1. Conceptual Models for Origins and Evolutions of Convective Storms

Instructor Notes: Welcome to Lesson 3 of IC Severe 1, which will focus on conceptual models related to heavy rainfall and flash floods events. This lesson should take you about 40 minutes to complete.

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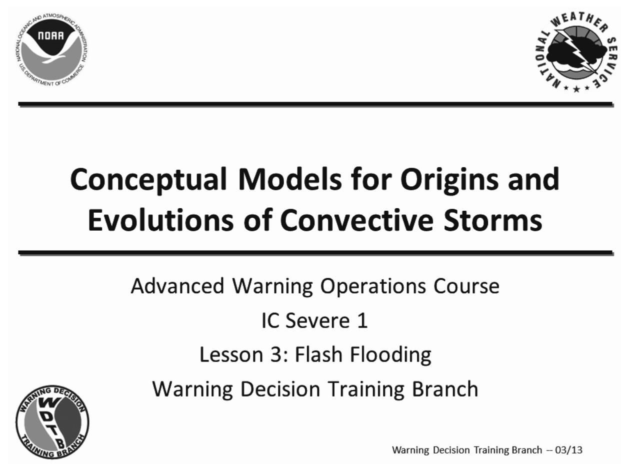

2. Learning Objectives

Instructor Notes: There are three primary learning objectives for this lesson. Most of this module will concentrate on research that identified synoptic scale patterns and meteorological ingredients that are associate with heavy rainfall and flash flood events. Later in the module, we will discuss other events and features that provide heavy rainfall and flash flooding, such as tropical cyclones, predecessor rain events, and atmospheric rivers.

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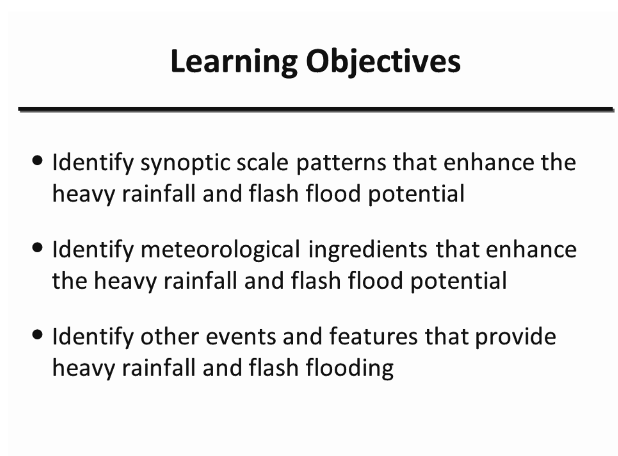

3. Pattern Recognition of Heavy Rainfall Events - Maddox et al.

Instructor Notes: In January of 2011, the National Weather Service released a service assessment on the record floods of middle Tennessee and western Kentucky that occurred from May 1-4, 2010. This lesson will help address Finding #12 of that assessment, which discusses forecaster experience in pattern recognition of heavy rainfall events. We will begin with the work by Maddox et al. from 1979. In their research, they analyzed 151 flood events from 1973 to 1977. Using these events, they were able to define some basic synoptic scale patterns. It should be noted that 139 of these events had precipitation totals greater than or equal to 4 inches (10 centimeters). All the storms were convective in nature and exhibited similar basic atmospheric characteristics, such as high surface dew points, large moisture content, and weak to moderate vertical wind shear.

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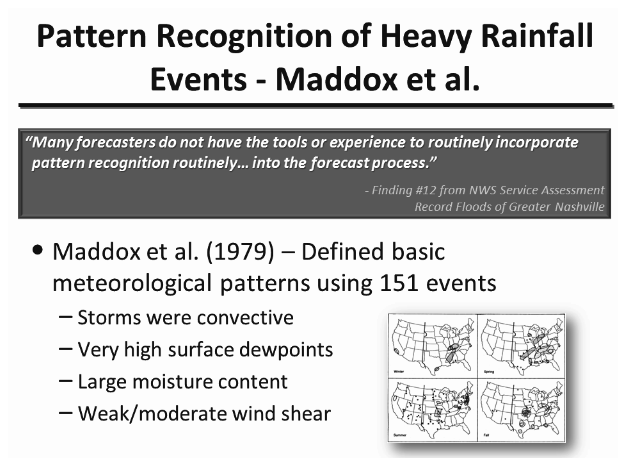

4. Maddox Synoptic Pattern

Instructor Notes: The first pattern we will look at is the synoptic pattern. The heavy rainfall event with this pattern is defined by its association with an intense synoptic scale cyclone or frontal system. Using a top-down approach, Maddox et al. noted a major trough at the 500 mb level that would move slowly to the east or northeast. The atmosphere ahead of the 500 mb trough axis would be considerably moist, defined here by the region of dew point depressions less than 6°C. The 850 mb level is characterized by a strong southerly low-level flow and abundant moisture transport, highlighted here with dew point temperatures greater than 10°C. There is also little speed or directional shear in the 850-300 mb level. The average wind difference observed was about 25 kts with 40 degrees of veering, depending upon the orientation of the synoptic scale system and surface fronts. And speaking of the surface fronts, they were often found to be quasi-stationary and generally oriented SSW to NNE. Development of the heaviest rain, highlighted by the shaded boxes, is located on the warm side of both the quasi-stationary front and a warm front. The warm front limits the northern extent of the development of the heaviest rainfall, but it also aides in triggering new development farther eastward.

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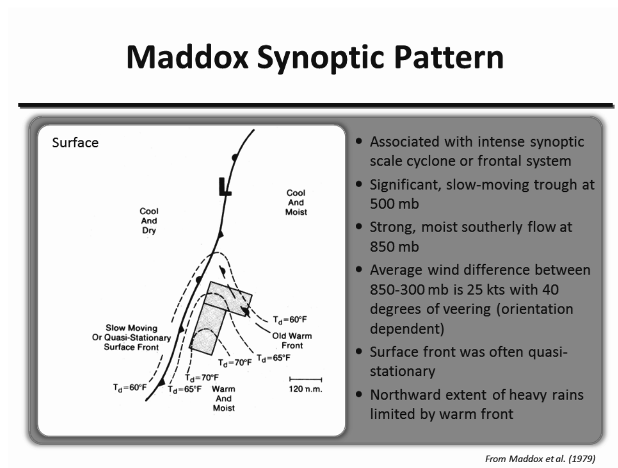

5. Maddox Frontal Pattern

Instructor Notes: The frontal pattern is defined by a stationary or slow moving zonally oriented synoptic scale frontal boundary. Starting again with the top-down approach, the 500 mb pattern shows a large ridge to the southeast with the area of heaviest rainfall occurring within a region of dew point depressions less than 6°C near the large-scale ridge axis. Most events had some weak meso-α scale trough or a mesolow along the frontal boundary, which can assist in frontal overrunning and small-scale convergence. Just like the synoptic pattern, the 850 mb level shows a strong low-level jet feeding very moist air into the area of interest. There is little speed shear in the 850-300 mb level, but there is a significant amount of veering in the wind profile. At the surface, Maddox et al. noted that the heaviest rainfall fell on the cool side of the E-W oriented front as warm unstable air flowed over the frontal zone. Since the winds aloft (i.e., the 700-200 mb level) paralleled the front, the greatest rainfall totals were a result of repeated convective development and training.

