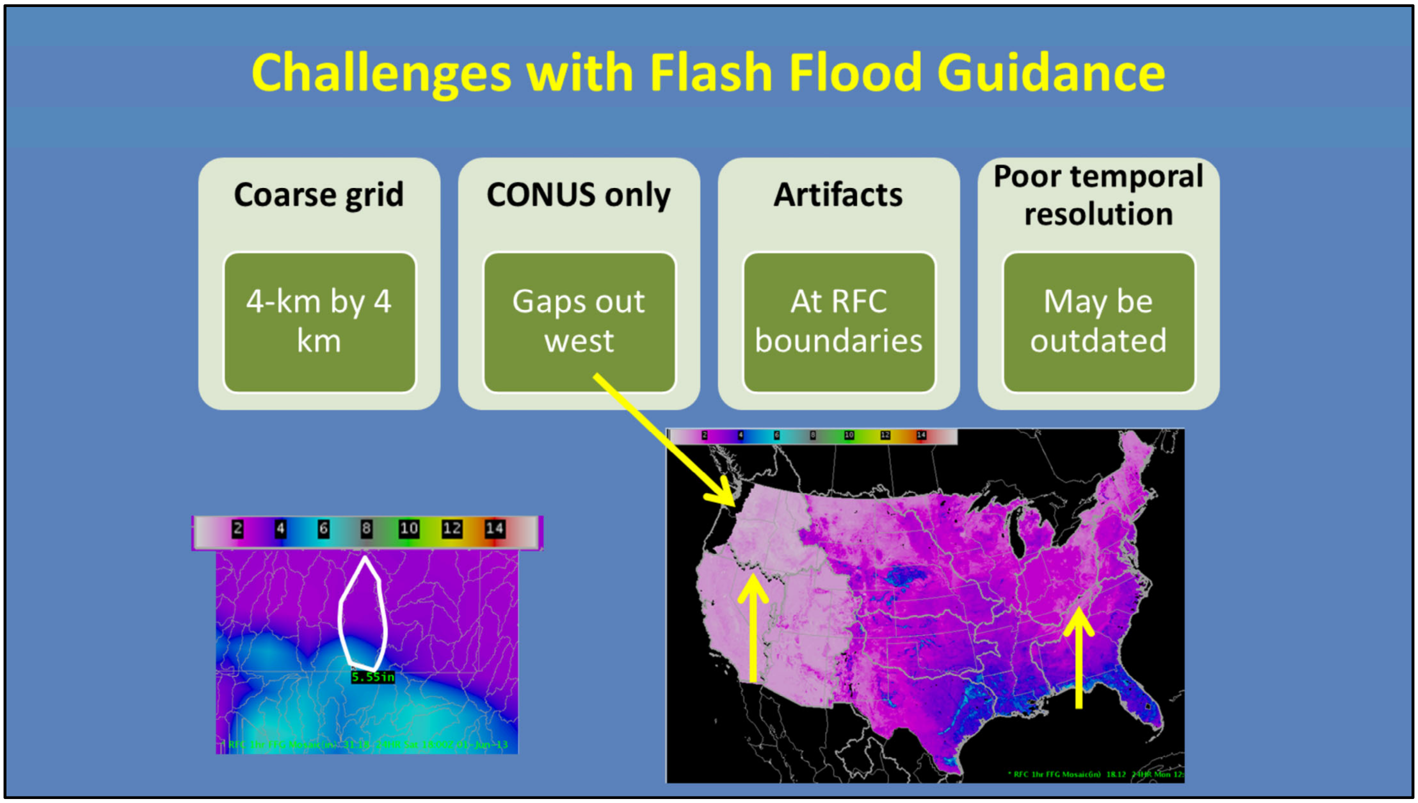


Okay, so you've identified the best QPE. The next step is to determine if the runoff will cause flash flooding. This is where you use your local rules of thumb for flashy basins, compare the best QPE to the RFC Flash Flood Guidance, and assess runoff threat via FLASH.



If you have an idea of how much rain has fallen and you are going to compare it against RFC flash flood guidance, it is important to note some of the challenges.

1. For one, RFC FFG has a rather coarse grid (approximately 4km by 4km) relative to the small size of many basins. Take this zoomed in 1-hr FFG product. Over this particular basin, FFG ranges from a little over 2 inches to the north to 5.55 inches to the south. FFMP is going to average this out to one number, which may not adequately represent the hydrology over this basin.
2. Second, it's coverage is only over the CONUS, with some gaps out west, as shown here.
3. Next, there are artifacts along some RFC boundaries where different methods of calculating guidance result in non-realistic sharp gradients, which we can see when overlaying the boundaries.
4. Finally, FFG is only updated up to 4 times a day. Oftentimes with flash flooding, you may have a fast-moving, high-rate event that will saturate the ground. And before FFG has a chance to update, another event moves over the same area. FFG's poor temporal resolution could inhibit your interpretation if you don't take into account the earlier storm.

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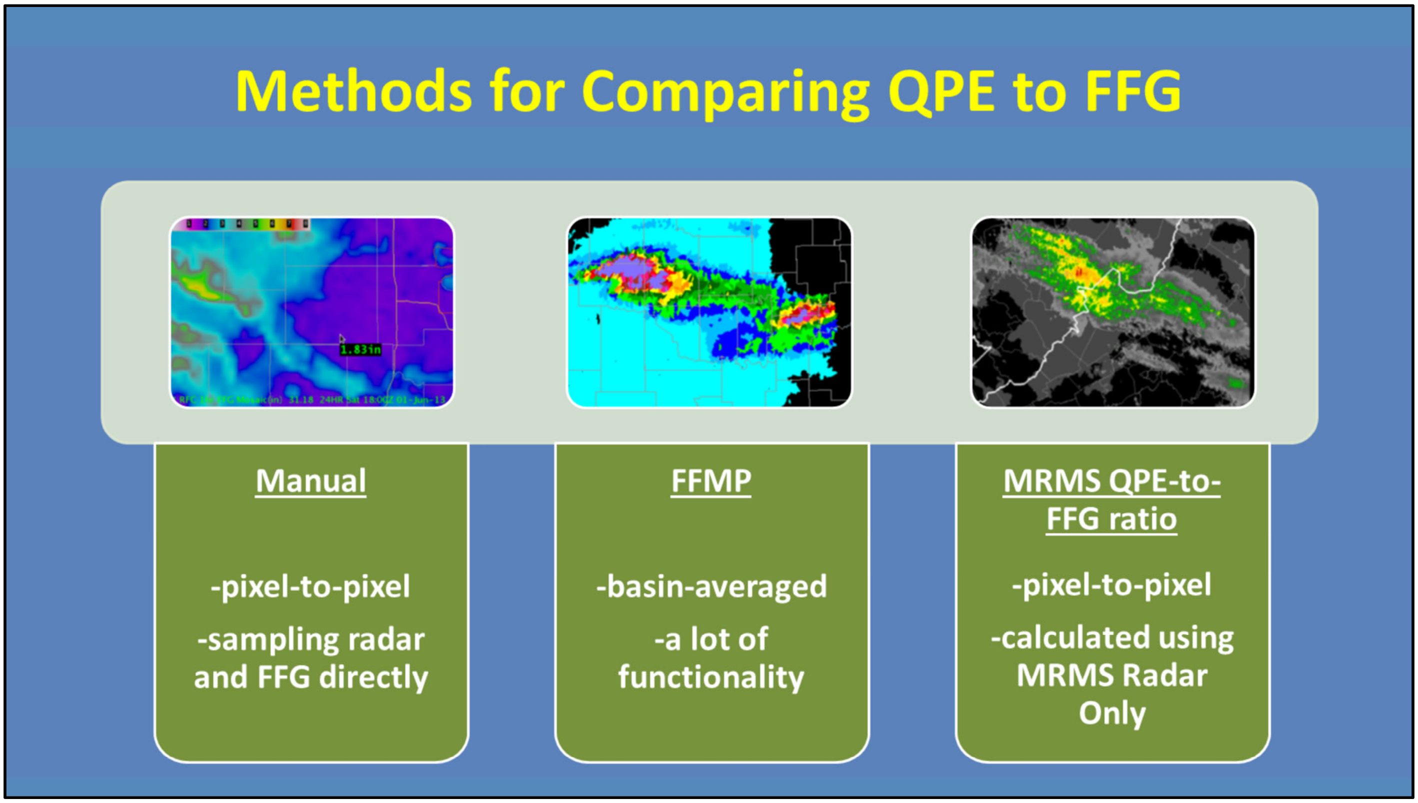
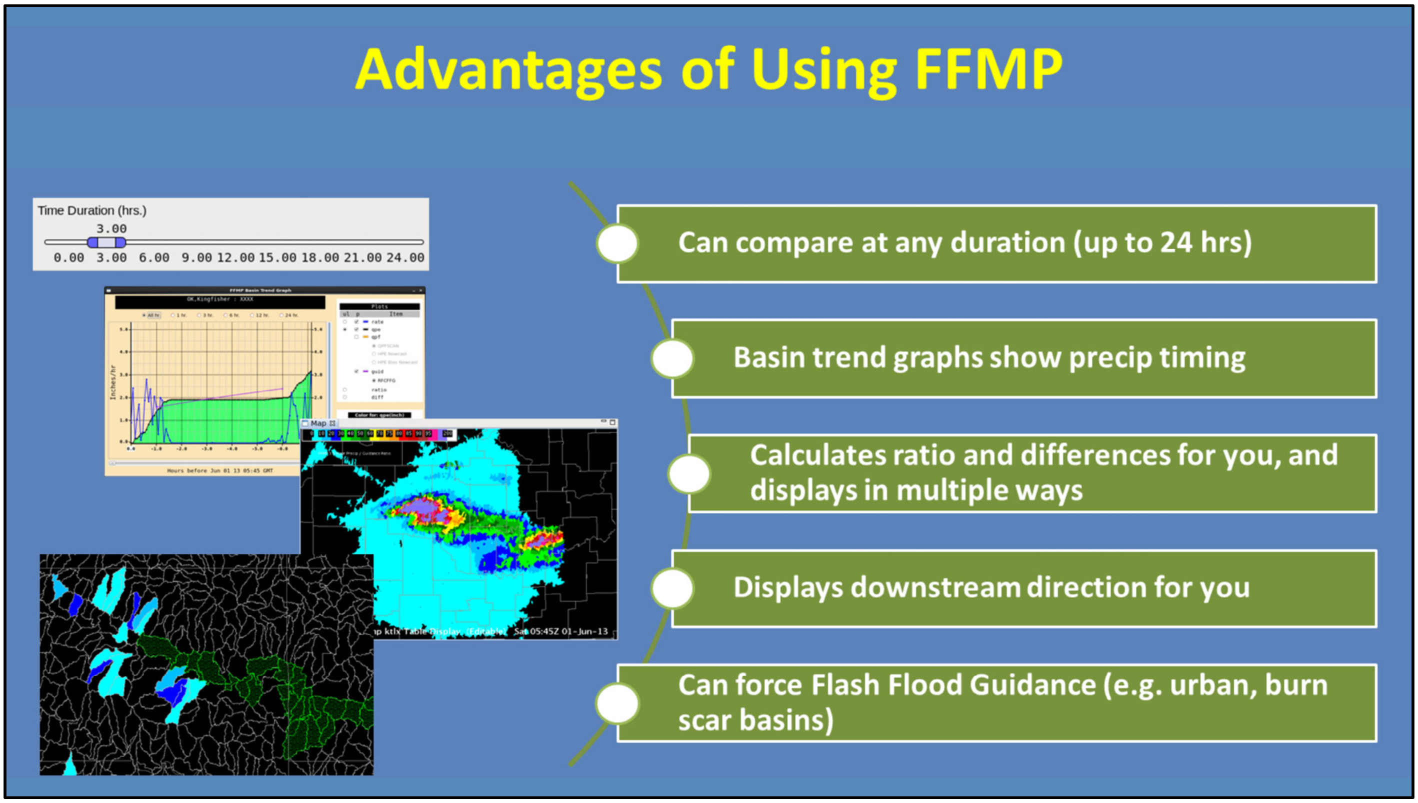


In AWIPS, there are three methods to compare QPE to Flash Flood Guidance. For one, you can manually load the radar accumulations and RFC FFG, and sample out the values directly. The next option is to use FFMP, which provides basin-averaged comparisons. FFMP has a lot of functionality that we will discuss shortly. Finally, there's the MRMS QPE-to-FFG ratio product. As it sounds, it provides a ratio comparison based on the MRMS precip source.



When it comes to comparing QPEs to Flash Flood Guidance, FFMP is your most powerful tool. Here are some advantages to using it:

1. First, FFMP accumulates precip every time a rate product is ingested, so one of its greatest strengths is the ability to display any accumulation duration (up to 24 hours).
2. This accumulation-on-the-fly approach also allows FFMP to display the precip timing information in the basin trend graphs. This is helpful to determine when precip occurred with training storms over long periods of time.
3. Another fundamental strength of FFMP is that it calculates QPE and FFG ratios and differences for you, and can display this information in a number of ways.
4. FFMP will also show you drainage and downstream information quickly and easily.
5. Finally, FFMP also has a tool to create your own forced FFG which can be very useful in urban and burn scar basins.

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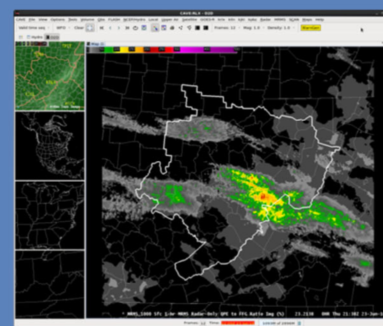
MRMS QPE-to-FFG Ratio

Analogous to ratios in FFMP, just not basin-averaged

- Pro: Does not smooth out extremes
- Con: Does not account for hydrologic extent (i.e. basins)



Calculated using nationally-mosaicked FFG grid

- Does not account for local variations (i.e. forced FFG)

Use when:

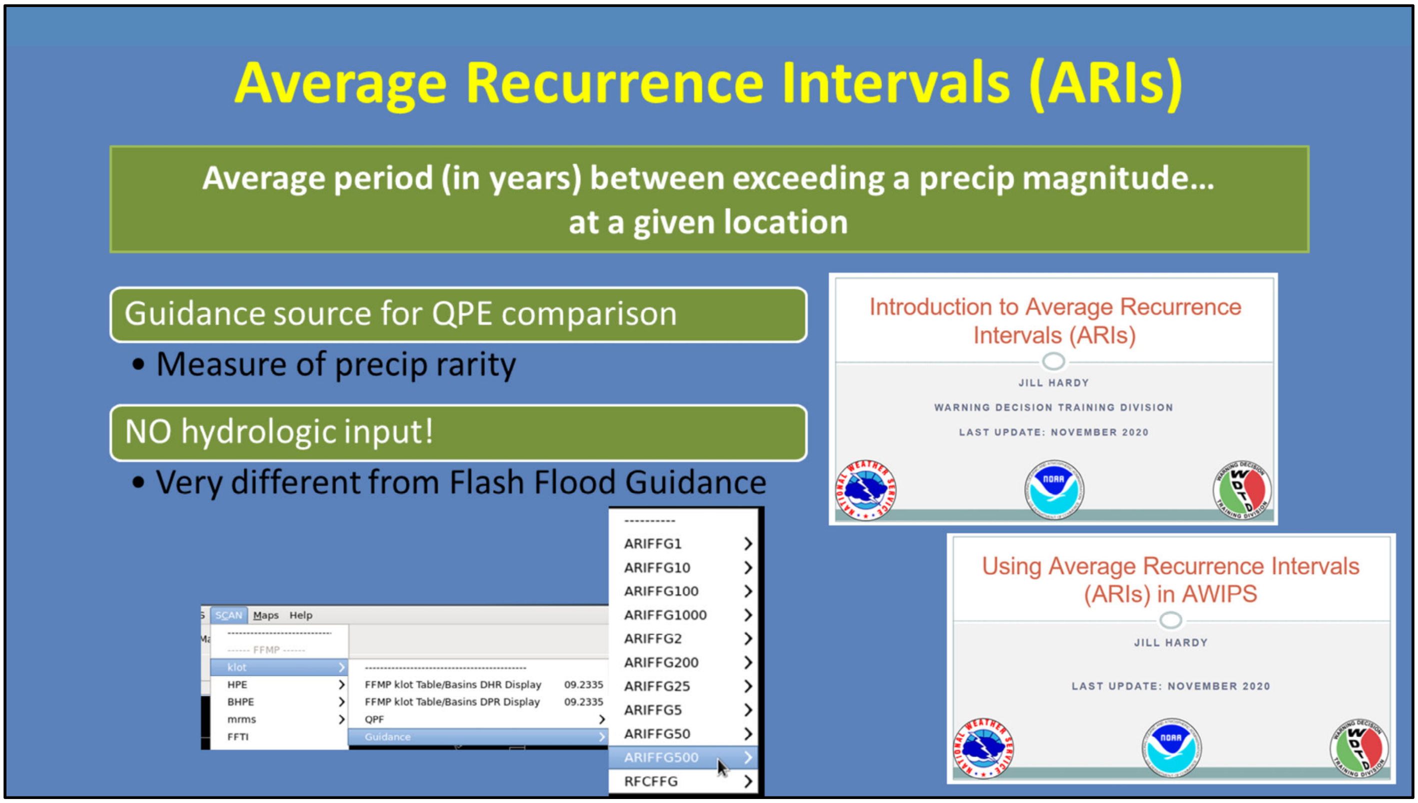
- You want a quick look at ratios
- You want to easily overlay with other products

There are more details in the "FLASH Best Practices" lesson in the WOC Flash Flood course, but here is a quick introduction to this ratio product:

It is analogous to interpreting ratio in FFMP, it's just not basin-averaged. A benefit to looking at ratios in this way is that it does not smooth out the extremes which may help you pinpoint higher threat areas. However, it also doesn't account for the hydrologic extent of the threat the way basin-averaging is made to do.

Another caveat is that the RFC Flash Flood Guidance grid that is used here is from a national mosaic created hourly at WPC. Therefore, any local changes made to the grid, like forced FFG, are not captured.

To summarize, this product is useful when you want a quick look at ratios without opening FFMP, or when you want to easily overlay the data with other products. Otherwise, FFMP is far more customizable.



Since 2016, AWIPS includes Average Recurrence Intervals (or ARIs). An ARI is defined as the average period (in years) between exceeding a precip magnitude, at a given location. You are probably more familiar hearing ARIs used like “Yesterday’s 24-hour rainfall total was a 100-year rainfall event”.

We bring up ARIs here because they are a guidance source for QPE comparison, and you will see them when maneuvering around AWIPS and FFMP. For instance, here is a SCAN FFMP menu. Under the Guidance submenu, it’s no longer just RFC FFG, but also a lot of ARI data, as well. One of the most important things to remember when using this dataset is that it was created solely as a measure of precip rarity. It does not include any hydrologic inputs. Therefore, it is fundamentally different than Flash Flood Guidance, even though they appear in a similar fashion throughout AWIPS and FFMP.

Before you begin using this dataset, we highly recommend taking our two ARI lessons. There are a lot of details covered in these lessons that are crucial to effectively interpret and relay this information. These lessons are included in WOC Flash Flood, if you plan to enroll in this course.

Last, but certainly not least, is to assess the runoff threat using the FLASH hydrologic products.

Probably the most useful product is the Max Unit Streamflow since it highlights areas experiencing higher than normal flow. There are 3 models to consider. CREST is the top image here, and tends to better highlight urban areas, as well as having an overall stronger, quicker response compared to SAC-SMA (which is the bottom image). SAC-SMA has a more focused response, and better highlights specific basins. Finally, the hydrophobic is a good proxy for burn scars.

The majority of research and evaluation has been on the CREST model, so we have the best understanding of its applications. However, use all 3 in operations to get a better idea of what works for your area. And don't forget that FLASH has other products that can also help in warning operations, so take the "FLASH Best Practices" lesson for more details.

Key Takeaways for Using Precip & Guidance Sources

Anticipate uncertainties in QPEs, gauges, and FFG

- Don't misinterpret precision

NAME	RATE	QPE	RFCFFG GUID	RFCFFG RATIO	RFCFFG DIFF
XXXX	2.35	1.54	1.55	99	-0.01

Calibrate using reports and surface observations

Think ahead!

- Anticipate threat evolution, runoff direction, etc.

There are several key takeaways for using your precip and guidance sources.

For one, anticipate uncertainties in QPEs, gauges, and FFG. It is not uncommon to encounter uncertainties on the order of 25%, or more. However, AWIPS generally displays these values with two decimal places. Don't misinterpret this precision. For instance while the selected basin may appear 0.01" below FFG, this could easily be a quarter inch above or below FFG due to uncertainties in both the raw QPE or FFG data.

Therefore it is important for you to be routinely calibrating QPE using reports and surface observations, keeping in mind that surface obs can also have their own uncertainty.

Finally, always think ahead. It is easy to become fixated on the complexities of what is going on now with tools like FFMP. Anticipate threat evolution by considering where the storms are moving and what the hydrological conditions will be in those areas. This will give you important lead time when drawing your FFW polygons.

