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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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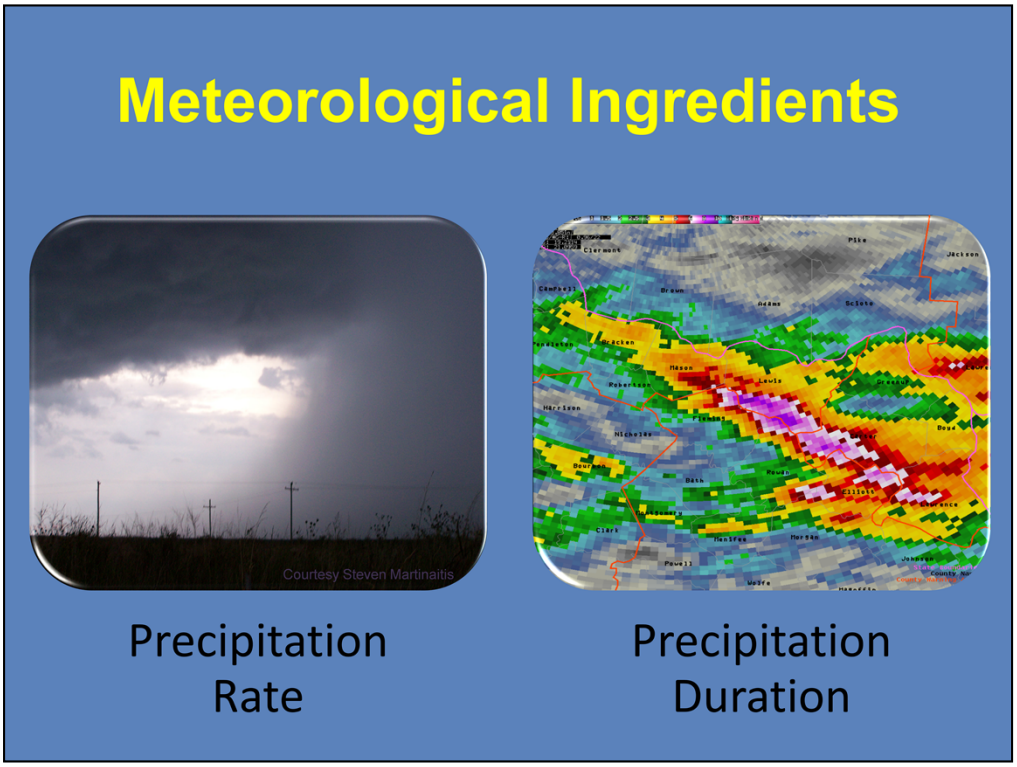

When it comes to the meteorological aspects of flash flooding, the two most important things to consider are the precipitation rate and the precipitation duration. Let's focus on the factors that influence the rate first.

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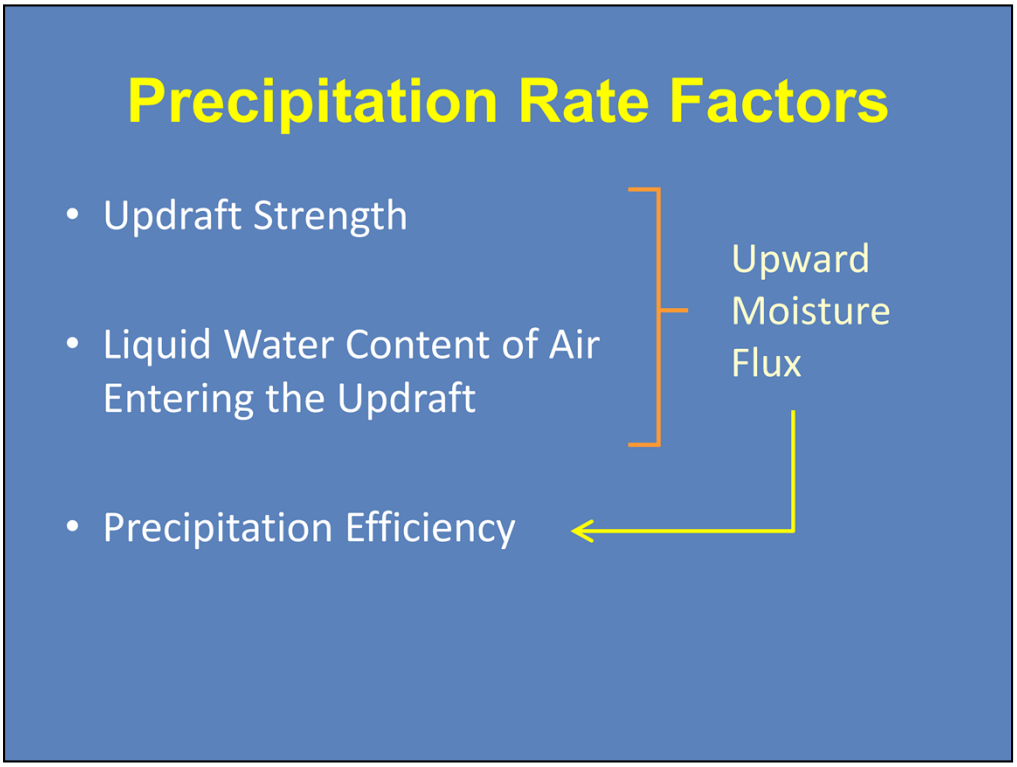

There are several factors that help determine the precipitation rate. The updraft strength and the liquid water content of the air that is entering the updraft contribute to the upward moisture flux into a storm. The percentage of that moisture flux that returns to earth as precipitation characterizes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

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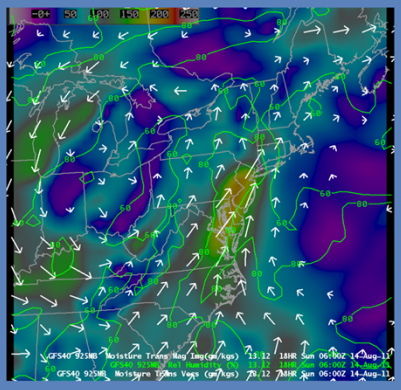
Precipitation Efficiency

- 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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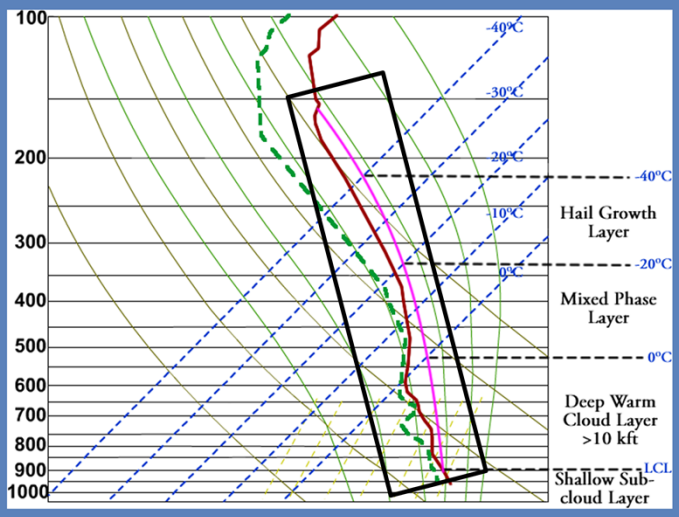
Updraft Strength: Relation to Upward Moisture Flux



- CAPE Profile
  - Long, Skinny
  - < 1000 J/kg
- Too much CAPE leads to hydrometeors lofted into hail growth zone

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.

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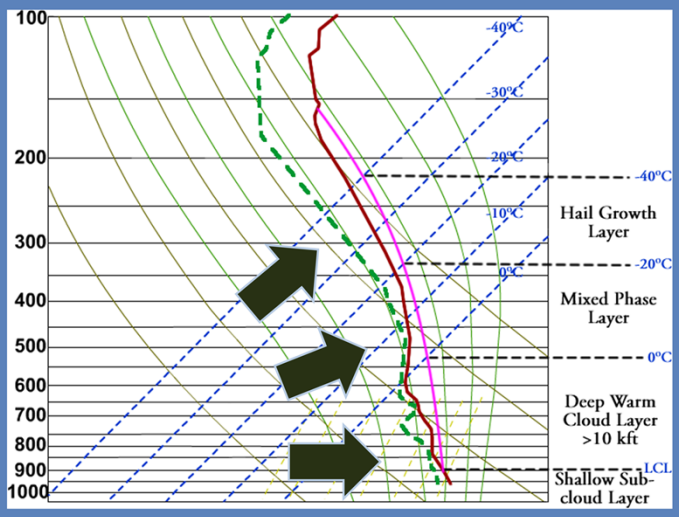
Vertical Moisture Profile: Liquid Water Content



- Entire vertical profile is moist
  - High RH values
  - Lack of mid and upper-level dry air
- Above normal precipitable water (PW) values

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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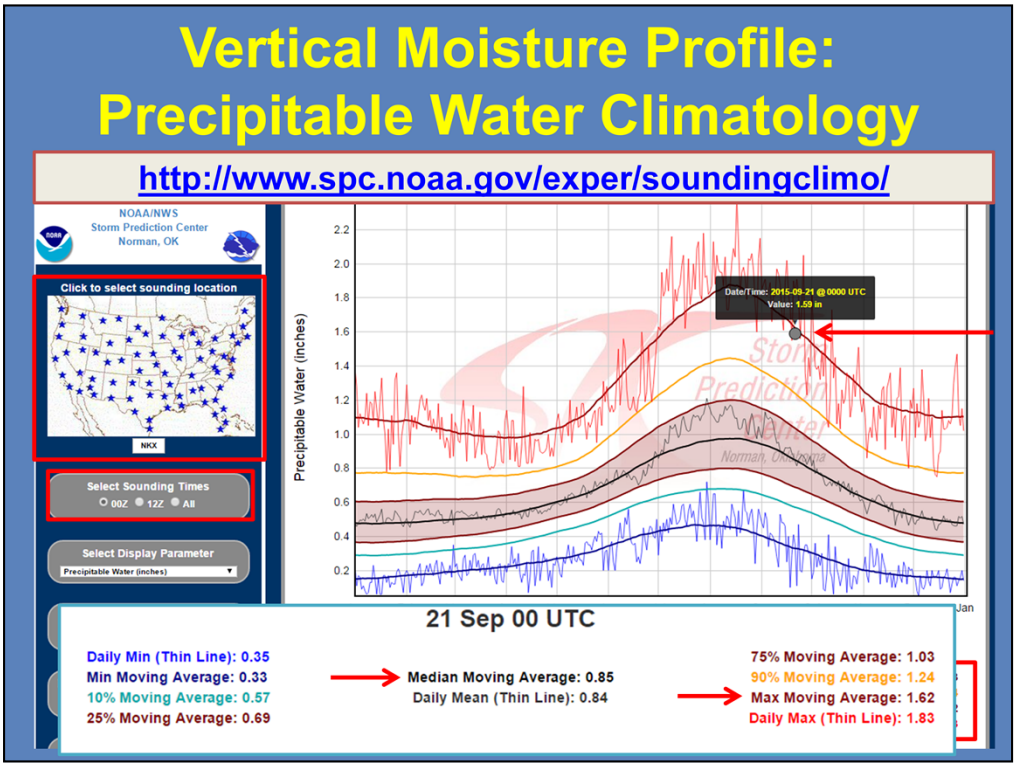

I'm going to briefly hop in here, as there's been a change since this lesson was created. Many of you may have been familiar with Matt Bunkers' Precipitable Water Climatology page. However, the SPC now hosts the point sounding climatologies, similar to the previous website.

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!

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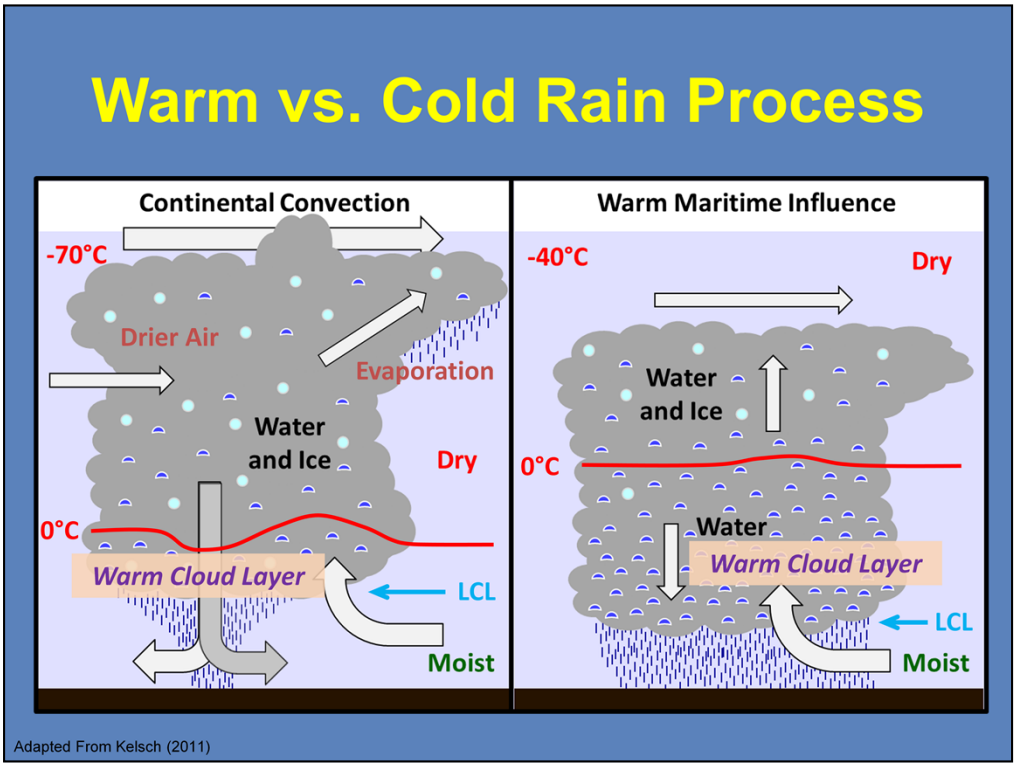

Now that we have analyzed the CAPE and moisture profile of the atmosphere, we can see how it helps determine whether a warm rain or a cold rain process is the predominant precipitation production method. Recall that precipitation forms through collisions and coalescence within a warm rain process while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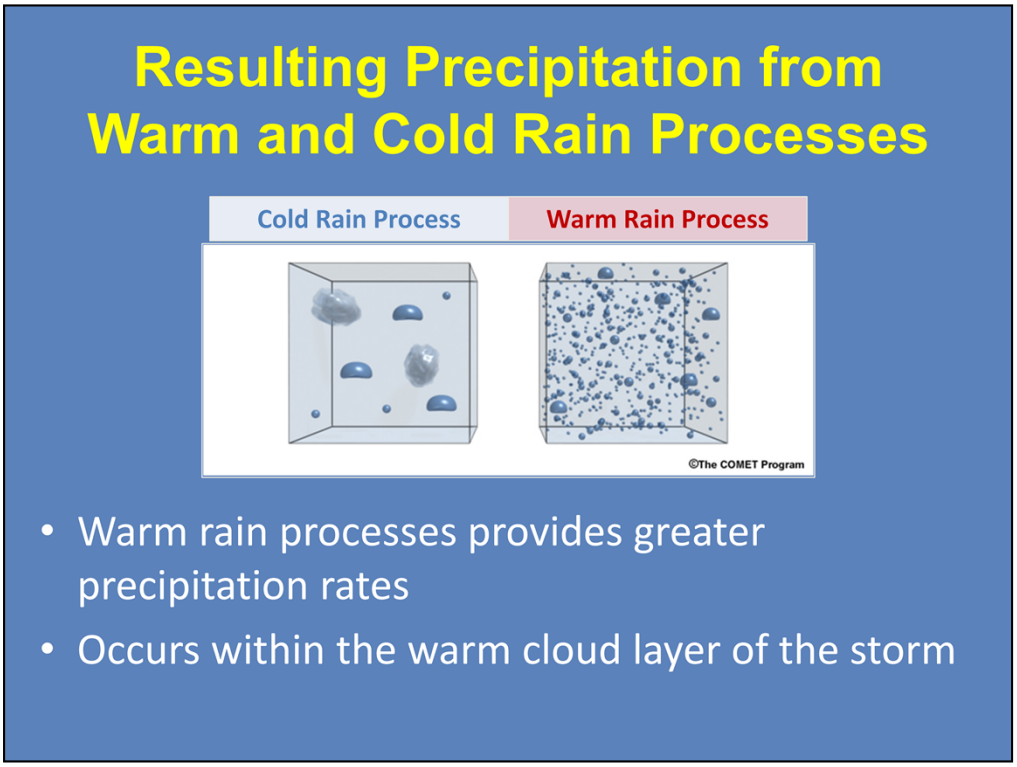

Comparing the resulting precipitation at the surface, you can see the dominant cold rain processes from the continental airmass yields a small quantity of rain drops that are generally large in size and can also include hail stones. The dominant warm rain processes in the maritime airmass has a substantial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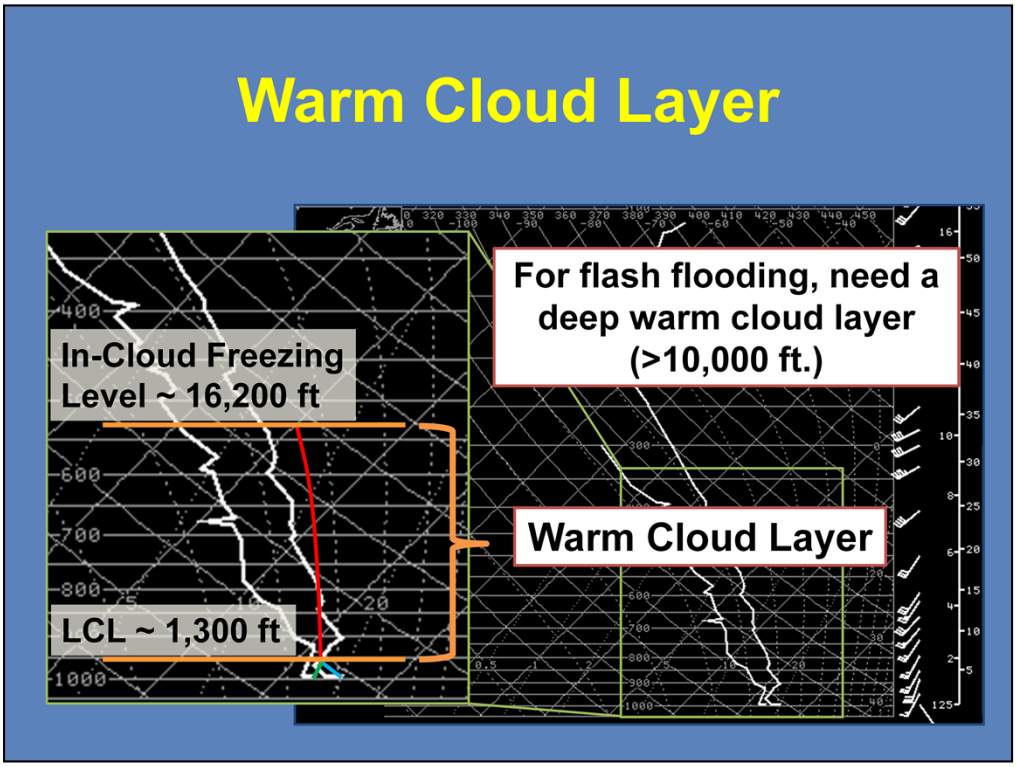

To calculate the warm cloud layer, we will use this sounding from Grey, ME during a summer-time convective event that had some flash flooding. Focusing on the lower and mid levels of the atmosphere, you would start by finding the LCL. Follow the dry adiabatic lapse rate from the surface temperature and 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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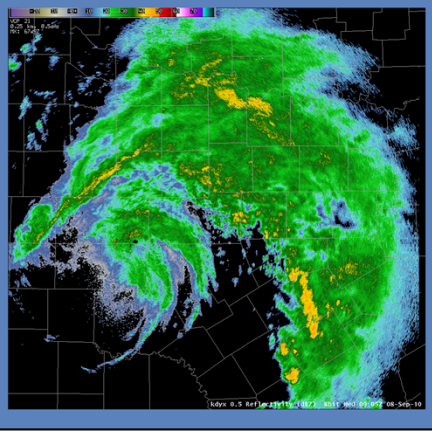
Cloud Seeding

- 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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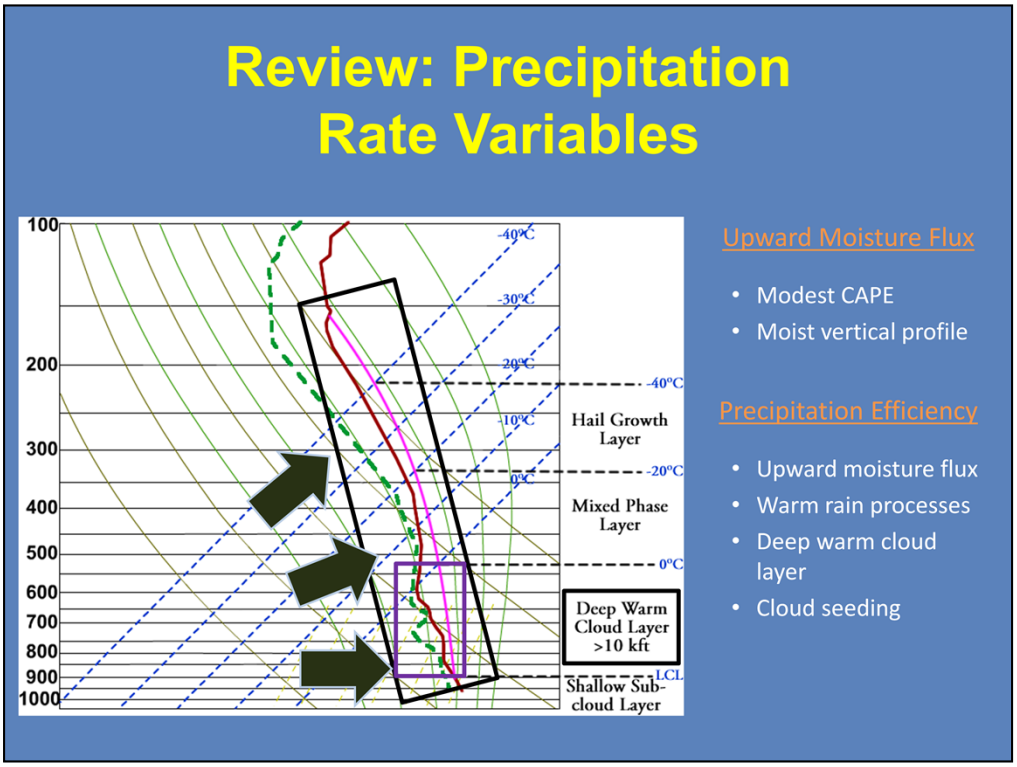

Let's quickly recap what influences the precipitation rate. First, you have to consider the variables that go into the upward moisture flux of a convective storm, such as a modest CAPE profile, generally under 1000 J/kg, and a moist vertical atmospheric profile.

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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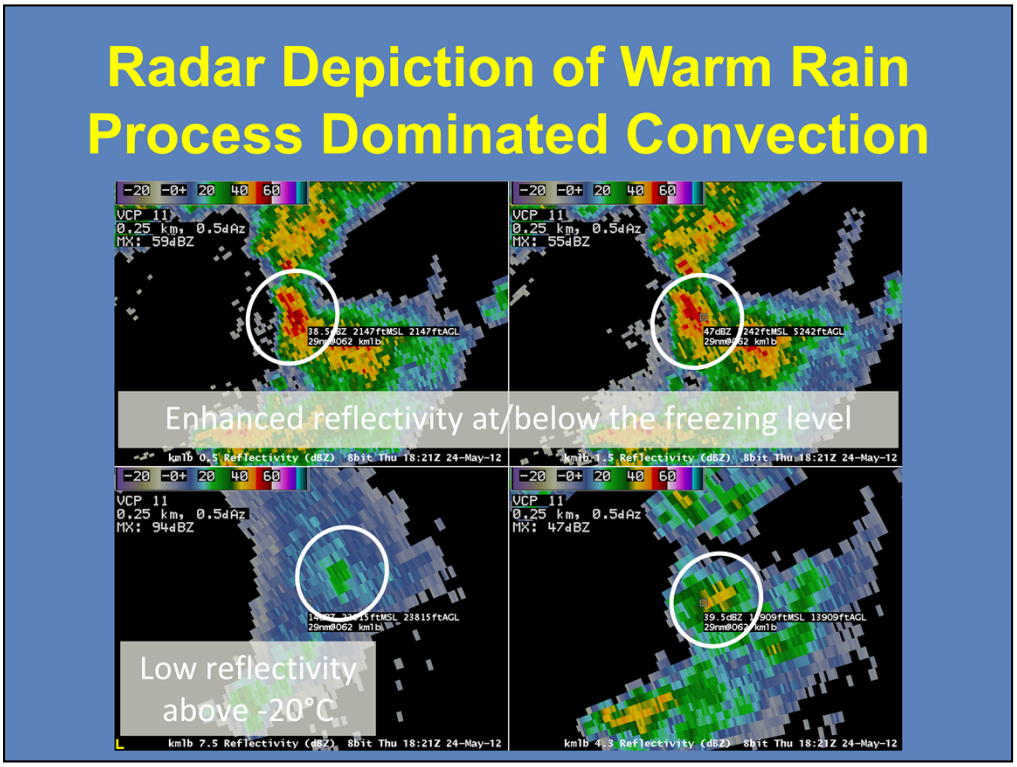

So what does convection dominated by the warm rain process look like on radar? Honestly, not much unless you know what you are looking for. The two main characteristics of convection dominated by the warm rain process are enhanced reflectivity values at or below the freezing level and low to non-existent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

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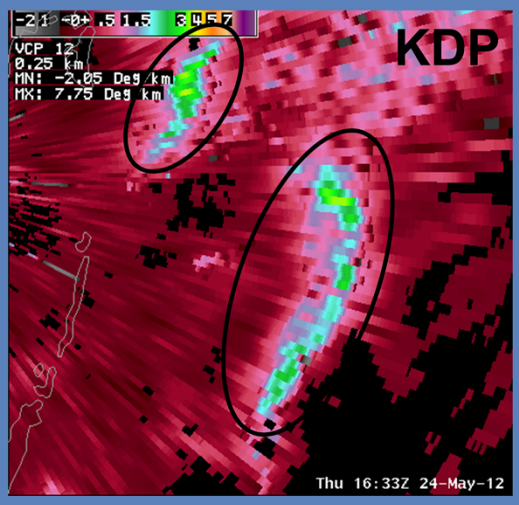
Identifying Heavy Rainfall using Dual-Polarization

Characteristics

- 50 dBZ < Z < 60 dBZ
  - 40 < Z < 55 dBZ

  for tropical environments
- 2.0 dB < ZDR < 5.0 dB
  - 0.5 < ZDR < 3.0 dB

  for tropical environments
- CC > 0.96
- KDP > 1.0 deg/km



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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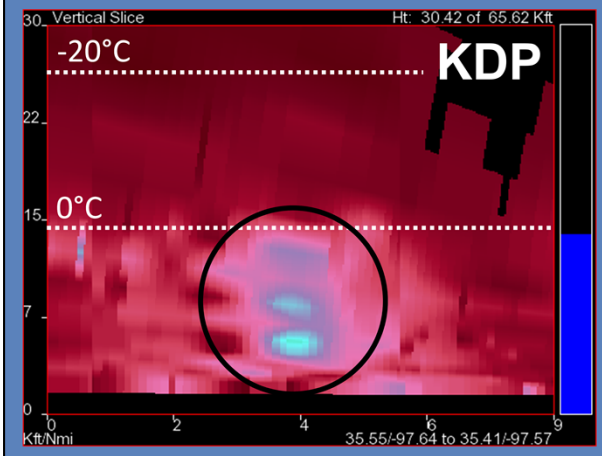
Dual-Pol: Low-Echo Centroid Signature Cross Section



- Greatest reflectivity and ZDR values at/below freezing level
- CC constant > 0.98 throughout
- Greatest KDP values below freezing level

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.