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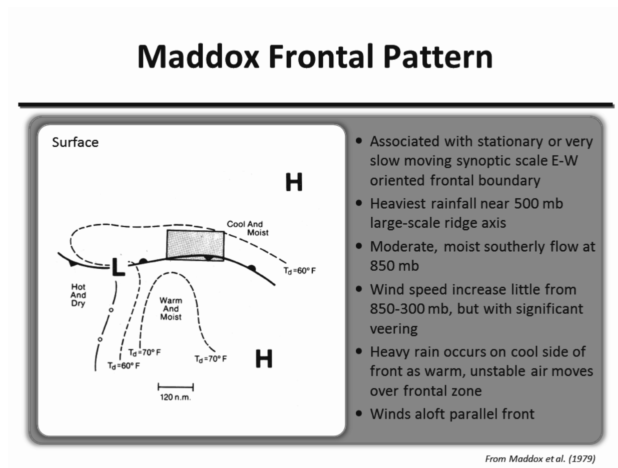

6. Maddox Mesohigh Pattern

Instructor Notes: The mesohigh pattern was the most common event sampled during the work of Maddox et al. (34% of events). Mesohigh events are the result of quasi-stationary thunderstorm outflow boundaries (generated from previous convection), and they usually occurred during the summer months. The 500 mb and 850 mb patterns are similar to that of the frontal pattern, where the greatest rainfall totals occurred in an area of low dew point depressions near the large-scale ridge axis, the presence of a weak trough to the west, and moderate southerly flow in the low-levels. Again, there is little speed shear but significant veering in the 850-300 mb level. The details regarding the mesohigh pattern reside in the surface features. Maddox et al. noted that half of their events occurred to the east of a large-scale frontal system, while the other half were not located near any notable surface fronts. The diagram here shows the previously generated quasi-stationary outflow boundary and associated mesohigh. The greatest rainfall would occur along the cool side of the boundary usually to the south or southwest of the mesohigh. Convection would repeatedly develop and train over the same area since the winds aloft were near parallel to the outflow boundary.

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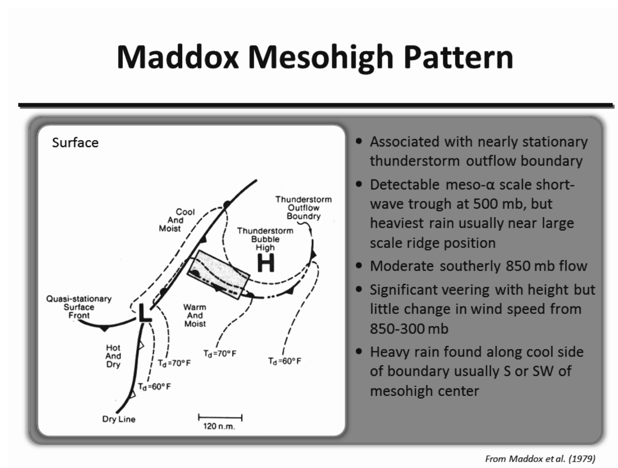

7. Maddox Western Pattern

Instructor Notes: The final type of event that Maddox et al. observed were those in the western U.S. In their work, typical surface and upper-air maps were not developed due to weak large-scale patterns without well-defined surface features. A lack of surface observations also hindered their ability to define any pattern(s) from these events. However, they noted that the heaviest rainfall from western events occurred near old frontal boundaries, thunderstorm outflow boundaries, or induced by orographic features. Maddox et al. also noted that the atmosphere was quite moist and had large conditional instability, generally in the area ahead of a mid-tropospheric meso-α scale trough.

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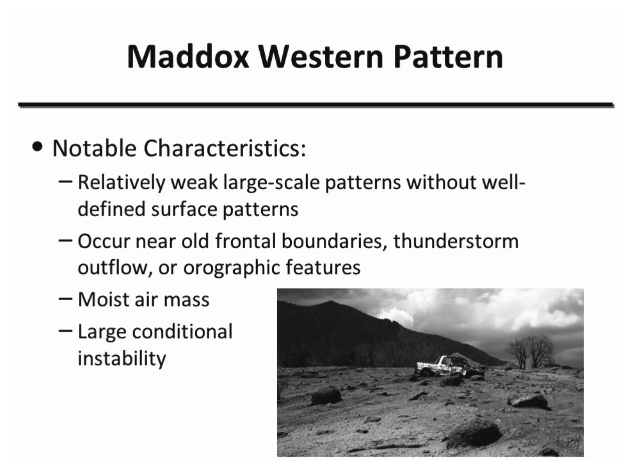

8. Ingredients Based Methodology – Doswell et al.

Instructor Notes: The work by Doswell et al. in 1996 focused on an ingredients based methodology, rather than a pattern-based approach, to forecasting heavy rainfall events. In their work, they noted that heavy rainfall and flood events from a variety of meteorological situations all contained similar atmospheric ingredients. Thus, the ability of a forecaster to identify such critical ingredients can be used in the recognition of heavy precipitation potential. Doswell et al. stated that "In order for a flash flood to occur, heavy precipitation must fall in a region that has appropriate hydrological ingredients in place." From there, the heavy precipitation factor was separated into two key ingredients: high rainfall rates and long rainfall duration. The rainfall rates were found to be influenced by rapid ascension of moist air and occurring with deep moist convection. Rainfall durations were characterized by storm motion and size. The hydrologic ingredients were not addressed in their work.

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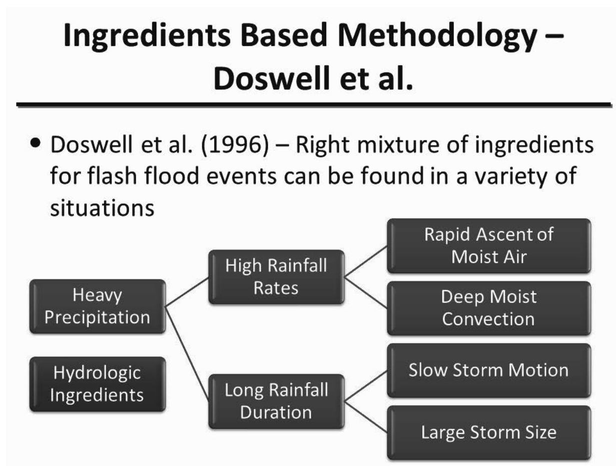

9. Heavy Precipitation and Precipitation Efficiency

Instructor Notes: Using an analogy attributable to Charles Chappell, “The heaviest precipitation occurs where the rainfall rate is highest for the longest time.” Doswell et al. stated that is an “almost absurdly simple concept,” but in its simplicity brings forth the very fundamentals behind heavy rainfall events. Starting with rainfall rate, the total precipitation for a given point is reduced to the equation, P=(R bar)D, where the total precipitation (P) is the combination of the average rainfall rate (R bar) and the duration of rainfall (D). The instantaneous rainfall rate (R) is assumed to be proportional to the vertical moisture flux, which is the combination of the ascent rate (w) and mixing ratio of the rising air (q). Rapidly ascending water vapor then condenses and falls as precipitation. However, not all water vapor falls as precipitation. This leads to the coefficient of proportionality relating the rainfall rate to input water vapor flux, otherwise know as the average precipitation efficiency (E). Doswell et al. states that the precipitation efficiency is a function of space and time (as seen in the diagram on the slide), and the key is to “anticipate the efficiency in a general sense” over the average of the life-time of the event.