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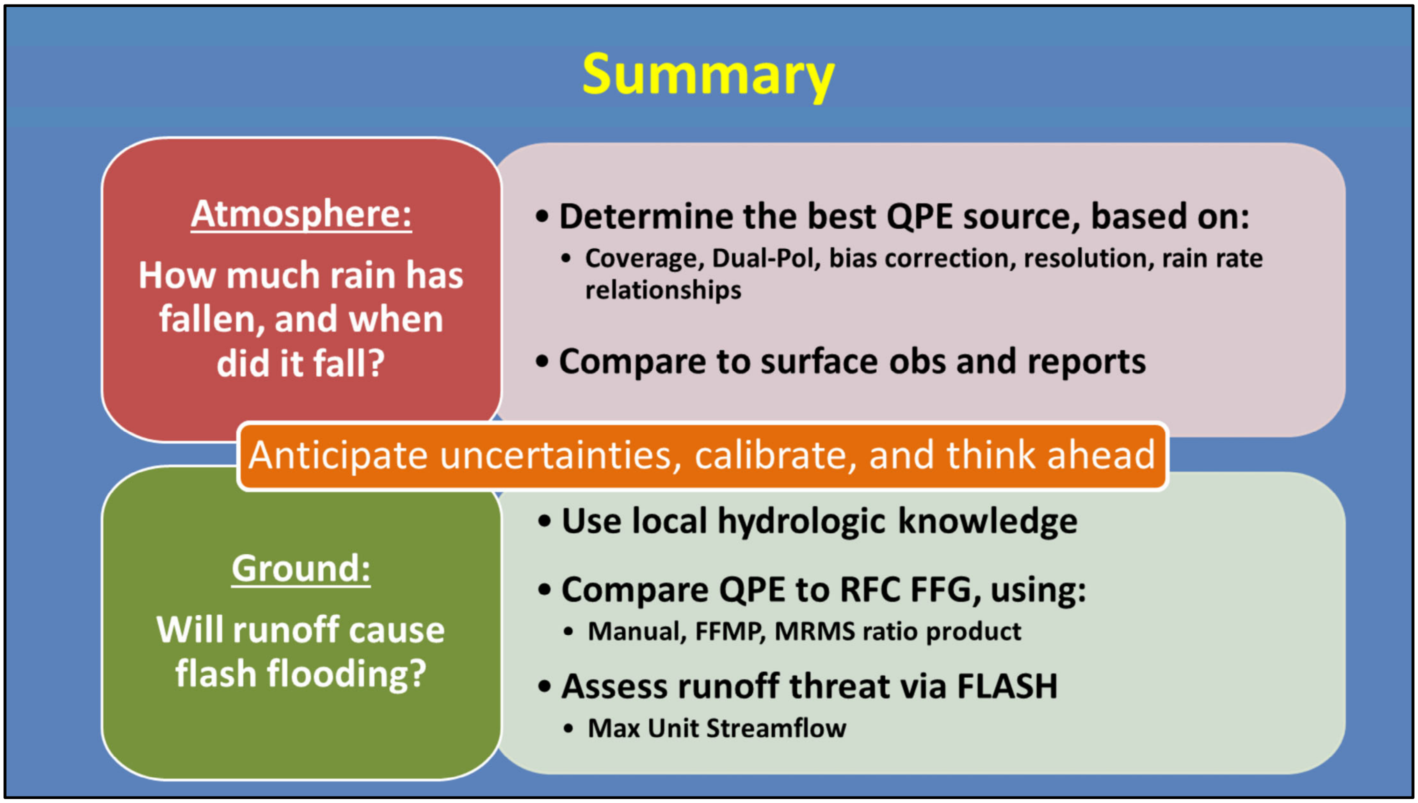


To summarize, the basic approach to flash flood decision making begins by assessing how much rain has fallen, and when. To do this you need to evaluate multiple precip sources and choose the best precip source based off factors like: the coverage of the product, whether it's Dual-Pol or has a bias correction, the resolution, and how the rain rate relationships are calculated.

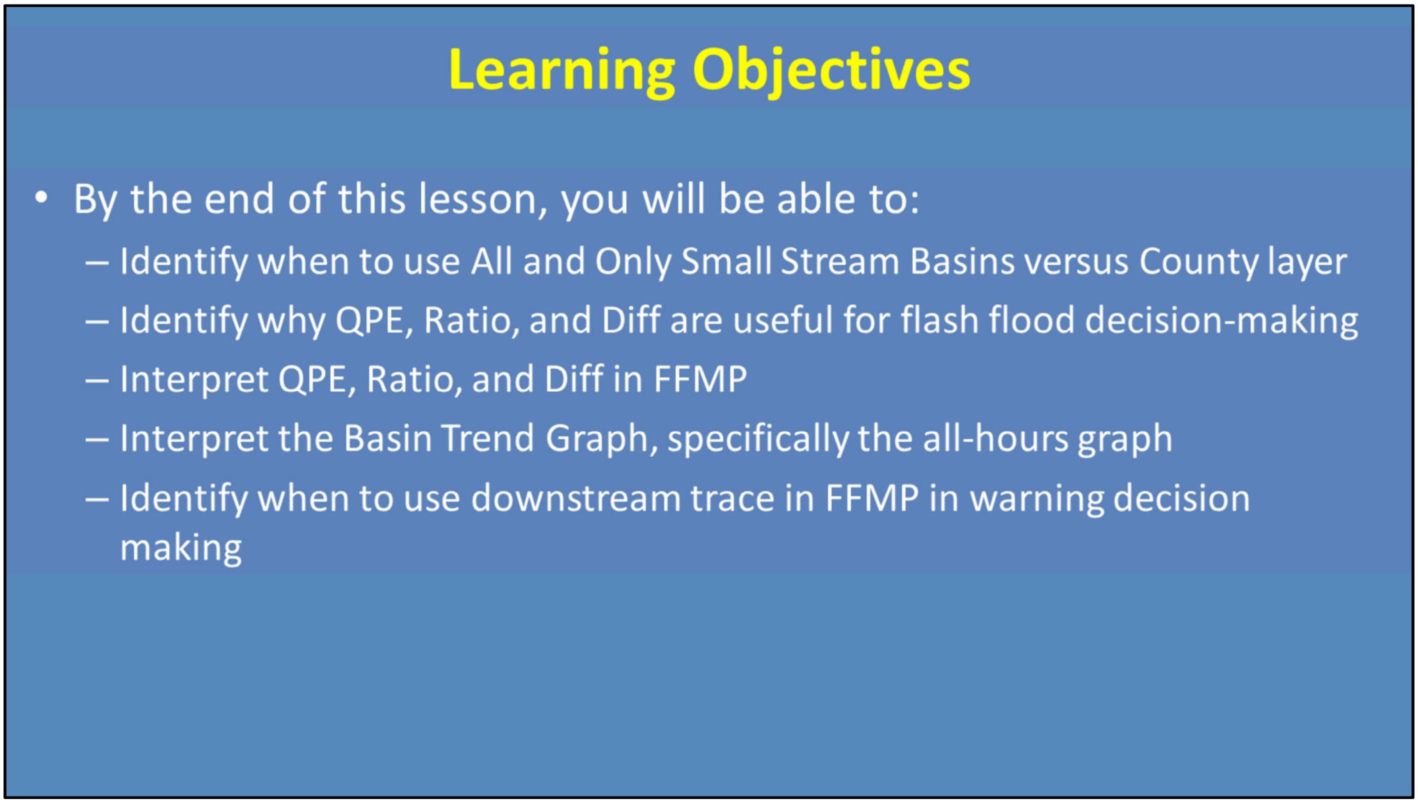
Just as important as your initial precip source selection, is to routinely compare all precip sources with surface observations, gauges, and spotter reports. The best precip source can change over the course of an event.

The next step determines if the runoff will result in flash flooding. Use your local hydrological knowledge. Then compare your QPE to the RFC FFG. Consider the challenges that come with using FFG, as well as the various methods to interpret it. Additionally, assess runoff threat using the FLASH hydrologic products, particularly the Max Unit Streamflow.

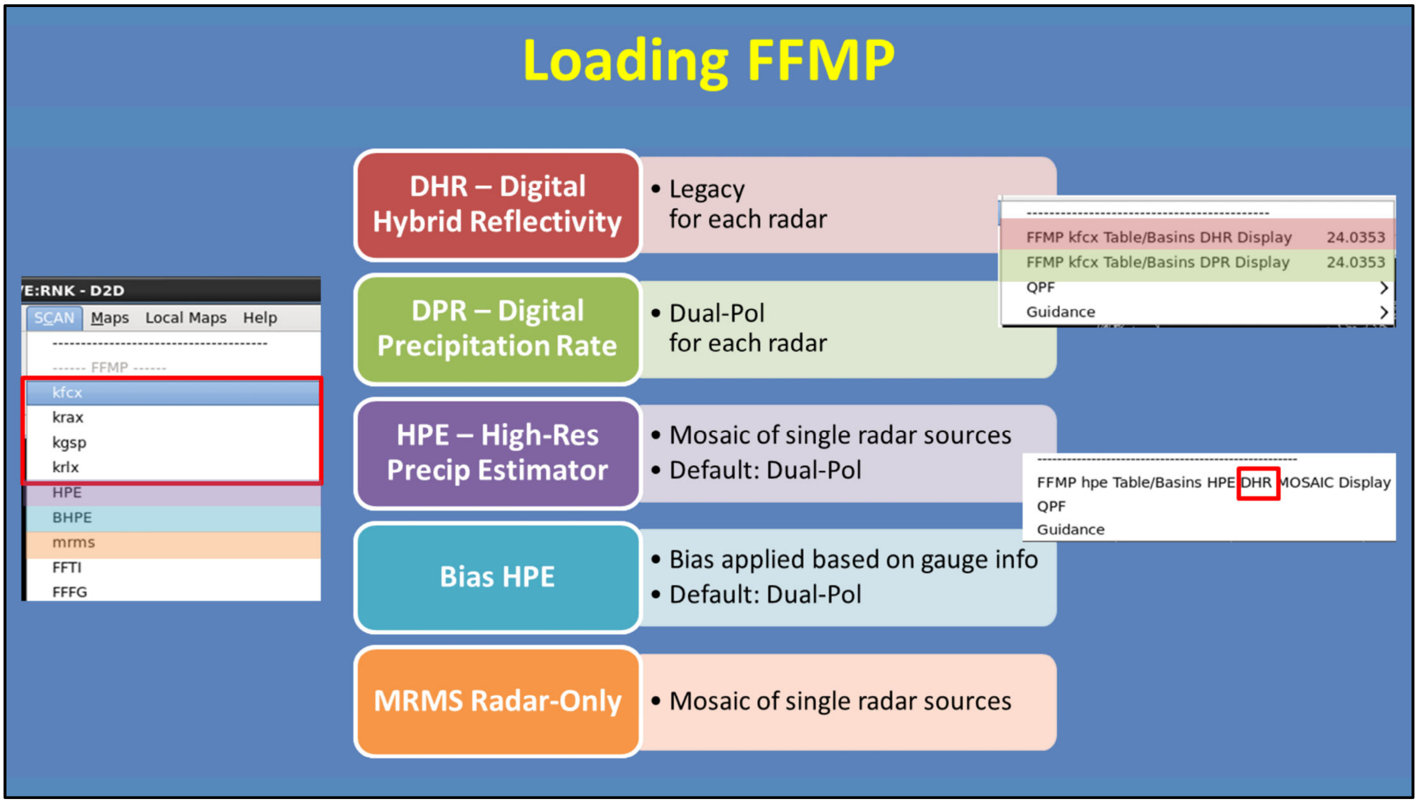
Finally, always anticipate uncertainty in QPEs, gauges, and FFG. Calibrate accordingly, and remember to think ahead to anticipate future risk.

This is the end of this lesson. When you are ready, move onto the next slide to take the quiz and receive credit on the LMS.

Hi, my name is Jill Hardy and welcome to this lesson which will focus on using FFMP to diagnose a flash flood threat.



Here are the learning objectives for this lesson. When you have finished reading them, please continue to the next slide.

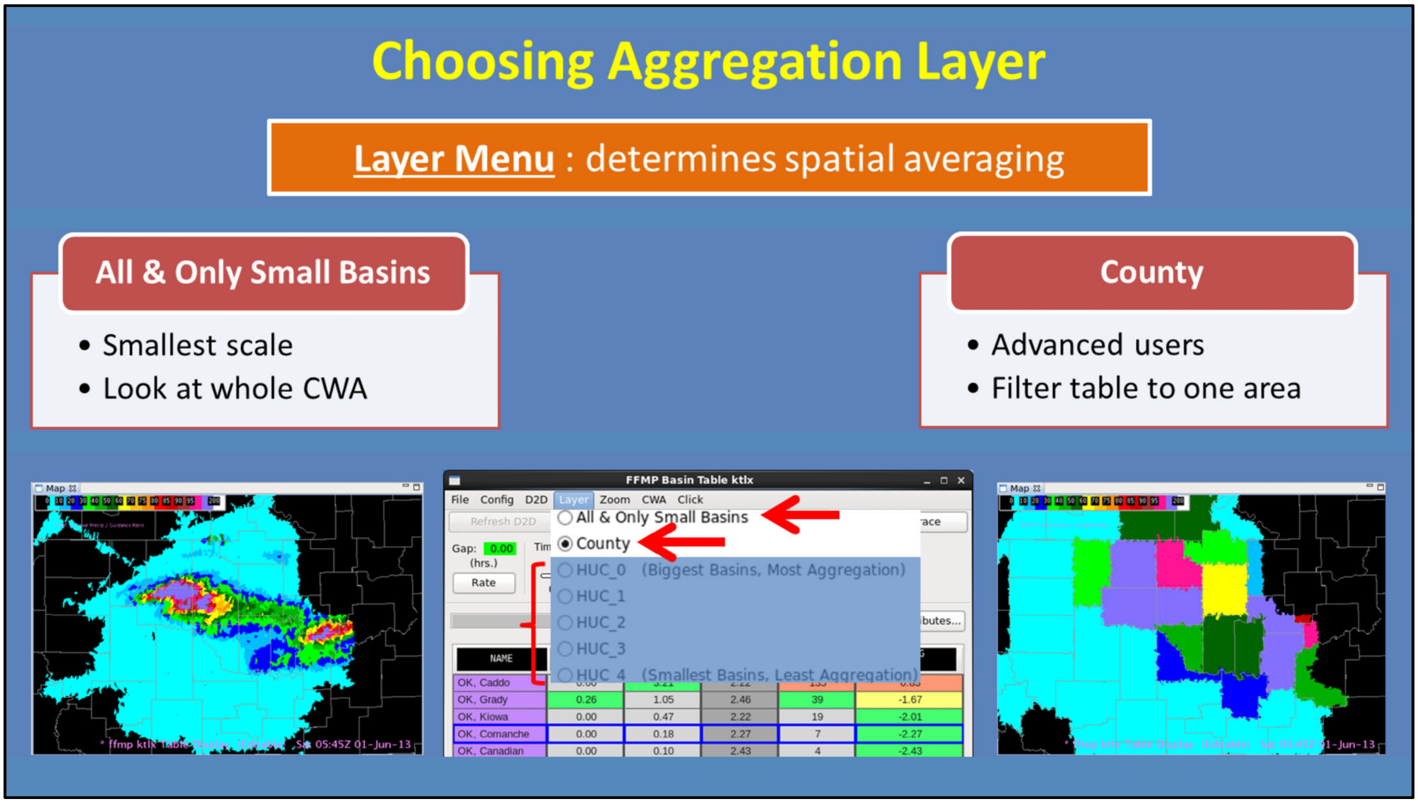


First thing's first: loading FFMP with your desired precip source from the SCAN menu.

The single-radar products are available under the menu referenced by the radar name. As seen here, under each radar submenu, there is the DHR source (which is Legacy), and the DPR source (for Dual-Pol).

Next, since the HPE and Bias HPE products are mosaics, they are identified as HPE and BHPE on the SCAN FFMP menu. Keep in mind there's a labeling error for these products. Both use Dual-Pol in their creation, however, their submenu reads “DHR MOSAIC”. Just be aware that this is a typo.

Finally, the MRMS Radar Only mosaic is also available from the SCAN FFMP menu.

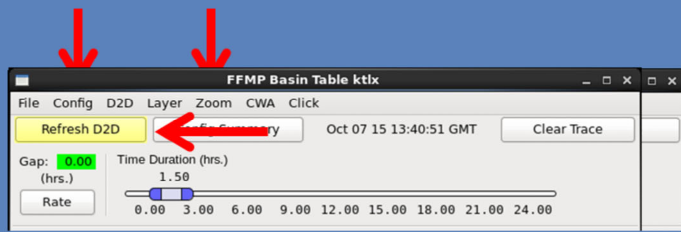


One of the most important steps in using FFMP is choosing the aggregation layer, which defines what spatial scale FFMP averages the QPE and FFG. The two layers we will focus on for flash flooding are the All & Only Small Basins and County.

When you first open FFMP and begin your flash flood interrogation, we recommend starting with the “All and Only Small Basins” layer option. This will give you a simple look over the whole CWA on the most relevant hydrologic scale to see what basins stand out in QPE, ratio, or diff.

As you become more advanced with FFMP, you can switch to using the “County” layer option to organize the basins in the FFMP table by county. This is done to make it easier to find particular basins and virtual gauge basins. There are a lot more settings to pay attention to when using county layer, though, so just be careful. The HUC layers are collections of small stream basins for larger scales and are not used frequently for flash flood decision making.

FFMP Recommended Settings



	All & Only Small Basins	County
Zoom Menu: zooming options when aggregation layer is clicked		
Maintain Layer	OFF	OFF
Only Basins in Parent	OFF	OFF
Config Menu: display options		
Link to Frame	ON	ON
Worst Case for Aggregate	ON	ON
Auto-Refresh	ON	ON

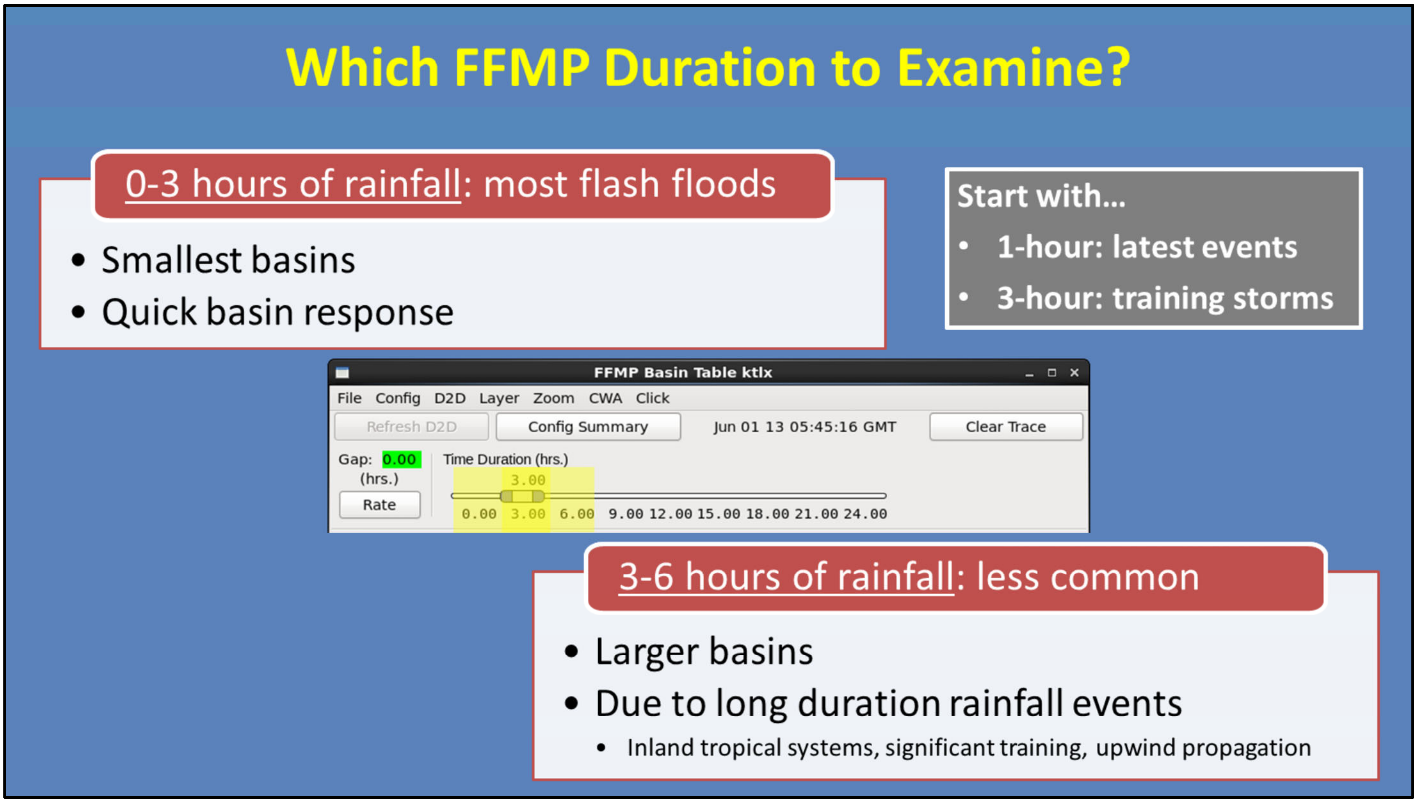
There are several FFMP Table menu options that can enhance your D2D display, as well as your FFMP basin table display.

First, the Zoom menu controls how FFMP zooms into smaller basins when an aggregation layer is clicked in the table. In either “All and Only Small Basins” or “County” layer, we recommend these options be turned off. They do not have an effect on your display when using “All and Only Small Basins”. But if you use “County” layer, and the “Maintain Layer” option is OFF, the D2D will show the individual basins (instead of just the whole county). Setting “Only Basins in Parent” to OFF allows any neighboring basins outside of the county to be displayed in D2D, so you can see flash flood threats crossing the county line.

Next, the Config menu helps with general display of the data. The “Link to Frame” ensures the D2D and the table are kept in sync when stepping through multiple frames.

Next is the “Worst Case for Aggregate” option. This option only comes into play when you have chosen a layer larger than “All and Only Small Basins”. When turned on, this option sets the values in the FFMP table to show the “worst case” value for **any** basin within the larger aggregate layer. However, be aware that the “worst case” values may not always be within the same basins (which can make interpretation tricky).