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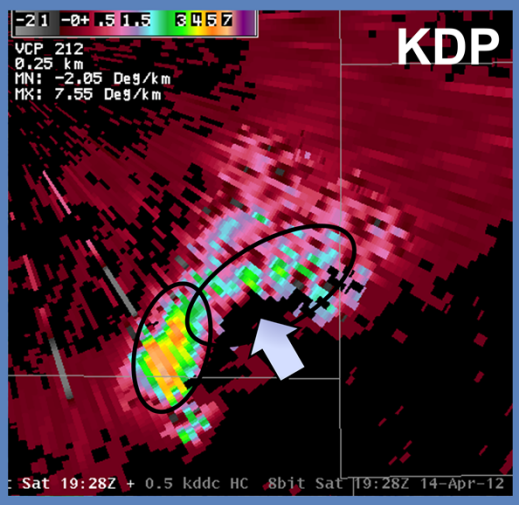
Dual-Pol: Identifying Heavy Rainfall with Supercells

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.

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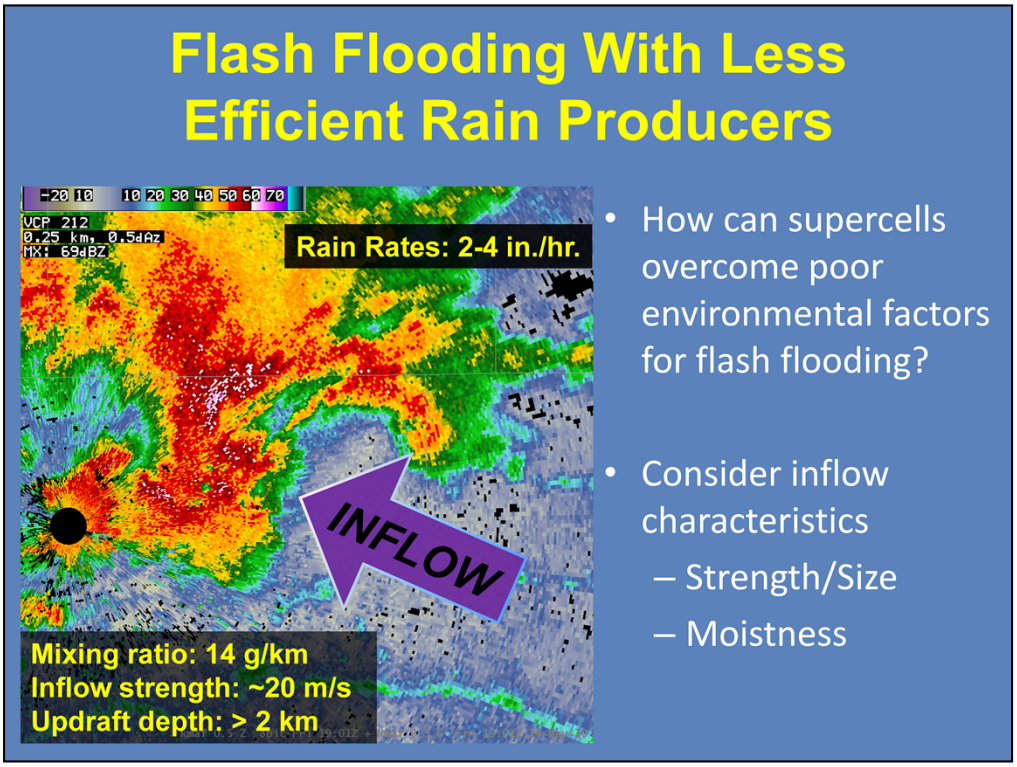

The key to high precipitation rates with supercells is understanding why supercells are such a threat despite poor precipitation efficiencies and at times swift movement. You just saw the dual-polarization characteristics of a supercell. However, there are some environmental factors to consider. In this 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.

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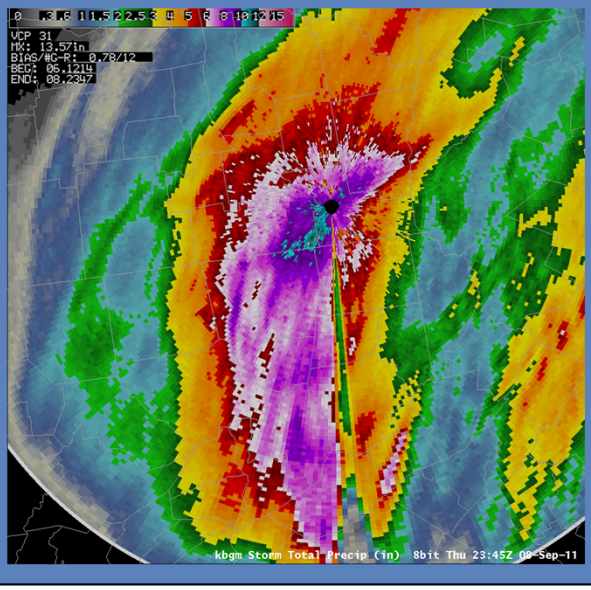
Precipitation Duration Factors

- 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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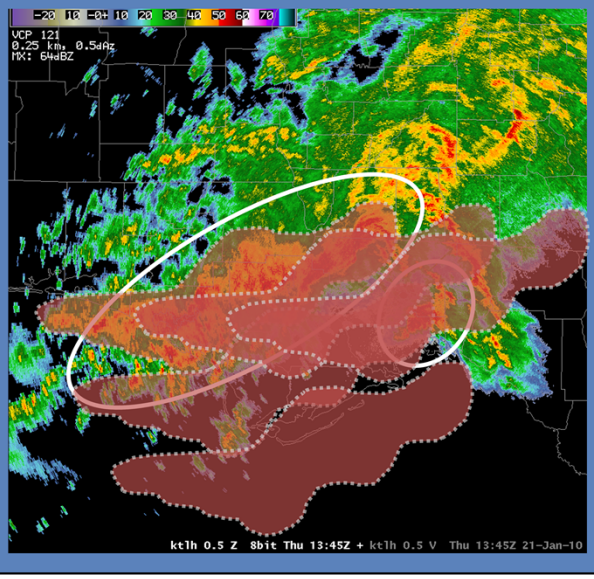
Rainfall Area

- Size and shape
- Orientation along motion path



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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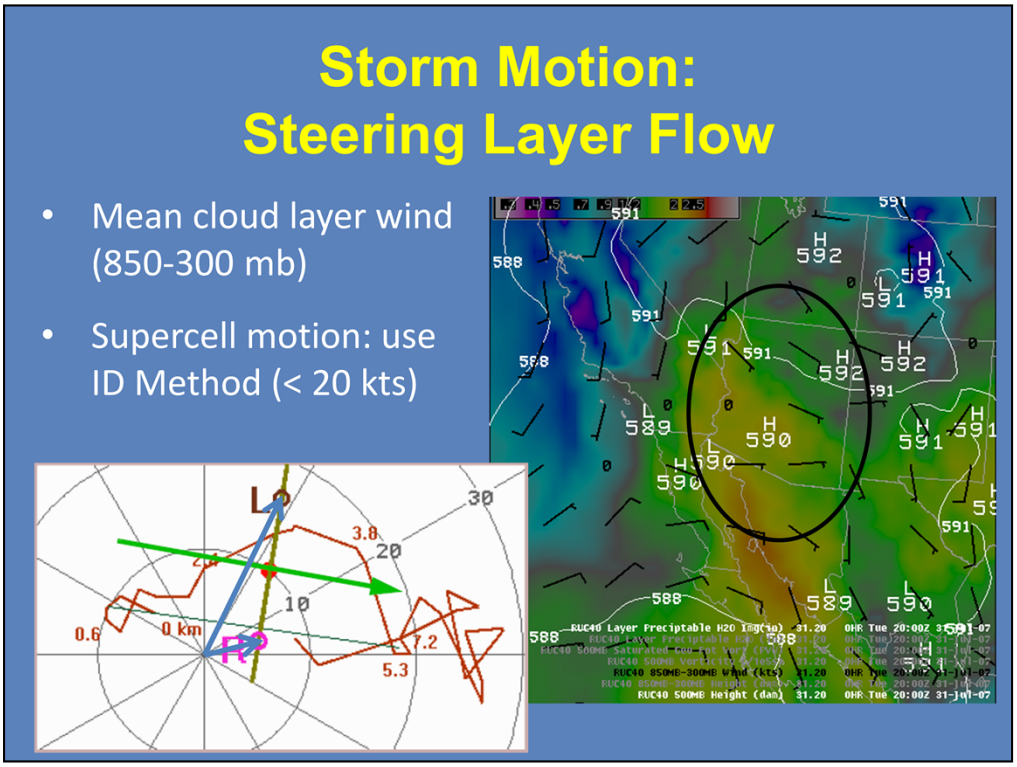

Storm motion is a significant factor when it comes to precipitation residence time over an area. Obviously, slower storm motions lead to longer durations. But what would you look for to determine storm motion?

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.

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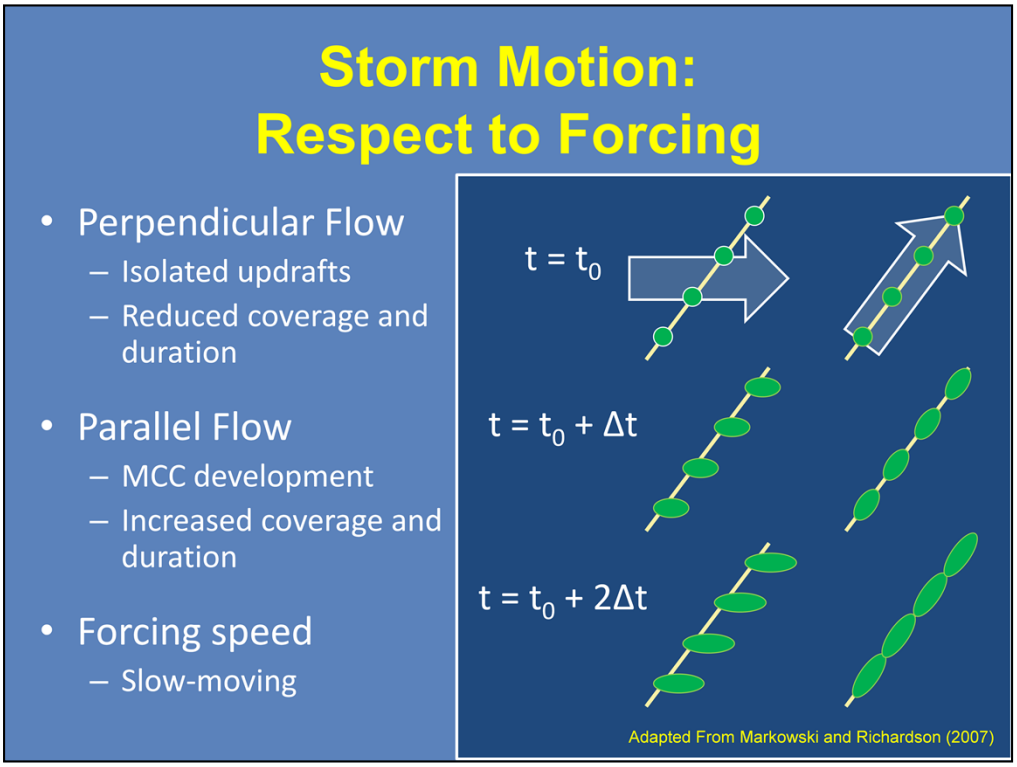

Forcing mechanisms play an integral role in the development and motion of convection. A forcing mechanism can range from fronts to outflow boundaries to topographic features. How storms form and move along a boundary can determine whether you have isolated updrafts or consolidated line segments and mesoscale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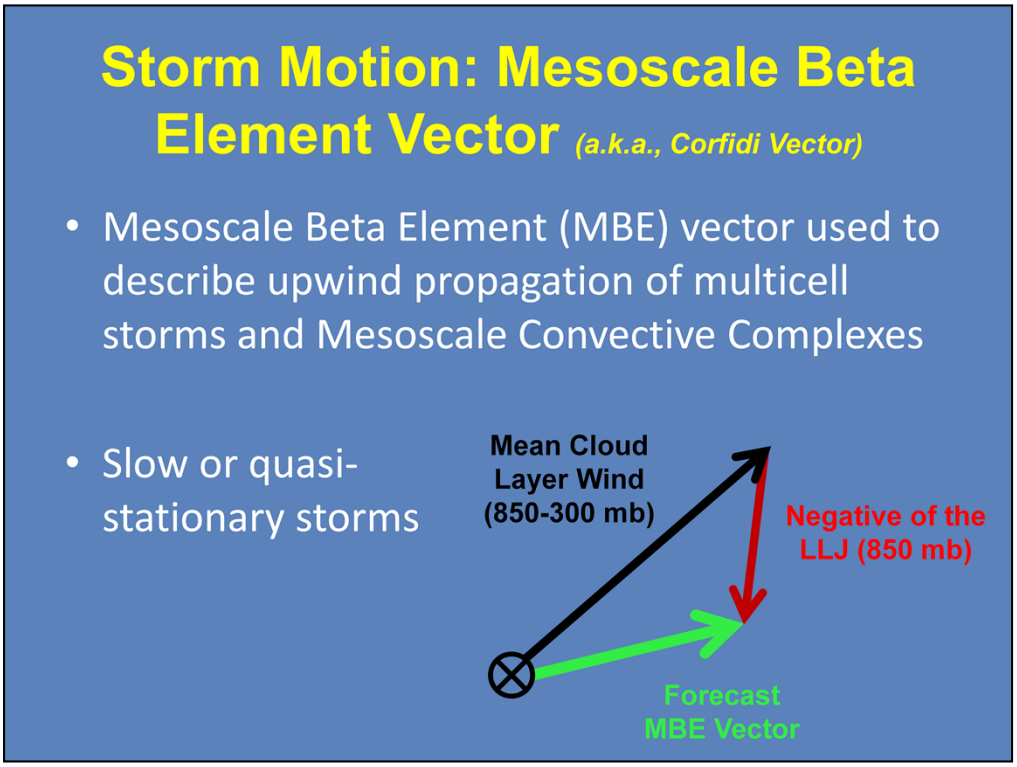

When dealing with multicell storms and mesoscale convective complexes (MCCs), the Mesoscale Beta Element (MBE) vector can help describe the upwind propagation of multicells and MCCs. Recall from the lesson on Multicell Motion that the MBE vector is calculated from taking the mean cloud layer wind and 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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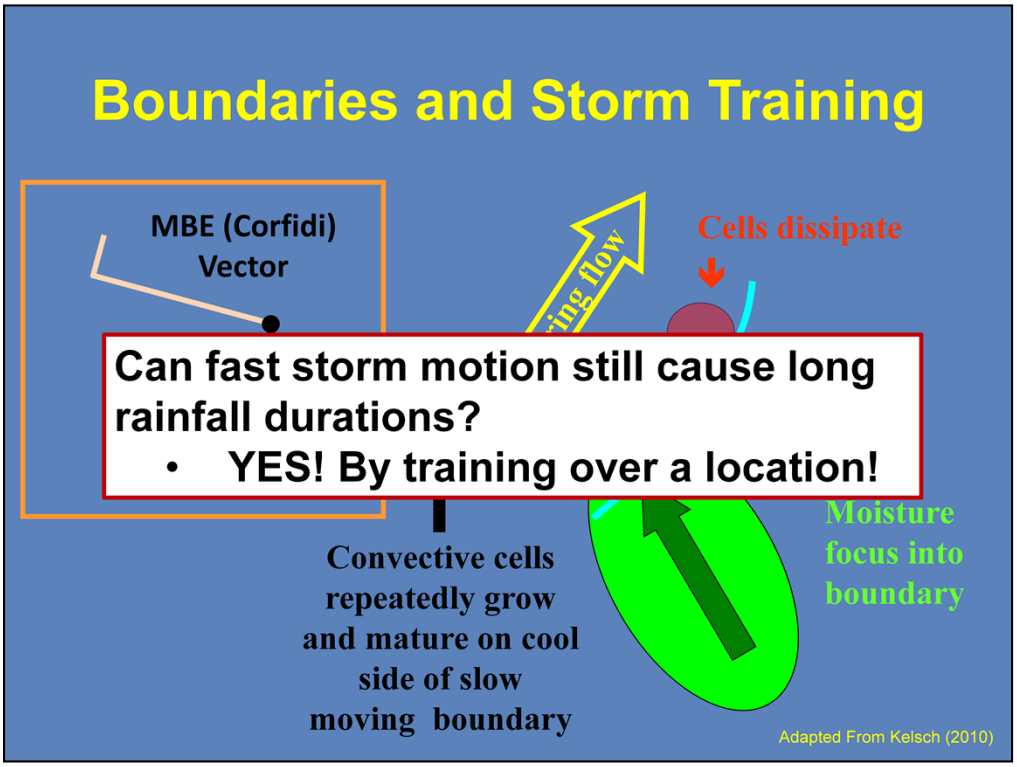

So far, we have talked about slow storm motions. What if storm motions are relatively fast? Can we still get large durations of rainfall? The answer is definitely yes.

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.

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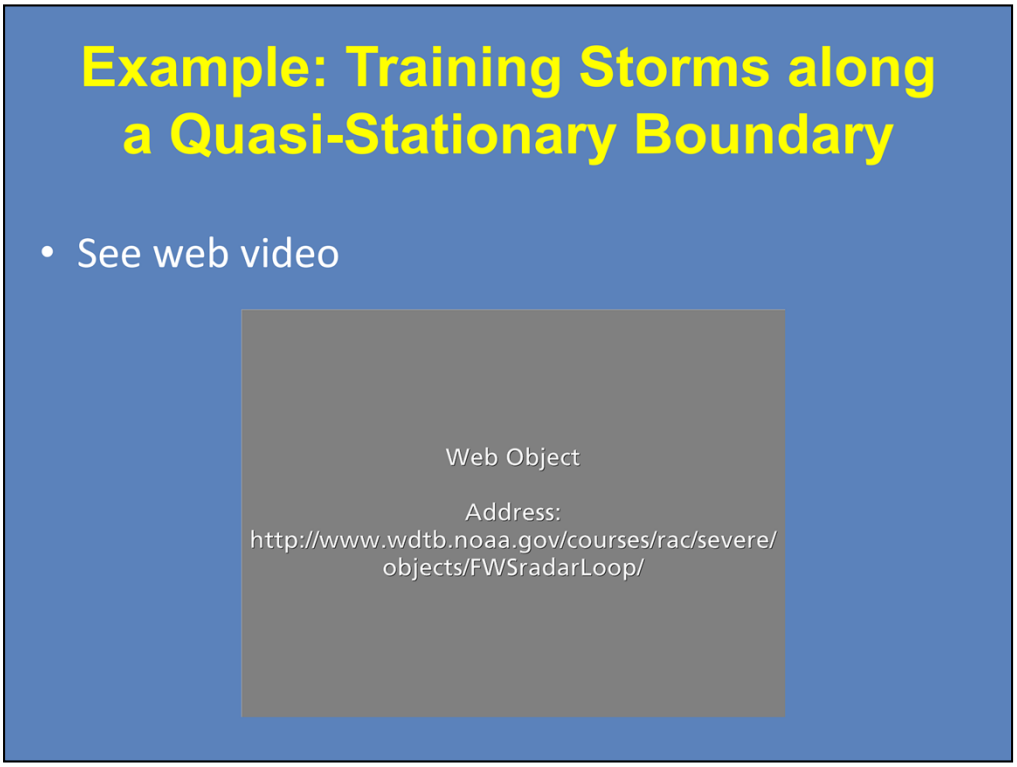

Here is an example of training storms that led to significant flash flooding. In this case from the Dallas/Fort Worth office, a series of storms train over the northern part of Texas near the Red River. This loop shows 5 ½ hours of radar data from KFWS. The star on the map shows the relative area of 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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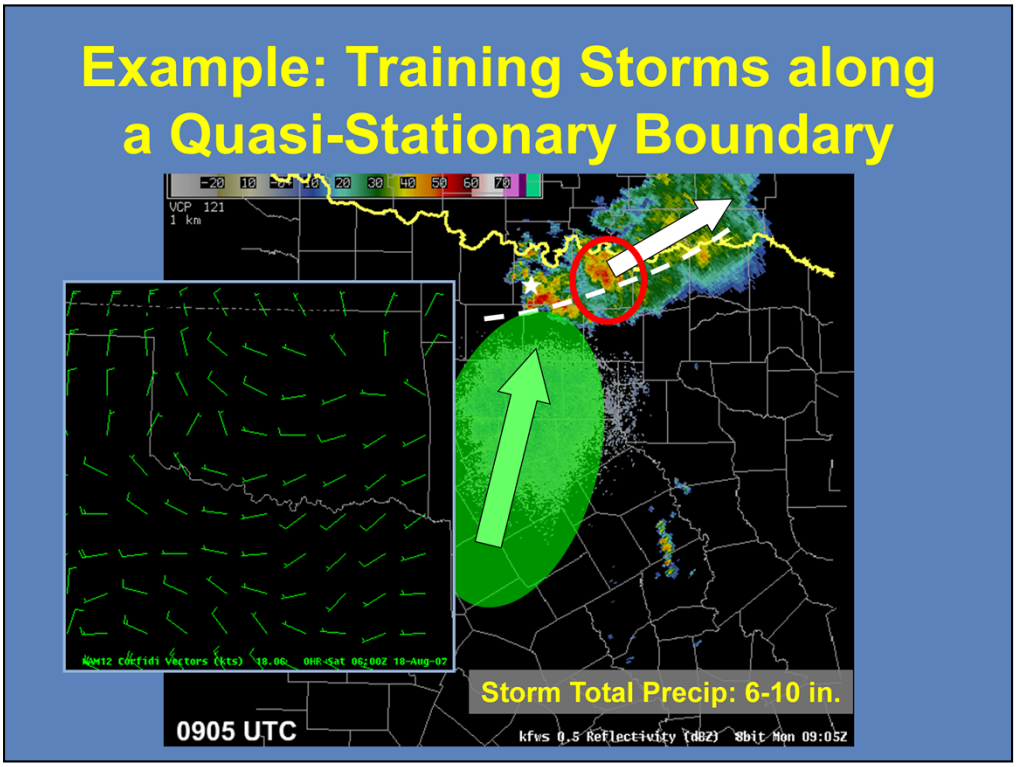

This event was created from a remnant mid-level circulation and boundary where a small vorticity maximum around the southern periphery is providing focus along the axis of forcing. The 1200 UTC sounding from Dallas/Fort Worth showed a very moist southerly 850 mb winds at 35 kts. You saw that storms initiated 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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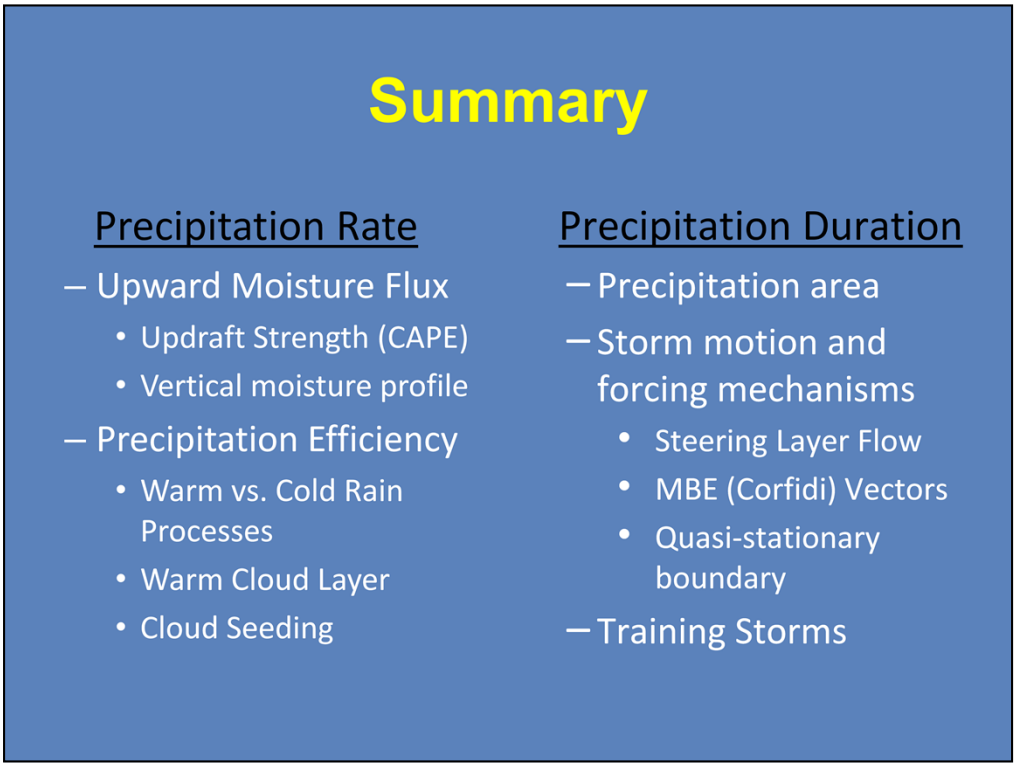

In summary, you saw that there were two primary meteorological factors regarding rainfall and flash flooding. With precipitation rate, you saw how the strength of the updraft and the overall vertical moisture profile played a role in the upward moisture flux into a storm. The fraction of that that is 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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Jill Hardy again and welcome to this lesson on flash flood hydrology. Steve Martinaitis of OU CIMMS at NSSL will again be narrating. 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 basic details of flash flood guidance
- Identify the hydrologic characteristics that impact the flash flood potential and flash flood guidance

There are two objectives to this lesson. At the end of this presentation, you should be able to identify the basic details regarding the creation of flash flood guidance and to identify the hydrologic characteristics that can impact the flash flood potential and the flash flood guidance product.