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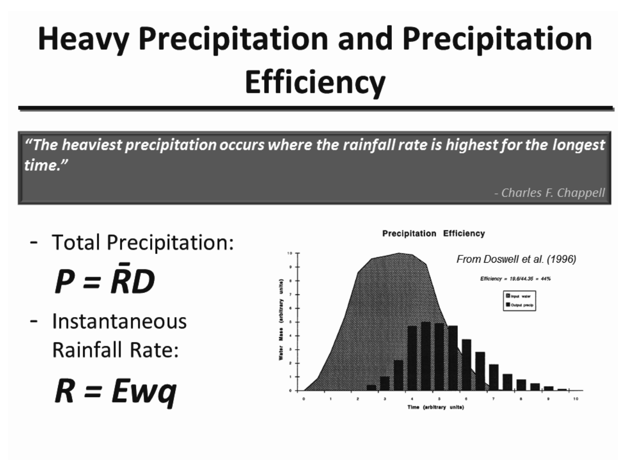

10. Storm Motion and Duration

Instructor Notes: Moving on from rate to duration, Chappell (1986) stated that “Quasi-stationary or slow moving MCSs pose the greatest threat for excessive rains and flash floods.” Individual convective cells have lifetimes that are too short to produce heavy rainfall, so a system of multiple convective cells does provide the desired duration to produce flash flooding. Doswell et al. expanded upon this by stating that duration of high precipitation rates for a given location is related to system movement, system size, and within-system rainfall rate variability. The equation for the duration of rainfall for a given point is the combination of the length of the system (Ls) and the inverse of the system motion vector (Cs). In the diagram shown here, a N-S oriented MCS with the motion vector, C, will not produce long-lasting high rainfall rates at a given point. If the motion vector is more parallel to the precipitation orientation, then high rainfall rates will occur at a given point for a much longer duration, resulting in more rainfall. Although Doswell et al. did not quantify any of the aforementioned features, they found that these conceptual models of rainfall rate and duration can be useful in providing a framework for forecasters to analyze model and/or observed data for heavy rainfall events.

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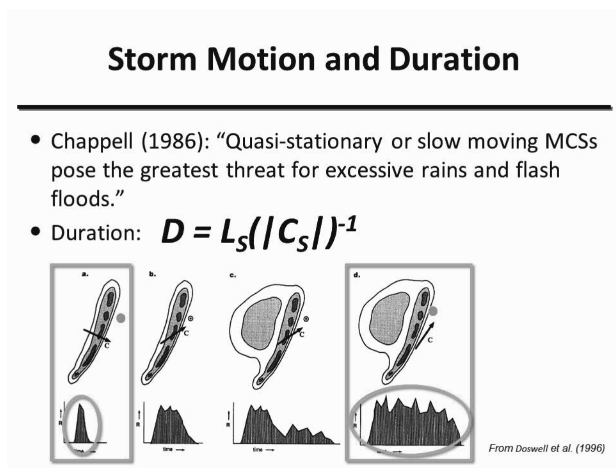

11. Moisture Flux Convergence and Mean Flow – Junker et al.

Instructor Notes: The work by Junker et al. in 1999 followed the Doswell et al. ingredients-based approach and applied it to the heavy rainfall events that resulted in the Great Midwest Flood of 1993. Their work identified 85 heavy rainfall events, and the events were categorized by the areal size of the three inch isohyet. They noted that the heavy rainfall events occurred north (downwind) of the axis of greatest 850 mb winds and greatest moisture flux in an area of 850 mb temperature and equivalent potential temperature advection. Junker et al. evaluated a variety of meteorological fields to determine what fields were related to the scale and intensity of the heavy rainfall events. The scale and intensity of these events were then found to be influenced by the magnitude of the warm air advection, the 1000-500 mb mean relative humidity, the breadth of the moisture transport axis, and the strength and orientation of the moisture flux convergence. We will start by discussing the moisture flux convergence.

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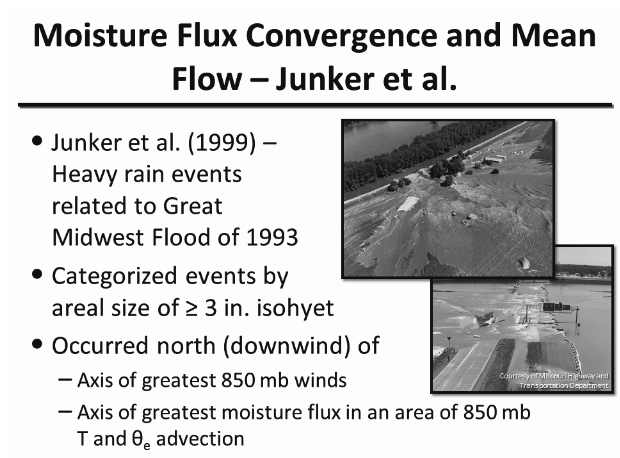

12. Moisture Flux Convergence and Mean Flow

Instructor Notes: We will begin with a quasi-stationary E-W oriented surface boundary with a broad, southerly 850 mb flow. Junker et al. noted that the breadth, location, and movement of the moisture flux appears to attribute to altering the rainfall in the area. They found that a broad axis of low-level moisture flux into the boundary created a large area of moderate-to-strong moisture flux convergence, which can assist in convective development. In the more extreme cases, the axis of strongest low-level winds and moisture flux translated downstream more slowly than in more moderate heavy rainfall cases. Another critical element of this is the orientation of the mean flow with respect to the surface boundary and the axis of low-level moisture flux convergence. The more extreme events were characterized by having a mean flow that is roughly parallel to the surface boundary (and consequently, parallel to the axis of low-level moisture flux convergence). This allows for the increased opportunity for continuous cell generation and training, including backward propagating MCSs.