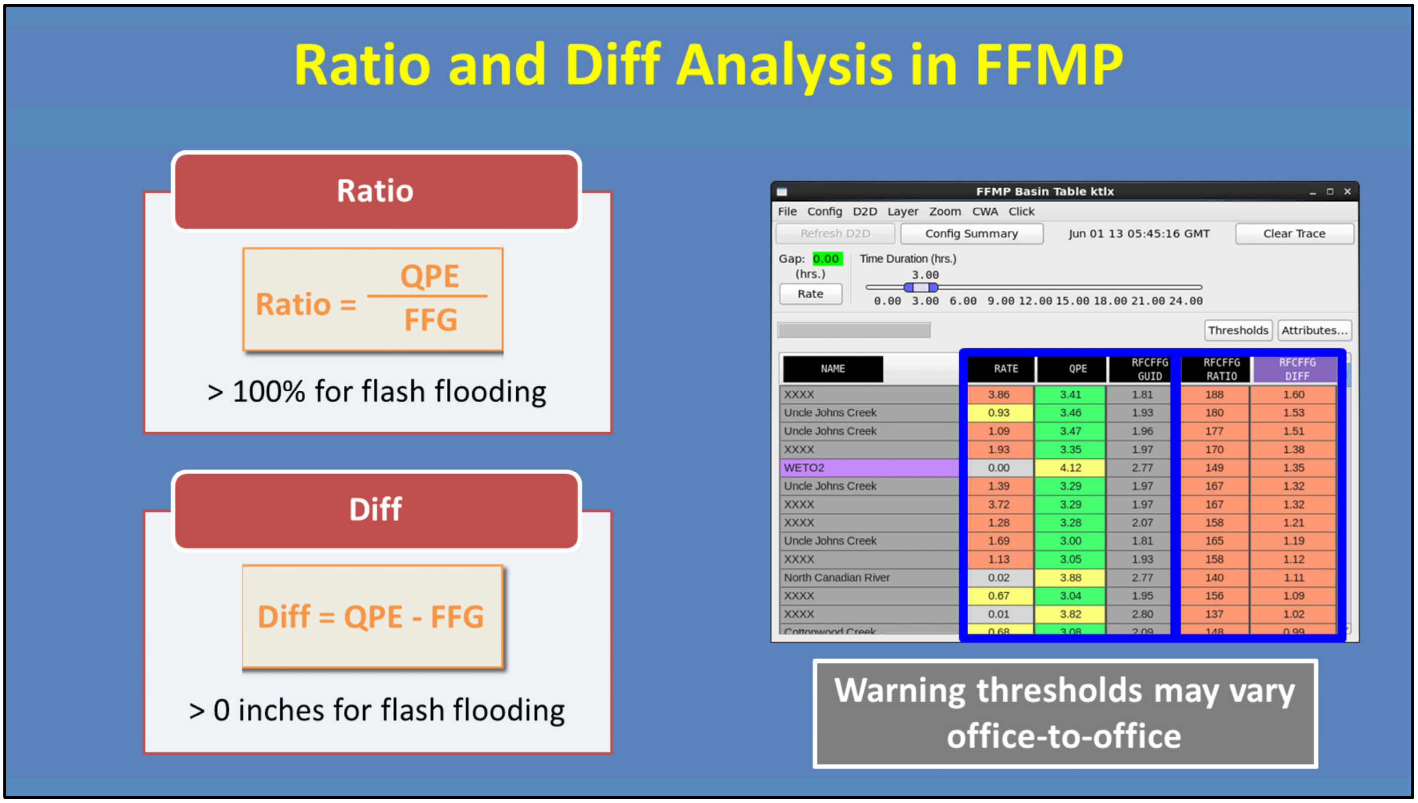
Finally, there is the Auto-Refresh option. This automatically updates the D2D display with any configuration changes made to the FFMP table. We recommend this be turned ON. However, if you notice performance problems with FFMP, you may consider turning it OFF. When it is off, you need to remember to click on the “Refresh D2D” button to manually update the display after making changes.



Now that we have reviewed the FFMP settings, let's talk about what durations are good to examine.

The majority of flash flood events take place due to less than 3 hours of rainfall, sometimes less than an hour of heavy rainfall. This is because they occur in very small basins. These tiny basins have quick responses to the rainfall, and thus inundate rapidly. Therefore, we suggest you focus on the 1-hour duration for the latest events, and the 3-hour duration for training storms. The duration slider bar feature in FFMP makes this easy to do.

However, certain meteorological environments are conducive to flash flooding larger basins, and thus require a longer duration to get things going. Inland tropical storms, significant cell training, and upwind propagation along a quasi-stationary boundary are examples of long duration heavy rainfall events that may result in flash flooding of large basins. In these types of set-ups, in addition to looking at 1 and 3 hour duration, it would be wise to also check out the 6-hour duration.



Okay, so you have your settings the way you want, and you know the duration you want to examine. So what should you look at? In addition to instantaneous rate, basin-averaged QPE, and basin-averaged FFG, FFMP has two other options for what can be displayed in the table: Ratio and Difference.

By default, these two take into account the Flash Flood Guidance values, and thus, are useful for analyzing exceedance threat. So let's take a look.

For Ratio, it is QPE divided by FFG. So, as Ratio approaches and exceeds 100%, that means QPE is near or exceeding FFG, and thus, the theoretical flash flood threat increases. To calculate the Difference, it is QPE minus FFG. So as Diff approaches zero or becomes positive, similarly, the theoretical flash flood threat increases.

But remember, all QPE sources have uncertainty and RFC FFG accuracy varies significantly across the country and over time. So you may find that ratio and difference warning thresholds vary from office-to-office. For instance, at some WFOs, flash flooding may typically start at 0.5 inches over FFG while another may start near flash flood guidance. But let's take a minute to review an example of QPE, ratio, and difference values.

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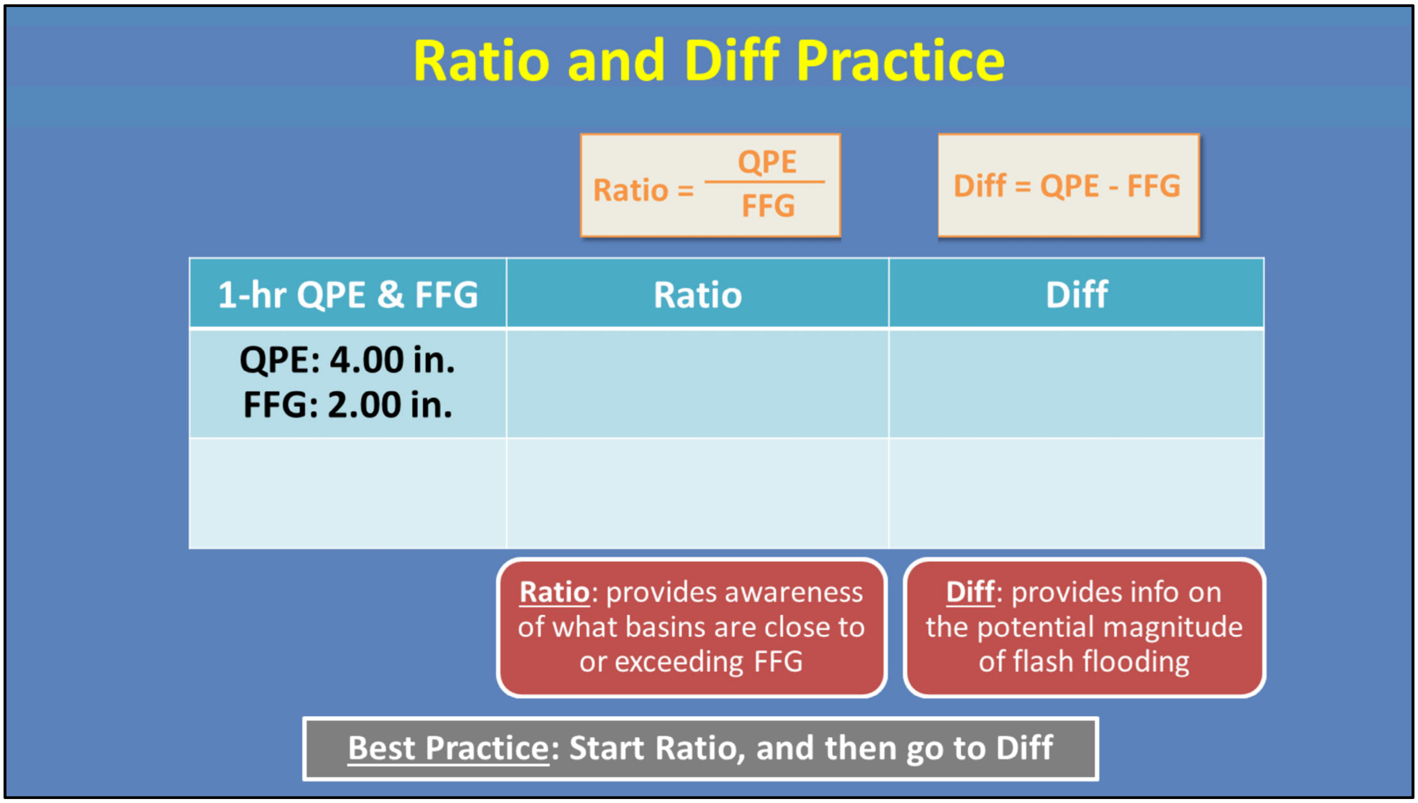
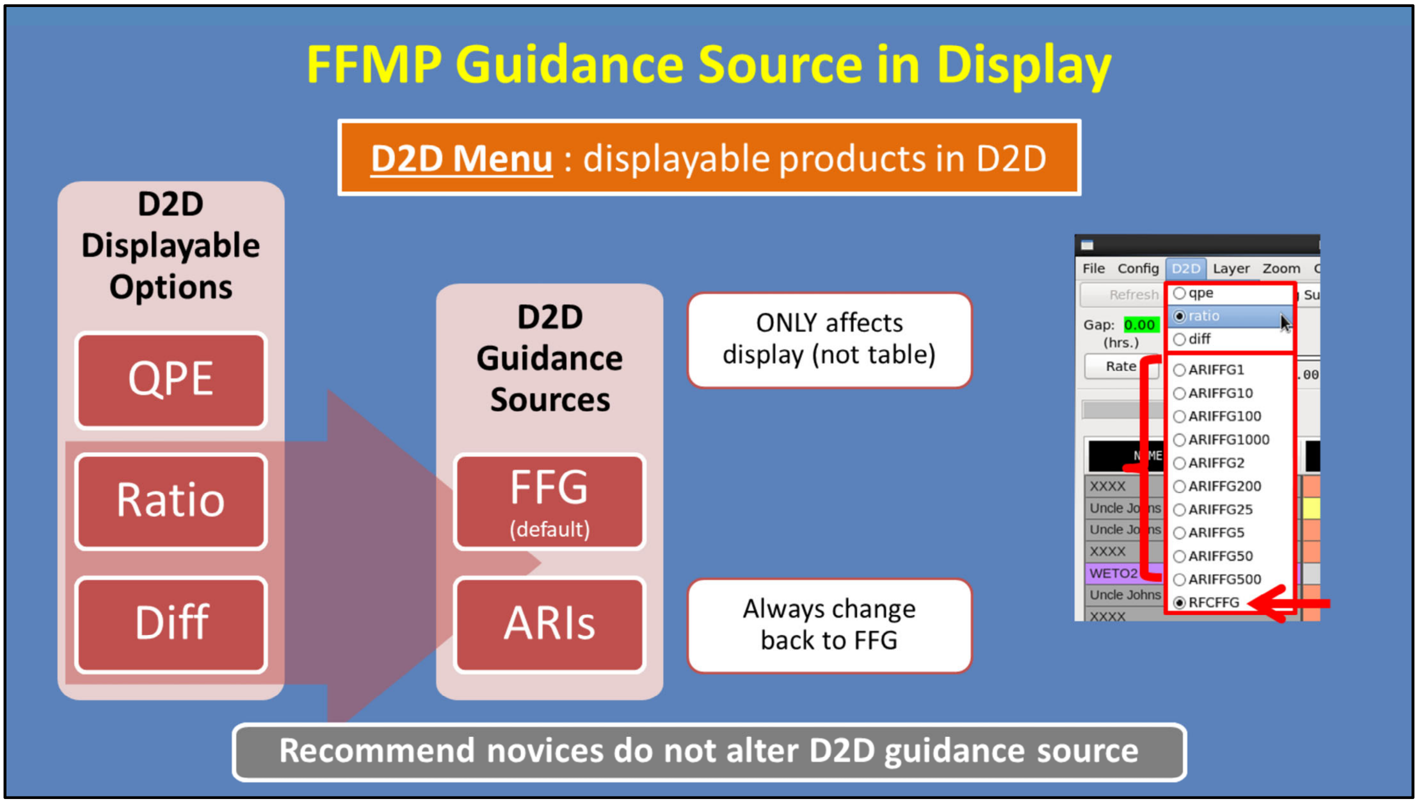


Alright, let’s say we have a hypothetical basin that has basin-averaged rainfall of 4 inches in one hour, and the flash flood guidance is 2 inches in one hour. Thus, the Ratio would be 200%, and the Diff value would be 2 inches. Now imagine that for a different rainfall event, the same basin receives 1 inch of rain in an hour, and the FFG is only 0.50 inches.

The Ratio is still 200%, but the Difference is now 0.5 inches. This Ratio value could lead you to believe a significant flash flood was possible, as in the first case. However, comparing the two Difference values, the 1st event would have much more significant flash flooding given that FFG was exceeded by 2 inches, rather than only 0.50 inches during the second event.

Ratio can be used as a quick awareness tool for basins that are close to or already exceeded flash flood guidance. While, the Diff values give information on the potential magnitude of the flash flooding.

After identifying your areas of precip using QPE, we recommend that you start with viewing the Ratio, in order to pinpoint areas that may be approaching or exceeding FFG. Then, switch over to the Difference to tell how much you are over or under in those areas.



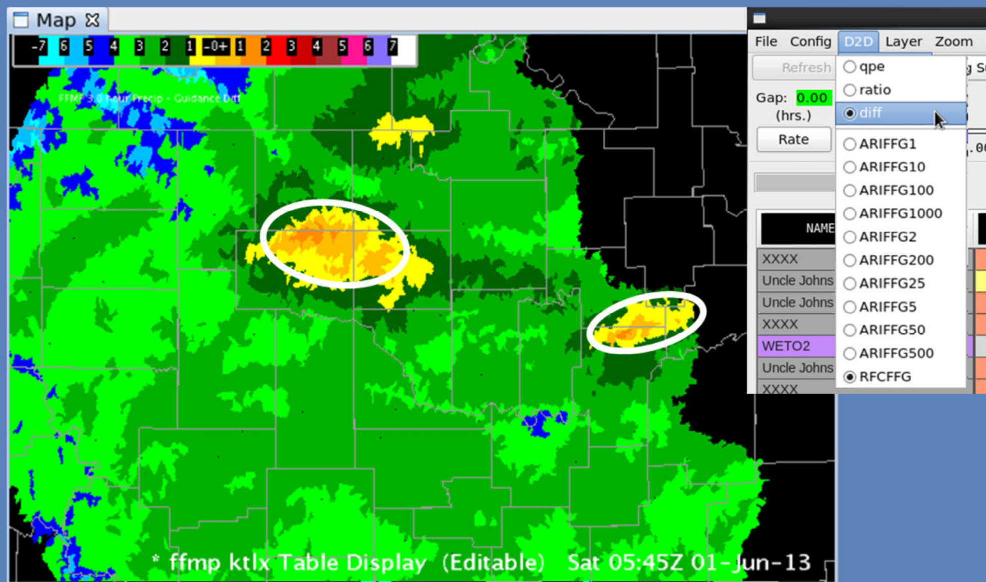
The last menu to discuss is the D2D menu, which determines what is being displayed in D2D. The three options are QPE, Ratio, and Diff, with the default being QPE.

Based on the best practice from the previous slide, it is usually good to start with QPE to get a feel for the high precip areas, and then move to Ratio and Diff to analyze the flash flood threat. When you switch the D2D menu option from QPE to Ratio or Diff, FFMP wants to determine what guidance source is being used for the ratio calculation. The default is RFC FFG, as shown here.

However, Average Recurrence Intervals (or ARIs) are a new guidance source option in FFMP. To force the D2D display to show ratio (or diff) calculated against ARI, simply choose one of the various ARI options. Keep in mind this change ONLY affects the display, and not the table values. Therefore, it can become confusing if you set the *display* to use ARIs to calculate ratio and diff, but your *table* uses FFG. So do NOT forget to always switch your D2D display back to FFG once you are done with the ARIs.

There is a lot to learn about ARIs before you start using them in AWIPS. For novices, we recommend you do not use ARIs in FFMP, and therefore do not alter the D2D menu guidance source. Rather, wait until you take WOC Flash Flood to learn more.

Example: QPE, Ratio, and Diff



Here is an example of how to interpret the D2D options.

So FFMP defaults to displaying QPE. Simply looking at this output, we see there is a large area of greater than 1 inch in three hours, with isolated areas having upwards of 3 inches of rain in three hours. This information is useful for situational awareness, however it does not tell us anything about the hydrological response.

Therefore, your next move is to look at the Ratio product. Remember, for this, we are interested in areas that are approaching or have exceeded 100%. If rain is continuing in the area, then also consider the areas of 80 and 90%, since they are close to exceeding FFG. With this methodology, we have narrowed our threats to the circled regions.

Finally, use the Difference display to see by how much FFG has been exceeded. In this example, within our areas of interest, we have generally exceeded FFG within 1 inch. But there are some areas exceeding by 1-2 inches, which is where the more significant flash flooding threat is located.

So you see how this process helps you narrow down your flash flood threat, while providing details on magnitude that may be useful when considering your warning text.

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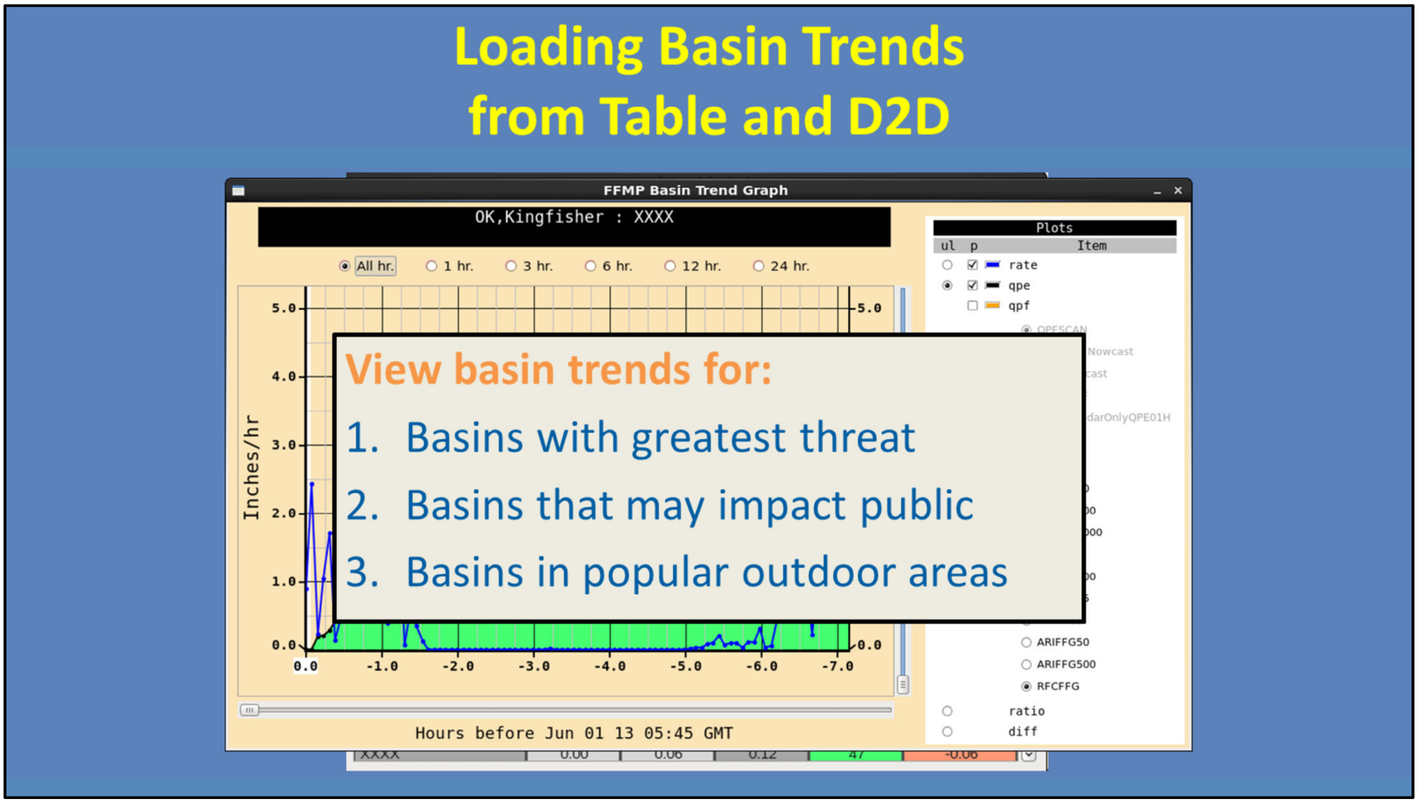

By this point you have zeroed in on the primary threat areas using Ratio and Diff and by monitoring rain rates. The next useful functionality in FFMP are basin trend graphs.

To load a Basin Trend, there are two options: First, you can load it by right-clicking on a basin name from the basin table. Second, you can set the Click menu option to “Basin Trend”, then go to the D2D pane with FFMP and make the display “editable” (by middle clicking on the text in the legend), and then right-click on any basin in the display to load a basin trend for that basin.

Because there could be tens of thousands of small basins in your localization, it is best to focus on basins that: 1) have the greatest current or projected threat; 2) perhaps those basins that might significantly impact the general public (like urban basins); or 3) basins in a National Park that normally contain numerous hikers and campers.

Basin trend graphs are critical to interpreting information on the timing and relationship between the QPE and guidance for different durations. And with time, you will become more familiar with using them. We'll start you off with an example on the next slide.