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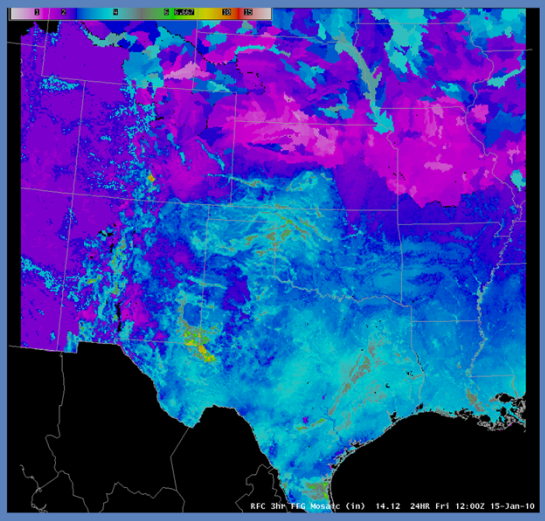
Why Hydrology is Important



Flash Flood Guidance

Amount of rainfall needed within a certain period of time for small streams to overflow their banks

Understanding hydrologic properties, such as basin geometry, land use, and soil moisture, can help in determining what areas are prone to flash flooding and why. The flash flood guidance (FFG) product is created using these hydrologic properties to provide NWS forecasters a rainfall value needed within a certain temporal period for small streams and creeks to overflow their banks. And as you can see, these values can vary quite drastically across the country.

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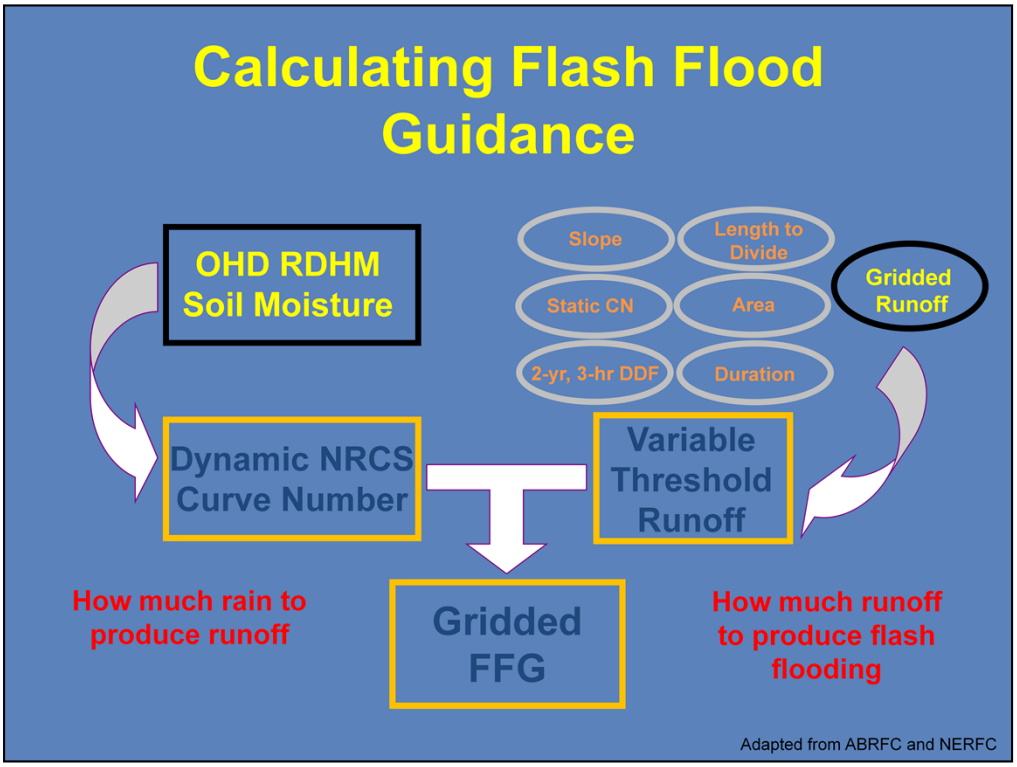

Most river forecast centers (RFCs) create a gridded flash flood guidance (FFG) product generally four or more times a day. FFG is derived from how much rainfall is needed to produce runoff via a dynamic National Resources Conservation Service, or NRCS, curve number (CN) and how much runoff is needed to produce flash flooding via a threshold runoff, or Thresh-R, value.

Both the NRCS curve numbers and Thresh-R values are calculated using different hydrologic properties. We will first focus on what hydrologic conditions influence the NRCS curve number.

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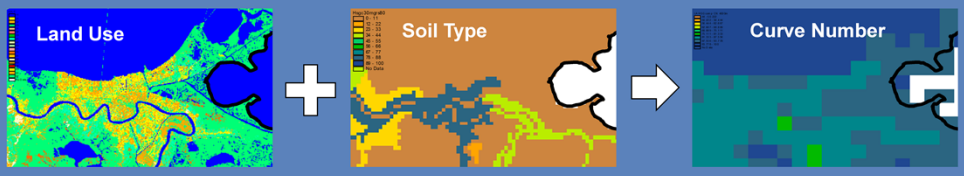
Defining the Curve Number

- National Resources Conservation Service (NRCS) Curve Number (CN) – Empirical parameter for predicting direct runoff



- Let's first talk about some of the land/soil properties…

The National Resources Conservation Service, or NRCS, Curve Number (CN) is an empirical parameter for predicting direct runoff. The curve number is generally based on soil type and land use, which both impact the amount of rainfall that is intercepted and infiltrated. The higher the curve number, the less rain is needed to create runoff. So, before we go into the operational details of the curve number, let's focus on the characteristics of land usage and soil types.

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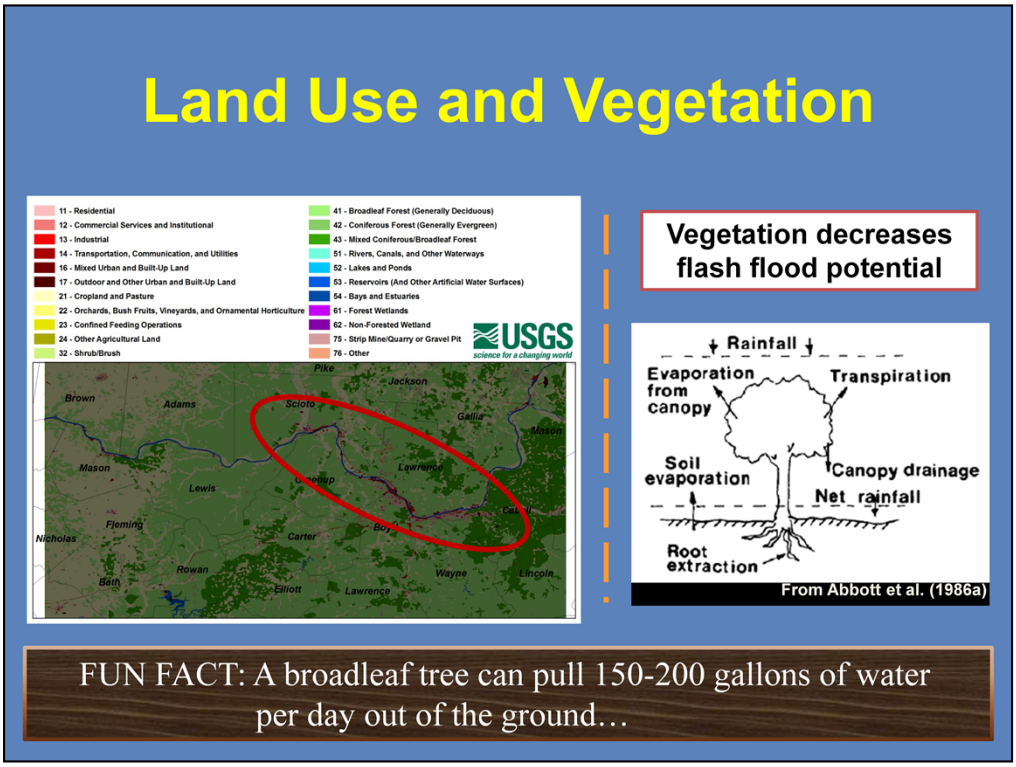

Land use can help determine how much water can be intercepted and how much water can be translated into runoff. Shown here is an example of a land use map for southern Ohio and northern Kentucky. The western part of this domain is dominated by croplands and pastures. The eastern two-thirds is a combination of broadleaf and coniferous forests. Urbanized areas are located along the Ohio River, and we will talk about the impacts of urbanization later in the module.

One the bigger influences of land use on the curve number is vegetation. Vegetation of all types help decrease the flash flood potential. Leaves can intercept rainfall before it reaches the surface. Water on and within the foliage undergo evapotranspiration. Roots help increase infiltration and can extract water from the surface and top layers of the soil. Did you know that one broadleaf tree can extract 150-200 gallons of water from the ground in one day? That's a lot of water. This is why areas devoid of vegetation or have been deforested have higher curve numbers and a higher potential to flash flood.

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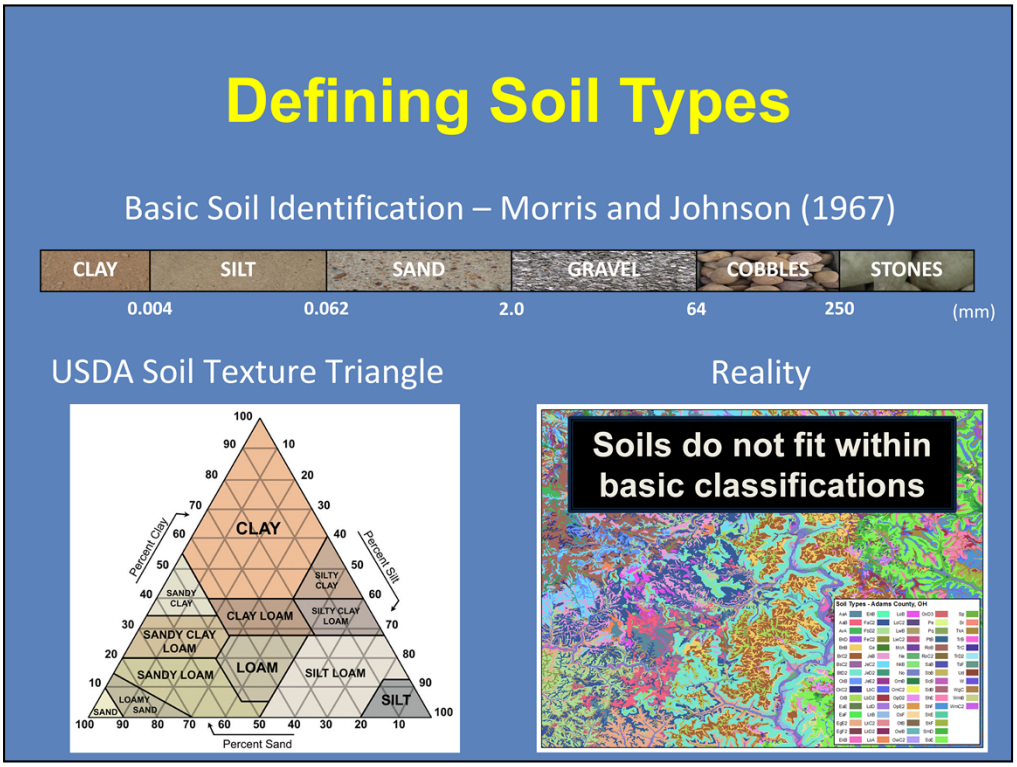

How soils are defined has evolved over the decades. The work by Morris and Johnson in 1967 defined the three basic soil types by the average size of their particles. Clay was defined by particles less than 0.004 mm while sand particles can approach 2 mm in size. The USDA then developed a soil texture triangle to better determine soil types based on the proportion of sand, silt, and clay after particles larger than sand have been removed. The USDA soil texture triangle defines 12 different soil types, including loam, which is a soil composed of sand, silt, and clay in relatively even proportion, and these types are commonly used in curve number and modeling calculations.

In reality, there are dozens upon dozens of soil types in the country. This image here shows 76 different soil types just within Adams County, OH. And in reality, soils do not fit within their basic classifications, such as those described by Morris and Johnson (1967).

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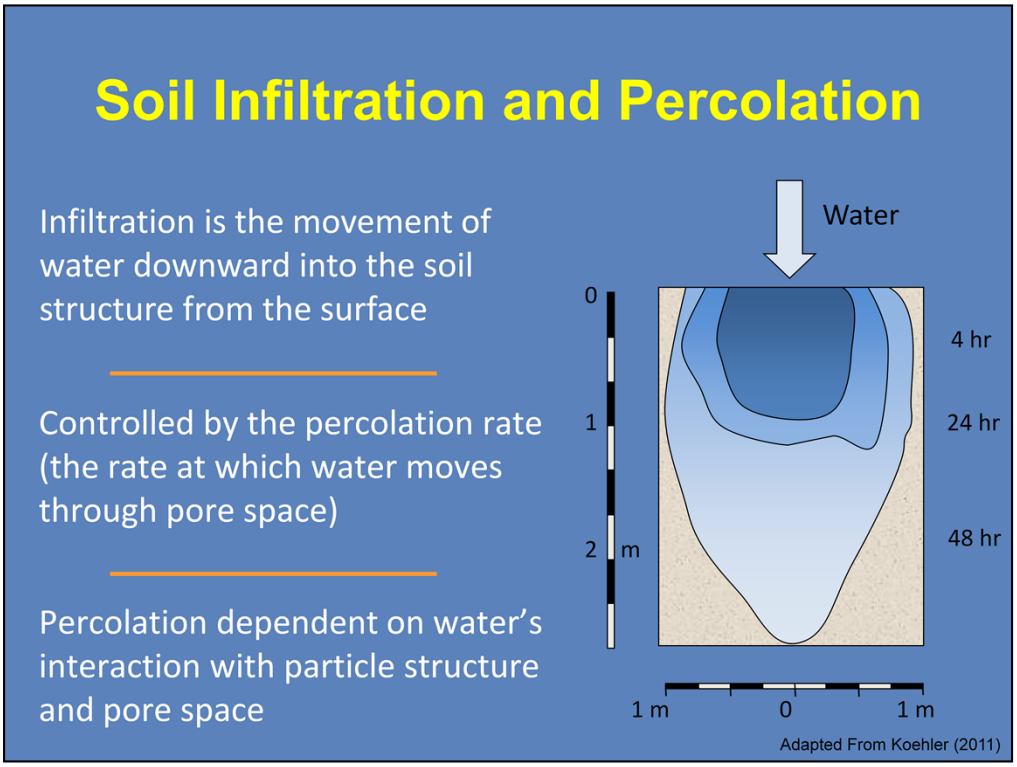

One of the most important characteristics of soil that impact runoff potential is the ability of water to infiltrate the soil. Infiltration is the downward movement of water from the soil surface into the soil structure. The ability of water to infiltrate the soil structure is controlled by the percolation rate, which is defined as the rate at which water moves through pore space. The percolation rate is generally dependent upon how water interacts with the particle structure and volume of porous space. For example, the pore space of clay-type soils can vary, but how water interacts with the clay particle reduce the infiltration and percolation rates. Thus, it takes less water to generate runoff. There are a number of different equations that can be used to calculate soil infiltration, which will not be discussed here.

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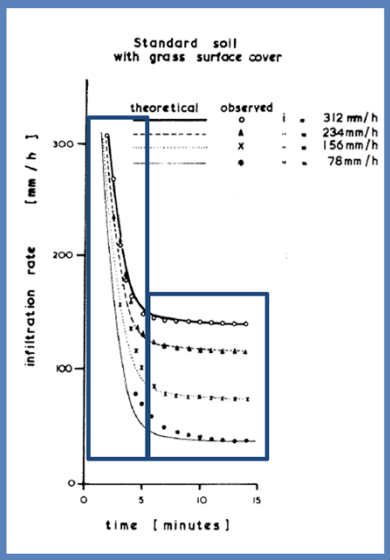
Decay of Infiltration During a Rain Event

- Infiltration capacity decreases exponentially to an equilibrium rate
- Influencing Factors
  - Percolation
  - Storage of water
  - Particle absorption and swelling



From Nassif and Wilson (1975)

One important thing to know is that the maximum infiltration rate of the soil, more commonly referred to as the infiltration capacity, is *not constant*. A study by Nassif and Wilson (1975) compared rainfall rates with the infiltration properties of various soils. They tested different soil types, including some with grass surfaces, at different slopes using large soil trays and a sprinkler-type system to simulate instantaneous rain rates from 3-12 in./hr.

During their experiments, they found that within the first 5-10 minutes of applying the simulated rainfall, the infiltration rates of the soils decreased exponentially and began reaching an equilibrium rate. The experiment also demonstrated why a saturated ground cannot take in as much water as an unsaturated ground. The biggest factor that influences the ability of water to infiltrate the soil is percolation, while storage of water in the soil and particle absorption and swelling also influence this process.

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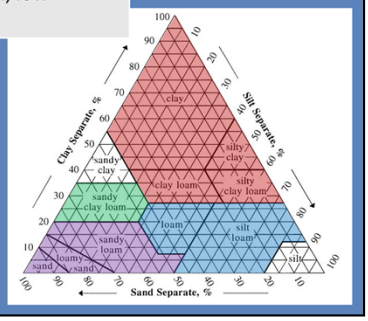
Soil Infiltration and Curve Number

HSG	Soil Type	Characteristic
A	Sand, Loamy Sand, Sandy Loam	Low runoff potential, high infiltration rates
B	Silt Loam, Loam	Moderate infiltration rates
C	Sandy Clay Loam	Low infiltration rates
D	Clay Loam, Silty Clay Loam, Silty Clay, Clay	High runoff potential, low infiltration rates

- Hydrologic Soil Group (HSG) classification used to determine NRCS Curve Number



Knowing all of this, we look back at how soil types and land use are operationally applied. NRCS soil scientists categorized the soil types defined by the USDA soil texture triangle into four Hydrologic Soil Groups (HSGs) based on infiltration, runoff characteristics, and texture. Group A consists of mostly sandy-based soils that have low runoff potential and high infiltration rates. Group B consists of silt loam and loam that have moderate infiltration rates and moderately coarse to fine particle textures. Group C consists of sandy clay loam, which is has low infiltration rates with moderately fine textures. And finally, Group D consists of mostly clay-based soils that have high runoff potential and low infiltration rates.

These four HSGs are then used to determine the NRCS curve number.

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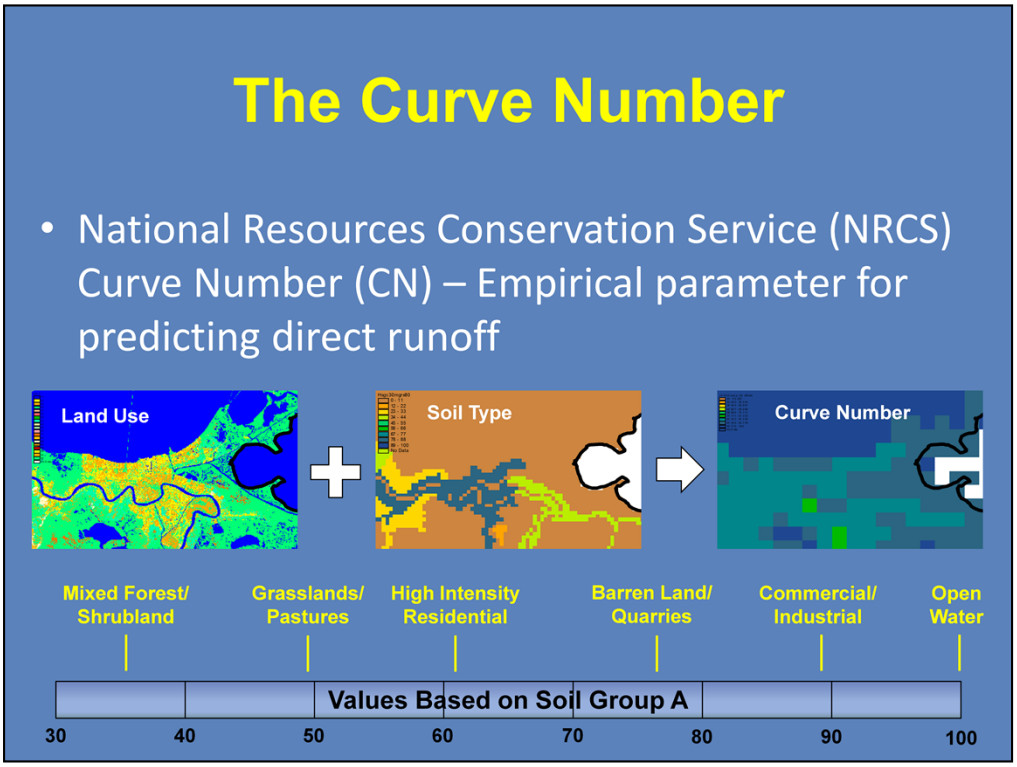

So let's see how the land use and soil types impact the NRCS curve number (CN). The CN is a unit-less number that ranges from 30 to 100. The higher the number, the less rain is needed to create runoff. Each type of land use is given four CNs, one for each Hydrologic Soil Group (HSG). In this example here, we will define the curve number for a variety of land uses for soil Group A, the sandy-based soils with low runoff potential and high infiltration rates.

Mixed forests, shrublands, grasslands, and pastures all have low curve numbers, which means these land uses for this soil group have low runoff potential and would need a lot of rain to generate any runoff. Here are where high intensity residential areas, barren lands, quarries, and commercial/industrial areas fall on the curve number spectrum. Notice how more urbanized land and land devoid of vegetation have much higher curve numbers. Open water has a curve number of 100, meaning all rainfall becomes runoff. Remember that these values are for Group A, the sandy-based soils. The curve number for each land use type is much higher with Groups B, C, and especially D.

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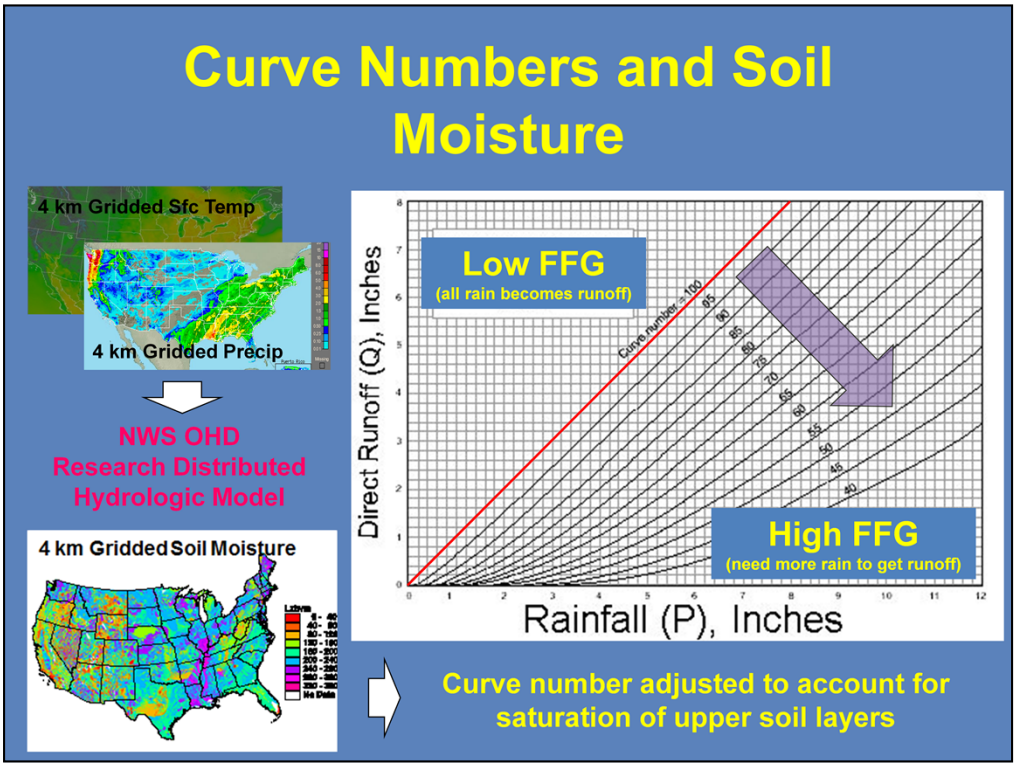

For gridded FFG, the National Weather Service (NWS) Office of Hydrologic Development (OHD) uses a research distributed hydrologic model to create a dynamic curve number. The model uses CONUS-scale 4 km gridded surface temperatures and 4 km gridded precipitation to create a gridded soil moisture product. The CN is then adjusted based on the soil moisture calculated to account for saturation of the upper soil layers. In areas that have seen recent, heavy rainfall, the curve number can be increased to near 100, which means that the FFG is reduced and nearly all rainfall can potentially be translated into runoff. The lower the curve number, the greater the FFG and the more rain that is needed to start generating runoff.