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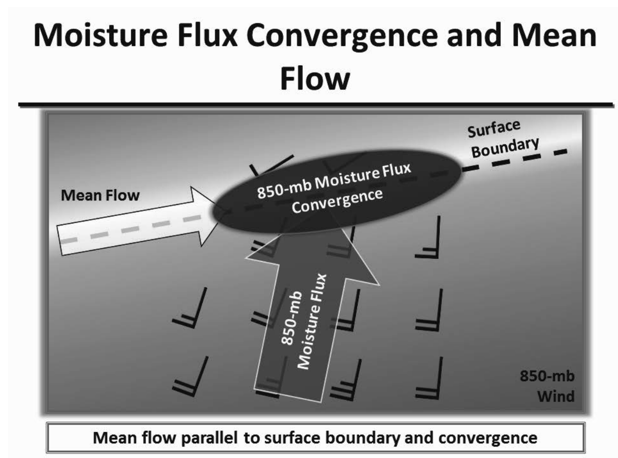

13. Available Moisture and Mean Relative Humidity

Instructor Notes: The other major factor that Junker et al. found was the magnitude of available moisture in the atmosphere. Recall that the heavy rainfall events were categorized by the areal size of the three inch isohyet. Events that were designated as "Category 0" had an areal extent of less than 36 nm2. Events that were designated as "Category 4" had an areal extent of greater than 3600 nm2. In the chart shown here, Junker et al. plotted each event again the average 1000-500 mb thickness and precipitable water (PW) value, which was based on the work by Funk (1991) and Lowry (1972). The 70% saturated thickness line was defined by Funk (1991) based on work by HPC stating that heavy rainfall events were typically associated with a 70% or greater mean relative humidity (assuming a standard atmosphere). Higher mean relative humidity values lie along and to the right of the line. Using this methodology, it was shown that most extreme heavy rainfall events (Category 3 and 4 type events) occurred to the right of the line. It was also noted that the core of the heaviest rainfall fell within the axis of the greatest relative humidity values.

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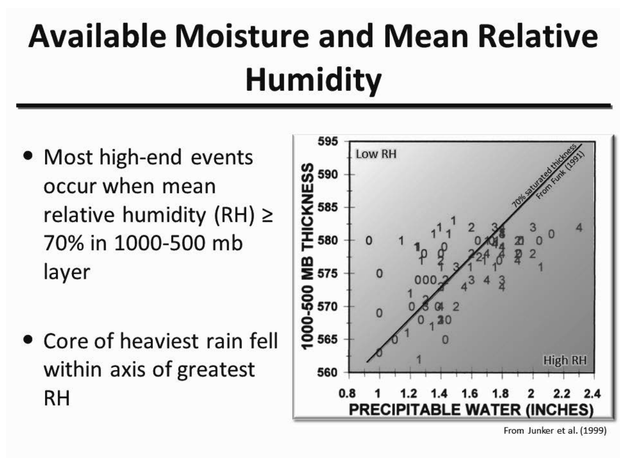

14. Recognition of a Heavy Rainfall Event: Patterns (500 mb)

Instructor Notes: Now, let's take the concepts from Maddox, Doswell, and Junker and apply them to a real-world event. The first AWIPS image here displays the GFS 500 mb wind, height, and dew point depressions less than 6°C (shown in color fill). There is a large ridge off the southeastern U.S. coast with predominantly zonal flow across the northern two-thirds of the country. The dew point depression analysis shows a region of moist mid-level air extending from the Rockies across the central U.S. to the mid-Atlantic region. So, on our map to the right, we will highlight the location of the ridge and the moist 500 mb region based on the low dewpoint depressions.

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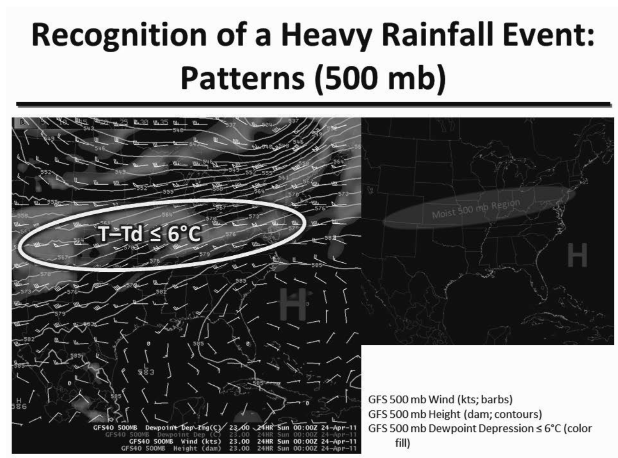

15. Recognition of a Heavy Rainfall Event: Patterns (850 mb)

Instructor Notes: Moving on, here is the 850 mb level with the height, wind, and dewpoint temperatures ≥ 10°C in color fill on display. The first thing that stands out is the plume of high dew point temperatures. This low-level moisture originates from the inter-tropical convergence zone (ITCZ) and streams northward through the southern Plains into the Ohio River valley. The moisture transport in this event is aided by south to southwesterly winds forecasted to be 30-35 kts. On our map to the right, we will highlight the region of 850 mb dewpoint temperatures ≥ 10°C and the 850 mb axis of maximum winds. There is now a region from the southern Plains to the mid-Atlantic coast where the moist 500 mb region overlaps with the 850 mb moisture transport.

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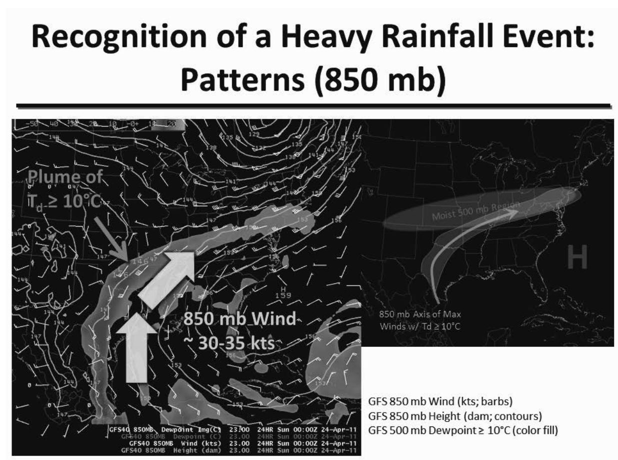

16. Recognition of a Heavy Rainfall Event: Patterns (SFC)

Instructor Notes: Now looking at the surface features, here is the GFS surface winds, temperature, and dew points temperatures ≥ 60°F in color fill. Starting with the wind and temperature analysis, there is a WSW-ENE oriented boundary located from the TX/OK border towards PA and the mid-Atlantic region. To the south of the boundary is a large pool of ≥ 60°F dew point temperatures with southerly winds at 5-10 kts. In our map to the right, let's first overlay the surface boundary and the southerly wind field. Now let's add the areas of ≥ 60°F dew point temperatures. You can see the analysis at the 500 mb level, the 850 mb level, and the surface all come together in a region from eastern OK extending up to OH. Based on the patterns we have seen described by Maddox et al., the setup appears similar to that of the frontal pattern. The region of highest heavy rainfall potential is located north of the boundary within the area denoted by the white box.