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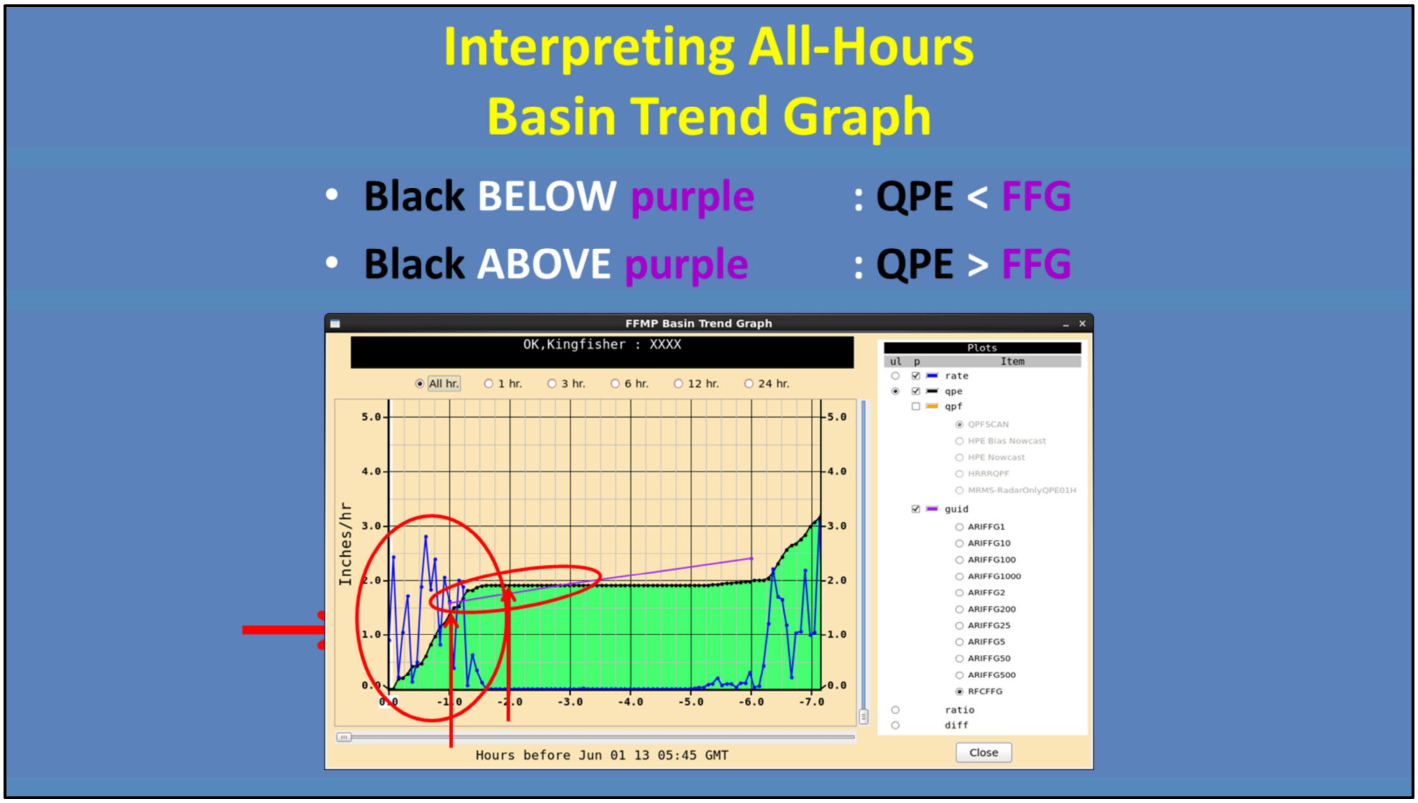


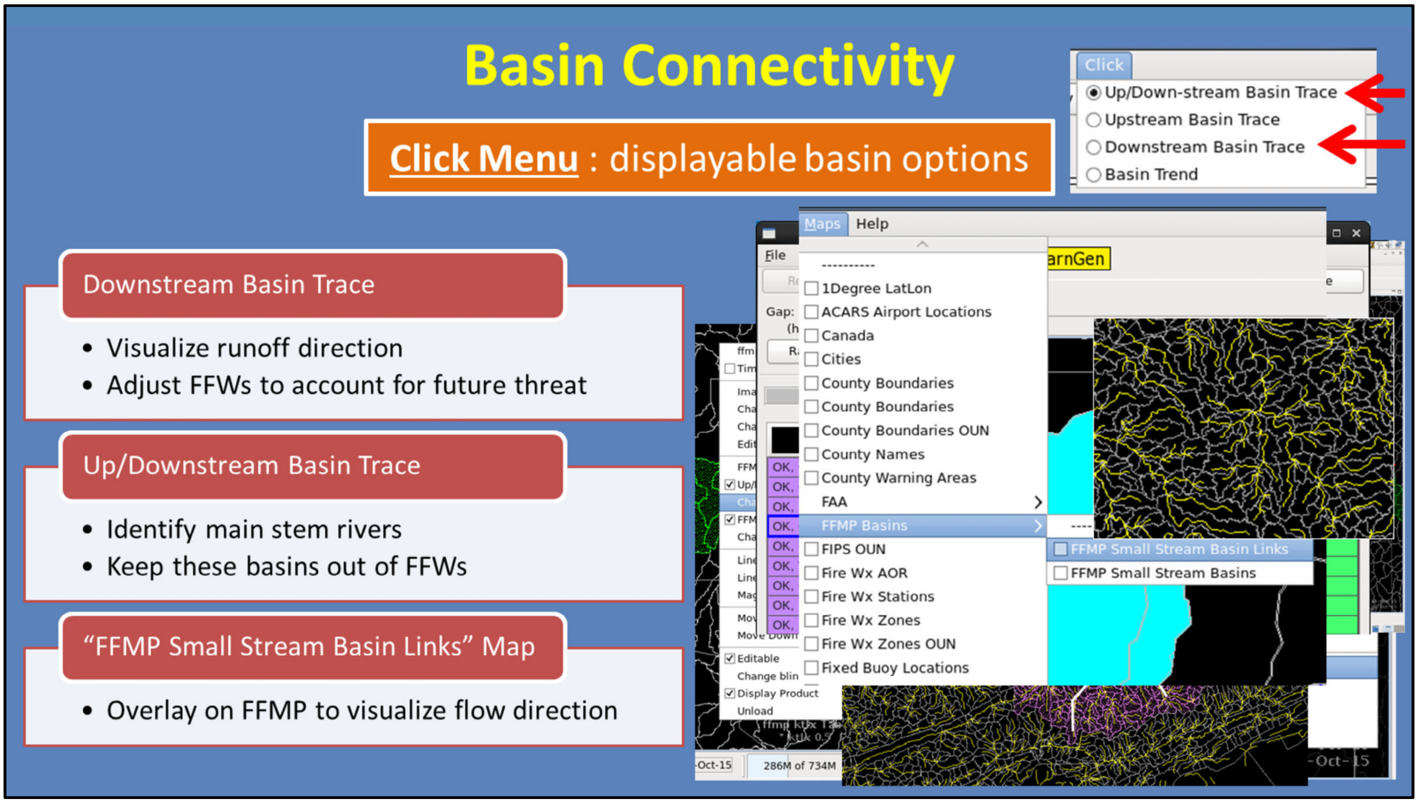
Okay, let's take a look at this basin, which is only three-hundredths of an inch away from exceeding the 3-hour FFG and is currently experiencing instantaneous rain rates of 0.89 in/hr. As a warning forecaster, I would like to know when within the three hours that 1.90 inches of QPE fell, so I right-click on the basin to load a basin trend graph shown here.

First, you want to look at the blue line, which is the instantaneous rate trend. Each blue dot represents the instantaneous rate for a particular volume scan. From this we see that rates of ~ 2 in/hr occurred primarily over the last 1.5 hrs, and there was no precip 3 hrs ago and 4 hrs ago.

Next, the black line is the precip accumulation for different durations. You will notice the accumulations increase every time there is an instantaneous precipitation rate > 0. The instantaneous rate is multiplied by the volume scan time step in order to increase the accumulation. To interpret this line, we see about 1.3" has accumulated over the 1-hour duration, while 1.9" have accumulated over the most recent 2-hour duration. We see the 1.9" accumulation lasts through the 5-hour duration, because there was no precip falling between 2 and 5 hours ago.

Finally, there is the purple line, which shows FFG for the 1-, 3-, and 6-hour durations. Whenever the black QPE line is BELOW the purple FFG line, QPE is less than FFG for that duration interval. When the black line is ABOVE the purple line, QPE is greater than FFG. Here, QPE is always below FFG, except for durations between 1 and 3 hours where FFG is exceeded by about 0.25" for the 1.5-hour duration. This may be enough to cause flash flooding, particularly since the instantaneous rates are continuing at the current time, and the longer duration FFG values (like 3- and 6-hour) are going to be exceeded more and more as that continues.

Now we're going to take a few minutes and let you have some practice with basin trend graphs. The following quiz is NOT graded.

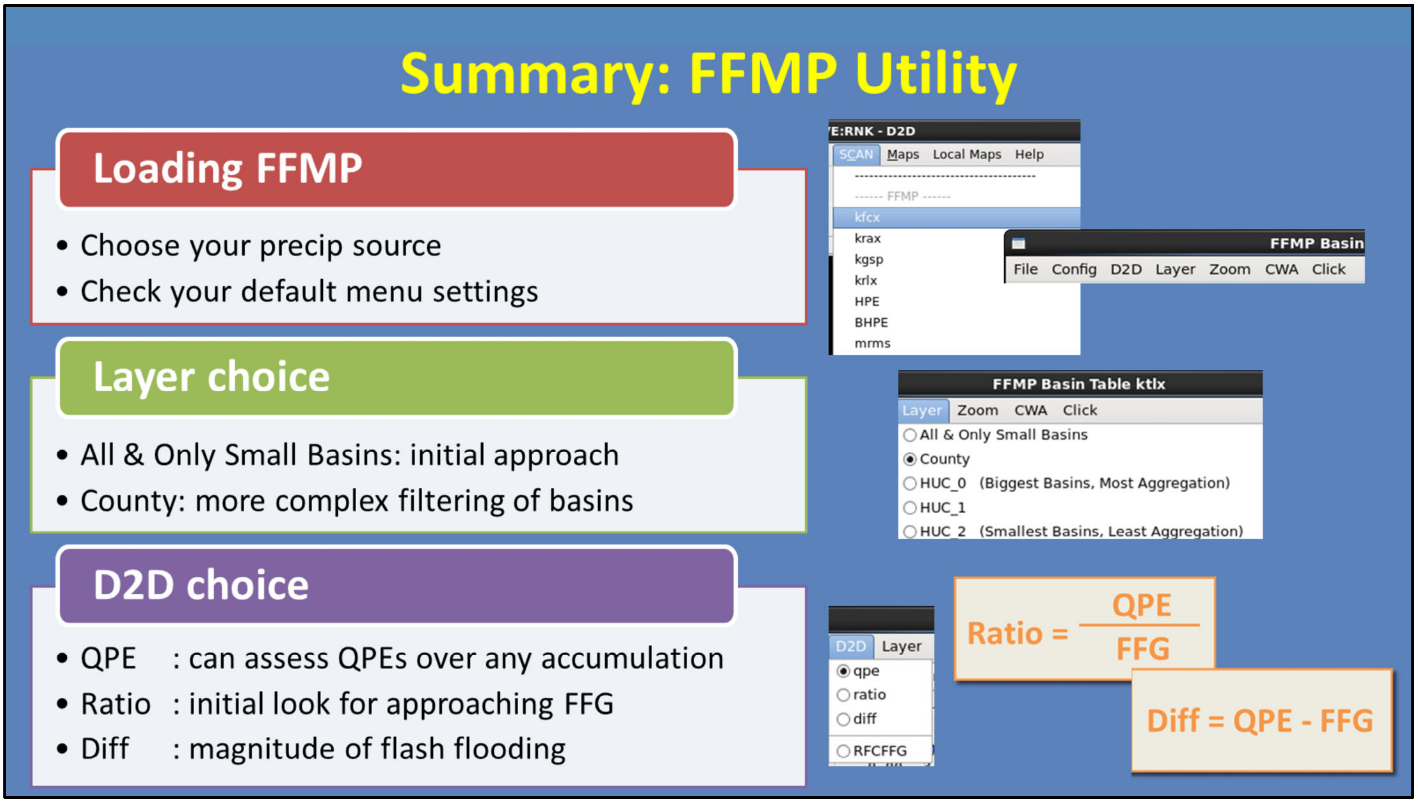


Finally, FFMP allows you to see basin connectivity on the D2D display as configured in the "Click" menu. Once you have pinpointed your current threat area, it is important to look downstream to see where the runoff will go. If the current accumulation is great enough and the downstream basins are flashy, those downstream basins can have flash flooding even without receiving a drop of rain. Knowing this can help you adjust your warning polygons to account for the future threat.

To do this, simply select "Downstream" from this menu, and then go to the D2D display and make the FFMP display editable. Once editable, your right-click button will highlight all basins downstream of the basin you selected. If it is hard to see the highlighting, you can change the color of the trace, like I did to green. And whenever you want to get rid of your trace or change the type of trace, simply "Clear Trace" on the FFMP Table.

Additionally, you may want to identify major main stem rivers. Since they typically don't *flash* flood, this may help you pull basins out of your warning. To do this, use the upstream and downstream option from the menu. Here is an example where the star denotes the selected basin. You can see the large area upstream of the basin that is feeding into that point. And then where it goes downstream to the north.

Finally, you can also visualize flow by overlaying the "FFMP Small Stream Basin Links" from the Map menu in D2D. I made them yellow in this graphic.

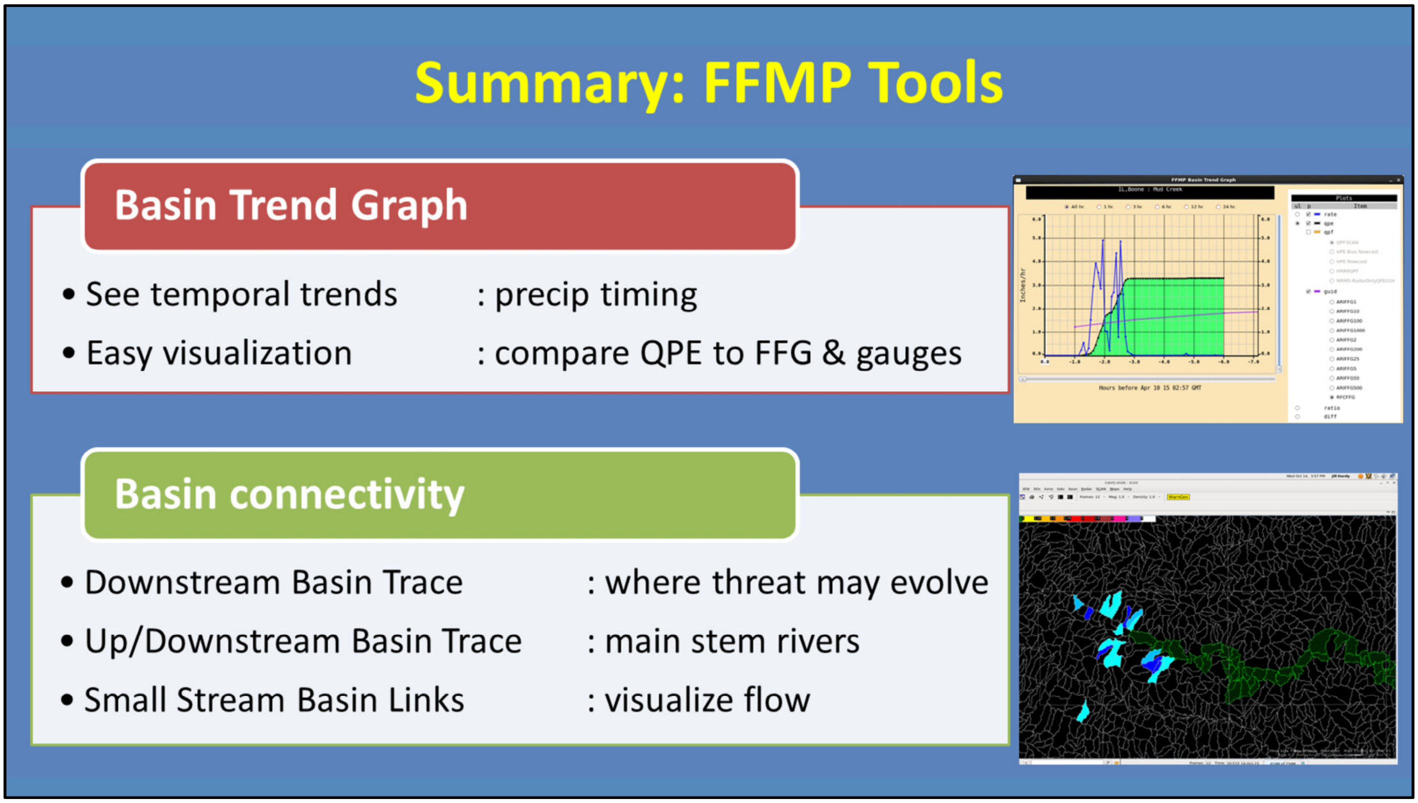


Because FFMP has a number of unique strengths, we focused this lesson on using it to its fullest in flash flood warning operations.

First, when loading FFMP, make sure to follow the guidance in the "Choosing Your Precip and Guidance Sources" lesson to consider all of your available precip sources. Also, make sure the menu settings across the top of the FFMP table are what you would like.

Next, start using the All & Only Small Basins layer to identify areas where QPE is approaching or exceeding FFG. You may change to County layer when you need more complex filtering of basins in the table.

Within FFMP, D2D can be configured to show any one of three options. QPE allows you to assess things like HPE, Bias HPE, and MRMS accumulation durations that aren’t usually readily available. The ratio product is one the best ways to identify areas of flash flooding threat so we recommend starting there, and using Diff to help assess the potential magnitude of flash flooding.



FFMP has a lot of useful functionality, as long as you know how to use it.

The Basin Trend Graph allows you to see temporal trends for rainfall rate, accumulation, and Flash Flood Guidance for a selected basin. As well as, provides easy visualization when comparing QPE to FFG, and to gauges when using VGBs.

FFMP also has basin connectivity features to help identify where the flash flood threat may be evolving, where main stem rivers exist versus headwaters, and how to visualize flow outside of FFMP.

This concludes this lesson. When you are ready, please move onto the next slide to take the quiz and receive credit on the LMS.

Flash Flood Warning Fundamentals

Introduction

Notes:

Hi, my name is Katy Christian and welcome to this lesson where we will discuss the fundamentals of flash flood warnings!

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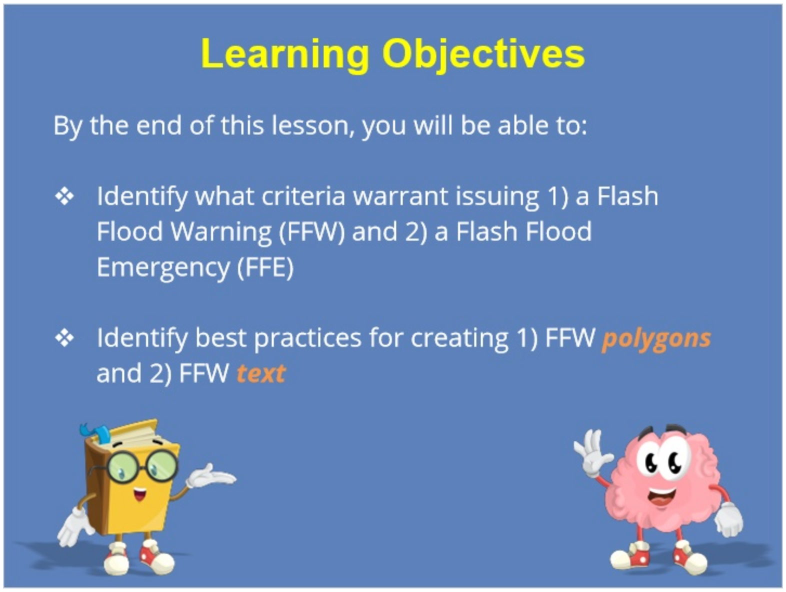
Learning Objectives



Notes:

Here are the learning objectives for this lesson. Take a minute to read them and when you're done, click "next" to move on.

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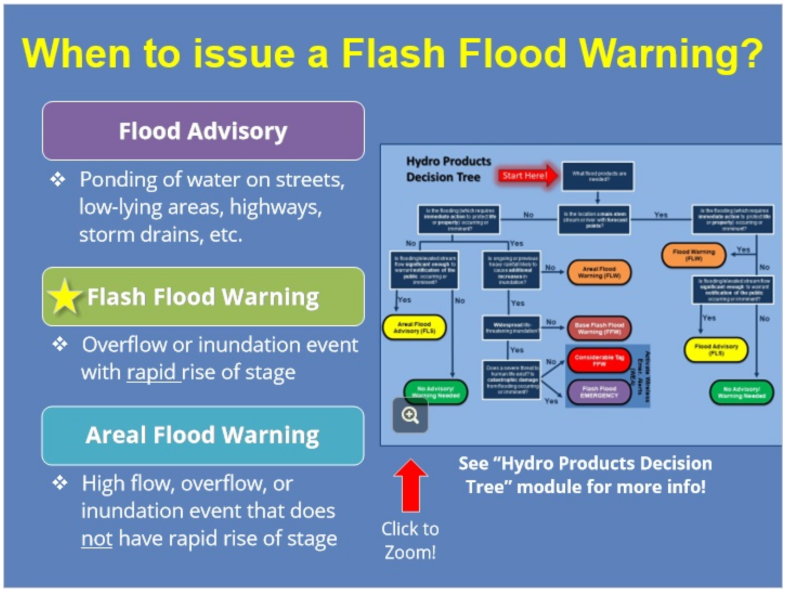
When to issue a Flash Flood Warning?



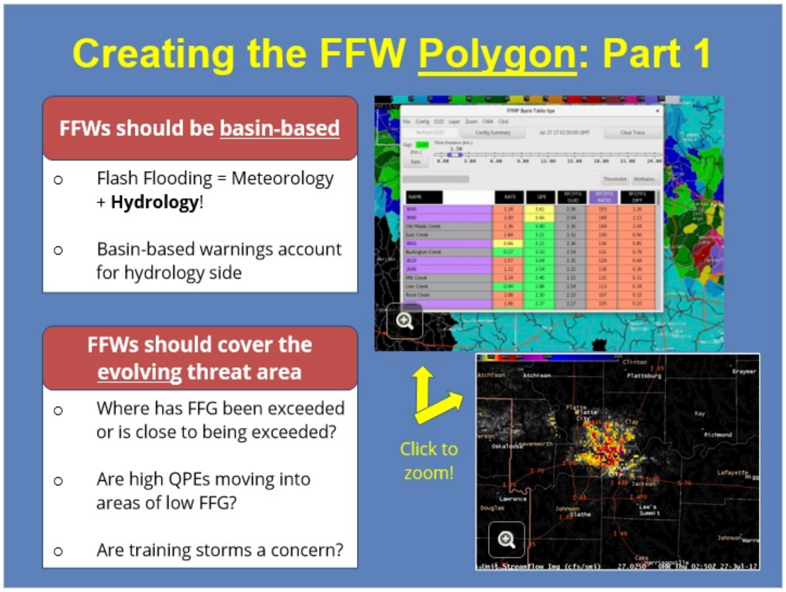
Notes:

Okay, let's start moving through the things to think about while on the hydro desk. Let's say you've diagnosed that the potential for flooding is likely. How do you know which hydro product to issue? There are a few routes you can take so be sure to talk to your office to see if they have any local protocol in place.