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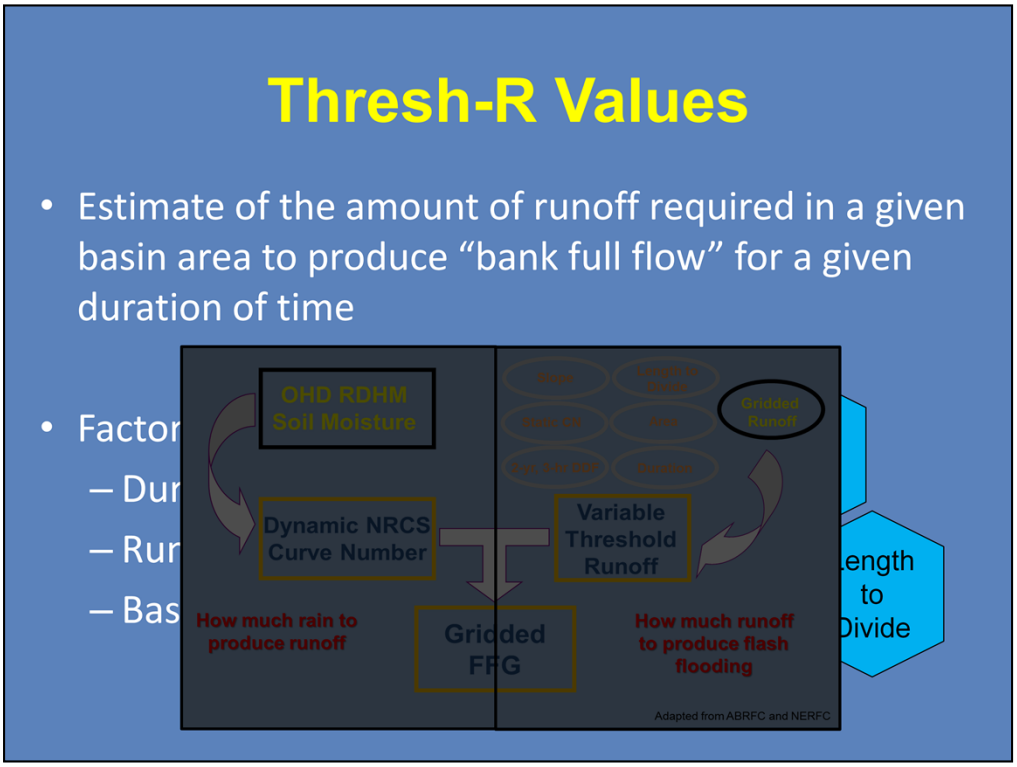

So we looked at the first half of the FFG calculation that asks how much rain does it take to generate runoff. Now we will focus on how much runoff will it take for small creeks and streams to reach "bank full flow" conditions, which is defined by the Thresh-R value.

The Thresh-R value considers a number of different factors, including duration of rainfall, runoff estimation, and a variety of basin characteristics. In this module, we will focus on what impacts basins have on the FFG.

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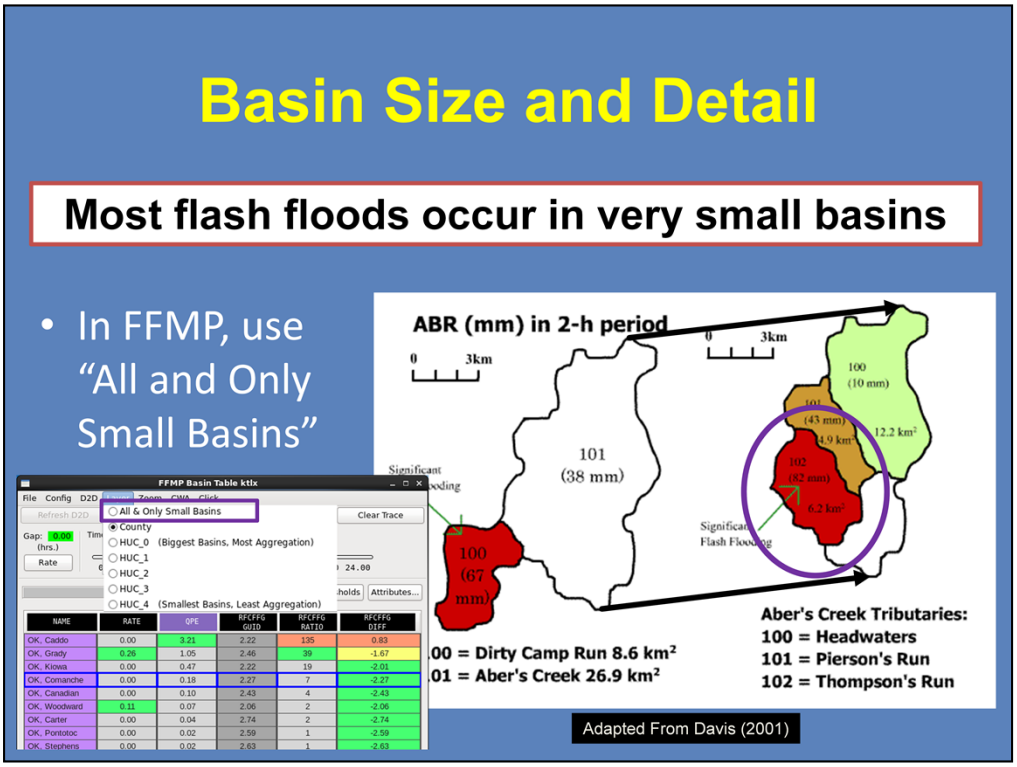

There are many levels of basin detail, ranging from the parent basin, such as the Mississippi River Basin or the Florida Watershed, to the smaller basins and sub-basins that compose them (a couple of square kilometers). The majority of flash floods occur in very small basins, mainly because the scale of the heaviest rainfall is also quite small.

Using this example from the Aberdeen, SD office, you can see two adjoining basins, Dirty Camp Run (#100) and Aber's Creek (#101). Significant flash flooding occurred in the Dirty Camp Run basin as a result of an average of over 2.5 inches of rain in two hours across the basin. In Aber's Creek, there was an average of 1.5 inches of rain across the basin. However, if you were to split the Aber's Creek basin into its sub-basins, you can see that the southwest part of the basin had almost 3.25 inches of rain in this two-hour period. Without looking at the smallest basins, it is possible that some areas would have went unwarned due to large scale basin averaging.

When using FFMP, you will get the greatest detail by going to the Layer menu in the FFMP Basin Table and selecting "All & Only Small Basins."

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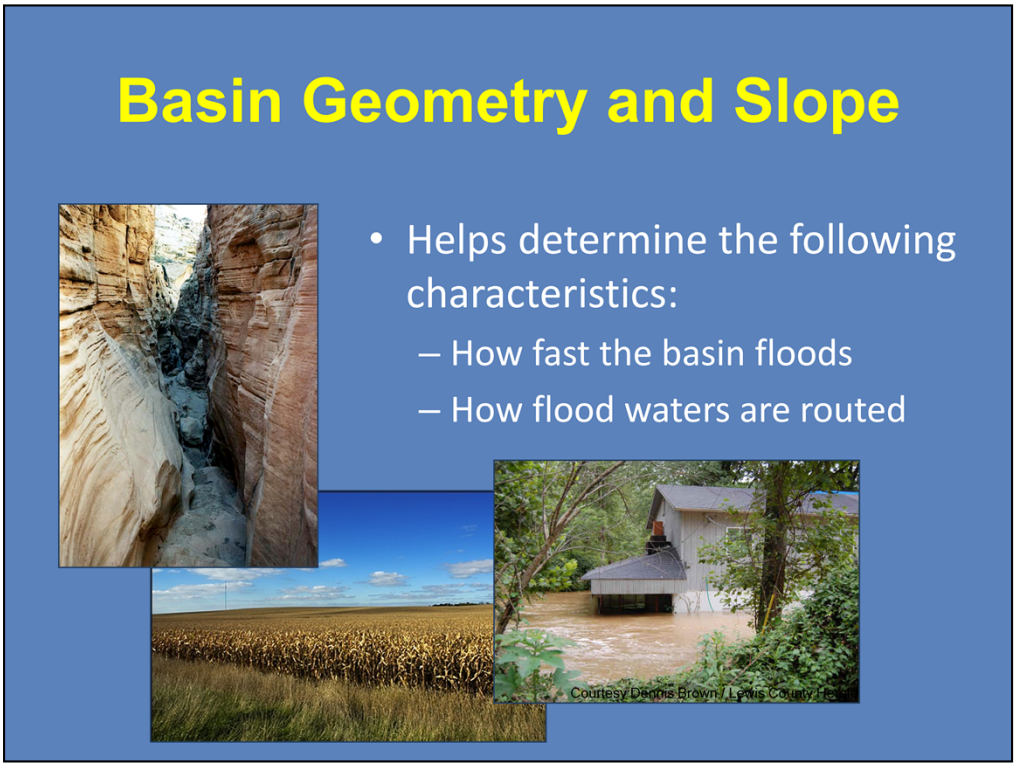

The three-dimensional geometric characteristics of a basin is important when determining how fast a basin can flood and how the flood waters are routed within the basin. A lot of this is dependent upon the slope of the terrain. If we are talking about the flat fields of the central Plains, then it could take awhile for runoff to move out of the area. In contrast, if you look at the mountainous terrain and slot canyons of the western U.S., then water can be quickly routed downstream. Think of a marble on a shelf. If the shelf is level, the marble is stationary. If the shelf sits at an angle, then marble rolls off. The same theory applies here.

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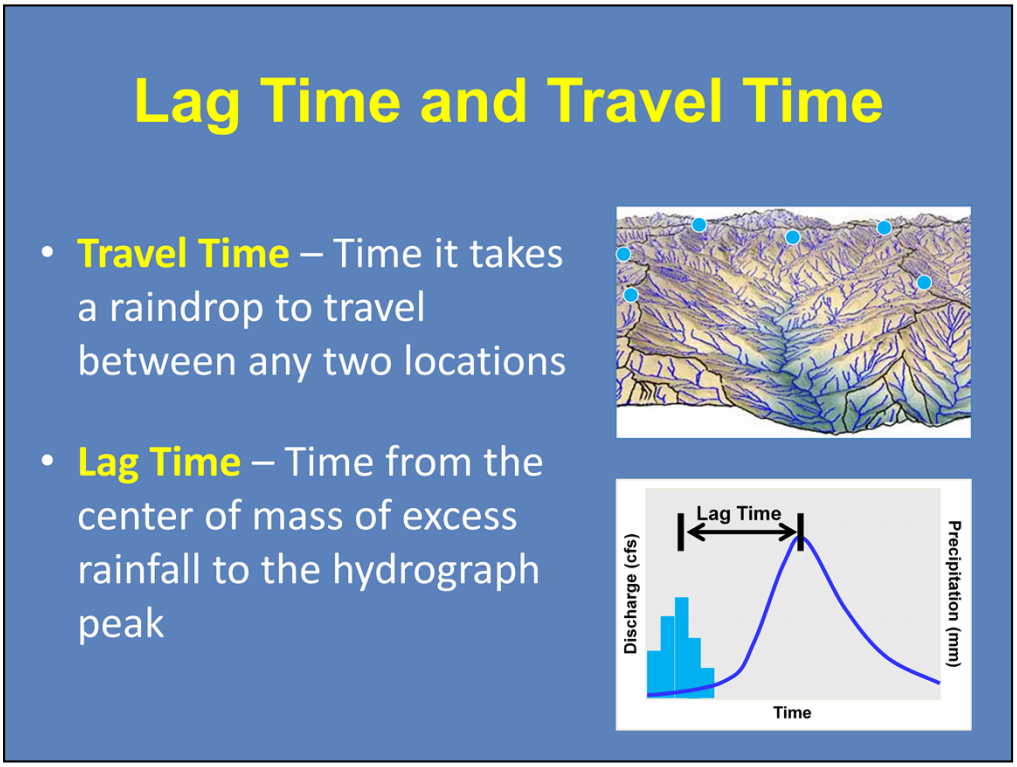

Two terms that are used when talking about runoff in a basin is lag time and travel time. Travel time is the time that it takes a raindrop of water to travel between any two locations.

Lag time is the time difference between the center of mass of excess rainfall and the peak in a river hydrograph.

Both of these are dependent upon the size and shape of the basin, as well as the slope of the ground within the basin. Basins that are prone to flash flooding can have a lag time of just 15 minutes and the water can sometimes travel a considerable distance in a short amount of time. Basins not prone to flash flooding can have lag times that can exceed one hour.

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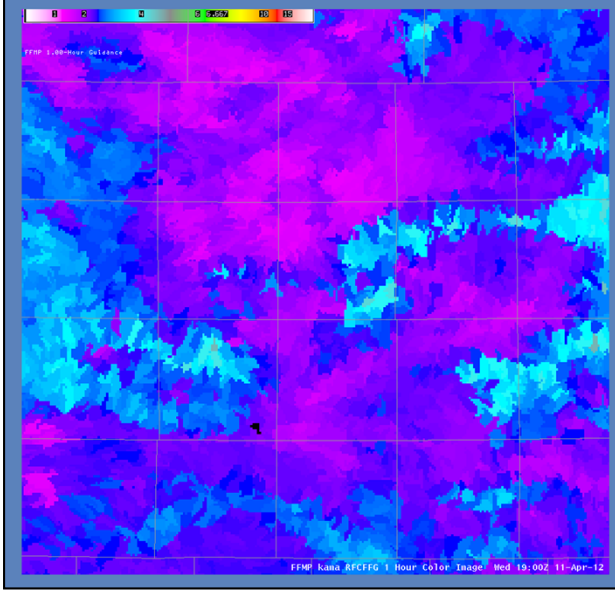
End Result = FFG



- Issued by RFCs generally four times a day
  - Updated more frequently as needed
- Adjusted to account for saturated soils during events
- Local forcing of FFG

Through hydrologic modeling, the combination of dynamic NRCS curve numbers and Thresh-R values creates the operational FFG that we use today. FFG is issued by the RFCs generally four times a day, and they can be updated more frequently as needed. Since gridded FFG accounts for recent changes in soil moisture, they can be adjusted for saturated conditions during events. FFG can also be forced locally using a GUI in the AWIPS workstation.

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Areas that have compromised FFG, and where FFG is generally forced, are urban areas and wildfire burn scars. Let's start with how urbanization impacts FFG.

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Urbanization can create as much as five times more runoff than that of a completely forested area. This primarily has to do with areas being covered by concrete instead of soils and vegetation. The infiltration rate of concrete is near zero, so almost all rain that falls on to concrete surfaces is translated into runoff. In addition to the "concrete jungle," drainage systems within urban areas may not be adequate enough to handle very high quantities of water. But there is more to urbanization than just creating more precipitation runoff.

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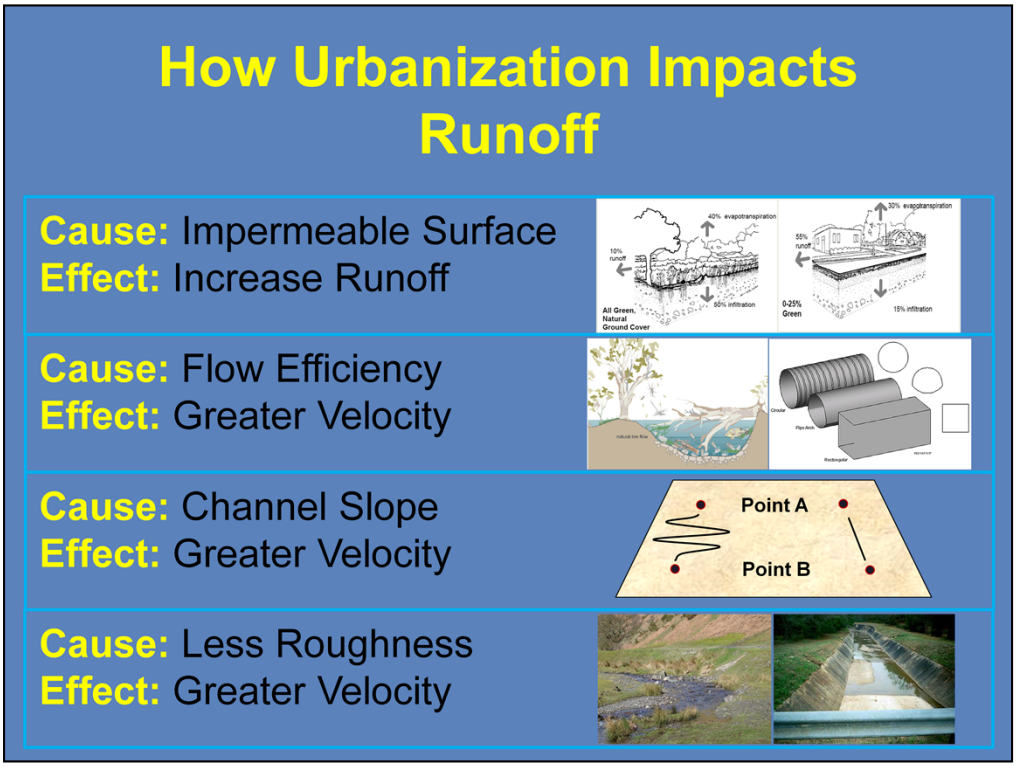

We know that when you have more impermeable surfaces (i.e., areas covered by concrete and asphalt), you are able to generate more runoff. But we must also look at what other factors urbanization can have on runoff.

Natural rivers and streams have very complex shapes, while urban drainage systems, culverts, pipes, etc. have simple shapes. This allows for greater flow efficiency of the runoff, and thus, gives the runoff a greater velocity.

Streams and rivers have a tendency to meander and are never really straight. Urban areas tend to have very straight drainage paths. When placing a meandering path and straight path on a sloped surface, not only does the straight path take less time for runoff to go from Point A to Point B, the overall slope of the straight channel is much greater. Straighter channels in sloped urban areas will have a greater channel slope and a greater runoff velocity.

Also, natural streams and rivers have a lot of roughness that come from rocks, vegetation, and complex channel shapes. On the other hand, urban channels, especially those that are paved, tend to be quite smooth, and thus have less roughness. This again translates into greater runoff velocity.

So, not only does urbanization create more runoff, it can also provide a greater velocity to the runoff, which makes it that much more dangerous to life and property.

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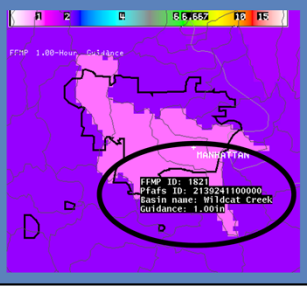
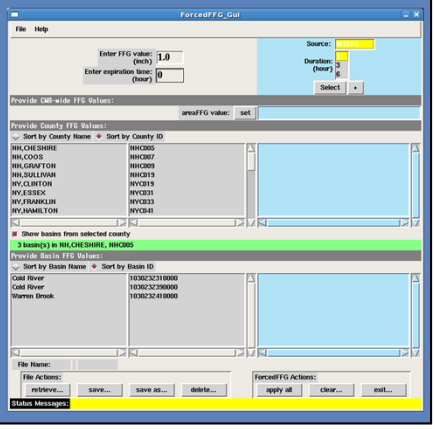
Flash Flood Guidance for Urban Areas

- Reduced FFG in urban areas is NOT accounted for in FFG from RFCs
- Use Forced Flash Flood Guidance Tool
  - Forced FFG = **0.75 - 2.00 in./hr.**
  - Dependent upon urban area





The reduced flash flood guidance (FFG) for urban areas are not accounted for in the FFG delivered by the RFCs. However, you can use AWIPS to force FFG for these areas. Depending upon the urban area, it can take anywhere from 0.75-2.00 in./hr. for flash flooding to occur. Ask your AWIPS focal point about using the Forced FFG interface.

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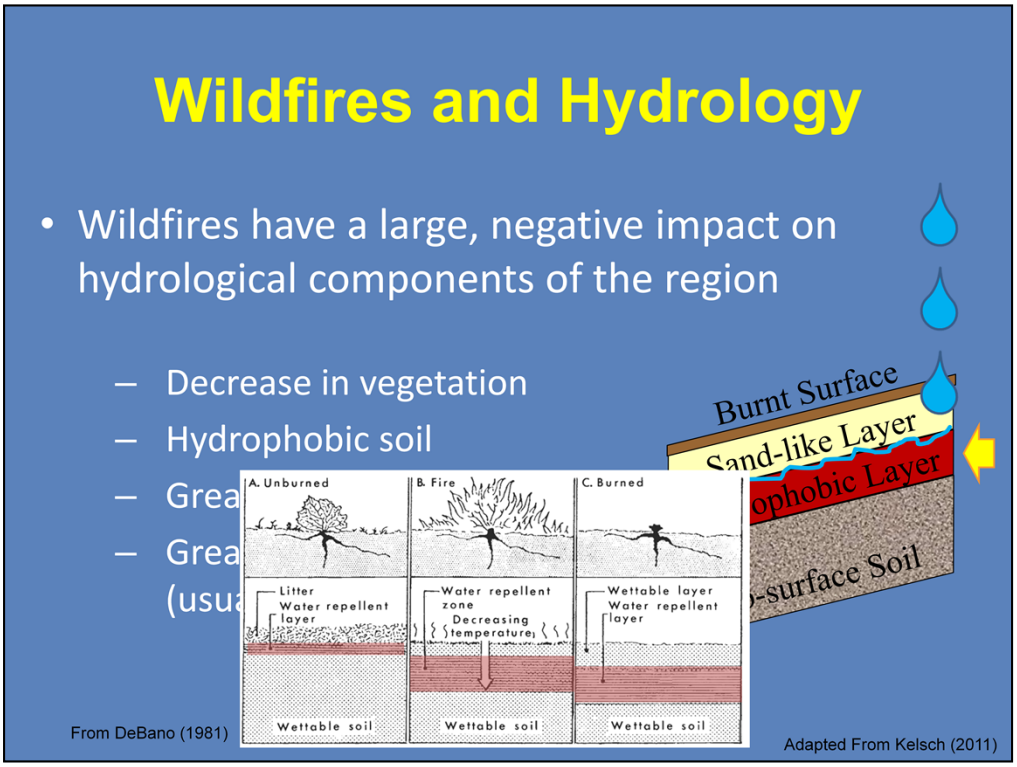

Now, I'm going to make a pretty obvious statement here and say that wildfires have a large and very negative impact on the hydrologic factors related to flash flooding. But, it is how the fires impact the area and for how long those impacts last that are critical to hydrology and flash flooding.

The part that we do see is the removal of vegetation. As we discussed earlier, vegetation helps capture water and increase soil infiltration, which reduces the potential for flash flooding. Without vegetation, there are no leaves to intercept rainfall or roots to extract water. One of the byproducts of combusting vegetation, especially in high-intensity forest fires, is the creation of a heavy gas that sinks and penetrates the soil profile. As this gas cools, it condenses and solidifies into a hydrophobic waxy coating around the soil particles. This is the part that we don't see and is very critical to flash flooding in burn scars. So, in the aftermath of high-intensity fires, a water-repellent sub-surface layer of soil is present. The greatest impacts from this occur within the first year after the fire, and these impacts remain for three to five years afterwards.

So, when it rains, the water will penetrate an initial layer of burnt soil and surface material and then a less-stable sand-like layer (all byproducts of the fire). When the water reaches the hydrophobic layer, it cannot penetrate any further. The water then becomes runoff with a high yield of sediment from the soils above this hydrophobic layer. Flash flood guidance is greatly compromised in burn scars, and it is usually around 0.50 in./hr.

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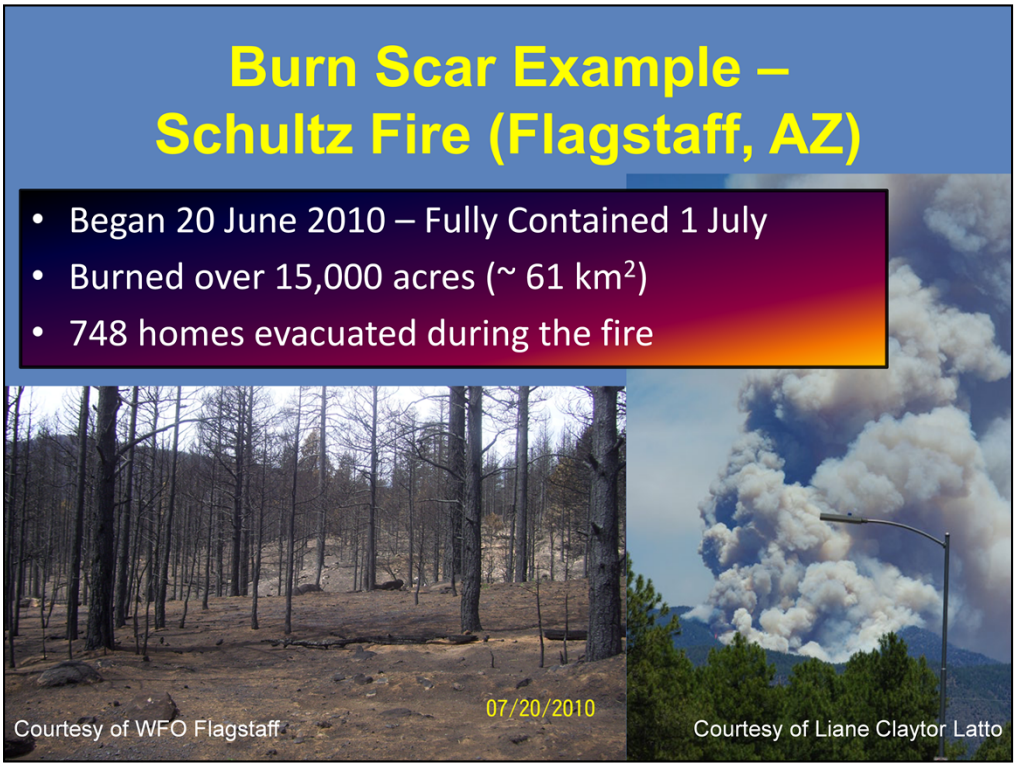

To show the impacts of a heavy rainfall event over a burn scar, we will look at the Schultz Fire of 2010. The fire began on the west side of the San Francisco Peaks, a volcanic mountain range north of Flagstaff, AZ, on June 20th, and the fire lasted about 12 days. The fire burned approximately 15,000 acres and resulted in the evacuations of nearly 750 homes.

The picture on the left shows what the terrain looks like one month after the fires. Note how the trees are devoid of any green vegetation and how the ground is burnt and lacks any underbrush or grass. Two hours after when this picture was taken, convection began to develop in the area.