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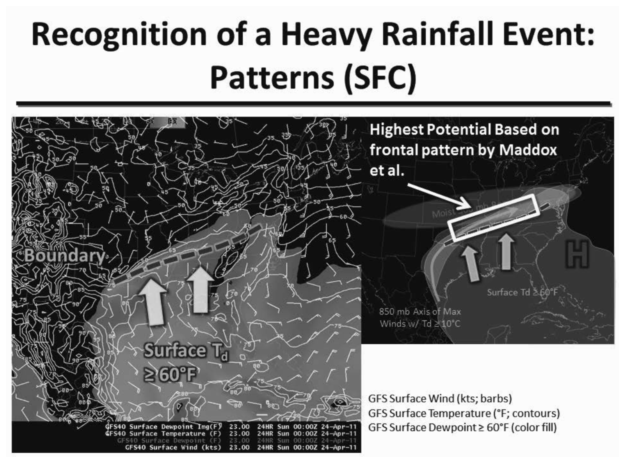

17. Recognition of a Heavy Rainfall Event: Ingredients

Instructor Notes: We will take the same event and apply a more ingredients-based approach from that of Junker et al. and Doswell et al. Here, we are looking at the 850-300 mb winds and the 850 mb moisture transport magnitude shown in color fill overlaid with the boundary location based on our previous surface analysis. The first thing you notice is that the moisture transport is focused in the area of the boundary. This is where you would expect the greatest low-level moisture convergence (not shown). Looking at the mean wind over the region, it is generally from the WSW around 40-45 kts. The individual storm motion over this region would be rather quick, but it is important to note that mean will is near parallel to the surface boundary and moisture convergence. Therefore, this region is primed for continuous convective generation and training over the same area if the boundary and axis of moisture flux transport moves slowly.

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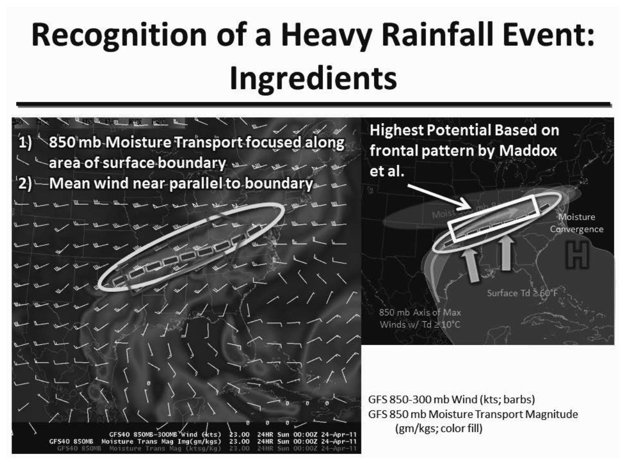

18. Recognition of a Heavy Rainfall Event: Ingredients

Instructor Notes: Finally, we will assess the moisture content of the atmosphere. Here is the GFS precipitable water (PW) plotted in contours and in color fill for values greater than one inch along with the 1000-500 mb thickness. Values of PW above 1.50 inches exist in the region of the surface boundary. Areas of very moist air in a region of forcing is one of the factors Doswell et al. described in the production of high rainfall rates. When comparing the 1000-500 mb thickness and the PW values against the 70% saturation thickness rule (as done in Junker et al.), the maximum PW value of 1.65 inches with a thickness of 565 dam would be located here on the graph. This is well to the right of the 70% saturation thickness line, meaning that the atmosphere in this layer is very moist. To graphically show this, here is the GFS 1000-500 mb relative humidity (RH) with it color filled for values of 70% and above. Note how the greater RH values are co-located with the region of highest heavy rainfall potential based on the pattern analysis and area of moisture convergence. Now that we have completed our analysis of this event, let's see how it verifies.

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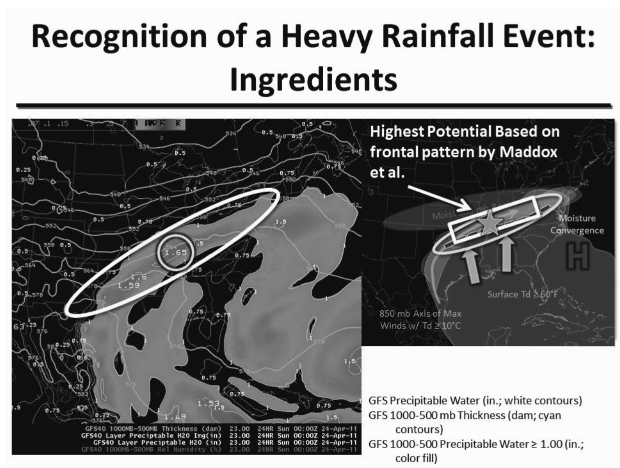

19. Recognition of a Heavy Rainfall Event: Resulting QPE

Instructor Notes: We defined our area of interest along and north of a WSW-ENE oriented surface boundary from eastern OK to southern OH, and we have a fairly high confidence that this region could see significant rainfall totals. The 24-hour multisensor precipitation estimator (MPE) totals depict a large area of rainfall of over 1.50 inches in our area of interest, with precipitation totals of 3-6 inches from northwest AR to southern IN. Continuous heavy rainfall over consecutive days in this area led to significant flash flooding with numerous evacuations and water rescues.

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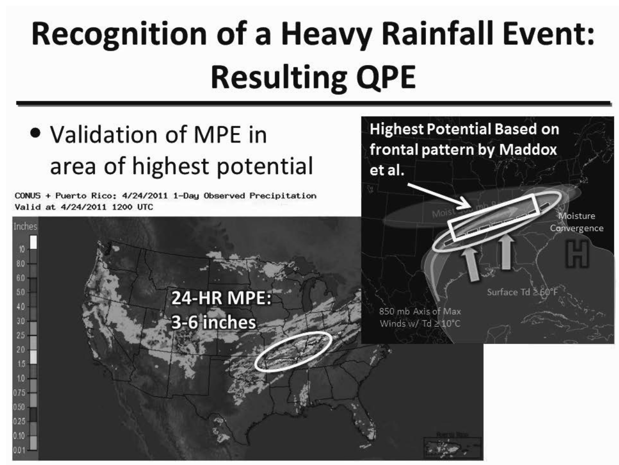

20. Heavy Rainfall with Tropical Cyclones

Instructor Notes: Now that we have discussed basic meteorological patterns and ingredients associated with flash flood forecasting, let's take a look at other scenarios that also result in heavy rainfall and flash flooding. Let's start with the very obvious tropical cyclones. We know that these systems are very efficient precipitation producers with modest CAPE values, a very deep warm cloud layer, and extremely high precipitable water (PW) content. Rainfall with tropical cyclones can also be enhanced by interactions with boundaries and topography. Unfortunately, the copious amounts of rainfall that induce flash flooding are the most lethal part of a landfalling tropical cyclone. Almost 60% of tropical cyclone fatalities are associated with freshwater flooding.