Generally, a Flood Advisory covers any sort of ponding that is not life-threatening. A Flash Flood Warning should be used when there is a RAPID rise of water, within 6 hours. In contrast, an Areal Flood Warning would be used if there is high flow, but it is not a rapid rise.

For this lesson, we're going to just focus on Flash Flood Warnings. But in WOC Flash Flood, there is a great lesson by Justin Gibbs called the "Hydro Products Decision Tree" that walks you through the process of picking between all of your product options.

FFW Polygon Fundamentals: Part 1



Notes:

Once you've decided that a FFW is the correct hydro product to issue for the current situation, you'll need to start drawing up your FFW polygon. So, let's take a look at some of the fundamentals of FFW polygons.
Firstly, your warning should be basin-based, rather than storm-based. Remember that flash flooding occurs as a result of meteorological AND hydrological factors. Basin-based FFWs help account for the hydrologic side of flash flooding. Furthermore, basin-based warnings allow you to warn the areas where flash flooding is imminent or already imminent, as well as areas immediately downstream which we'll talk about shortly.

Next, your FFW polygon should properly cover the evolving threat area. To make sure you cover the proper threat area, think about the following questions: Where has flash flood guidance been exceeded and by how much? Is there any area of very high QPEs moving into an area of low FFG? Are training storms a concern? The main takeaway is to always be thinking ahead when drawing up your FFW polygon. Both FFMP and FLASH focus heavily on what is happening now, based mainly on QPE input. But as a forecaster, you must mentally extrapolate storm movement and threat evolution to generate proper lead time, particularly for rapid runoff in urban areas.

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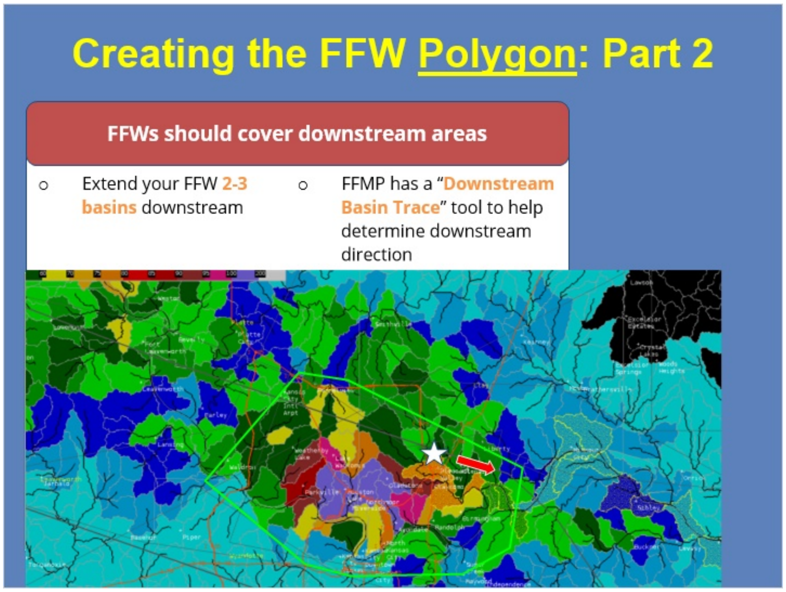
FFW Polygon Fundamentals: Part 2



Notes:

Once you've figured out the immediate threat area, you'll want to extend your warning polygon to cover the downstream threat. Let's quickly talk through an example.

Here we have a plot of rainfall intensity over time. Let's say Station #1 is very close to where the rainfall fell. It is going to respond quickly to the rainfall, with a sharp jump in stage. Let's say Station #2 is a little further downstream, so its response is later than the first, with a more gradual rise in stage that isn't as high as Station 1. Finally, Station #3 is the farthest downstream, so it only sees a slight rise in stage.

This progression can be expected in most cases, however effects can change based on many stream factors. A good place to start in the absence of any local hydrological knowledge is to expand your FFW 2-3 basins, not counties, downstream to account for runoff. This is in addition to the expanding threat due to training storms and the short-term movement of precipitation areas.

FFMP has a tool called the "Downstream Basin Trace" that can help you determine the downstream flow direction of runoff so you know where to buffer your FFW polygon when drawing it up. Take a look at the example below. Let's say that the basin with the white star on it was initially going to be the eastern extent of your FFW polygon edge. However, with the "Downstream Basin Trace" tool, the yellow hatched areas show how water will flow downstream from that basin. So ideally, you'd want to extend your FFW polygon 2-3 basins to the east/southeast to account for the downstream flow of rainfall in that basin.

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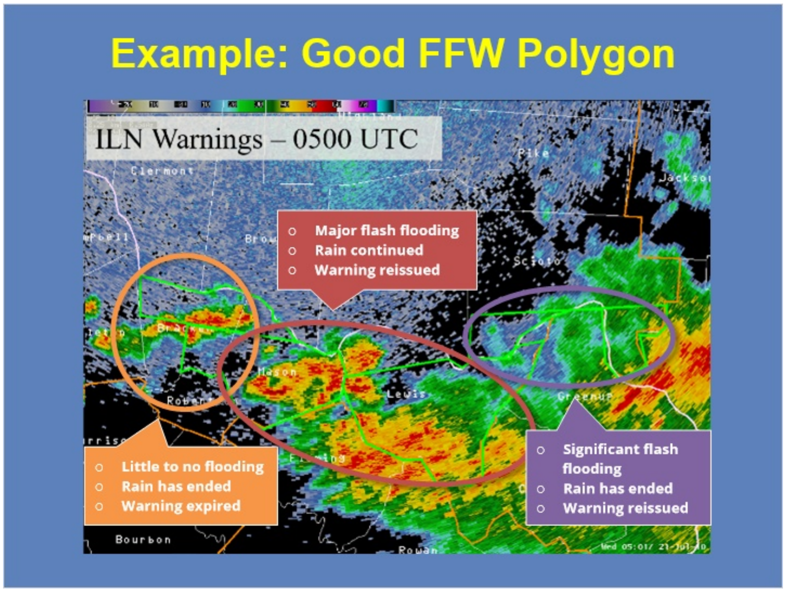
FFW Polygon Examples: Good Polygon



Notes:

Let's now take a look at some FFW polygon examples. The example here shows four active warnings from the Wilmington, Ohio office at 0500 UTC. Let's go ahead and circle the different threat areas, combining the two warnings in the middle.

Now, let's move forward an hour to 0600 UTC. For the far western threat area, there was little to no flooding, and the rain has ended. So this warning was allowed to expire. Moving east, there was major flash flooding occurring at this time, and the rain is continuing. Therefore, the office reissued the warning, and combined the threat area. Finally, the far eastern area had significant flash flooding, even though the rain had ended. Therefore, the warning was reissued.

In this case, the warnings were properly itemized, so to explain the evolving threats. The four original warnings were also made to expire at the same time, which helped in the reissuing process at the later time.

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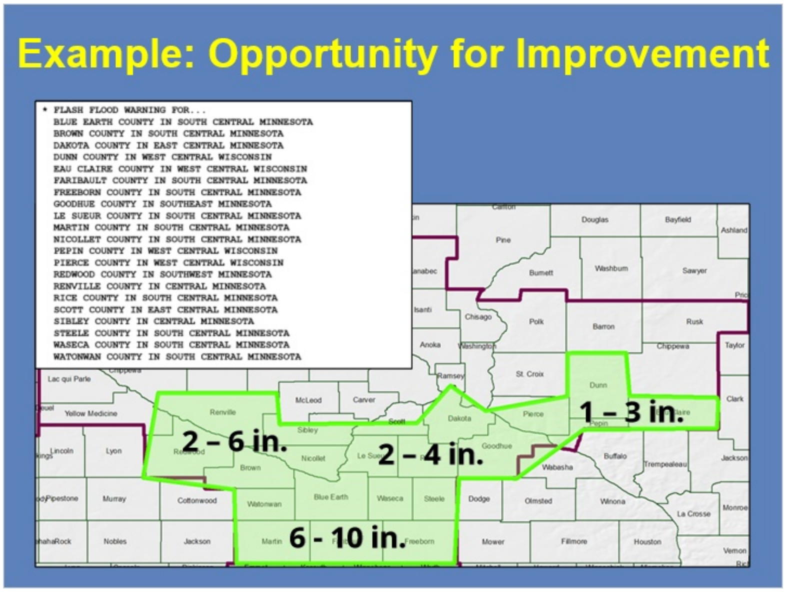
FFW Polygon Examples: Opportunity for Improvement



Notes:

Let’s take another look at a FFW polygon. Do you think the warning polygon properly covers the threat area? In this case, there are 21 counties included in one warning. Would you expect the threat to be the same across all locations? In most cases, it would likely not. In fact, there was a spread of 1-10 inches across the warning area. Yet, all areas are receiving the same message, which isn’t ideal. So this is an example of a FFW that needs to be broken up into separate warnings to properly itemize the varying magnitude of threats across different locations.

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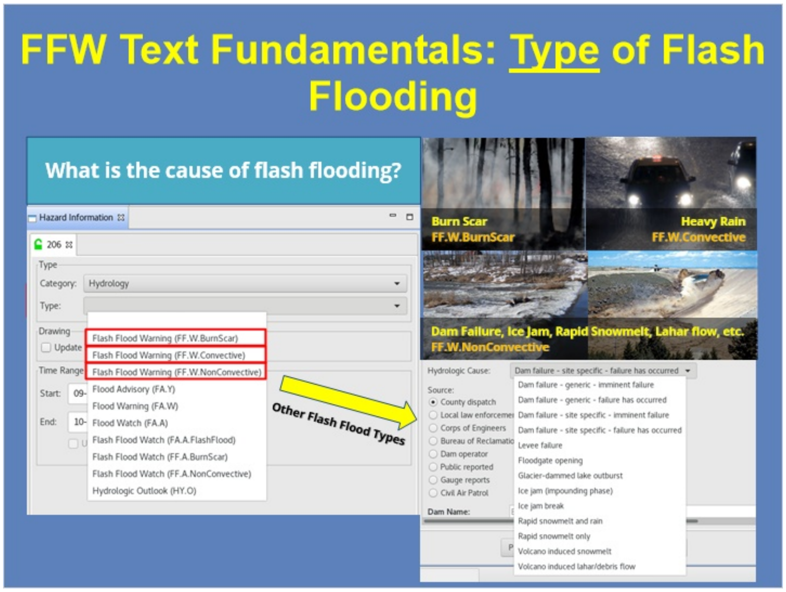
FFW Text Fundamentals: Type of Flash Flooding



Notes:

Okay, now that we've covered how to go about drawing up a FFW, let's now walk through what should be included in the text portion of a FFW. The first option you'll need to select is: what is the type or cause of flash flooding? While in the Hydrology category, click on the "Type" box to see all of your hydro-related hazards.

Since we're just focusing on Flash Flood Warnings, let's talk through the top 3 options available. If you are dealing with flash flooding occurring over a burn scar area, you'd want to choose the FF.W.BurnScar option as it will allow you to include additional details about the burned area. If the cause of your flash flooding is heavy rain, which will most likely be the case a majority of the time, you'd choose the convective option. And lastly, if you're dealing with flash flooding that is NOT due to convective rainfall, you'd choose the non-convective warning option. If you went that route, here are some of the types of flash flooding that fall in that category: dam failures, ice jams, rapid snowmelt, volcano induced lahar flow, and more. So, the important takeaway here is that you need to know the type of flash flooding that is occurring as this will dictate what sort of information is made available for you to include in your warning text.

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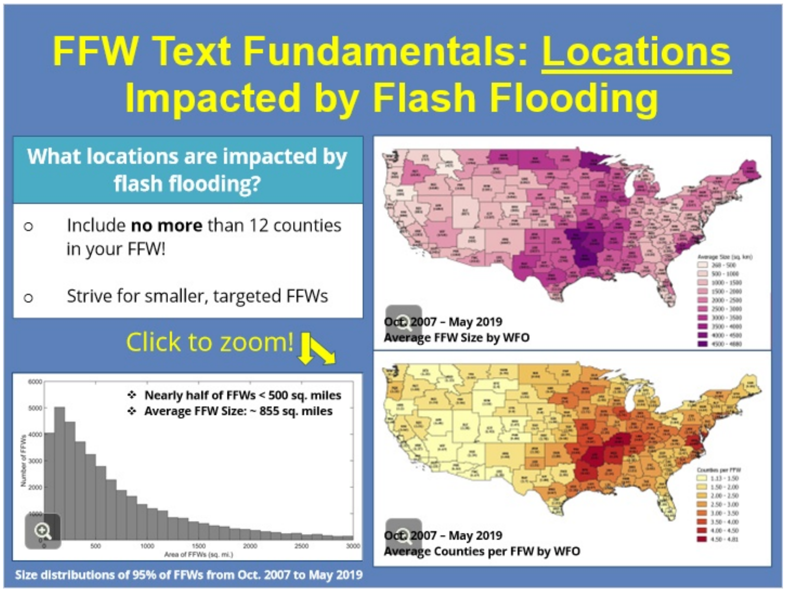
FFW Text Fundamentals: Locations Impacted



Notes:

The next piece of information you'll need to include in your FFW is: what locations are expected to be impacted? In Hazard Services, whether you draw up your warning or use the flash flood recommender tool, any counties included in your FFW polygon will be populated and listed in the text portion of the FFW.

When it comes to how many counties you should include in your FFW, consider the following image that shows the average number of counties per FFW from October 2007 to May 2019 for each WFO. You can see that there is variation in the number of counties included across the country and this has to do with both the average county size in that particular part of the country as well as each local WFOs tendency to draw larger or smaller FFWs. For example, counties in the western U.S. are typically much larger than those along the East coast so the number of counties included per FFW in the West will typically be less as you can see in this image. On average though, the number of counties included per FFW ranges anywhere from 1 to 4 across the country. The max number of counties you should include in a FFW is no more than 12, but definitely don't try to reach that number!

Since county size varies greatly across the U.S., let's also take a look at the average FFW size so you have a general idea of what to expect. The figure here shows the average FFW size from October 2007 to May 2019 for each WFO. You can see right away that the average FFW area varies by WFO, with some offices issuing consistently larger FFWs than others depending on local office practices, hydrology, and the type of flash flooding common there.

In terms of a distribution, the figure here shows the size distribution of 95% of FFWs over the entire period of analysis. The remaining 5% of FFWs exceeded 3000 sq. miles and are not shown on this graph. Overall though, smaller FFWs are significantly more common than larger FFWs, with nearly half of all FFWs less than 500 sq. miles. This is good news as we want our FFWs to be small and focused so that you can appropriately message the magnitude and extent of the threat to your public and partners rather than issuing large warnings that don't give the public the level of detail that is needed. Over the entire period of analysis, the average FFW size is approximately 855 sq. miles.

The biggest takeaway from all of this is that across the country, there isn't one FFW size that fits all. However, you should strive to make your FFWs as small as possible so that they appropriately cover the threat area and provide the level of detail needed when messaging to your partners.

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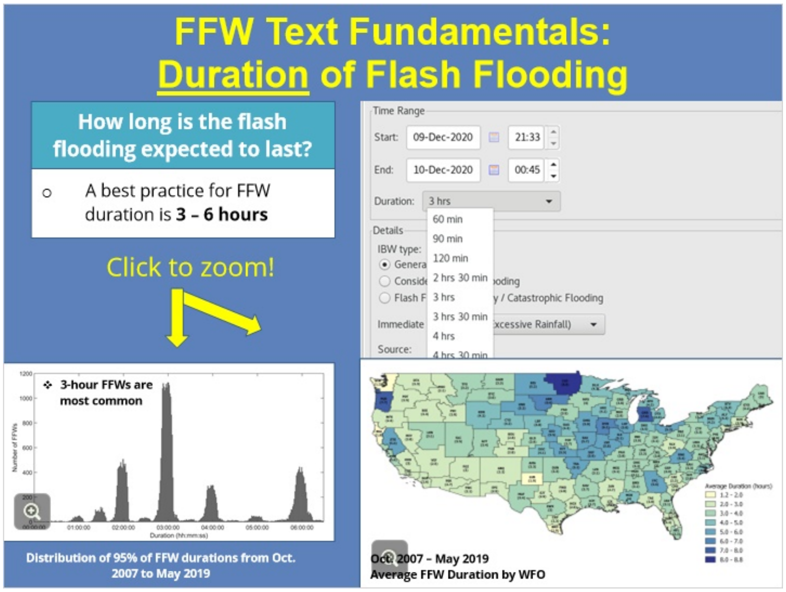
FFW Text Fundamentals: Duration of Flash Flooding



Notes:

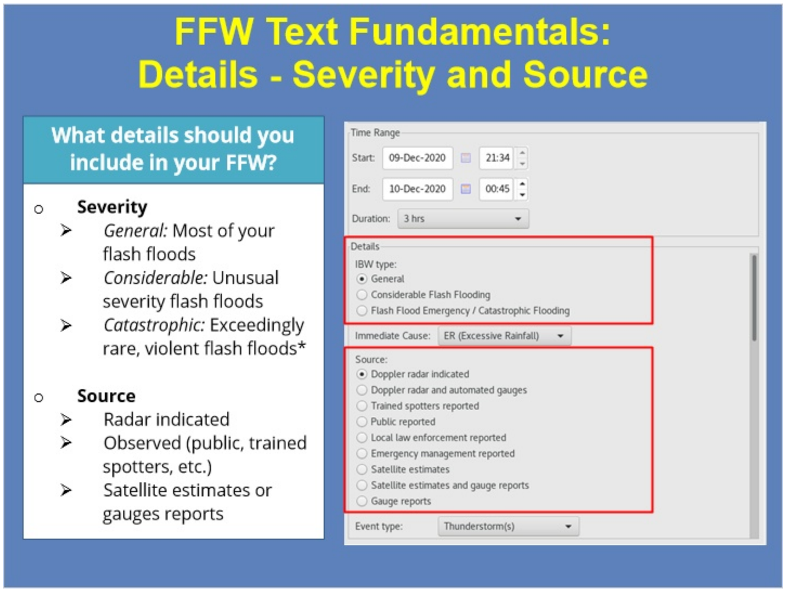
After determining location, you'll also need to include how long the flash flooding is expected to last in your warning. Click on the "Duration" box to see what options you have.

You can see that the default durations range from as short as 1 hour to as long as 8 hours. So, how does this vary across the country? Similar to FFW size, this will vary greatly depending on the cause of flash flooding and the geographic area impacted.

Take a look at the following figure that shows the average FFW duration from Oct. 2007 to May 2019 for each WFO. You can see that on average, FFW length varies greatly from one office to another. There are multiple reasons for this including local hydrology of different regions, WFO best practices, the type of flash flooding common to different areas, and no firm NWS directive on typical FFW length. For example, FFWs due to dam failures typically have a much longer warning duration than those just due to heavy rainfall.

If we take a look at the distribution of 95% of FFWs over the period of analysis, we see that most FFWs are issued around hourly durations, with 3-hour warnings being the most common. In the absence of unusual circumstances, a best practice is for FFWs to be between 3 and 6 hours. For routine FFWs, 3 hours allows for one hour for the event to begin and the rain to fall, one hour for runoff and the stage to crest, and one hour for the flood to recede.

FFW Text Fundamentals: Details about Flash Flooding



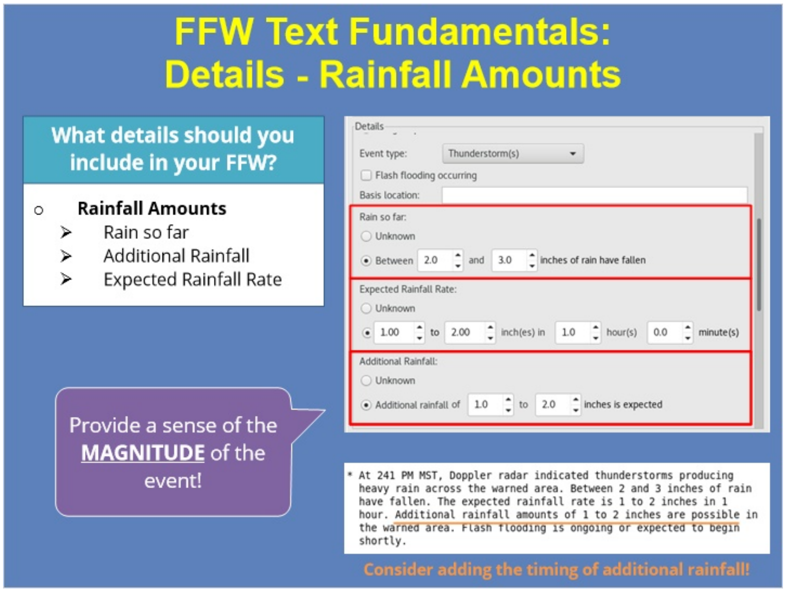
Notes:

Next, you'll need to include multiple details in your FFW regarding the flash flooding itself. Under the impact-based warnings (IBW) format for flash flooding, you'll need to select the severity of flash flooding.

"General" will be used most of the time, as this is your base FFW. "Considerable" is used for flash floods that have unusual severity of impact and require urgent action. Finally, "catastrophic" is reserved for those exceedingly rare, violent flash floods and we'll talk about what conditions warrant this use shortly.

You'll also need to include the source of your flash flood warning, whether that be radar indicated or any of the reported options.