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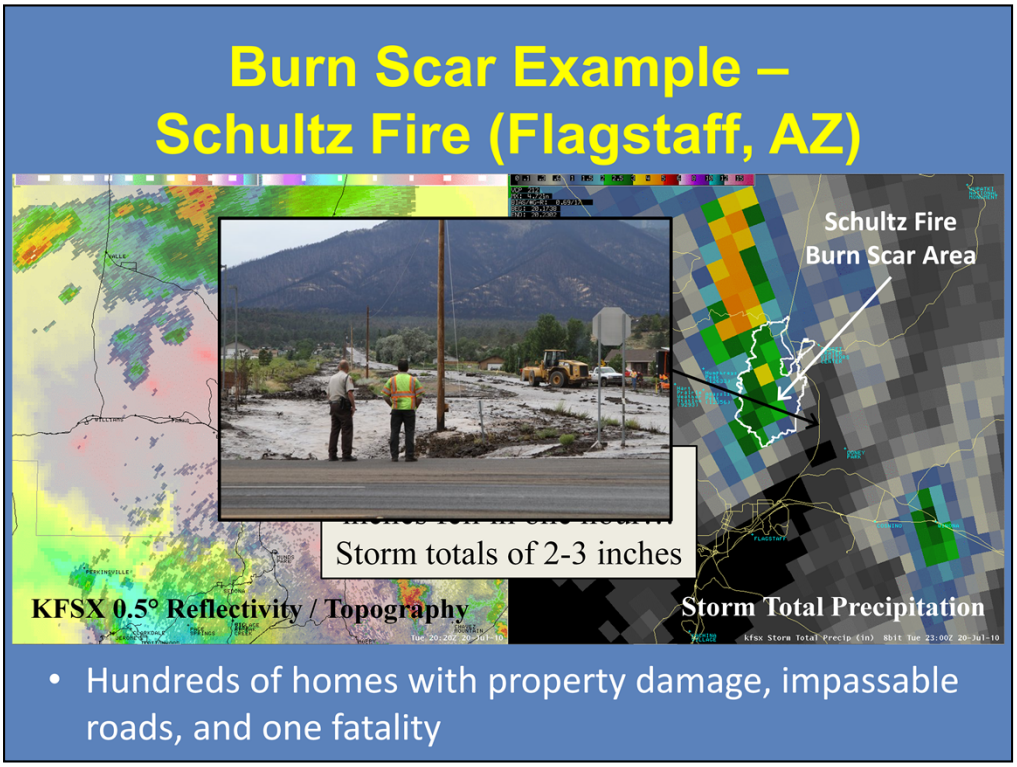

On the left is the KFSX 0.5° reflectivity and topography image combination. The blue contour north of Flagstaff represents the burn scar area from the Schultz Fire. On this day, there were slow moving storms in and around the mountain range. Once convection developed within the burn scar, the office issued a Flash Flood Warning in anticipation of flash flooding based on very slow storm motions and high precipitation rates.

The image on the right shows the storm total precipitation from the event. Two to three inches of rain fell within the burn scar, most within a one hour time period. The runoff and sediment quickly moved down the mountain, especially with the aid of paved roads, including Highway 89. Downstream suburban areas were heavily impacted with home and property damage and impassable roads. A 12 year old girl was killed during the event when she was swept away by the flood waters in her neighborhood. This was a case where you had runoff easily generated in a burn scar area, which quickly moved down a steep mountainside and traveled into an urbanized area where roads and culverts quickly channeled the water in this dangerous situation.

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Summary

- Basics of Flash Flood Guidance (FFG)
- Hydrologic Factors that Influence FFG
  - Land Use and Vegetation
  - Soil Infiltration and Soil Moisture
  - 3-D Basin Characteristics
- Areas with Compromised FFG
  - Urbanization
  - Burn Scars

In summary, you should have a basic understanding what Flash Flood Guidance (FFG) is and how it is calculated at the RFCs. We looked at a number of hydrologic factors that influence the values of FFG. We saw how land use, vegetation, and soil properties influence the dynamic curve number, which describes how much rain is needed to create runoff. We also saw how different basin characteristics help influence the Thresh-R value used to determine how much runoff is needed to create bank full conditions.

Finally, we took a look at two areas with greatly compromised flash flood guidance: Urbanized areas and burn scars from wildfires. The impacts of urbanization, such as large areas of concrete and hydraulically efficient channels, yield greater and faster moving water runoff. Meanwhile, the impacts of wildfire burn scars can last for years due to the removal of vegetation and the creation of a hydrophobic layer in the soil. Overall, both lead to situations where only a moderate amount of rain can produce dangerous flash flooding situations.

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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!

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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, Bias HPE, and HPN
  - Interpret HPE and Bias HPE text overlays in the Volume Browser and FFMP
    - Precipitation source
    - Bias source
    - Bias factor and gauge-radar pairs
  - Identify how to determine areas of higher confidence in Dual-Pol HPE/Bias HPE precipitation estimates

By the end of this lesson, you will be able to do the following…

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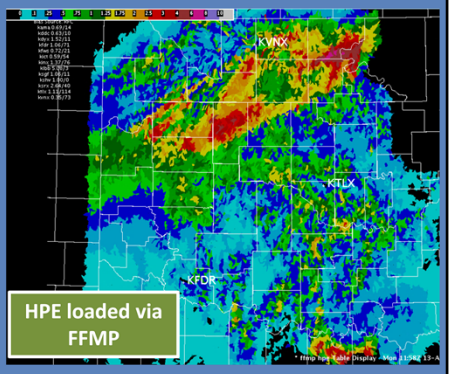
What is HPE?

- High-Resolution Precipitation Estimator (HPE)
  - Mosaic of single radar sources
    - Lowest altitude scan
      - Usually nearest radar unless beam blockage
  - Gridded rainfall fields
    - Instantaneous rain rate fields
    - Accumulated precipitation fields
      - Default = 60 min
  - Resolution: 1-km x 1-km; 5-min



--The High-Resolution Precipitation Estimator (or HPE) was released in 2008, and was designed as a mosaic of rainfall data from all radars within your coverage area.
--One of the motivations behind HPE was to create a single precipitation mosaic that FFMP could display for your CWA and your back-up CWA, such as the image on the right that includes the radars overlaid.
--The mosaic is created from using the lowest altitude scan, which is usually the nearest radar. However, in areas of beam blockage, the mosaic may employ higher tilts.
--The precipitation source used in the mosaic is configurable, and the current source options will be discussed on the next slide.
--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 by changing an HPE token 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.
--In addition to FFMP, all HPE products are also available in the Volume Browser.

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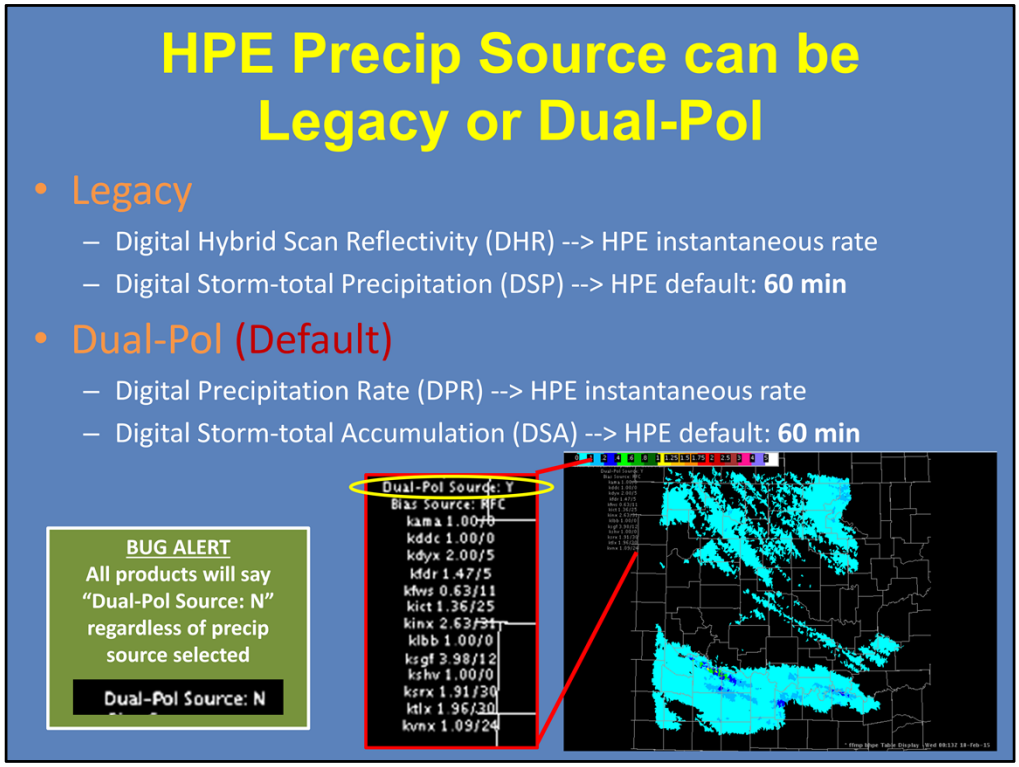

--Legacy OR Dual-Pol products can be configured by your hydro focal point to create the HPE and Bias HPE mosaics.

--When Legacy is the precip source, the DHR is used to create the HPE rain rates, and DSP to create the HPE accumulations.

--The default for HPE is to create a one hour accumulation.

--Similarly, the dual-pol counterparts are the DPR and the DSA.

--The Dual-Pol products are the default sources for creating the HPE and Bias HPE.

--The images below show 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.

--However, there is currently a pretty bad bug which causes this label to **always** read "Dual-Pol Source: N", regardless of the precip source selected. Most offices will have the default configured (i.e., Dual-Pol), which unfortunately means…for most offices, this bug is valid until it is fixed in 16.4.1. But for the rest of this lesson, we use examples with the *correct* labels to avoid confusion.

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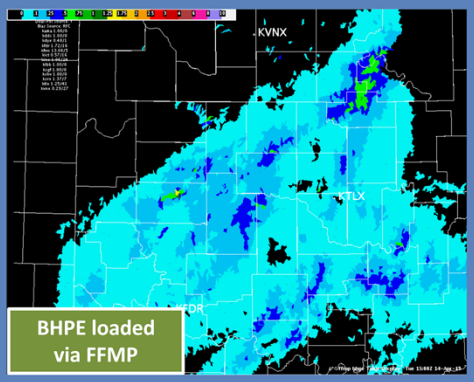
What is Bias HPE?

- Bias High-Resolution Precipitation Estimator (BHPE)
  - Bias factor applied for each radar in the mosaic
  - Bias calculated from rain gauges
  - Bias source configurable
  - Resolution: 1-km x 1-km; 5-min



--Bias HPE is the same as HPE, except that a bias factor is applied for each radar in the mosaic, meant to help correct for radar uncertainties.
--In short, the bias is calculated by comparing rain gauge information with co-located radar data.
--The bias source is configurable, chosen by your local hydro focal point.
--Both have the same resolution.

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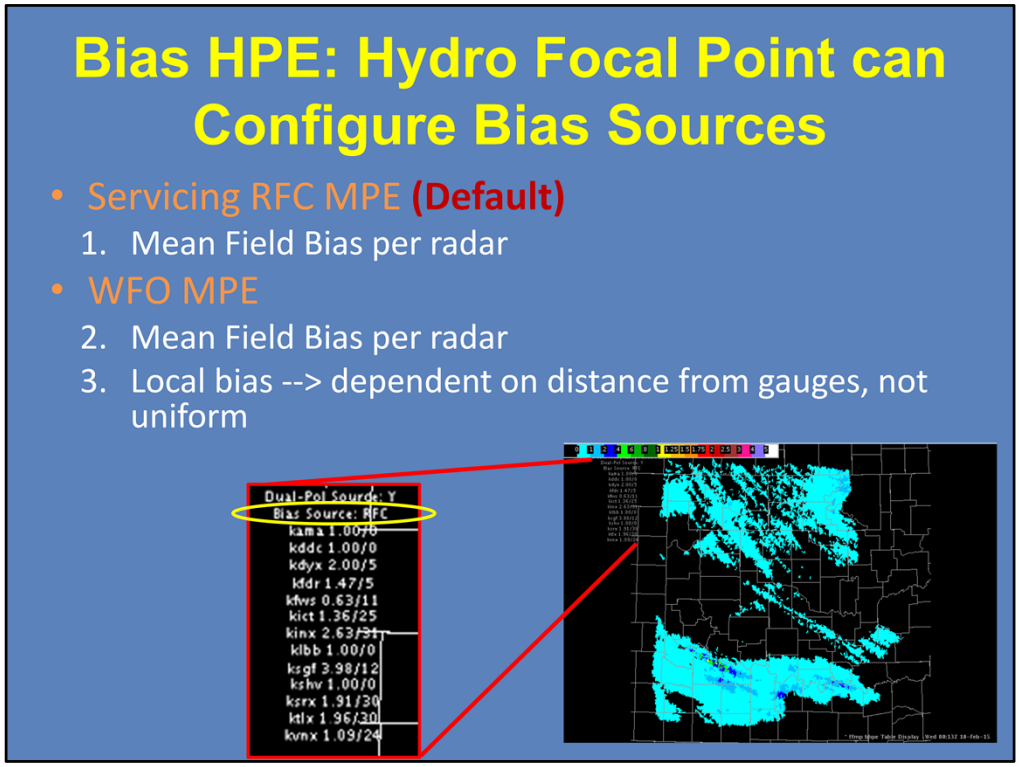

--There are three available bias sources for Bias HPE, and they are configurable by your local hydro focal point.

--First, you have the mean field bias for each radar, provided by the Mulitsensor Precipitation Estimator (or MPE) from your servicing RFC. This is the default bias source.

--The other option is to use your WFO's local MPE to choose from one of two biases.

--The first is a mean field bias per radar, similar to the RFC version.

--But the second option is what's called a “local bias”. Instead of one bias value being applied across the whole radar domain, this option applies different bias values across the domain. Each value is influenced by the nearby gauge-radar pairs, within a 40-km radius of influence. Some WFOs with more frequent flash flooding have found that the local bias has performed best.

--The image below shows an example where the bias source is the RFC mean field bias.

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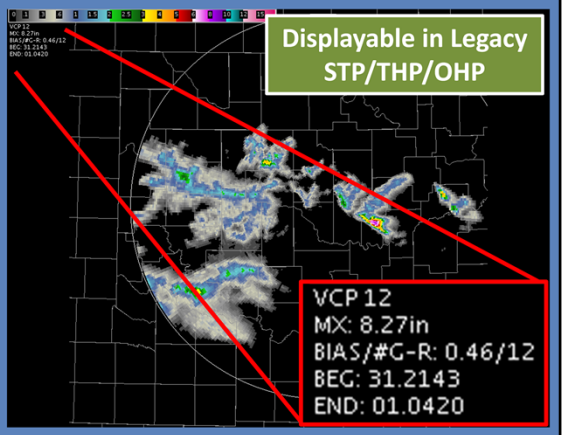
What is the Mean-Field Bias?

Mean Field Bias =

$$\frac{\text{SUM(gauge accum)}}{\text{SUM(radar accum)}}$$

Hourly for each radar!

- Applied in Bias HPE
- Can be applied at RPG (Legacy)
  - Default = not applied



--In order to understand how to effectively use the new displays with Dual-Pol Bias HPE, you need to understand what the mean-field bias is. The mean-field bias is calculated using gauge-radar pairs of at least light precipitation. The sum of the gauge accumulations is divided by the sum of the radar bin accumulations. And outlier biases are removed.

--This bias information is calculated hourly for each radar that contributes to the Bias HPE mosaic.

--It can also be applied at the RPG and is displayable for your Legacy one-hour, three-hour, and storm-total precip estimates, but the default is that it is not applied. For more information on how to identify if the bias has been applied at the RPG, see the attached reference material on the VLab.

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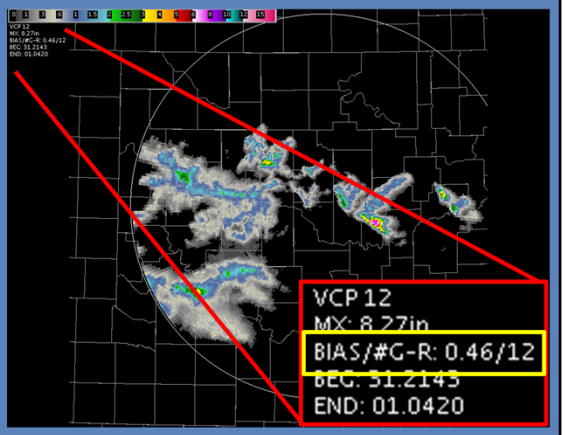
What is the Mean-Field Bias? (cont.)

Bias factor

- <1: radar QPE overestimating
- >1: radar QPE underestimating

Gauge-Radar pairs

- How many were used to calculate the bias
- More pairs: more reliable



BIAS/#G-R: 2.00/36

--Two of the most important components of the mean-field bias are, of course, the bias factor itself, and the gauge-radar pairs.

--The bias factor tells you if the radar's current precipitation source is under- or over-estimating rainfall, as compared to gauge measurements. It is a multiplicative factor, meaning this value is meant to be multiplied across the radar umbrella. For example, in this image, the bias factor is 0.46. Therefore, the DHR precipitation source is over-estimating precipitation, and the algorithm wants to multiply the QPEs by 0.46 to bring them down to where they should be. Similarly, a bias of 2.0 is saying that the QPEs are much lower than gauges measured, and therefore, should be doubled.

--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 12 gauge-radar pairs used to get the 0.46 bias factor.

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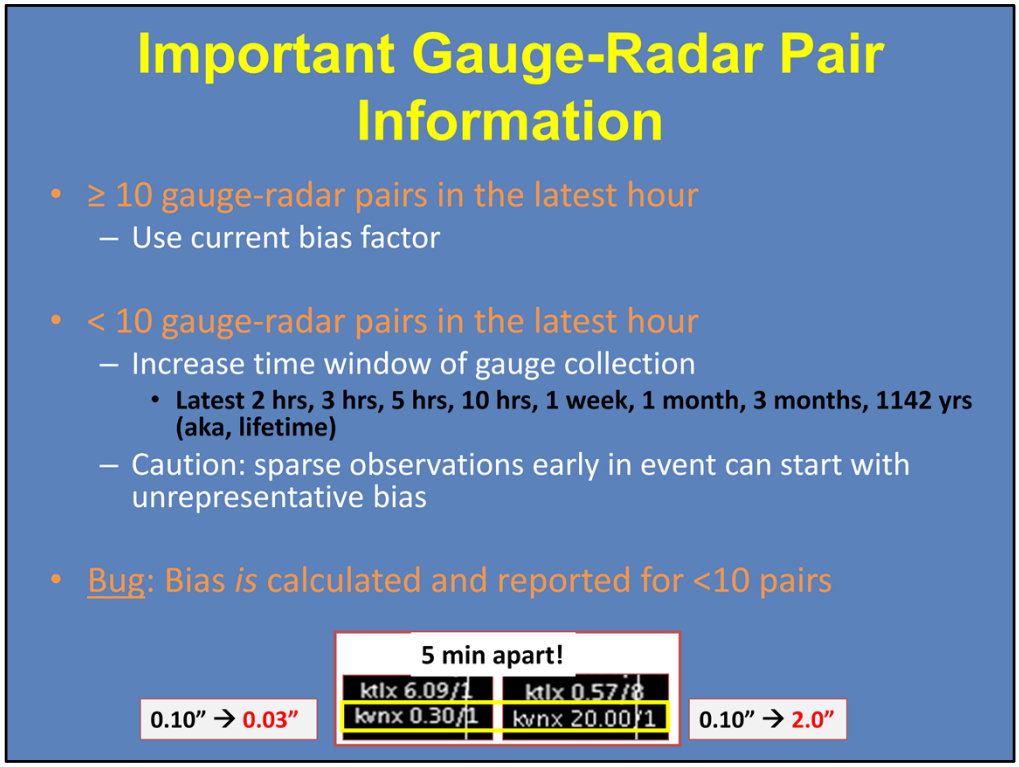

--There are a few important points to make about the gauge-radar pair information provided.
--First, how many gauge-radar pairs is significant to calculate a bias? The default number of pairs in MPE is 10.
--If there are 10 or more positive G/R pairs in the latest hour, then the current hour's bias factor is used.
--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.
--A caution of this method is that if you are early in an event, and there hasn't been recent rainfall to trigger gauge accumulations, then you might be looking VERY far back in time to reach the 10 G/R pair threshold. Old G/R information, as much as 3 months or even the lifetime of MPE, may not be representative of the current event, thus creating an unrepresentative bias.
--A final note: with this methodology, bias information should never be reported using any less than 10 pairs. However, there is currently a bug that does calculate and report biases with less than 10 pairs, as shown below for KTLX and KVNX. These values were reported only 5 minutes apart. For KVNX for example, both scans only have one gauge reporting that affects the whole domain. That means, in the first scan, a radar estimate of 0.10" will be brought down to 0.03". But the very next scan, multiplied by 20, and brought up to 2". So be **very** careful interpreting bias information when there are less than 10 gauge-radar pairs reporting.

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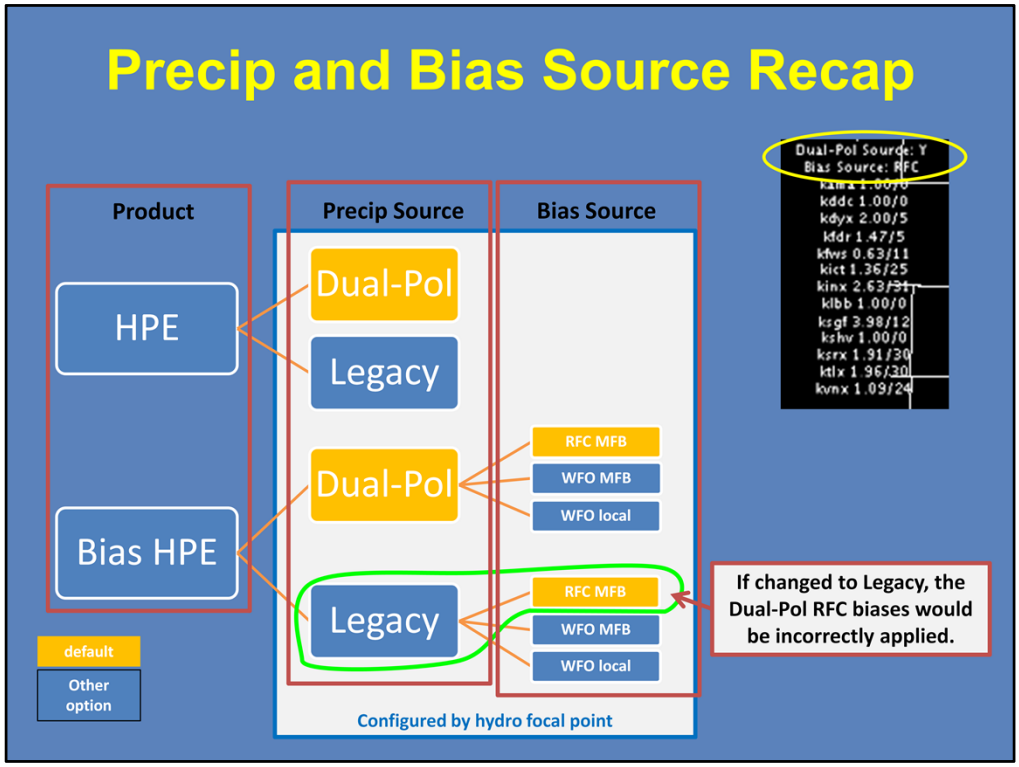

It can be a little confusing to keep track of all of the options between precip sources and bias sources. So here is a little flow chart to help summarize what is available. Default settings are in yellow.

--So you, as the forecaster, will have the option to choose 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, however, Dual-Pol is the default. If you choose Bias HPE, then one of three bias sources will be applied to the mosaic: either the RFC mean-field bias, WFO mean-field bias, or the WFO local bias. Here, RFC MFB is the default.

--All of these choices are configurable by your local hydro focal point. So as a forecaster, you will simply see what is configured in the product legend.

--If your local hydro focal point decides to change the default precip source from Dual-Pol to Legacy, it's important to understand that the biases being sent by the RFC are now dual-pol. Therefore, these Dual-Pol-derived mean field biases would be incorrectly applied to the DHR precip source. This will render the Bias HPE product unusable.

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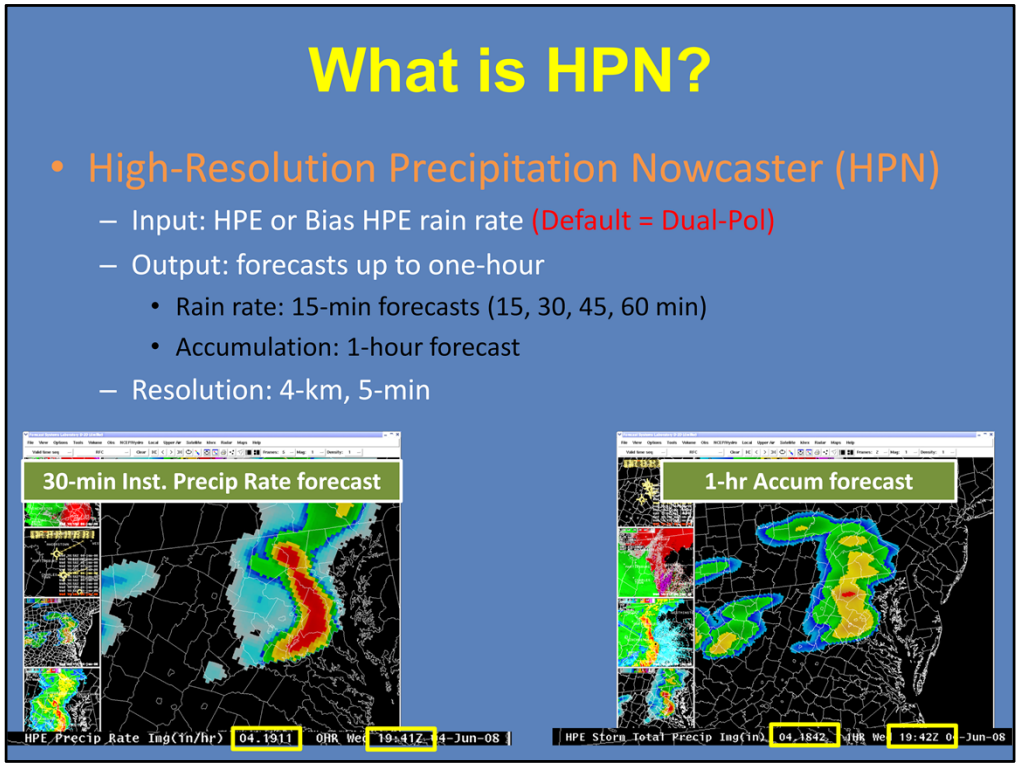

--The High-Resolution Precipitation Nowcaster (or HPN) is a QPF component of HPE and Bias HPE. Its intended use is to generate lead time in flash flooding for storms that are not rapidly changing.

--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.