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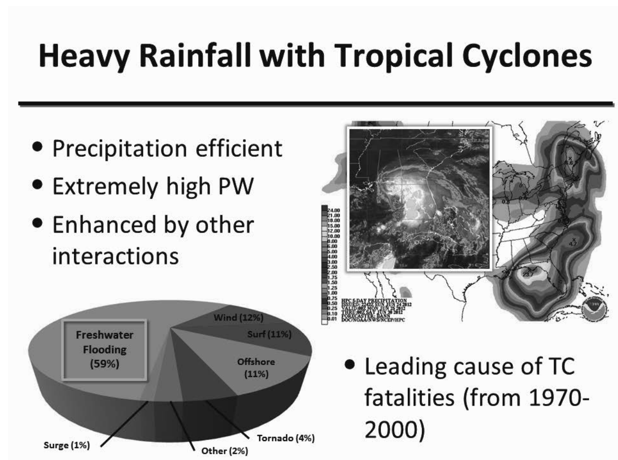

21. Precipitation During Extratropical Transition (ET) – Jones et al.

Instructor Notes: As tropical cyclones move toward the midlatitudes, they often decay and undergo a process that is referred to as extratropical transition (ET). During ET, tropical cyclones lose their symmetric appearance and deep convection and evolve into a broad “comma-shaped” extratropical cyclone. This module will only address the evolution of ET related to precipitation impacts. The work by Jones et al. in 2003 discussed the challenges of forecasting the different meteorological variables and their impacts with ET. In their precipitation analysis, a poleward expansion of the precipitation field began during the onset of ET and continues to generally bias left-of-track during the ET process. Research has shown that the interaction between a tropical cyclone and a baroclinic midlatitude environment during ET can lead to the development of midlatitude cylcone features, such as defined regions of warm and cold air advection and frontogenesis.

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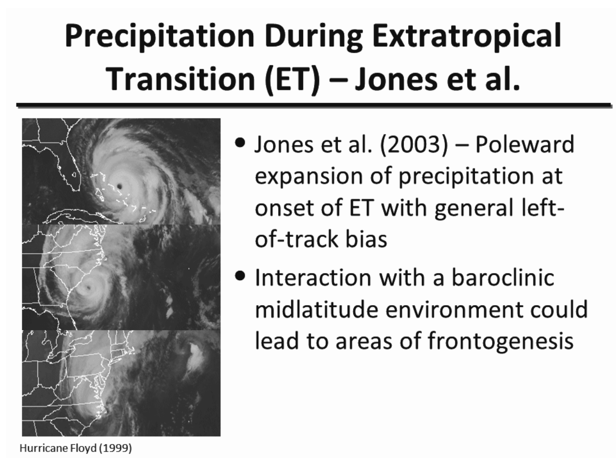

22. ET and Frontogenesis with Tropical Storm Hermine (2010)

Instructor Notes: We will use the remnants of Tropical Storm Hermine from September 2010 to show the impacts of frontogenesis after the completion of extratropical transition (ET). Hermine was located near the tail end of a cold frontal boundary that originated from a midlatitide cyclone over eastern Canada. Surface analysis near the time of this combination satellite/radar image shows the extension of that cold front into the southern Plains while the remnants of Hermine develop a warm frontal boundary near the center of the surface low. A secondary boundary begins to develop farther south and east as Hermine exhibits more trough-like characteristics. The heaviest precipitation occurred along and north of the E-W oriented front and along the developing N-S oriented boundary. Regions in eastern TX accumulated over six inches of rain in a 12 hour period due to the slow movement of the system. So, the key to heavy precipitation forecasting with ET is understanding the asymmetric transition of the storm and the rainfall with respect to the track. Remember that precipitation is enhanced along areas of frontogenetic forcing and large-scale ascent, and note that heavy rainfall can occur over land even without the tropical cyclone center ever making landfall.

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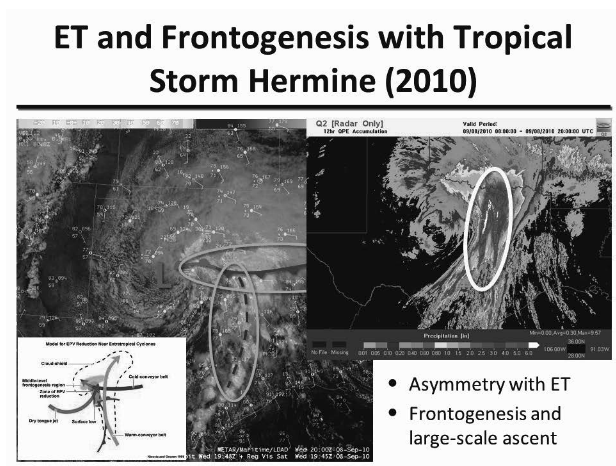

23. Predecessor Rain Events (PREs)

Instructor Notes: Another type of heavy rainfall event that is influence by tropical cyclones (TCs) are predecessor rain events (PREs). Predecessor rain events are defined by Galarneau et al. in 2010 as coherent areas of rain persisting for at least six hours with radar reflectivity values ≥ 35 dBZ that are displaced poleward within a region of moisture transport from the tropical cyclone. A PRE has to have clear separation on radar between its coherent area of rainfall and the precipitation field directly related to the TC. The work by Galarneau et al. noted that the average distance between a PRE and the TC is approximately 1000 km and have an average time lag of 36 hours between the PRE and TC passage for a given location. The average longevity of a PRE is approximately 15 hours and can contain maximum rainfall rates that are greater than 100 mm in a 24 hour period. The challenge with PREs is the ability to forecast these events, since they are dependent upon mesoscale features, such as surface boundaries and moisture plumes. These mesoscale features can be under-analyzed and/or improperly forecasted by operational models.

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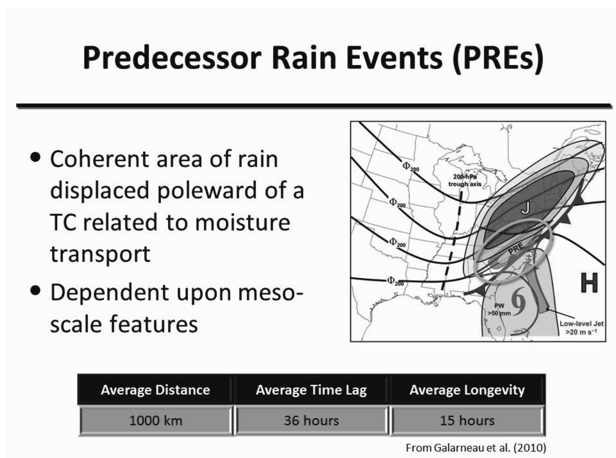

24. General PRE Patterns

Instructor Notes: In the work by Galarneau et al., predecessor rain event (PRE) patterns were defined by their location with respect to the forecast track (left-of-track, right-of-track, and along-track) and by the curvature of the 200 mb jet. The majority of PRE events occur left-of-track and within the presence of an anti-cyclonically curved 200 mb jet. The graphics shown here are the conceptual models of the synoptic-scale environment for a left-of-track PRE event. Starting with the broader view on the left, this conceptual model places a tropical cyclone (TC) and its associated precipitation area over the Carolinas. There is a clear separation between the precipitation directly related to the TC and the defined PRE locations. Representative TC tracks are highlighted here, showing that the PRE locations are occurring left of the representative track. This conceptual model shows the PREs occurring in the right-entrance region of the upper-level jet and on the western flank of a low-level theta-e ridge near a midlatitude trough. On the mesoscale level, heavy rainfall with PREs can be focused along features such as frontogenetic forcing or orographic upsloping.