FFW Text Fundamentals: Details about Flash Flooding



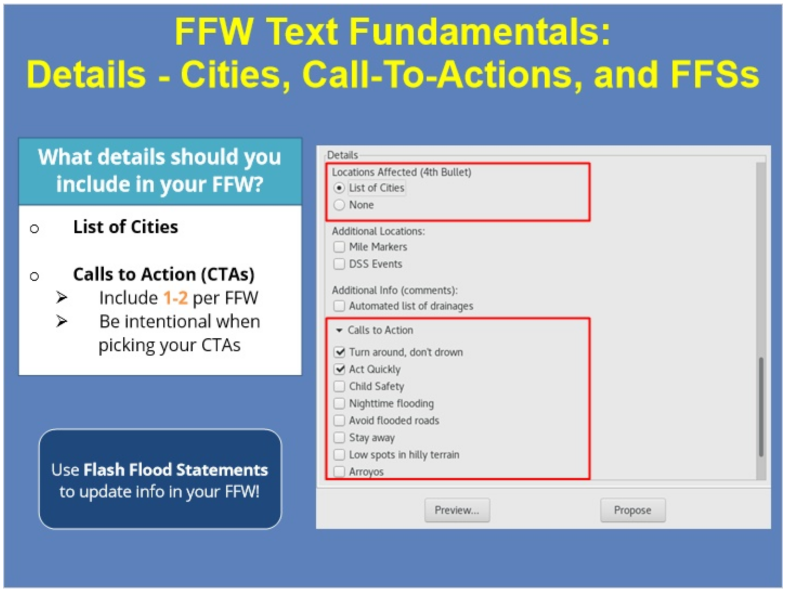
Notes:

Next up is providing some details about the rainfall amounts in your warning. In particular, you need to list how much rain has fallen so far, and a sense of how much more is expected. If you're comfortable providing specific details about rates, include the "Expected Rainfall Rate" information. At the very least, the "Additional Rainfall" option should be used to give a sense of the total amounts to expect.

With the selections made in this image, the text would read: "Between 2 and 3 inches of rain have fallen. The expected rainfall rate is 1 to 2 inches in 1 hour. Additional rainfall amounts of 1 to 2 inches are possible in the warned area." If you choose to exclude the rate information, it's always nice to give a sense of rainfall timing when you can. Here, you could simply say "1 to 2 inches are possible over the next hour".

An important thing I want to mention is that determining all these rainfall amounts is the trickiest part of creating your text. However, keep in mind that these amounts can be ranges, and that you don't have to be extremely precise if you don't have the information or confidence. Simply saying "2-3 inches have fallen" gives people a sense of the MAGNITUDE of the event.

FFW Text Fundamentals: Details about Flash Flooding



Notes:

Next, you need to select that cities in your FFW polygon be listed in the FFW text. And finally, you need to select what actions the public can do to protect themselves and their property. This will be addressed through the call-to-action statements that you chose to include in your warning.

As a best practice, you should include 1-2 call-to-action statements per FFW and make sure you are intentional about why you are picking a specific CTA. You don't want your warning bogged down by multiple CTA statements that are not relevant to the situation at hand.

Finally, don't forget to use Flash Flood Statements to regularly update info in your FFW during an ongoing event. Since FFWs are a relatively long-lived event, you'll want to use Flash Flood Statements to disseminate new and updated information as reports come in and the threat evolves over time.

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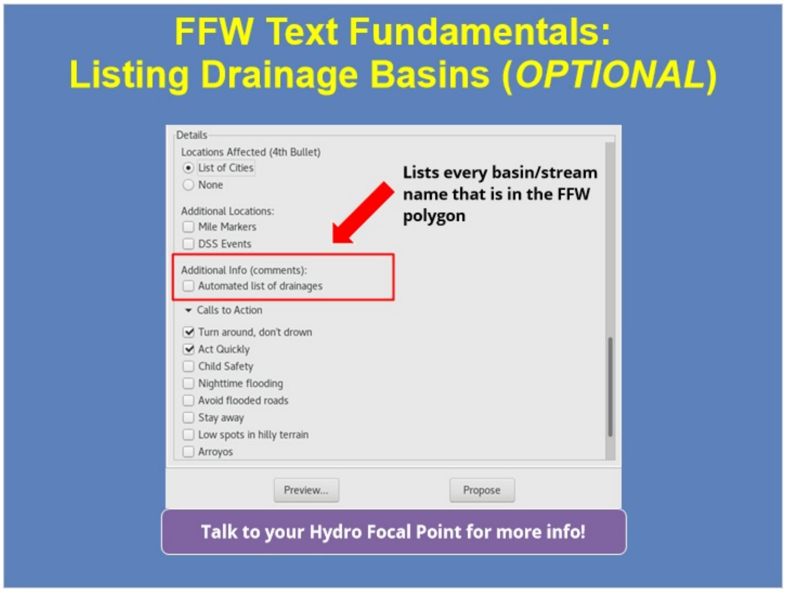
FFW Text Fundamentals: Listing Drainage Basins



Notes:

I want to quickly mention that you have the option of automatically inserting basin names into the FFW by clicking the “Automated list of drainages” option that is listed under “Additional Information.” What this does is include every single basin/stream name that falls within the warning polygon. The list of basins is maintained locally by your Hydro Focal Point. If you're interested in the pros and cons of using this option for your area, we recommend that you talk to your Hydro Focal Point.

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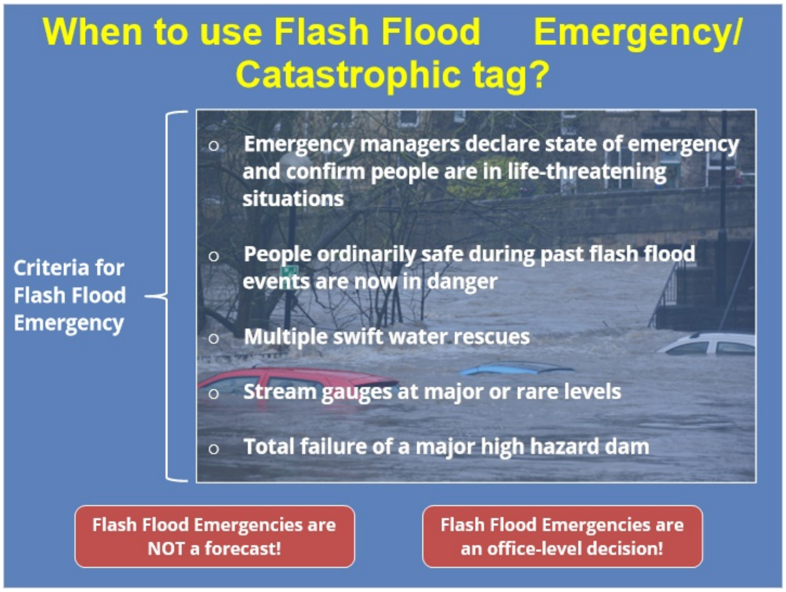
When to use Flash Flood Emergency/Catastrophic tag?



Notes:

Before we wrap up, I want to discuss the very special case of when you should use the Flash Flood Emergency, or catastrophic, tag. Keep in mind that these are very rare and should be reserved for high-end, violent flash flooding events.

Some criteria that warrant issuing a Flash Flood Emergency are 1) if emergency managers have declared a state of emergency and have confirmed flash flooding is placing or will place people in life-threatening situations, 2) if water has rapidly risen so that people ordinarily safe during previous flash flood events are now in life threatening situations, 3) if multiple swift water rescues are occurring or have occurred, 4) if stream gauges are at major or rare levels, and 5) if there is a total failure of a high hazard dam.

Keep in mind that Flash Flood Emergencies should be issued only AFTER you have reports and are not a forecast. However, while you'll want to wait until you know that the event is worthy of an emergency tag, you'll want to declare it as an emergency while it's still early enough to be useful to the public to take quick action. Flash Flood Emergencies are an office-level decision and must be coordinated with others and relayed to partners immediately.

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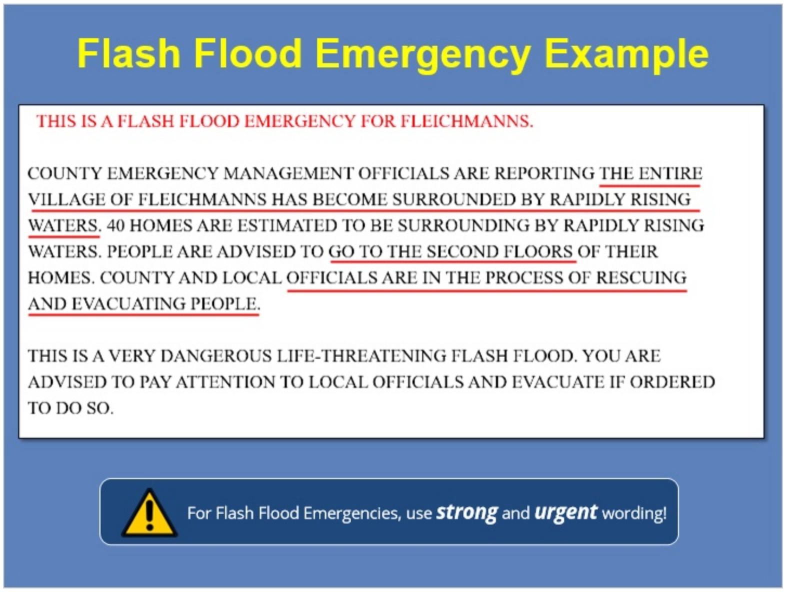
Flash Flood Emergency Example



Notes:

Here is a portion of text from a Flash Flood Emergency statement. Notice the strong and urgent language used: "…the entire village…has become surrounded by rapidly rising waters", "go to the second floors", and "officials are rescuing and evacuating people". Because Flash Flood Emergencies are for those really rare and catastrophic events, you'll want to use strong wording to get people to change their behavior. You can find more details about flash flood emergencies in the WOC Flash Flood Course.

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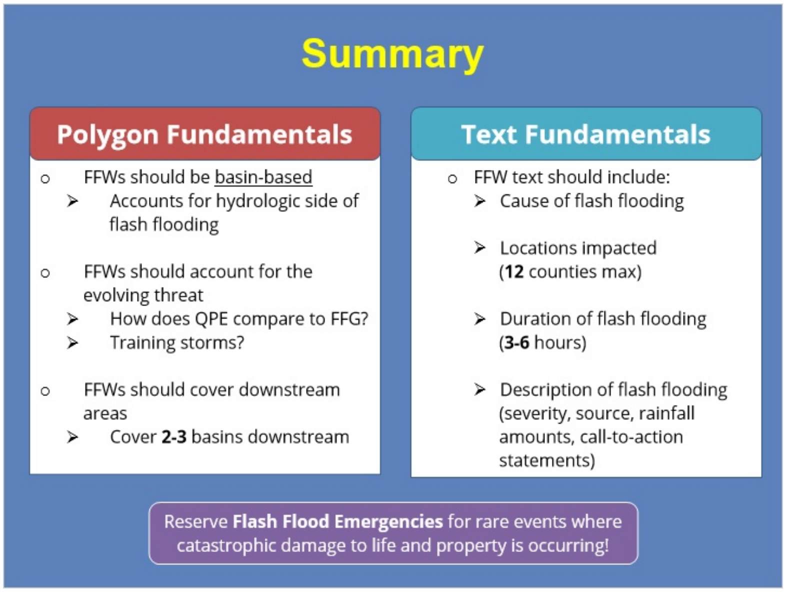
Summary



Notes:

Let's quickly recap everything we've talked about so far. When you are drawing up your flash flood warning, be sure that it is basin-based, as this will help account for the hydrology side of flash flooding. Next, be sure your warning accounts for the evolving threat. For instance, if you've got an area of high QPEs moving into an area of low FFG or you have training storms, be sure to cover those areas with your FFW. Additionally, you should buffer your FFW 2-3 basins downstream to account for impacts there.

As for what you should include in the text of your FFW, you need to know the cause of flash flooding as this will determine what route you take in Hazard Services. Next, be sure the locations listed in your FFW do not exceed 12 counties. As a best practice, flash flood warnings should be between 3-6 hours, but this can vary based on the current situation. Lastly, with IBW, you need to include additional details about the flash flooding itself, such as the severity of flash flooding, source, rainfall amounts, and recommended response actions for the public to take. Finally, Flash Flood Emergencies should be used for those rare events where catastrophic impacts to life and property are occurring. All right, that's all for this lesson! When you are ready, click next to take the quiz.

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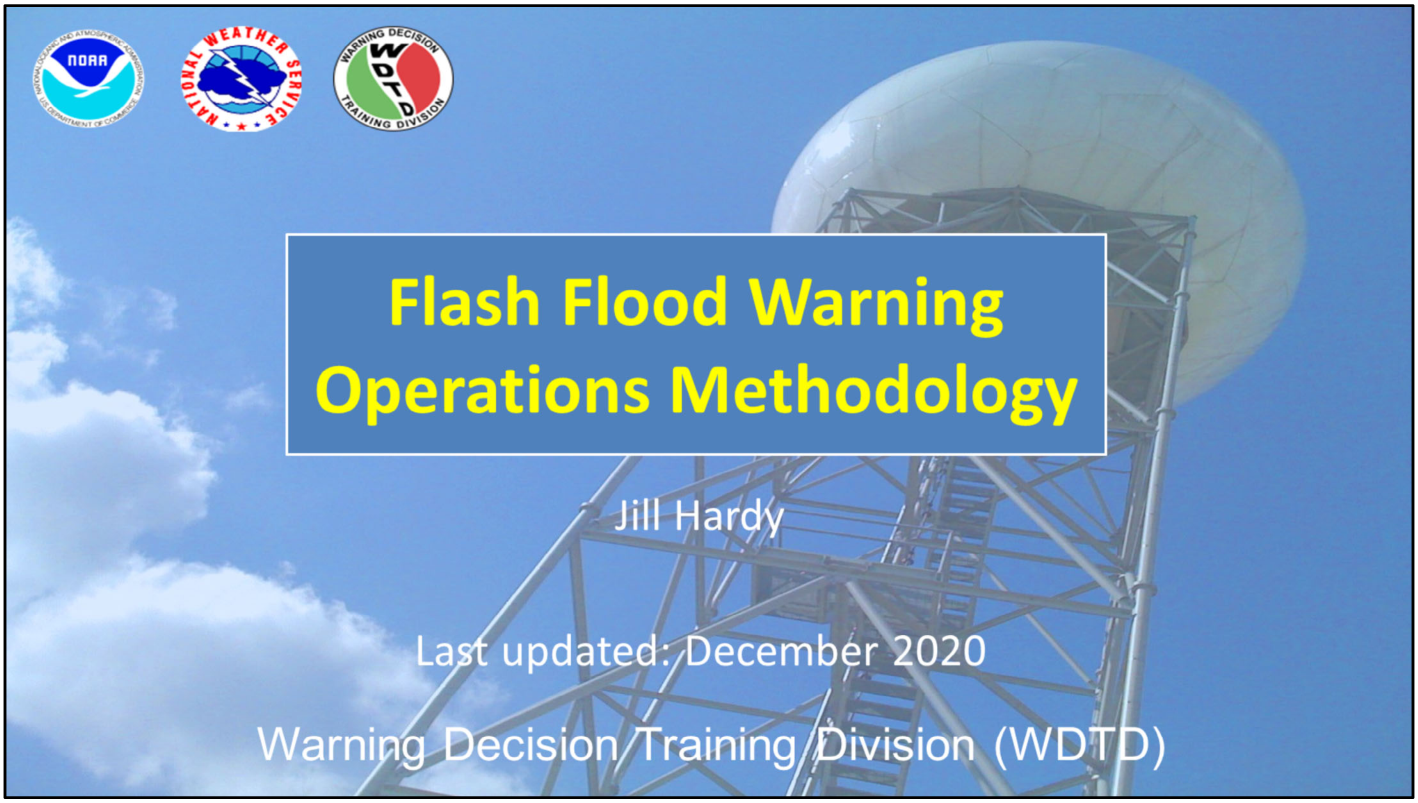
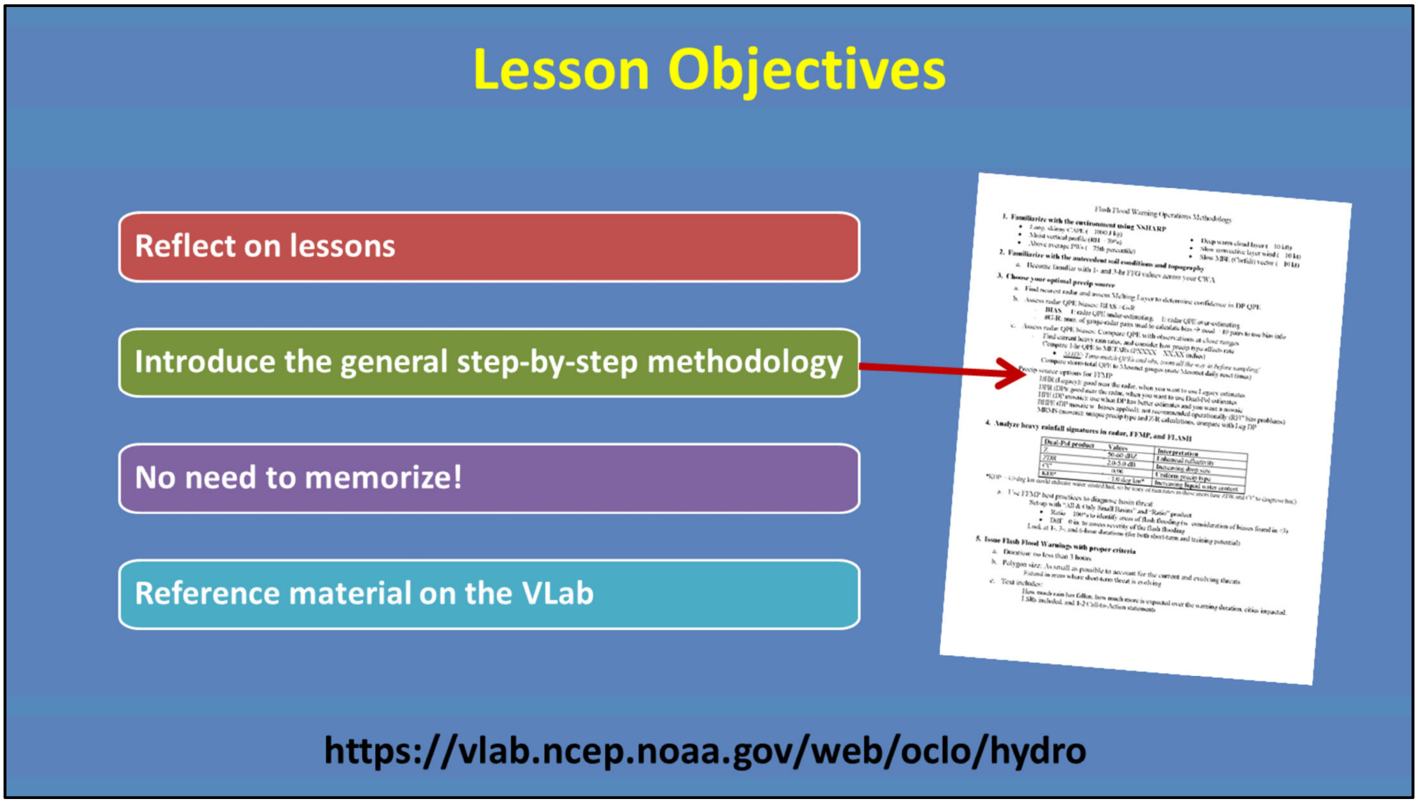
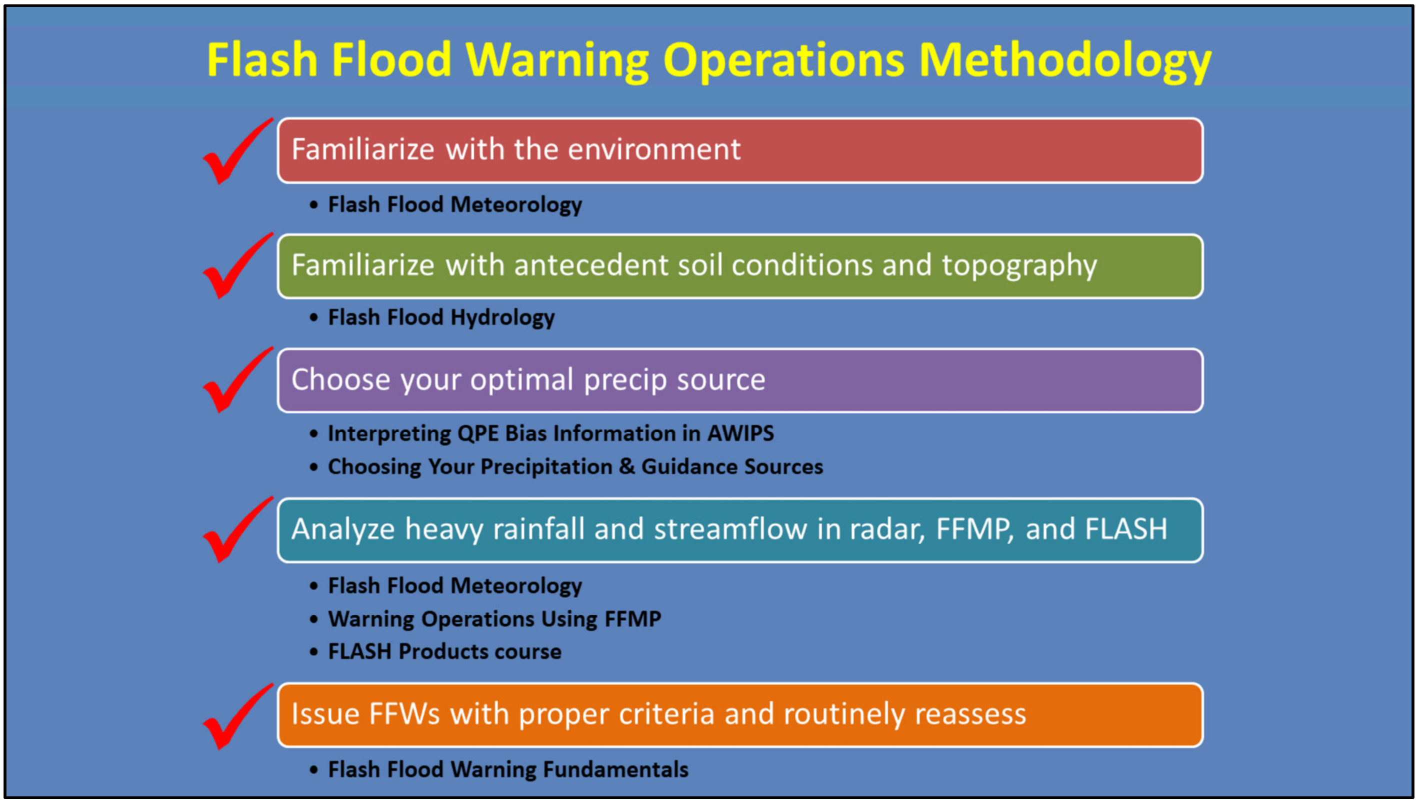


Hi, my name is Jill Hardy. This lesson is a brief summary of WDTD's recommended flash flood warning operations methodology. Basically, when you're the hydro warning forecaster on shift, what are the general steps and best practices to help you effectively issue flash flood warnings. Let's get started!