--These 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 1941Z. On the right is a one-hour accumulation, with the current time being 1842 and the forecast time as 1942Z.

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

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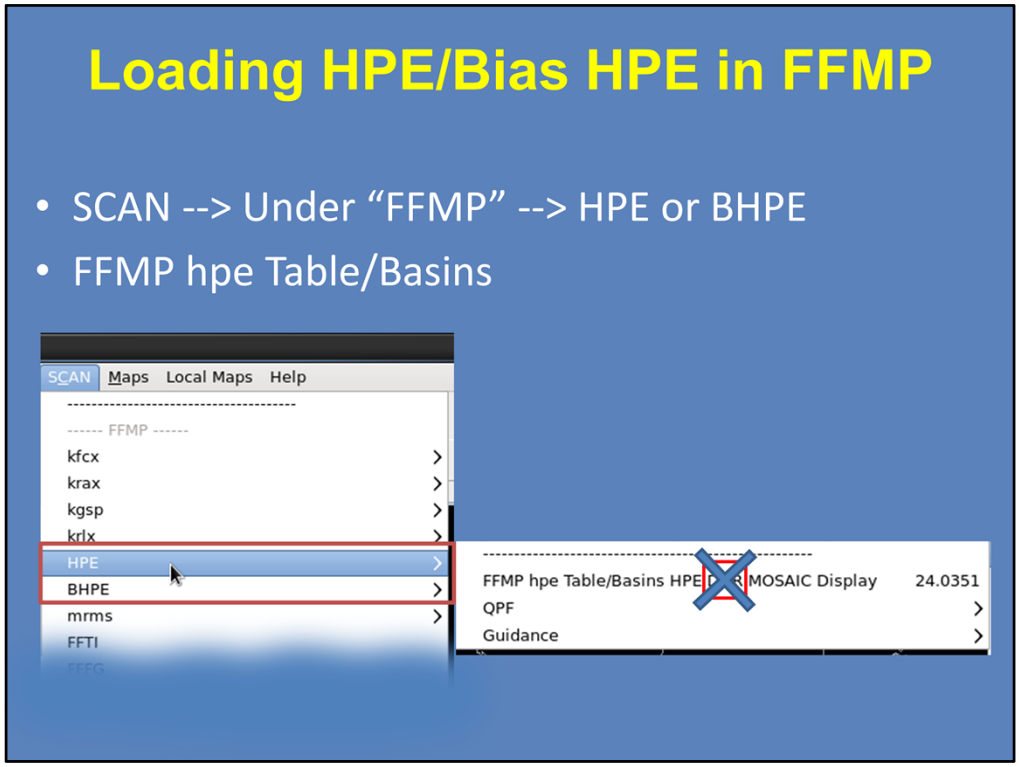

--HPE was designed to make it easier to view multiple radar data in one product. This is especially useful in FFMP because you can load just one HPE mosaic, instead of multiple FFMPs for different radars.

--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.

--It is important to remember that the default HPE source is Dual-Pol, though, the label incorrectly says “DHR MOSAIC Display”. To be correct, it should read “DPR MOSAIC Display”.

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

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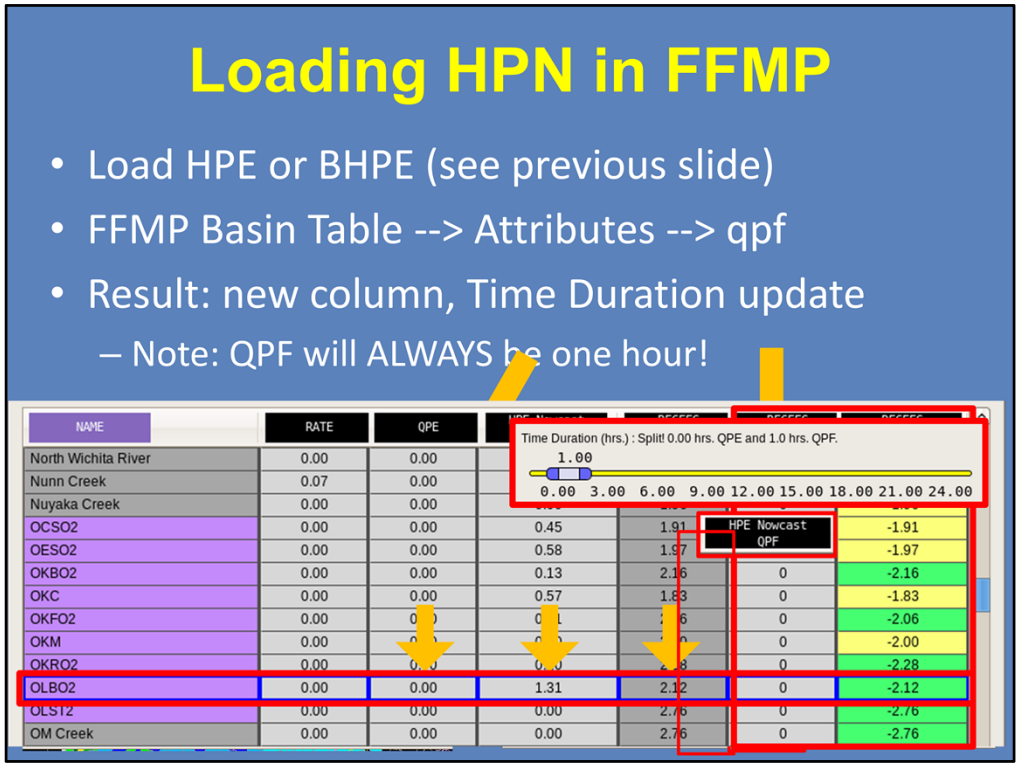

--So with the new default precip source being Dual Pol for both HPE and Bias HPE, the QPF extrapolation in the HPN forecast is also Dual Pol. Let's walk through how to load HPN QPFs in FFMP.

--Say we load HPE in FFMP (as described on the previous slide), and we click on the Attributes menu to turn on one of the QPF options. When the split window display comes up, we now have a 1 hour QPF combined with the QPE. Remember, the QPF extrapolation will ALWAYS be 1 hour, if this selection is made. It will never be more than 1 hour. We see the qpf column appear, and we can read off the forecasted precip one hour from now. Also, the Time Duration will tell you how many hours of QPE and QPF you are displaying, based on the slider bar total accumulation. In this example, since the slider bar is set for 1 hour, we have the 1-hour QPF in the "HPE Nowcast QPF" column, and there is no QPE displayed in the QPE column. If the slider bar was set to, let's say, 3 hours. Then the QPE column would have 2 hour accumulations, and the QPF column would remain the 1 hour forecast.

--In this example, the OLBO2 OKC west mesonet virtual gauge basin (highlighted with a purple name) had a QPF of 1.31", with no observed QPE due to storms just approaching the metro. The forecast was remarkably accurate (with 1.29" actually occurring), and it provided useful lead time information on some well-tracked storms. While the one-hour RFC FFG was only 2.12", this was enough precipitation to create urban flash flooding in the OKC metro.

--Unfortunately there is bug in FFMP of not incorporating the HPN QPF into the calculations for ratio and difference, but you can still get the QPF signal from the value in its column.

--For novice users, we recommend not using QPFs in FFMP because of the complexities discussed here.

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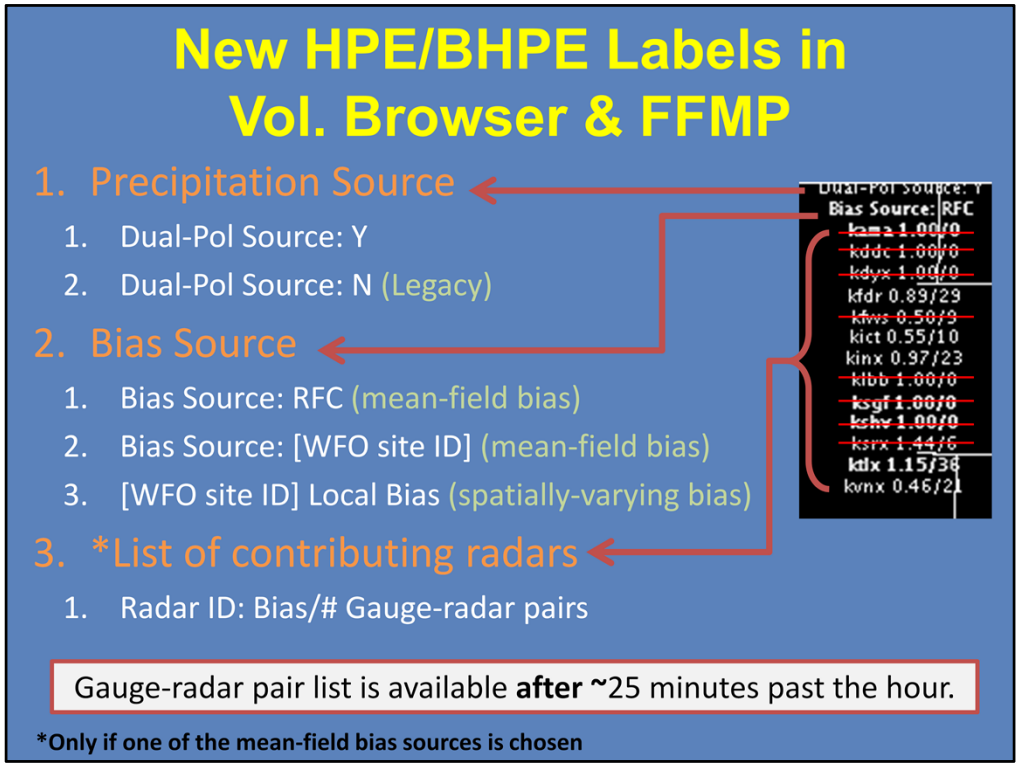

--With the option of Dual-Pol in HPE and Bias HPE, the labels on these products have changed to specify which precipitation source is being used, as well as adding more detailed bias information.
--The first line specifies the precipitation source. If it says “Dual-Pol: Y”, then Dual-Pol is being used. If it is an “N”, then Legacy is used.
--The second line specifies the bias source. Remember, there are three options here: if it is the RFC mean-field bias, it will say “Bias Source: RFC”, like in this example. If it is the WFO's mean-field bias, then it will state the WFO's three-letter identifier. If it is the local spatially-varying bias, then it will specify the WFO’s three-letter identifier with “Local Bias”. The bias source is only relevant for the Bias HPE though it is displayed on both HPE and Bias HPE products.
--Finally, if one of the mean-field bias sources is configured, then the bias factor and number of gauge-radar pairs is listed. You can use this to understand how the bias factors are changing the Bias HPE precip estimates each hour throughout your mosaic.
--Remember, have higher confidence in precip estimates when you have more than 10 gauge-radar pairs, and if you have < 10 gauge-radar pairs you should not trust the precipitation estimates in those regions of your mosaic as they likely indicate a bug in the bias factor creation.
--An important note: Your current hour’s gauge-radar pair list will NOT appear until after about 25 minutes past the hour. This is due to known latencies in gauge data collection. Therefore, after 25 minutes past the hour, the product overlay will automatically update on the current frame. But if you want to see the list for the earlier frames in the hour, you can clear and reload the HPE or Bias HPE product.

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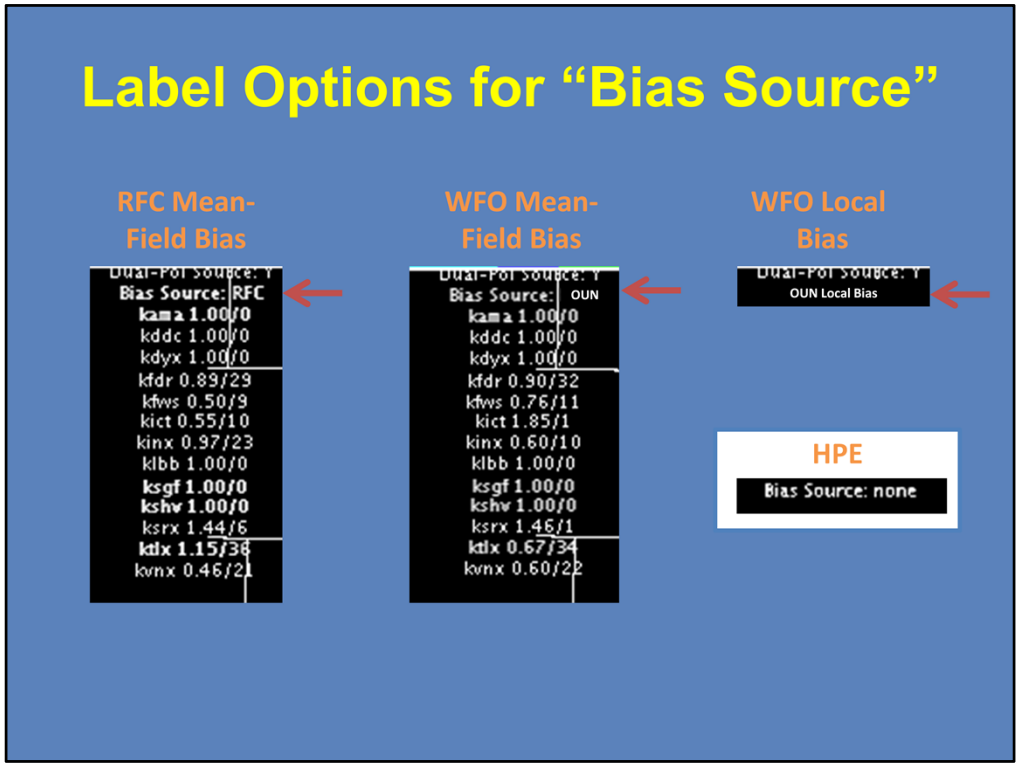

--So here are examples of how the three different bias sources display in Bias HPE.
--The first option is using the RFC MFB as the source. You will get "RFC" as the source, and a list of radars with their respective bias information.
--If the bias source is the WFO MFB, then the three-letter identifier is given (in this example, OUN), and the WFO MPE bias information is listed for each radar.
--Finally, if the bias source is the WFO's local 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.
--And since there are no biases applied for HPE, the bias source label simply says "none".

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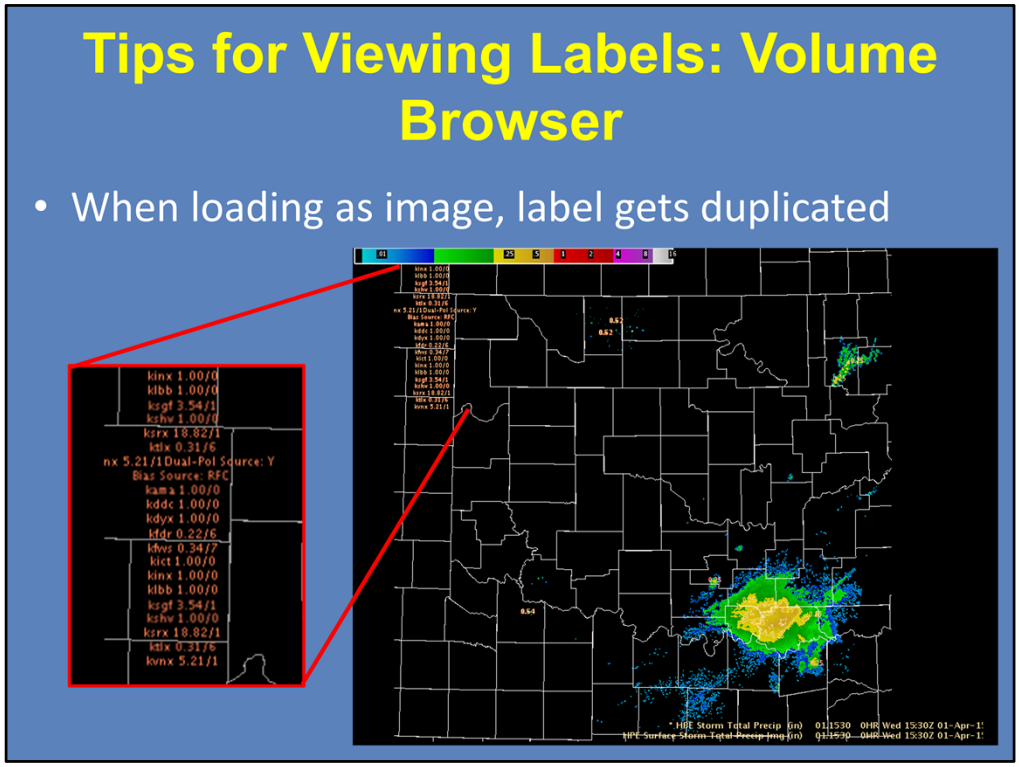

--There are a few things to be aware of when using this version of HPE and Bias HPE.
--When viewing in the Volume Browser, the label gets duplicated when you “Load as Image”. This can make it a little difficult to read, but none of the text is overlapping, so the important information is still visible.

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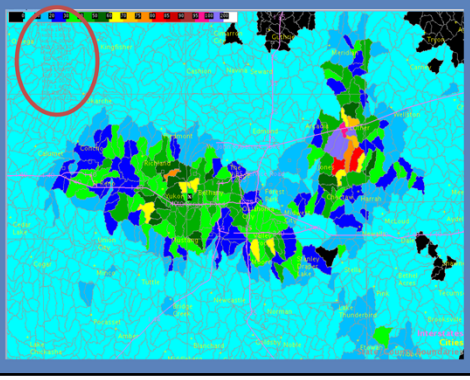
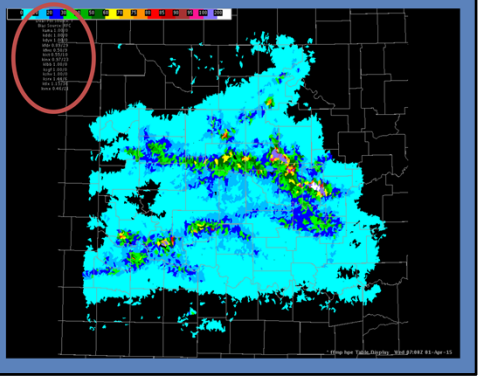
Tips for Viewing Labels: FFMP

- Zoom out and pan to read text easier

Zoomed in



Zoomed out



--Second, 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 text-legend 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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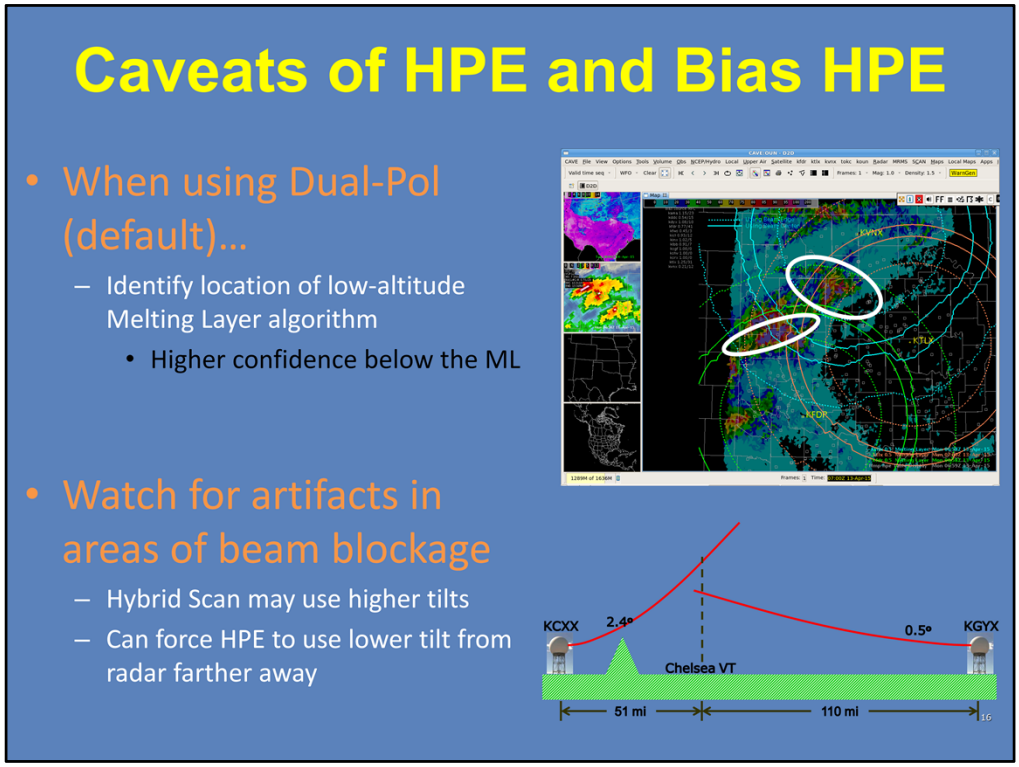

There are some caveats to using HPE and Bias HPE.

--For one, when using the dual-pol precipitation data in HPE, you should identify where the low-altitude melting layer algorithm begins to identify the melting layer. 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.

--On the right 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, for the southwestern circled area, it is within the green ML circles for the most southern radar. Thus, this area has more uncertainty. Checking the HHC to locate liquid precip types in the ML can further add to your confidence in this area.

--Secondly, watch for artifacts in areas of beam blockage. At times, your hybrid scan may be using elevations above the 0.5 degree slice in areas of beam blockage. But for QPE estimation, the lowest altitude estimate is the best. If there is a neighboring radar that uses the 0.5 degree tilt to cover the same area, that estimate may be better (even though the radar is farther way). You can force HPE to use the farther radar. So for more information on this topic, please see the Resources tab for the presentation from Greg Hanson, the service hydrologist at the Burlington, VT WFO.

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Summary: Products

- High-Resolution Precipitation Estimator (HPE)
  - Gridded rainfall mosaic of single radar sources
  - Rate or accumulation (default = one hour)
- Bias HPE
  - Similar to HPE, but with biases applied to radar estimates
- High-Resolution Precipitation Nowcaster (HPN)
  - Extrapolated QPF, using HPE or Bias HPE as the input

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.

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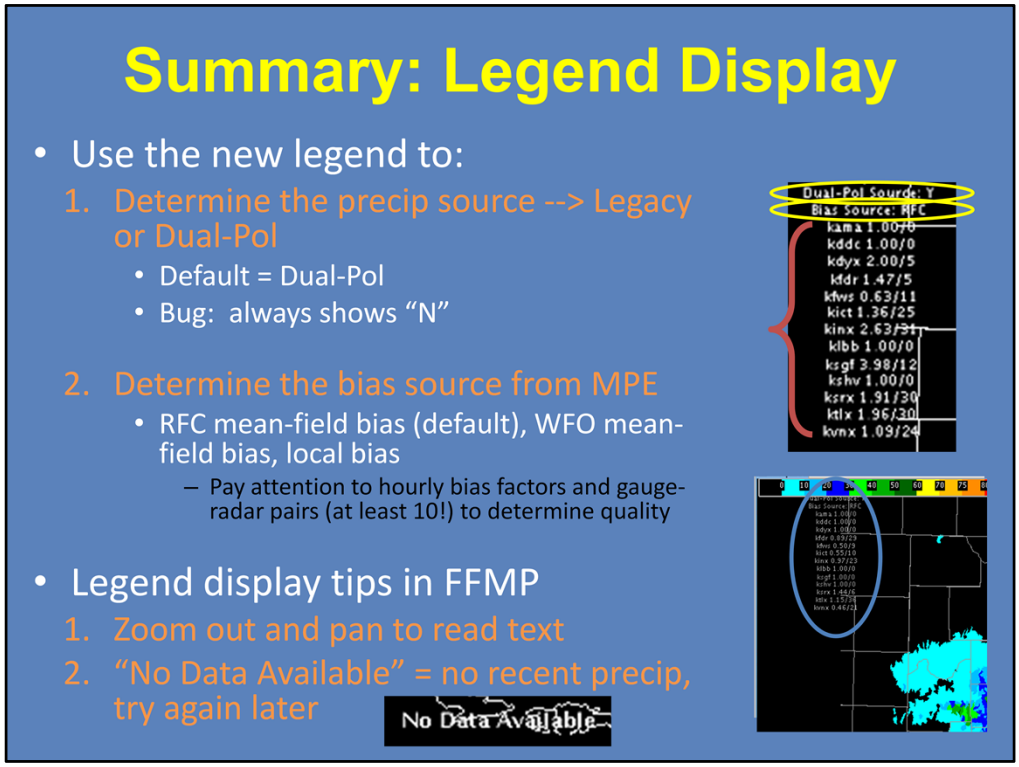

The legends for HPE and Bias HPE can be used to interpret valuable information about the products.

--For one, you can now see which precip source is being used, either Legacy or Dual-Pol. The default is to use Dual-Pol. Keep in mind there is currently a bug where this label will always say "N", even though most offices will have Dual-Pol configured.

--For Bias HPE, you can also determine the bias source from MPE. The default is the RFC mean-field bias, but you can also use your WFO mean-field bias or your WFO local bias.

--To get the most understanding out of these biases, make sure to pay attention to the hourly bias factors, as well as the number of gauge-radar pairs to determine the quality of the bias estimates.

--In FFMP, you can make viewing these legends easier by zooming out and panning to the edge to better read the text.

--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.

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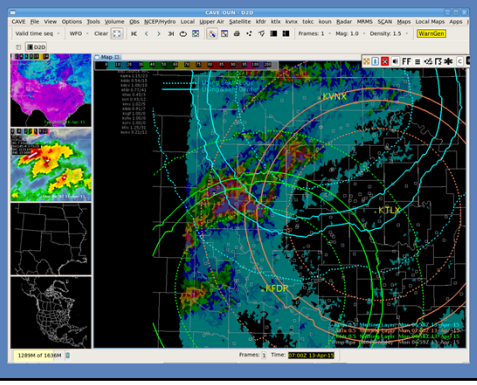
Summary: Applications

- HPE application considerations
  - For Dual-Pol HPE/BHPE, overlay low-altitude ML to identify areas of higher confidence precip estimates
  - Beware of beam blockage in complex terrain



In addition to the updates to the legend, there are some important takeaways to better apply HPE and Bias HPE.

--For Dual-Pol HPE or Bias HPE, 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.

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Hi, my name is Jill Hardy and welcome to this lesson. This is Part 1 of 2 about the flash flood decision-making process, with this lesson focusing on the general approach, as well as how to best choose your precip sources.