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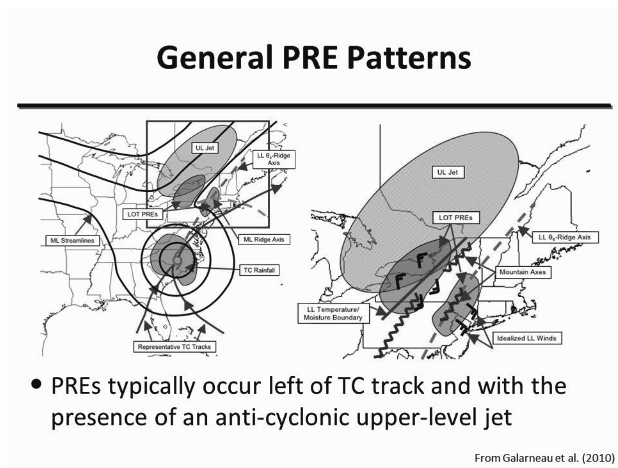

25. Tropical Storm Erin (2007) PRE Analysis

Instructor Notes: A well documented PRE was associated with the remnants of Tropical Storm Erin in August of 2007. In this event, a localized area of 5-15 inches of rain fell within a 24-48 hour period in southern MN and WI. As the remnants of Erin were located over OK, there was a significant poleward moisture flux associated with southerly 30-35 kt 850 mb winds. A slow moving warm front was located within a region of 850 mb vorticity and 700 mb quasi-geostrophic (QG) forcing in the presence of an anti-cyclonically curved 200 mb jet. Precipitation developed in this area of low-level voriticy and frontogenetic/QG forcing and evolved into a quasi-stationary MCS. Like the majority of PRE events, this event was poleward of the tropical system, occurred left-of-track, and was influenced by an anti-cyclonically curving upper-level jet. While the basic synoptic setup was present, and one could make the argument that it resembled that of the Maddox frontal pattern, it was the mesoscale features that influenced the heavy rainfall and flash flood potential.

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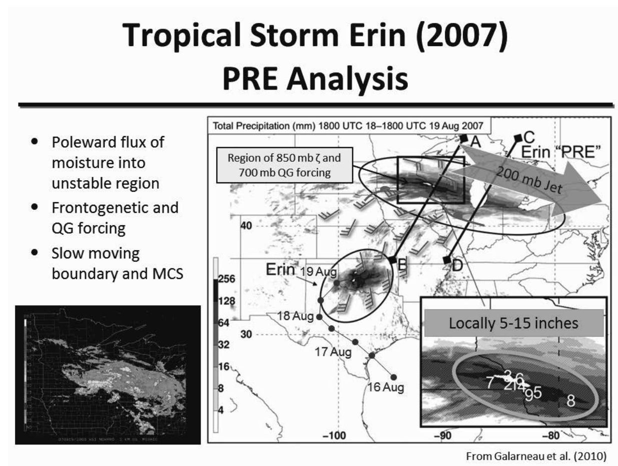

26. Atmospheric Rivers

Instructor Notes: Another scenario that typically results in heavy rainfall and enhanced flash flood potential is an atmospheric river. Atmospheric rivers were first defined by Zhu and Newell in 1998 as narrow plumes of water vapor flux that are typically situated near the leading edge of polar fronts. Their research determined that 95% of meridional water vapor flux occurs within these atmospheric rivers and that there are typically 3-5 of these plumes within a hemisphere at any one moment. The CALJET and PACJET experiments utilized various sensing techniques, including aircraft and dropsonde observations, to study the characteristics of atmospheric rivers. Their results showed that these long, narrow plumes have integrated water vapor (IWV) values of greater than 2 cm (0.8 inches), are generally narrow in size [around 400 km (250 mi.) in width], and occur in the vicinity of a low-level jet.

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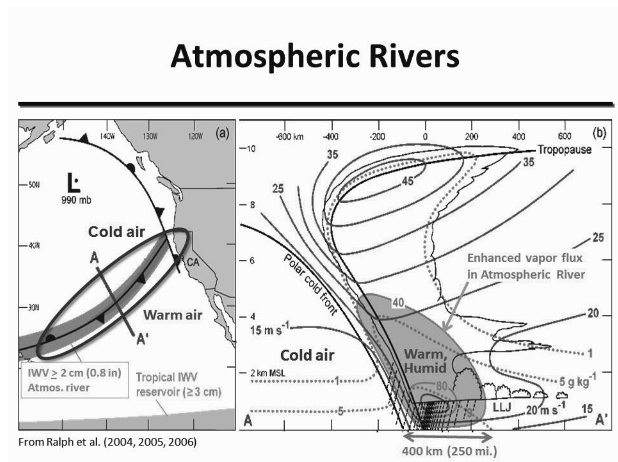

27. Role of Atmospheric Rivers in Western U.S. Extreme Rain Events

Instructor Notes: Atmospheric rivers can result in heavy rainfall events on both coasts. However, they are one the predominant methods for heavy rainfall in the western United States due to the characteristics of an atmospheric river combined with topographic features of the west coast. The moisture associated with an atmospheric river is shallow in depth, where research has shown that approximately 75% of the water vapor flux occurs in the lowest 2.5 km MSL. The CALJET and PACJET experiments also observed that the atmosphere below 3 km is in moist neutral stratification, meaning that the atmospheric profile follows the moist adiabat, and thus, has no resistance to any form of uplift. With the pre-cold frontal low-level jet (LLJ) maximized at 1 km MSL and the shallow moisture flux directed toward the coast, orographic rain enhancements occur along the coastal mountains.