This module is different than most WDTD lessons because it's a chance for you to step back and reflect on the lessons that have led to this point. We'll tie them all together into one general step-by-step warning ops methodology, and we don't expect you to memorize this process. In fact, we have it all laid out for you on the VLab to reference at any time.

If you're taking this lesson as part of the Radar & Applications Course, you'll have the chance to apply this material soon enough in the Workshop Primer and workshop simulations.

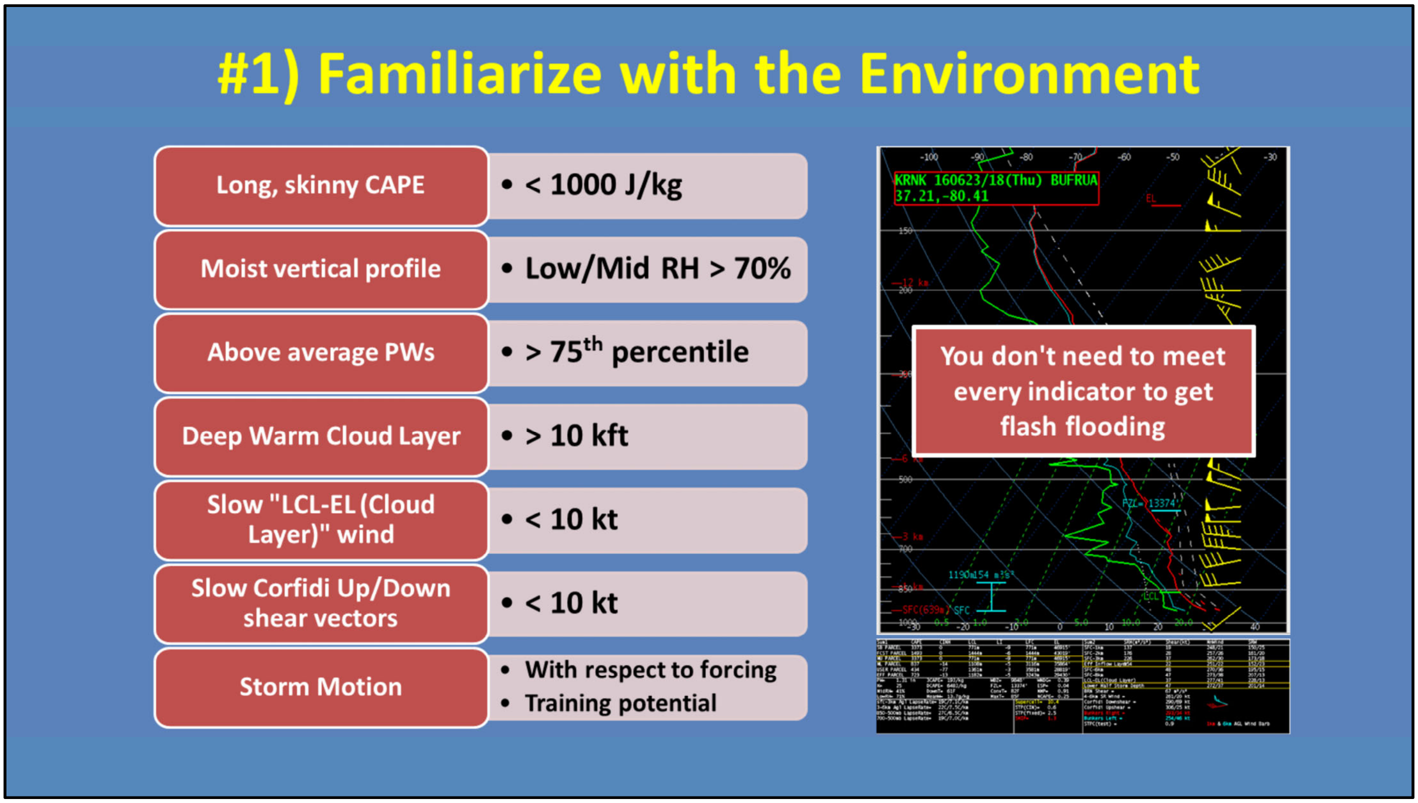


And here it is! This is the general process that we, at WDTD, think effectively aids in flash flood warning decision-making. While every office (and forecaster for that matter) will have differences when it comes to their hydro desk procedures, this step-by-step methodology is a good starting point.

It ensures you've: familiarized yourself with the current environment, antecedent soil conditions, and topography; are using the optimal precip source for the event; can analyze heavy rainfall and streamflow data via radar, FFMP, and FLASH; and are applying best practices when issuing warnings.

If you are taking this lesson as part of the RAC, congrats! You've already been introduced to each of these topics! But if you're taking this outside of RAC, please reference any of these WDTD lessons for more in-depth training.

The rest of this lesson will briefly summarize each of these steps.



At the warning desk, one of the best ways to familiarize yourself with the environment is through an NSHARP sounding analysis. For flash flooding, some good indicators that the environment is primed for heavy rainfall are:

--a long, skinny CAPE profile (<1000 J/kg)
--a moist vertical profile (RH > 70%)
--above average Precipitable Water values (>75th percentile)
--a deep warm cloud layer (> 10 kft),
--slow cloud layer wind (< 10 kt), and
--slow Corfidi up/down shear vectors (< 15 kts)
--In your analysis, also consider storm motion with respect to a forcing mechanism and training potential.

Keep in mind that you don't need to met every one of these indicators in order to get flash flooding. You can have a high moisture day where any initiation is going to dump buckets, or you can have an average moisture day where the winds point to training storms being the main concern.

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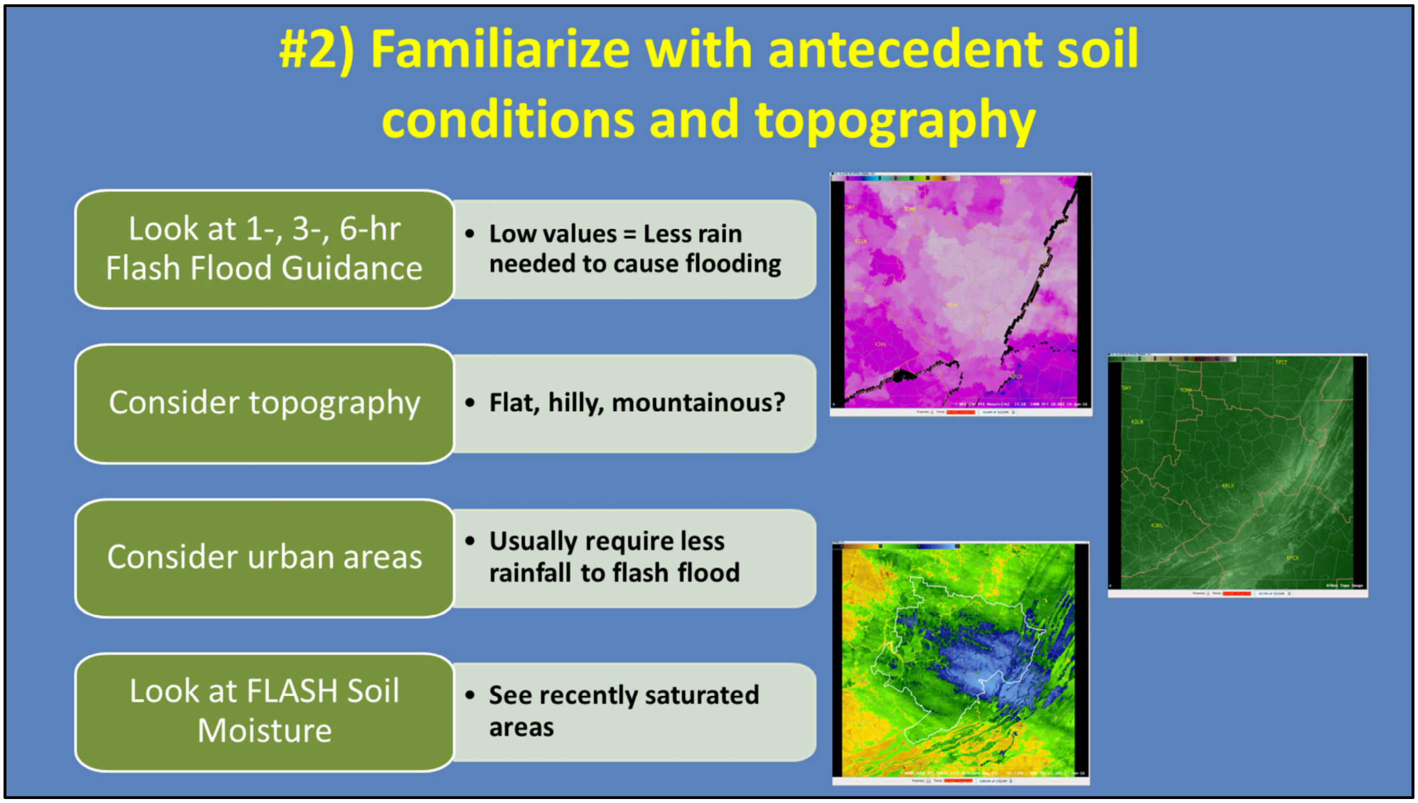
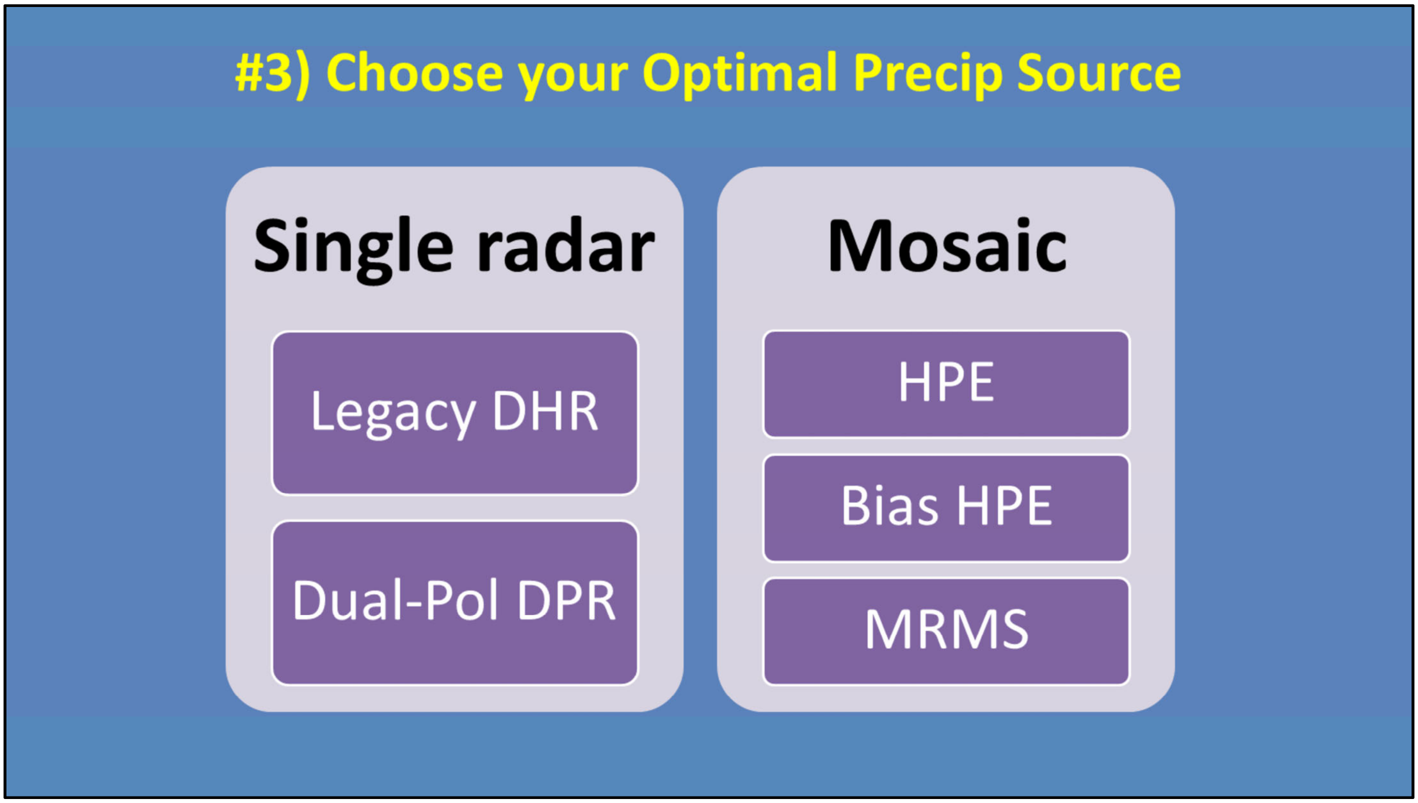


Next up is to familiarize yourself with the antecedent soil conditions and topography of your area. The easiest way to do this is using your Flash Flood Guidance products. For flash flooding, your 1-, 3-, and 6-hour FFG values will give you an idea of where recent rainfall may have already saturated soils. Remember, low values denote that less rainfall is needed for streams to overflow their banks. Keep in mind that these products are usually only updated up to 4 times a day, so if rainfall has occurred after the latest update, then it will not be reflected in the FFG products.

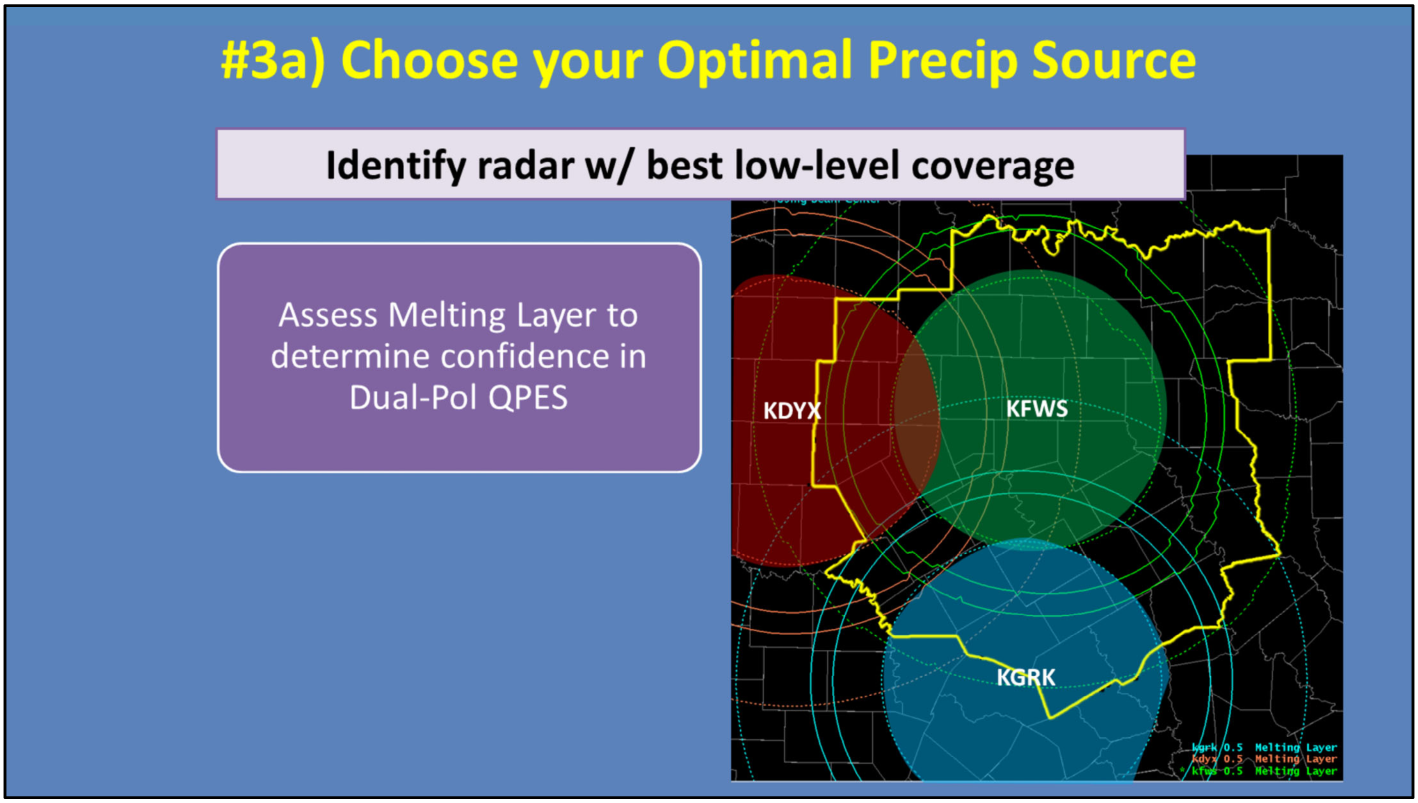
Topography also plays a role in where the water is routed during flash flooding, and how quickly it is routed. Also consider where your urban areas exist since they usually require even less rainfall to produce flash flooding.

Finally, if you use FLASH, consider each model's soil moisture product. This can help you see areas where FLASH has recently saturated soils and how that may affect model output.



Step 3 is to choose the optimal precip source for use during warning operations, and it's not a trivial step. The best source can often change, so we have created some general guidelines to help you decide.

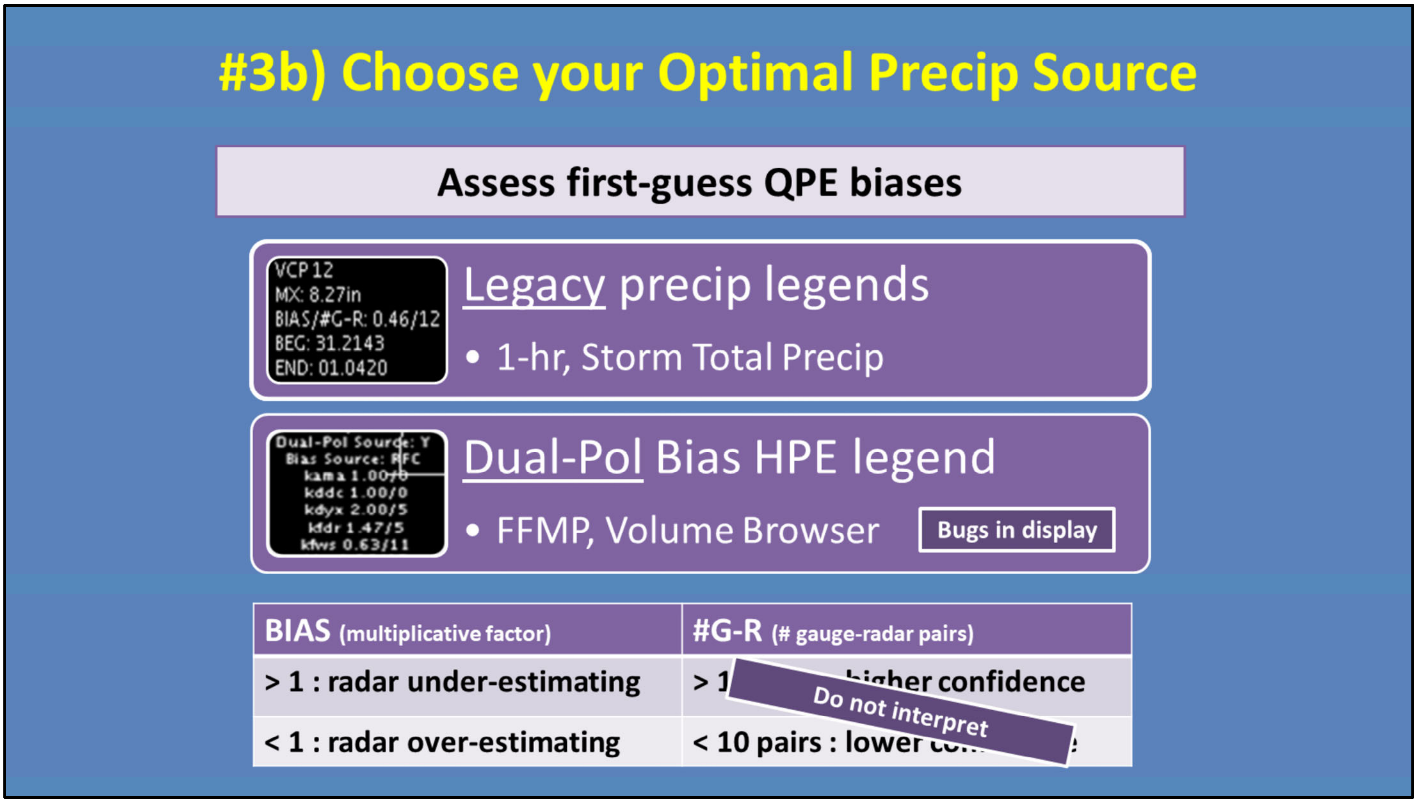
First, here is a list of what's available. You can learn more about the pros and cons of each one in the "Choosing Your Precipitation & Guidance Sources" lesson.



First and foremost, identify the radar with the best low-level coverage for the given storms. Keep in mind that this may not always be the *closest* radar, but usually that is the case. Here is an example of the Fort Worth CWA, with its 3 dedicated radars.

Assess the Melting Layer to determine where you can have higher confidence in your Dual-Pol QPEs. Your highest confidence is in areas that are below the Melting Layer, such as the green area of the KFWS radar. Within or above the Melting Layer, estimates could be affected by mixed or frozen precip classifications.

In this case, look at how much of the CWA isn't ideal for the KFWS radar. Depending on the location of the storms, using the surrounding blue and red radars may help you get the best QPEs.



So once you have an idea of which radar is best, you can get a first guess of the potential bias of a precip source by reviewing its bias information. For Legacy, this is readily available via the 1-hour or Storm-Total Precip product legends, as seen here. For Dual-Pol, look at the Bias HPE legend in either FFMP or the Volume Browser.