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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
    - Determining precip amounts, timing, hydro response, calibration
  - Identify how to choose a precipitation source

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

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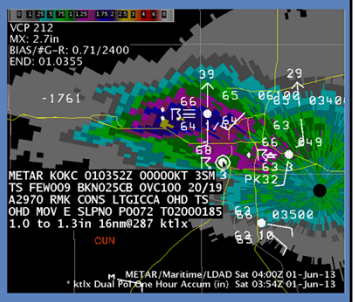
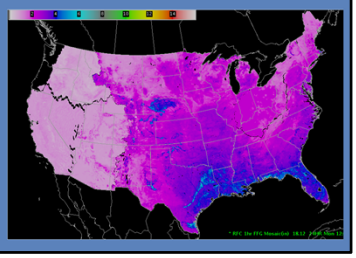
Flash Flood Decision Making Approach

- How much rain has fallen and when did it fall?
  - Best QPE
    - Compare to observations
    - Choose from multiple precip sources



- Will runoff cause flash flooding?
  - Local knowledge
  - RFC FFG



The first question you should ask yourself is “How much rain has fallen and when did it fall?”. To do this you will need to identify the QPE source that compares most favorably to surface observations and reports. There are multiple QPE options to choose from, so the next slide will step through the strengths and weaknesses of each to help you make an informed decision.

Next, you need to consider if runoff will cause flash flooding. Typically this starts with your local hydrological knowledge and is supplemented with River Forecast Center (RFC) Flash Flood Guidance, available at most CONUS WFOs.

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Choosing Initial Precip Sources

	Maximized coverage?	Dual-Pol?	Bias corrected?	Resolution	Accumulation products	Z-Rs
Single radar DHR	No	No	No (default, but configurable at RPG)	1 km x 1 deg 3-6 min	1-, 3-, STP (and user-selectable)	Single Z-R, set at RPG
Single radar DPR	No	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	Yes	No	1 km x 1 km 5 min	1-hr	Spatially-varying (Inherited from DPR for each radar)
Bias HPE mosaic Bugs in bias data	Yes	Yes	Yes	1 km x 1 km 5 min	1-hr	Spatially-varying (Inherited from DPR for each radar, bias-corrected)
MRMS radar-only mosaic	Yes	No	No	1 km x 1 km 2 min	(2-min) 1-hr (≥ 1 hr) 3-, 6-, 12-, 24-, 48-, 72-hr	Spatially-varying (based on SPT)

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

1. For one, consider the coverage area. The mosaic HPE and MRMS products 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. It is important to note that MRMS does NOT use Dual-Pol to calculate rain rates at this time, only for quality control purposes.
3. Do you want biases applied? By default, biases are only applied for Bias HPE. However, for DHR, the option is configurable by your local radar focal point. It is important to consider the quality of these biases. Only use these bias-adjusted products in areas where the biases make sense with reports you are getting from spotters or gauge reports you have confidence in. Note that MRMS does have bias-corrected products, but they are not timely enough for real-time flash flood use.
4. How do the resolutions compare? The single-radar DPR has the best spatial resolution at 250 m by 1 deg. This is useful for isolated 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

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to do one-time requests of user-selectable accumulations. On the other hand, the HPE products only produce 1-hour accumulations by default. And, MRMS only produces the 1-hour accumulation every two minutes, with all of the other accumulations being one-hourly or longer.

6. Finally, how are rain rate relationships managed during product creation? DHR only has one Z-R, set at the RPG. Every other source uses spatially-varying Z-R relationships based on precip type.

While generally it may seem that mosaicked products are preferred for their spatial coverage, there are times when we recommend DPR or DHR. They are good choices if either HPE or MRMS have artifacts, like when multiple radars are covering complex terrain. When you simply want to view more than one source, like looking at both Legacy and Dual-Pol. Or if there is an isolated event close to a radar, which may provide better spatial resolution information.

So now, which precip sources should you use? First, there is one caveat worth noting. The Bias HPE product can be buggy due to problems with the biases being sent over from the RFCs, so only use Bias HPE if you carefully analyze and agree with the bias factors used.

Therefore, our current recommendations are: the HPE mosaic product, since it has great coverage, is Dual-Pol, and has spatially-varying Z-Rs. And, MRMS for its coverage, temporal resolution, and spatially-varying Z-Rs. From here, routinely check these sources against observations to see if you need to make any changes.

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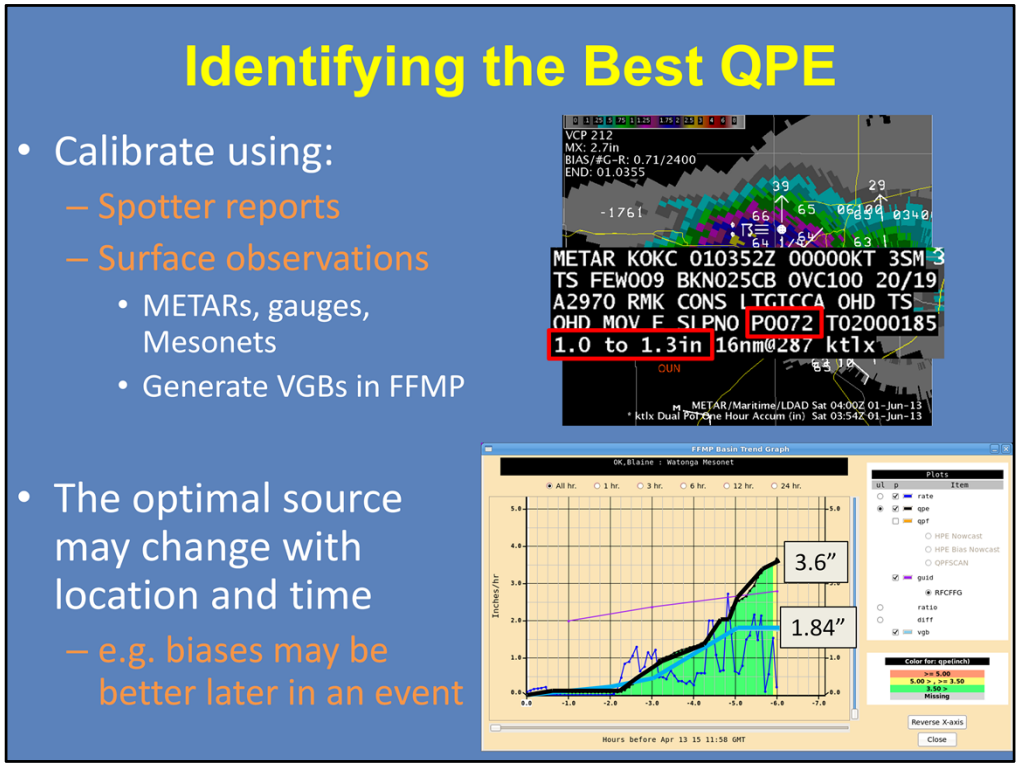

Choosing the right precip source doesn’t end after your initial selection. You should routinely compare your precip sources to spotters and surface observations throughout the event, particularly in potential flash flood areas. You can sample surface observations by checking METARs, gauges, or Mesonet stations, as well as generate Virtual Gauge Basins in FFMP.

Here is an example that shows the one-hour accumulation product overlaid with METARs. We see the METAR estimates 0.72 inches, while the 1-hour DPR estimates 1.0 to 1.3 inches during the same time period. This shows that DPR is overestimating precip by a quarter to half an inch. You can use this information to self-calibrate the QPE estimate, and when considering other precip sources.

The Virtual Gauge Basins (or VGBs) in FFMP are a convenient way to compare a QPE source to METARs and mesonet observations, though the hourly updates of the METARS/mesonets can take a little getting used to. This image is for the Watonga Mesonet site in Oklahoma. The mesonet accumulation is indicated by the light blue line, and shows that the Mesonet accumulated 1.84 inches in the last 6 hours. The DHR VGB source, denoted by the black line, shows that radar estimated around 3.6 inches during the same time period at that location. In this case, the radar drastically overestimated the precip compared to the Mesonet observations, and it is easy to interpret using the VGB graph.

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It is not unusual for the optimal precip source to change across your CWA and with time. For instance, once the bug is fixed in Bias HPE's raw data calculations, it typically improves over time as more gauge information is available. Routinely checking the precip estimates with gauges and reports is good best practice.

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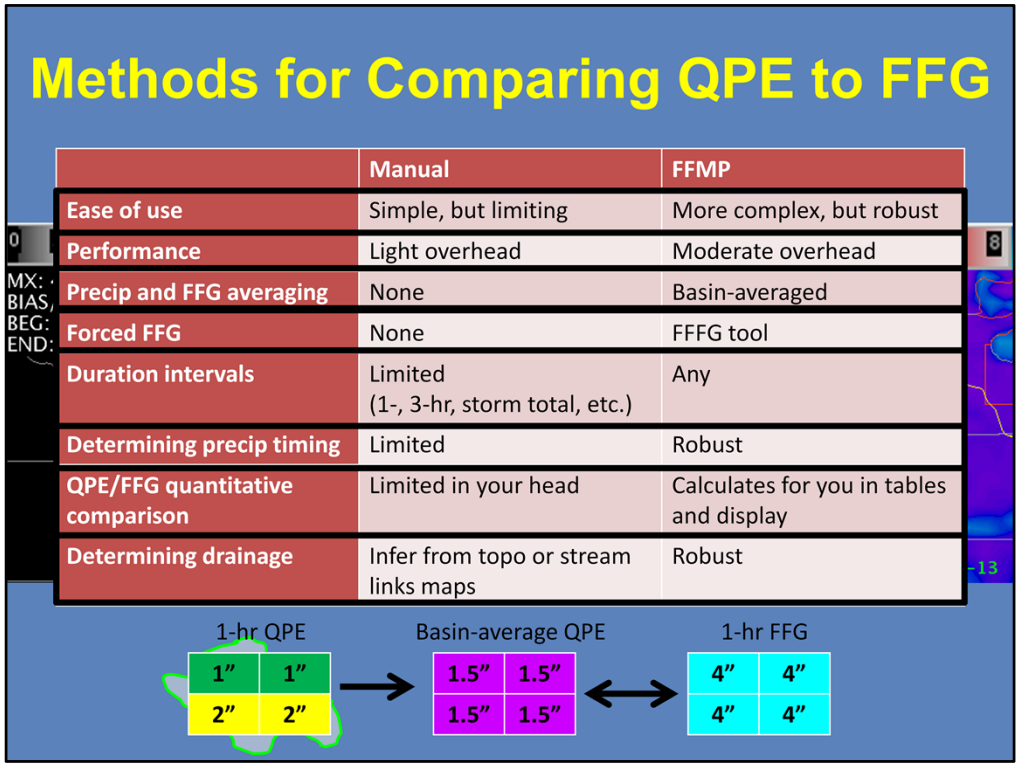

	Manual	FFMP
Ease of use	Simple, but limiting	More complex, but robust
Performance	Light overhead	Moderate overhead
Precip and FFG averaging	None	Basin-averaged
Forced FFG	None	FFFG tool
Duration intervals	Limited (1-, 3-hr, storm total, etc.)	Any
Determining precip timing	Limited	Robust
QPE/FFG quantitative comparison	Limited in your head	Calculates for you in tables and display
Determining drainage	Infer from topo or stream links maps	Robust

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 or you compare QPE to the RFC Flash Flood Guidance. In D2D, you can interrogate QPE and FFG in two ways. For one, you can load the radar accumulations and RFC FFG manually from the radar and NCEP/Hydro menus, as shown here, and do a one-to-one comparison. The other option is to use FFMP. Here is a table outlining the main differences:

1. Loading products manually is simple, but has many limitations. FFMP is more complex, but it has more robust capabilities.
2. Performance overhead on the machine is light with manual loading, and moderate with FFMP.
3. One of the fundamental differences is that FFMP averages both the QPE and FFG over the basin area to provide more hydrologically-relevant calculations. To show this, let's start with a basin. Overlaying the corresponding QPE, we see there are spatial variations across the basin. FFMP averages those values, and then compares them to basin-average FFG of the same interval.
4. FFMP also has a tool to create your own FFG, but there is no way to do that in manual loading.
5. In manual loading you are limited to fixed intervals like 1-hr and storm-total precip which can make it hard to determine accumulations for durations like 2 or 4 hours. Some products like HPE or Bias HPE are limited to only 1 hour accumulations in their raw products by default, so it can be very difficult to just figure out a 3-hour accumulation for HPE and Bias HPE. Because FFMP accumulates precip every time a

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rate product is ingested, one of its greatest strengths is the ability to display any accumulation duration.

6. This accumulation-on-the-fly approach also allows FFMP to robustly display the precipitation timing information in the basin trends. When manually loading, it can be difficult to determine when precip occurred with training storms over long periods of time.
7. Another fundamental strength of FFMP is that it calculates QPE and FFG ratios and differences for you, whereas you have to manually calculate that for a limited number of points when you load the products and sample them.
8. Finally, when loading products manually it can be challenging to infer drainage from topo and stream links maps, but FFMP will show you downstream areas graphically.

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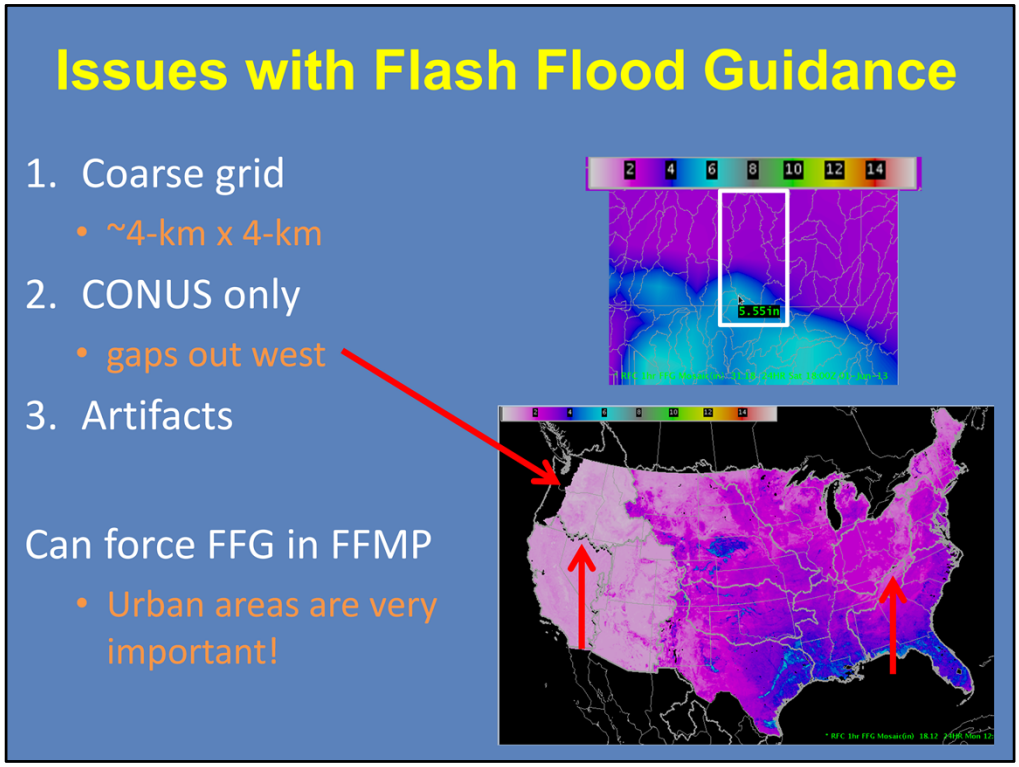

If you have an idea of how much rain has fallen and you are going to use RFC flash flood guidance, it is important to note some of the challenges.

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 5.55 inches, likely due to two grid point observations that are not resolving the basin-scale detail. 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. Finally, 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.

An advantage of using FFMP over manual comparison is: if you do not have RFC FFG or it isn't optimal, you can force it in FFMP. This is particularly useful in important urban areas which are not represented in RFC FFG. Overlaying your local "Urban Bounds" maps is a good practice to help locate urban flash flood-prone areas.

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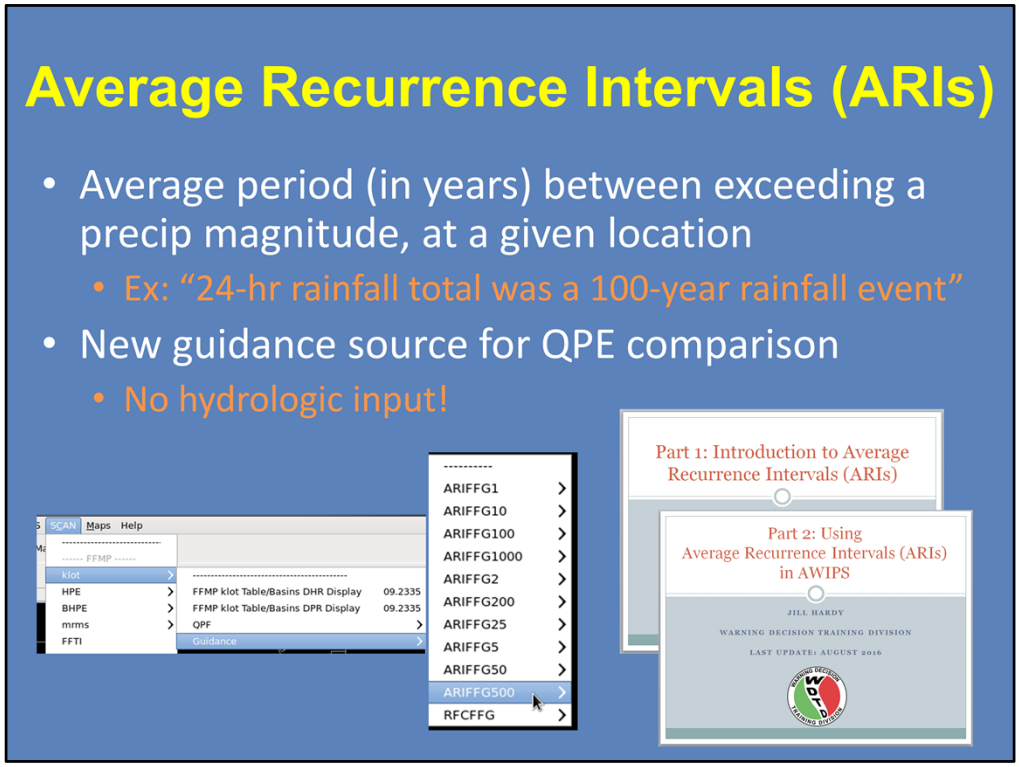

New to AWIPS, as of 16.2.1, are Average Recurrence Intervals (or ARIs). An ARI is defined as the average period (in years) between exceeding a precip magnitude, in a given location. You are probably more familiar hearing ARIs used like "Yesterday's 24-hour rainfall total was a 100-year rainfall event".

We bring ARIs up here because they are a new 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 rather a plethora 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 the two ARI lessons released by WDTD in August 2016. There are a lot of details covered in these lessons that are crucial to effectively interpret this information. These lessons are included in the Warning Operations Course (or WOC) Flash Flood Track, if you plan to enroll in this course after RAC.

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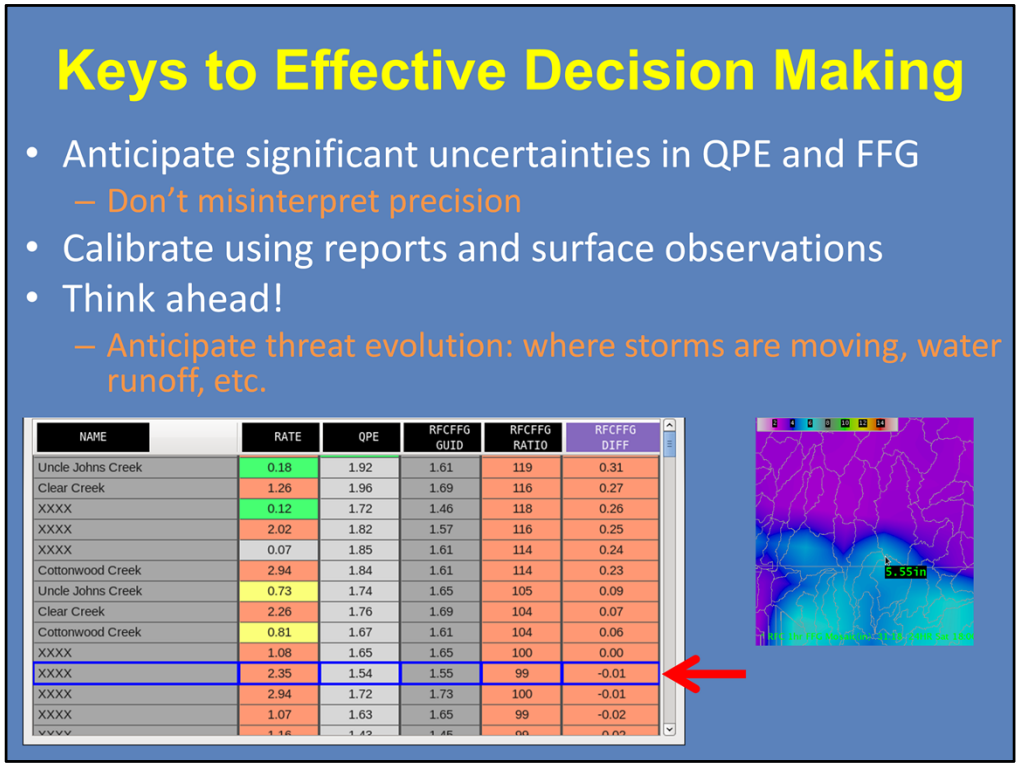

NAME	RATE	QPE	RFCFFG GUID	RFCFFG RATIO	RFCFFG DIFF
Uncle Johns Creek	0.18	1.92	1.61	119	0.31
Clear Creek	1.26	1.96	1.69	116	0.27
XXXX	0.12	1.72	1.46	118	0.26
XXXX	2.02	1.82	1.57	116	0.25
XXXX	0.07	1.85	1.61	114	0.24
Cottonwood Creek	2.94	1.84	1.61	114	0.23
Uncle Johns Creek	0.73	1.74	1.65	105	0.09
Clear Creek	2.26	1.76	1.69	104	0.07
Cottonwood Creek	0.81	1.67	1.61	104	0.06
XXXX	1.08	1.65	1.65	100	0.00
XXXX	2.35	1.54	1.55	99	-0.01
XXXX	2.94	1.72	1.73	100	-0.01
XXXX	1.07	1.63	1.65	99	-0.02

Now that you have been exposed to the general approach to flash flood decision making, there are several keys to making it as effective as possible.

For one, anticipate significant uncertainties in QPE and FFG. It is not uncommon to encounter QPE and FFG uncertainties on the order of 25%, or even 50% at times. However, when doing manual comparison or using FFMP, the values are shown with two decimal places. Don't misinterpret this precision. For instance while the selected basin may be 0.01" below FFG this could easily be a quarter inch above or below FFG due to uncertainties in 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 uncertainty.

Another key to effective decision making is to 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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Summary: FFW Decision Making Process

- Basic approach
  - How much rain has fallen, and timing? (QPE)
    - Choose the best precip source
      - Coverage, Dual-Pol, Bias correction, Resolution, Z-Rs
    - Calibrate with surface obs, gauges, and reports
  - Will runoff result in flash flooding? (FFG)
    - Use local hydrological knowledge
    - Compare QPE with FFG (manually or w/ FFMP)
- Anticipate significant uncertainty in QPE and FFG

To summarize, the basic approach to flash flood decision making first involves 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.
-Is the source Dual-Pol?
-Whether there is a bias correction, and if the biases seem reasonable.
-What is the resolution?
-And how are the rain rate relationships 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 second part of the process involves comparing your QPE with rules of thumb for local flashy basins, or to the RFC FFG. While you can evaluate some of the raw data with manual loading of precip products in D2D, FFMP provides more robust ways to interrogate multiple times and durations.

Always anticipate significant uncertainty in QPE and FFG. QPE uncertainties exist due to numerous radar sampling limitations. FFG is coarse, only over the CONUS, and has artifacts across some RFC boundaries.

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Summary: FFMP Utility

- FFMP strengths vs. simple manual product loading
  - Automated quantitative comparison: QPE and FFG
  - Flexible durations: useful for sources with limited accumulation products (i.e. HPE, BHPE, MRMS)
  - Precipitation timing: basin trend graphs
  - Drainage visualization: connectivity functions

And finally, because FFMP has a number of unique strengths relative to simple manual product loading, Part 2 will focus on how to effectively use it.

The strengths include having automated quantitative comparison of QPE and FFG for any duration. It has flexible durations, which is useful when you want to consider accumulations outside of what is available as a gridded product. Precip timing is also more readily available using the Basin Trend Graphs. And you can better visualize drainage flow using the basin connectivity functions.

Alright, that's the end of Part 1 of the Flash Flood Decision Making lessons. When you are ready, 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. This is Part 2 of 2 about flash flood decision-making. In Part 1, we introduced the general approach to flash flood decision making, as well as compared the different precip and guidance sources available. This lesson will now focus on using FFMP to diagnose a flash flood threat.

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Learning Objectives

- By the end of this lesson, you will be able to:
  - Identify when to use:
    - All and Only Small Stream Basins layer versus County layer
    - QPE, ratio, difference, VGBs,
    - The Basin Trend Graph, specifically the all-hours graph
    - Downstream trace in warning decision making

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

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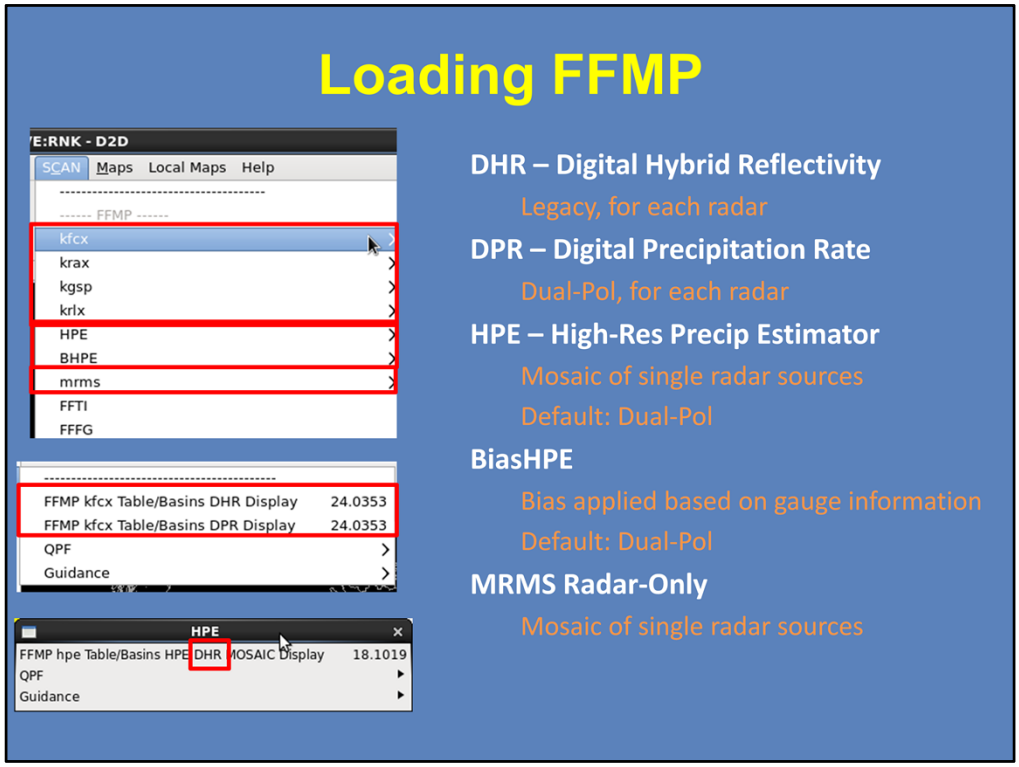

First thing's first: loading FFMP with your desired precip source from the SCAN menu.