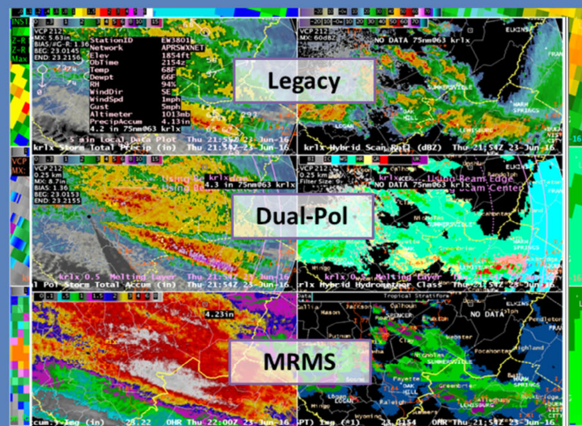
As a reminder, the two values displayed are the bias factor itself, which can tell you if the radar is under- or over-estimating, and the number of gauge-radar pairs, which tells you how many pairs were used to calculate the bias. Do not interpret the gauge-radar pair information in these displays as there are bugs. Please review the "HPE and Bias HPE" lesson, as well as the "Interpreting QPE Bias Information in AWIPS" lesson for details and work-arounds.

#3c) Choose your Optimal Precip Source

Manually assess QPE biases at gauges

Compare QPEs w/ surface observations at close ranges

- Identify significant differences between precip type and rates
- Compare 1-hr QPEs w/ 1-hr obs (e.g. METARs)
- Compare storm-total QPEs w/ long-term obs (e.g. Mesonets)



Probably the best way to get a feel for how each precip source is doing at any given time is to manually compare the QPEs with surface observations at close ranges. While gauges have been known to have their own issues, they are still the primary form of ground truth to calibrate yourself with potential precip source biases.

--Start by looking at Legacy, Dual-Pol and MRMS side-by-side to identify any significant differences between the precip types and their associated rates.
--Next, compare 1-hour QPEs with 1-hour observations, most likely through METARs. Keep in mind that you MUST remember to time-match in order to get a proper comparison.
--Finally, compare storm-total QPEs to longer term obs, like Mesonets, if you've got em. Get to know the local networks to know when these running totals reset, in order to make the best comparison possible.

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#3) Choose your Optimal Precip Source

	Coverage	Dual-Pol?	Bias corrected?	Resolution	Accumulation products outside of FFMP	Z-Rs
Legacy DHR	Single-radar	No	No (default, configurable at RPG)	1 km x 1 deg 3-6 min	1-, 3-, STP (and user-selectable)	Single Z-R (set at RPG)
Dual-Pol DPR	Single-radar	Yes	No	0.25 km x 1 deg 3-6 min	1-, 3-, STA (and user-selectable)	Spatially-varying (based on HHC)
HPE	Mosaic	Yes	No	1 km x 1 km 5 min	1-hr (harder to access from Vol. Browser & SCAN)	Spatially-varying (inherited from DPR for each radar)
Bias HPE	Mosaic	Yes	Yes (mean-field bias is default, configurable)	1 km x 1 km 5 min	1-hr (harder to access from Vol. Browser & SCAN)	Spatially-varying (inherited from DPR for each radar)
MRMS radar-only	Mosaic	Yes (as of Oct 2020)	No (Multi-Sensor QPEs only update hourly)	1 km x 1 km 2 min	1-hr (All other accum update hourly)	Spatially-varying (based on melting layer & SPT)

Now put it all together to actually pick the precip source to use in warning decision-making. Is Legacy, Dual-Pol, or MRMS performing the best compared to obs? Will a mosaic help? What about bias corrections being applied? All of these factors should be considered to make your ultimate decision.

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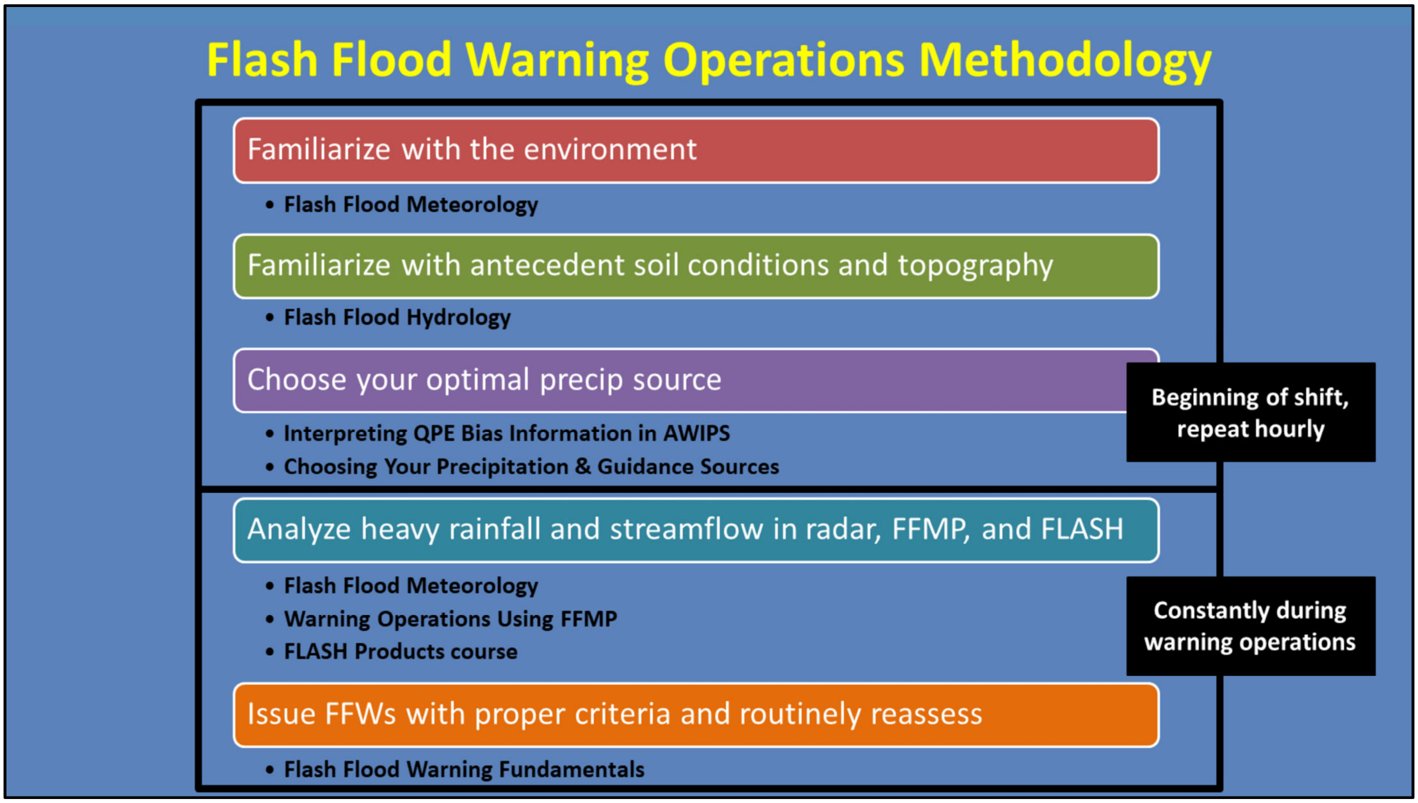

I'm going to step back for a moment and say...Steps 1-3 are ideally done at the beginning of a shift and/or beginning of an event. Once familiar with the environment, it shouldn't take much time to go back and repeat these steps each hour when new model runs, FFGs, and obs may be coming in.

As we move forward in our methodology, Steps 4 and 5 are then done continuously during warning ops. These steps are what you need to be able to do quickly and efficiently throughout your warning shift.

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#4) Analyze Heavy Rainfall/Streamflow: Radar

Product	Values	Interpretation
Z	50-60 dBZ (40-55 dBZ tropical)	Enhanced reflectivity
ZDR	2.0-5.0 dB (0.5-3.0 dB tropical)	Bigger drop size (Smaller drop size)
CC	> 0.96	Uniform precip type
KDP	> 1.0 deg/km* (> 4.0 deg/km : water-coated hail?)	Increasing liquid water content

- Low-echo centroid signatures : precip below the freezing level
- Favorable supercell characteristics : slow, large updraft; moist inflow region

Once you have settled into a precip source and are ready to start picking out storms for warning decisions, then begin analyzing heavy rainfall and streamflow.

Here are the Dual-Pol characteristics that provide a lot of insight into where warm rain processes are dominating. Additionally, look for low-echo centroid signatures that show the majority of precip cores below the freezing level.

And don't forget that supercells can also produce heavy rainfall if they are slow movers and/or have the right environmental factors, such as a large updraft or very moist inflow region.

#4) Analyze Heavy Rainfall/Streamflow: FFMP

All & Only Small Basins

- **Configure "Layer" menu**

Start w/ Ratio, then to Diff

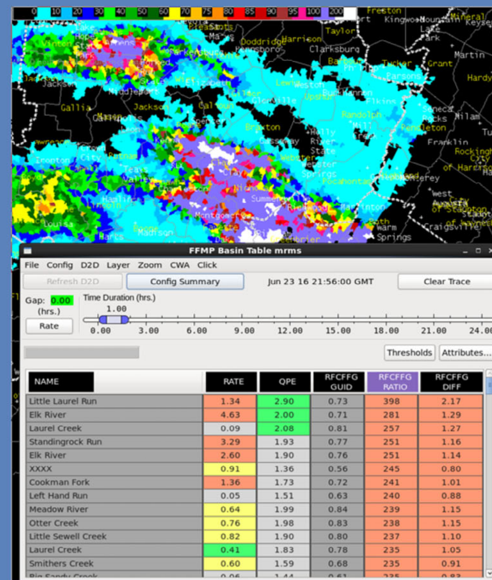
- **Ratio > 100% : location of the threat**
- **Diff > 0 in. : magnitude of the threat**

Duration

- **1-hr : short term**
- **3- and 6-hr : training storms**

Determine downstream direction

- **Configure "Click" menu**



FFMP is a powerful tool that can help you slice and dice QPE and compare to FFG in order to diagnose flash flood threat. Here's some of the basics to effectively use FFMP:

--Always look at your smallest basins, since they are the most flash flood prone.
--Use Ratio AND Difference together to understand the location and magnitude of the threat.
--Consider 1-, 3-, and 6-hour durations for both short-term and training potential.
--And determine the downstream direction so you can anticipate where additional impacts could occur.

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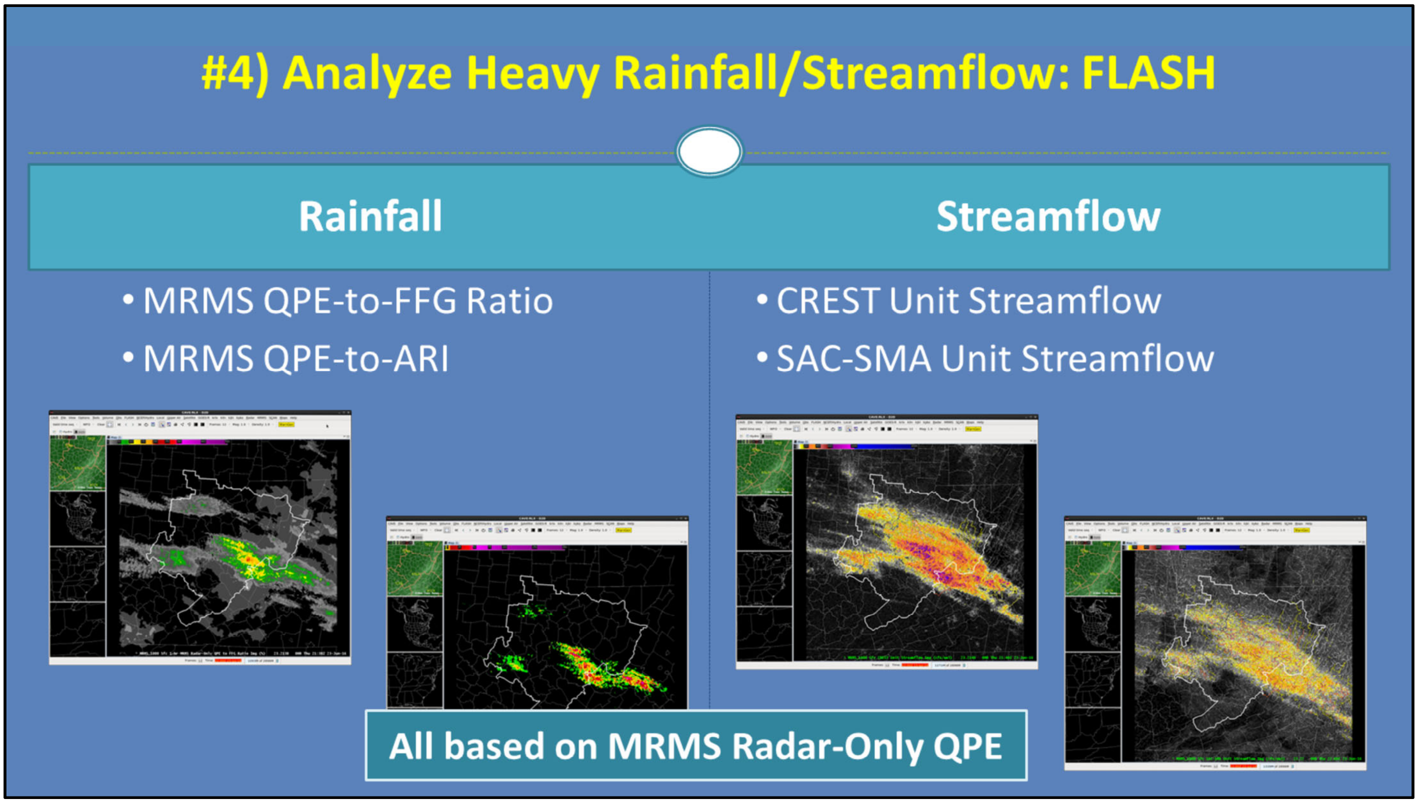
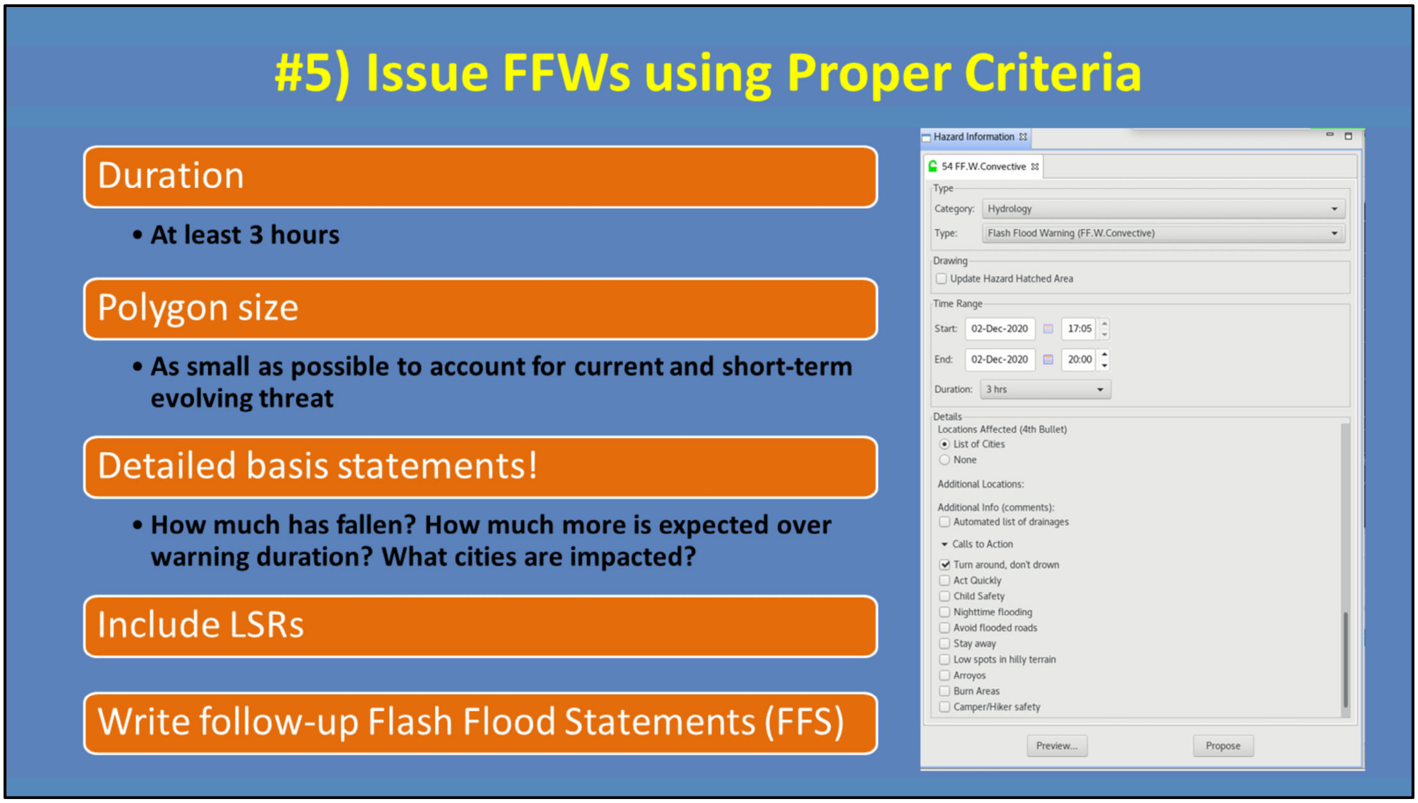


The FLASH suite of products is still new and its full applications are still being investigated. But there are some products that we know are useful now.

When you are interested in analyzing heavy rainfall, the MRMS QPE-to-FFG Ratio product gives a quick look at ratios similar to FFMP. And the MRMS Precip Return Period product compares the current rainfall to ARI thresholds. These gridded products are available at multiple durations.

When you want to analyze the hydrologic response, the unit streamflow products for both the CREST and SAC-SMA models are useful for diagnosing where above normal flow is occurring.

Keep in mind that all of these products are based around the MRMS Radar-Only estimates. So any biases in the QPE will immediately affect all of these products.



It all comes together in the final step of issuing a sound warning.

--Your warnings will generally be at least 3 hours in duration to account for rainfall, runoff, and receding time.
--Polygons should effectively cover the current and short-term evolving threat.
--The warning text should include relevant details about current and forecasted rainfall amounts and impacts.
--Always include Local Storm Reports if you've got em.
--Effectively communicate impacts through frequent updates, at least once per warning, when important reports arrive or information changes.

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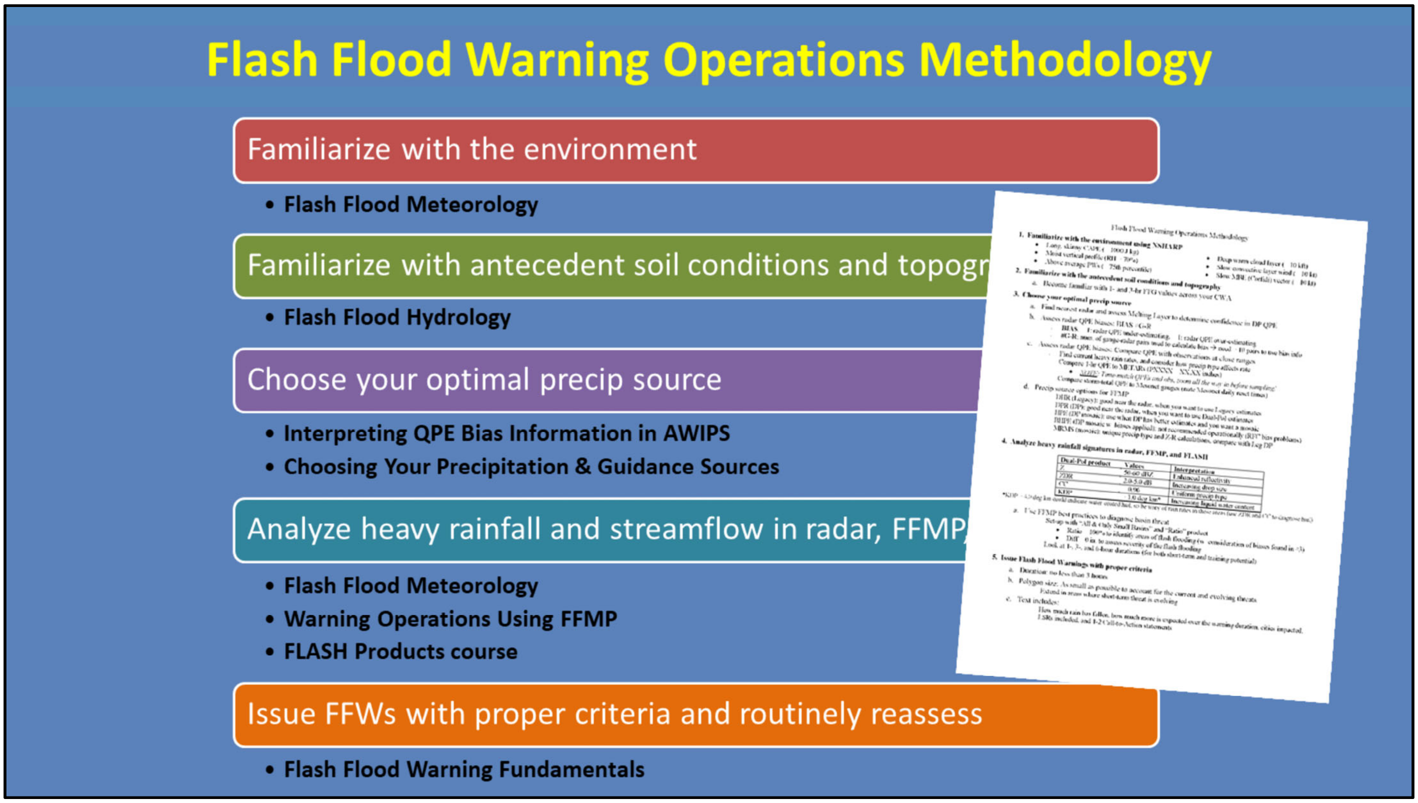

And there ya have it! Our Flash Flood Warning Operations Methodology in a nutshell. Remember to refer back to any of these lessons to get a better breakdown of each step. Additionally, we have created a one-page reference guide that summarizes all of this information in a printable form. It is available through the VLab page on the link in the Resources tab.

Thanks for taking this lesson! There is no quiz, so just close when you are ready.