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 the 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.

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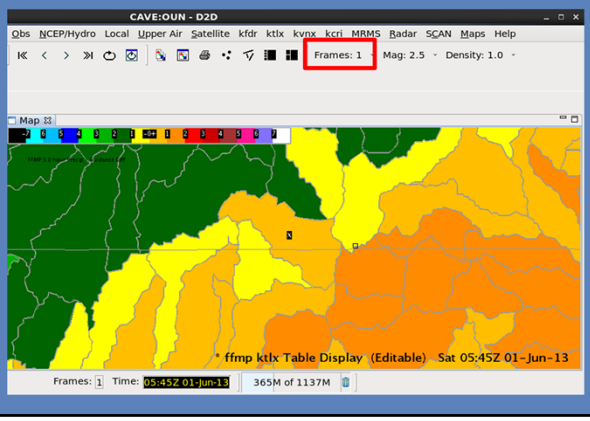
Loading FFMP (cont.)

- FFMP defaults to opening one frame
  - Be judicious when increasing frame count
- Open one FFMP at a time



Once you have decided which precip source to use, you can load FFMP with that source. Note that FFMP defaults to loading just one frame. This is because FFMP uses a lot of system resources. You can increase this manually, just be judicious for performance reasons.

Also, while it is possible to load more than one FFMP at a time (using a different precip source), it can be hard to keep straight which table goes with which D2D display, not to mention adding to potential performance issues. So we don't recommend doing this. Rather, use reports and observations to calibrate whether you need to change your FFMP source.

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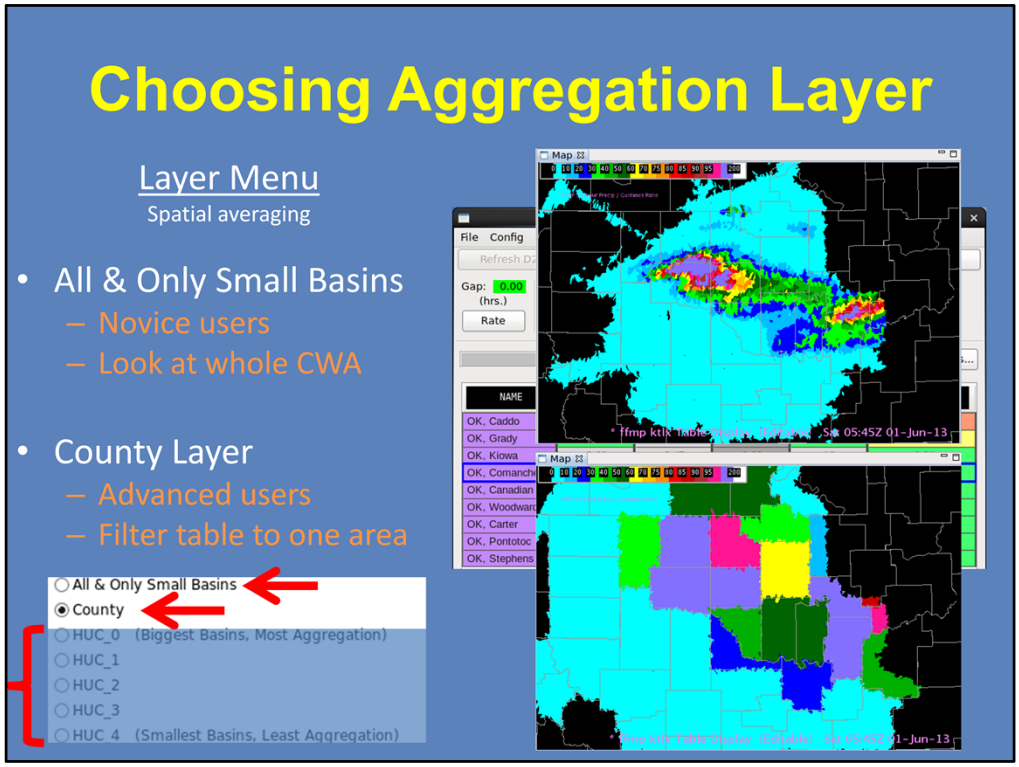

One of the most important steps in using FFMP is choosing the aggregation layer, which defines what spatial scale FFMP averages the QPE and FFG. The two layers we will focus on for flash flooding are the All & Only Small Basins and County.

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 that allow you to overlay the METAR/mesonet observations in the basin trends. There are a lot more settings to pay attention to when using county layer, though. The HUC layers are collections of small stream basins for larger scales and are not used frequently for flash flood decision making.

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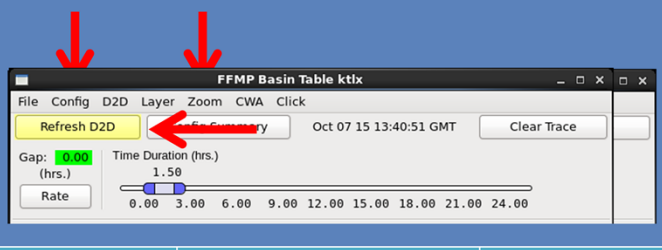
FFMP Recommended Settings



	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, with the “Maintain Layer” option OFF, the D2D will not maintain the county layer and will instead show the individual basins. Setting “Only Basins in Parent” to OFF with the “County” layer 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”, like “County”. 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.

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.

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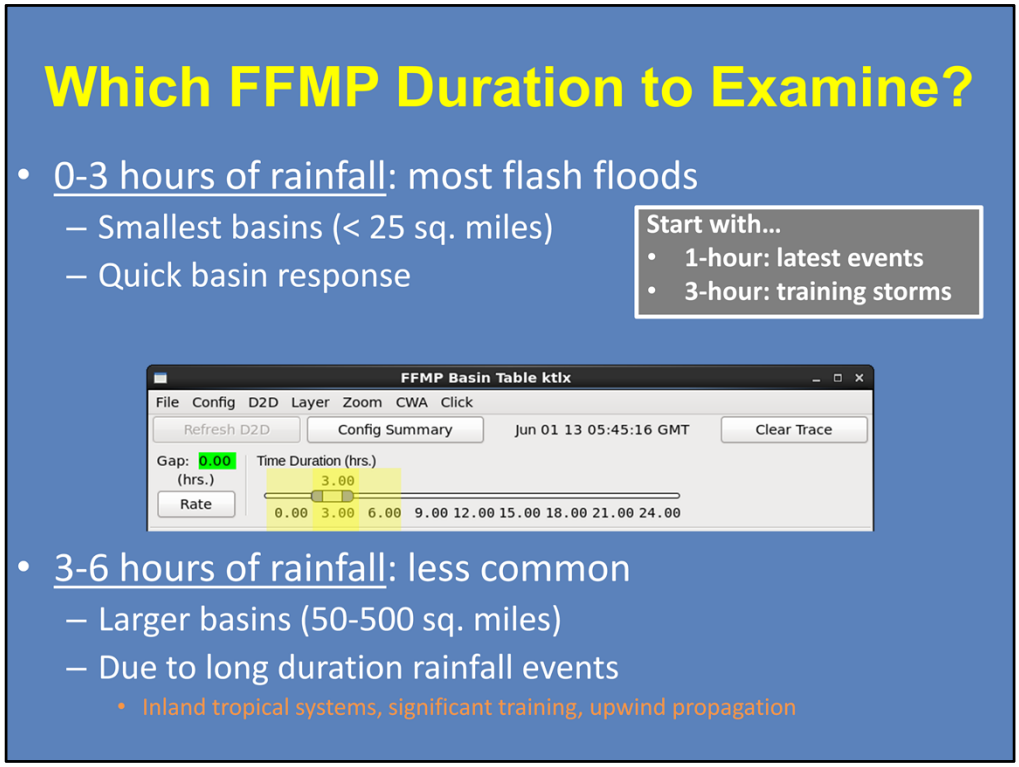

Now that we have reviewed the FFMP settings, let's talk about what durations are good to examine.

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 basins smaller than 25 square miles. These tiny basins have quick responses to the rainfall, and thus inundate rapidly. For RAC, we suggest you focus on the 1-hour duration from the FFMP basin table 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, say 50-500 square miles, 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 information from the basin table.

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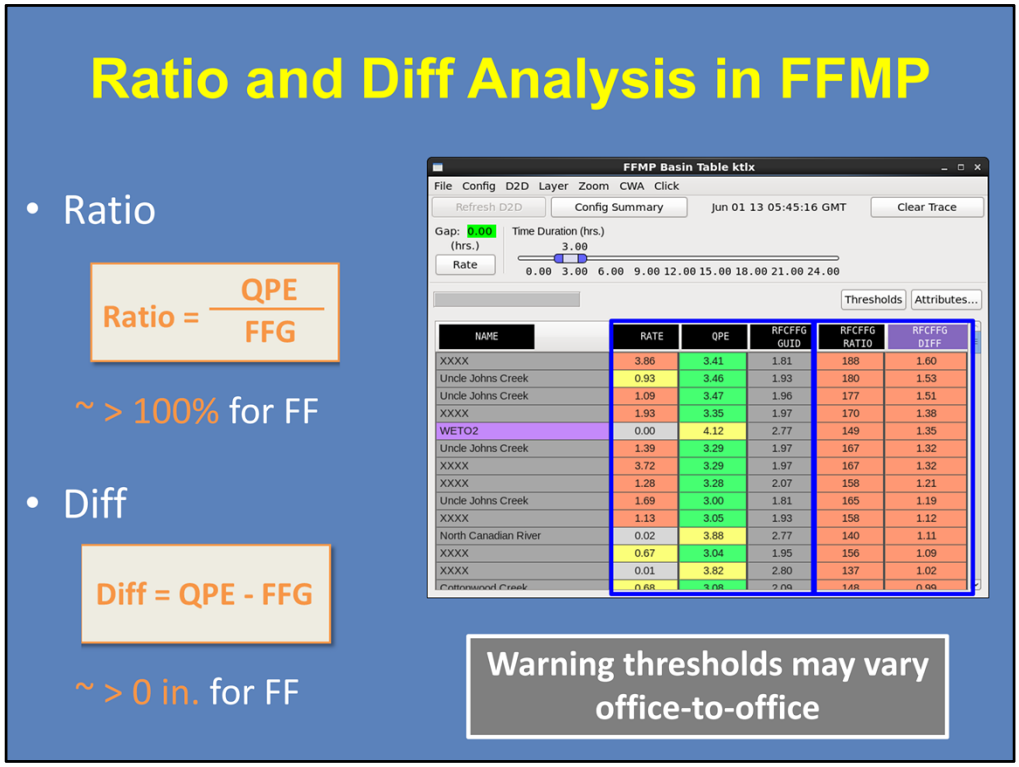

Okay, so you have your settings the way you want, and you know the duration you want to examine. So what should you look at? In addition to instantaneous rate, basin-averaged QPE, and basin-averaged FFG, FFMP has two other options for what can be displayed in the table: Ratio and Difference.

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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Ratio and Diff Practice

Diff = QPE - FFG	Ratio = $\frac{QPE}{FFG}$

1-HR QPE & FFG	Diff	Ratio
QPE: 4.00 in. FFG: 2.00 in.		

- ***Ratio*** provides awareness of what areas are approaching or exceeding FFG
- ***Diff*** provides information on the potential magnitude of flash flooding

Best Practice: Start Ratio, and then go to Diff

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 Diff value would be 2 inches while the ratio would be 200%. 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 Difference is now 0.5 inches, and the ratio is 200%. 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.

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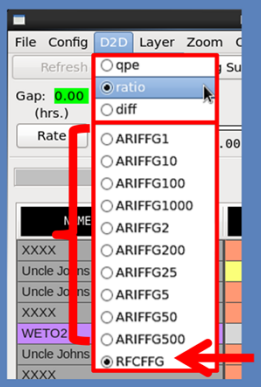
FFMP Guidance Source in Display

D2D Menu

Displayable products in D2D

- qpe, ratio, diff
- For ratio or diff:
  - Set guid. source: FFG (default) or ARIs
- Guidance source change ONLY affects display (not table)
  - Always switch back to FFG when done
- Recommend novices do not alter D2D menu guidance source



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, as mentioned in Part 1, 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.

To reiterate from Part 1, 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.

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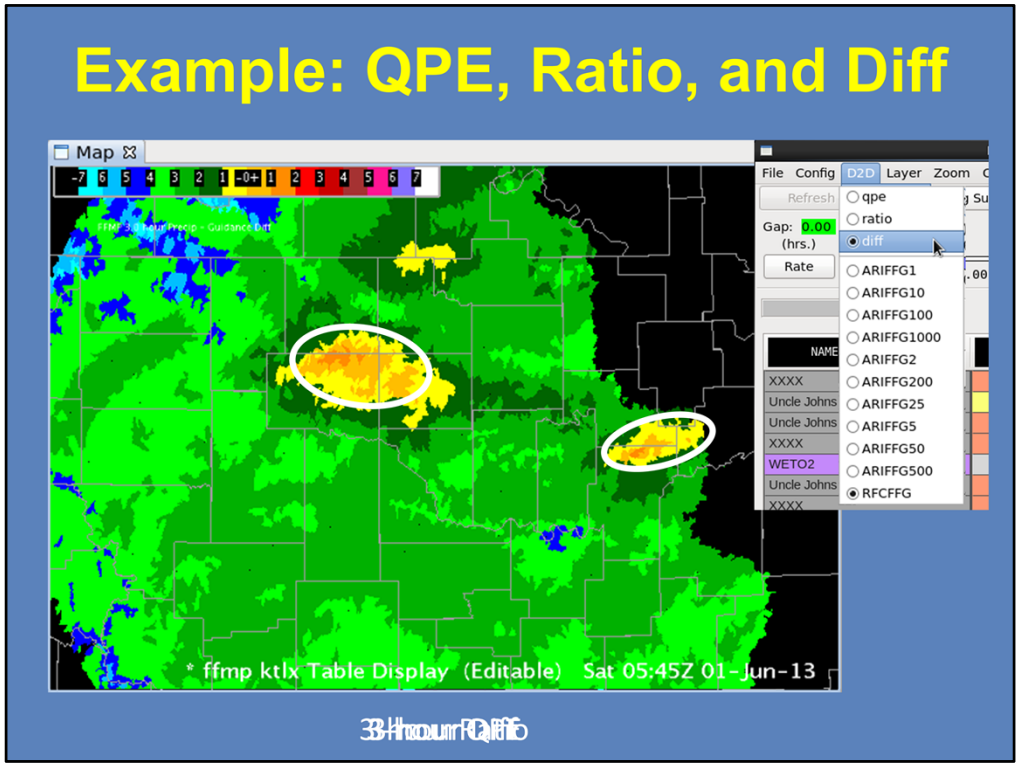

Here is an example of how to interpret the D2D options.

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%. Begin by seeking out the purple areas, or those that have exceeded FFG. If rain is continuing, then also consider the dark reds and pinks, since those areas are approaching 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. Within our areas of interest, light orange is 0-1 inches, and darker orange is 1-2 inches, which is where the more significant flash flooding threat is located.

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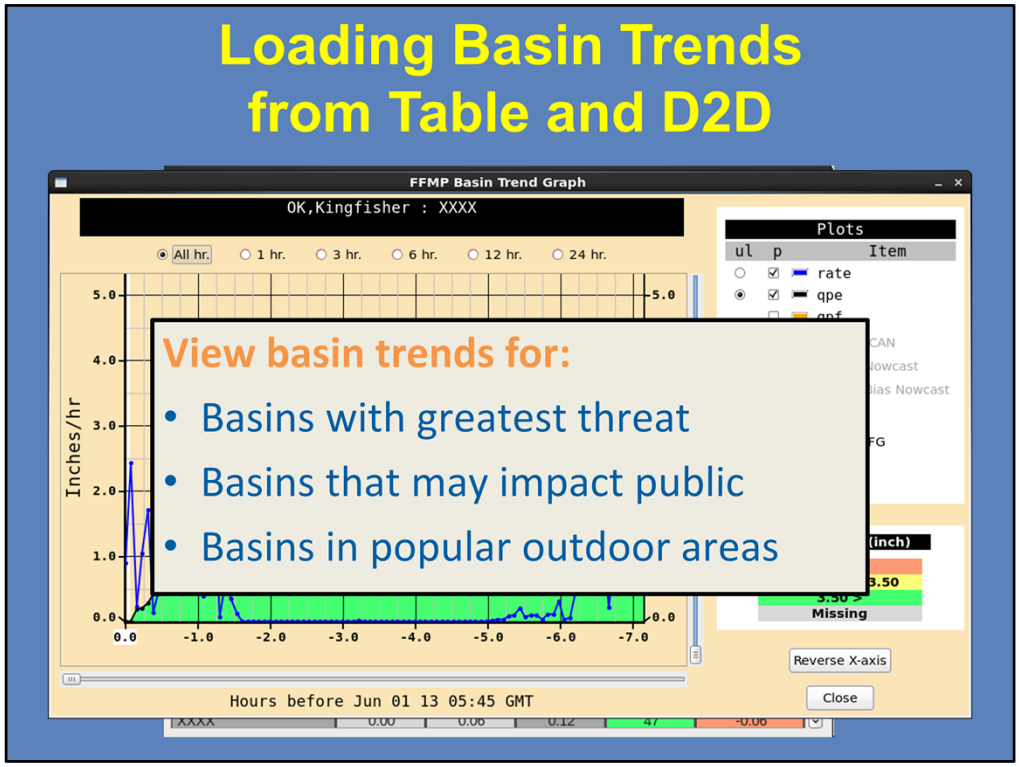

By this point you have zeroed in on the primary threat areas using Ratio and Diff and by monitoring rain rates. Though basin trend graphs in FFMP take some time to get used to, they contain critical information on the timing and relationship between the QPE and guidance for different durations.

To load a Basin Trend, there are two options: First, you can load it by right-clicking on a small 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 and it would be time intensive to view large numbers of basin trends, it is best to view the basin trends for 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.

The basin trend graph gives you an easy way to view history of rainfall rates and accumulations as they relate to flash flood guidance. Now let’s look at how to interpret one.

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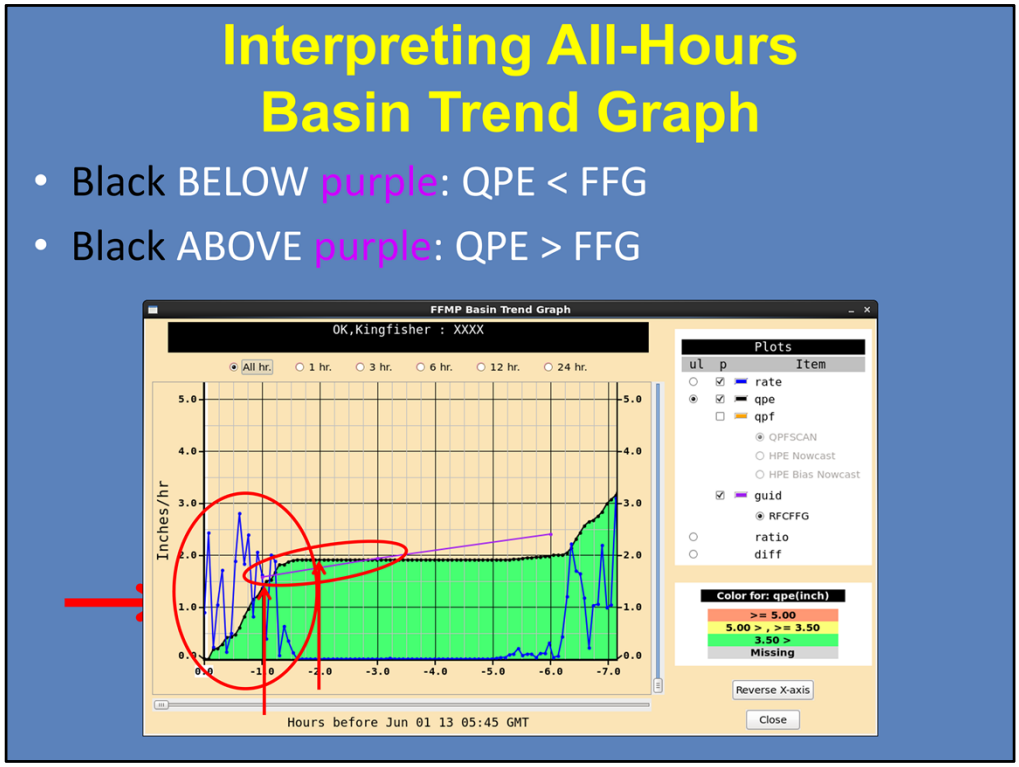

Okay, let's take a look at this basin, which is only three-hundredths of an inch away from exceeding the 3-hour FFG and is currently experiencing instantaneous rain rates of 0.89 in/hr. As a warning forecaster, I would like to know when within the three hours 1.90 inches of QPE fell, so I right-click 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 ~ 2in/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-hourr 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.

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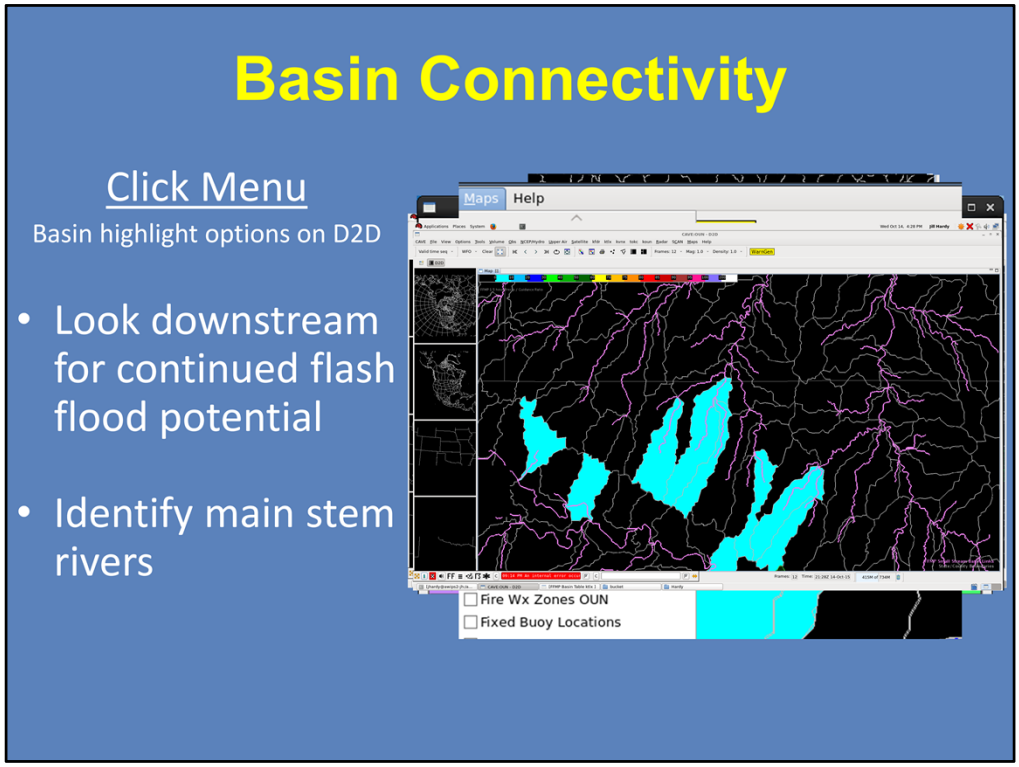

Finally, FFMP allows you to see basin connectivity on the D2D display as configured in the "Click" menu. For instance if you select "Downstream" from this menu, then you go to the D2D display and make the FFMP display editable. Once editable, your right-click button will highlight the basins downstream 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.

Once you have pinpointed your current threat area, it is important to look downstream to see where the runoff will go. If upstream accumulation is great enough and the downstream basin is 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.

Additionally, major main stem rivers typically don't *flash* flood, so using the upstream and downstream connectivity to help identify them and can be useful in adjusting your polygon.

A useful tool for visualizing downstream flow is by overlaying the "FFMP Small Stream Basin Links" from the Map menu in D2D. I made them purple in this graphic. As you can see, all of the basins with any response are in the most upstream headwaters, with no other basins feeding into them. These headwater basins tend to be the smallest, but with the quickest responses to rain, and thus, the highest risk for rapid flash flooding.

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Summary: FFMP Utility

- Loading FFMP
  - Choose your precip source
  - Limit frame count and number of FFMPs open
- Layer choice
  - All & Only Small Basins: initial approach
  - County: more complex filtering of basins
- D2D choice
  - QPE: can assess QPEs over unique accumulations
  - Ratio: initial look for approaching FFG
  - Diff: magnitude of flash flooding

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 Part 1 to consider all of your available precip sources. Also, be diligent with frame count, and only have one FFMP open at a time.

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 so you can find particular basins or the virtual gauge basins that can be used to compare METAR/mesonet to precipitation accumulations.

Within FFMP, D2D can be configured to show QPE in order to uniquely be able 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.

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Summary: FFMP Tools

- Basin Trend Graph
  - See temporal trends: precip timing
  - Easy visualization: comparing QPE to FFG and gauges
- Basin connectivity
  - Downstream Basin Trace
  - Small Stream Basin Links

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 visualize where the flash flood threat may be evolving, including the Downstream Basin Trace that highlights basins downstream of the selected basin, as well as the Small Stream Basin Links feature for identifying main stem rivers.

This concludes Part 2 of the Flash Flood Decision-Making modules. When you are ready, please move onto the next slide to take the quiz and receive credit on the LMS.