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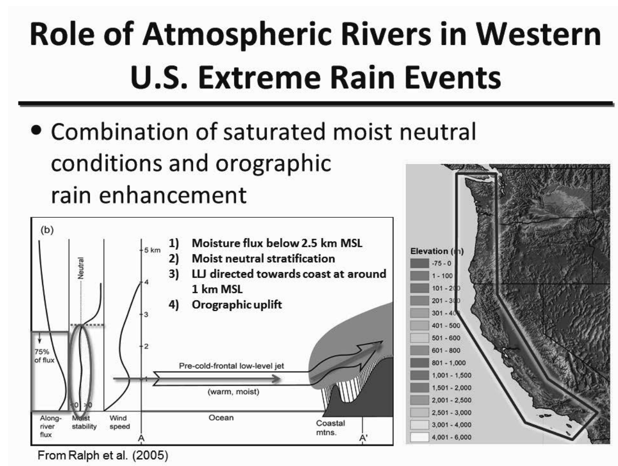

28. Northern/Central California Atmospheric River: October 2009

Instructor Notes: This heavy rainfall event in northern and central CA on October 13-14, 2009 is a classic example of an atmospheric river impacting the western United States. Starting with the SSMI water vapor content, you can clearly identify the atmospheric river originating from the tropical air in the western Pacific Ocean and advecting towards a low pressure system off the U.S. west coast. Low-level analysis shows a strong 850 mb jet (40-50 kts), with moisture flux values on the order of six standard deviations above normal. The Oakland, CA (OAK) sounding during the event shows a moist neutral profile that parallels the moist adiabat and is nearly saturated throughout the entire vertical column. Precipitable water values approached and even exceeded 1.50 inches. When compared to climatology, these values are near record levels for the month of October and are greater than two standard deviations above normal. This event resulted in a large area of 2-4 inches of rain with maximum 24-hour totals exceeding 10 inches in numerous locations (highlighted on map), including a maximum rainfall total of nearly 19 inches of rain along the CA coast.

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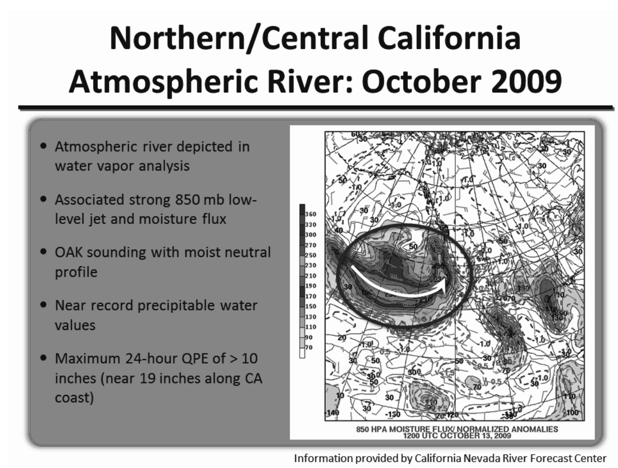

29. Determining the Significance of Events Through Anomalies

Instructor Notes: One thing we saw in the atmospheric river example was the use of anomaly data to describe how strong the 850 mb moisture flux was towards the California coast. We have spent the majority of this module examining the different patterns and ingredients that influence the flash flood and heavy rainfall potential. The use of standardized anomalies puts the strength of the pattern and ingredients into context. This four-panel display shows a SREF analysis of 250 mb height, 250 mb wind, 850 mb wind, and precipitable water (PW) values. You can easily recognize the amplified trough-ridge pattern in the upper-levels with an associated 140 kt (70 ms-1) jet across the Mississippi and Ohio River valleys. There is also a very strong southerly 850 mb low-level jet with winds exceeding 54 kts (28 ms-1), and PW values at or above 2 inches (50 mm) ahead of a SSW-NNE oriented surface front (surface analysis not shown). My attention is drawn to the southeastern U.S. with the strong low-level jet and high PW values near the surface front while being co-located under the right-entrance region of the upper-level jet. So, without knowing anything else, there appears to be a favorable setup that resembles the Maddox synoptic pattern. But the question is how strong is this pattern? With the use of standardized anomalies, you can see that all of the features here exceed three standard deviations of their normal climatology, and the 850 mb winds over TN and KY are between four and five standard deviations above normal. Using standardized anomalies allows you to distinguish ordinary rainfall events from significant, high-impact events, and thus, increasing your confidence in predicting a high-end hydrometeorological event. The anomalies shown here were from the record flood event in middle TN and western KY in May of 2010. This image of 48-hour MPE totals show a large area of > 6 inches of precipitation (yellow) with areas of central TN having received more than 12 inches of rain (light purple).

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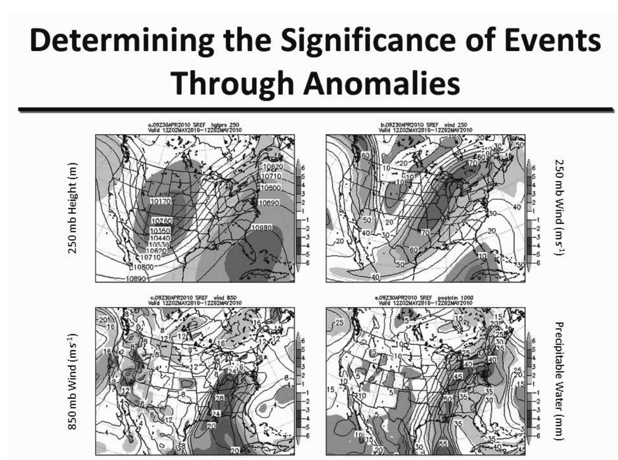

30. Not All Events are Identifiable on the Synoptic Scale

Instructor Notes: Be aware that not all events are identifiable on the synoptic scale. This example here shows the sea level pressure, precipitable water (PW), and 850 mb U- and V-wind component anomalies. We will focus our attention to the southern OH and northern KY region. Note that all but the PW values are within one standard deviation of normal climatology. Although other pressure levels and meteorological parameters are not shown here, there was no significant evidence of a synoptic-scale heavy rainfall potential. However, mesoscale features that are not easily distinguishable in the models played a factor in having a localized region of heavy rainfall and major flash flooding for this area. Short-term mesoscale forecasting becomes critical in identifying localized events and even determining the areas of greatest impact in large-scale events.

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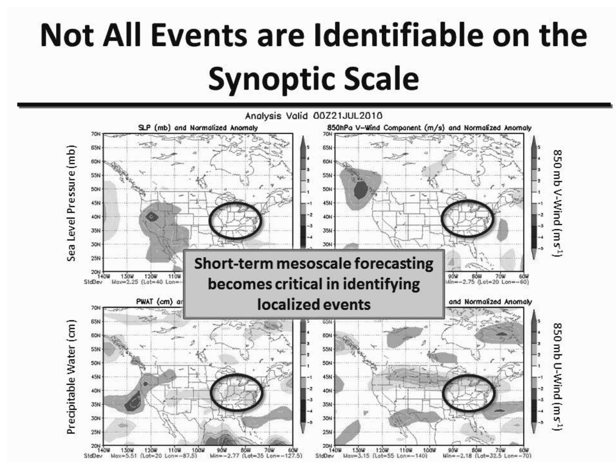

31. Summary

Instructor Notes: From this lesson, you should now be able to identify meteorological patterns and ingredients that are relevant to increasing the potential for heavy rainfall and flash flooding. We reviewed both pattern-based and ingredients-based methodologies for flash flood forecasting and applied them to a model forecast. We also identified other patterns and situations that enhance the flash flood potential, including tropical cyclones, predecessor rain events, and atmospheric rivers. There was also a brief discussion on applying standardized anomalies to increase confidence in forecasting high-end events. The ability to recognize synoptic-scale patterns and ingredients conducive to significant rainfall and flash flood events can provide forecasters the opportunity to better prepare for warning operations and decision support services.

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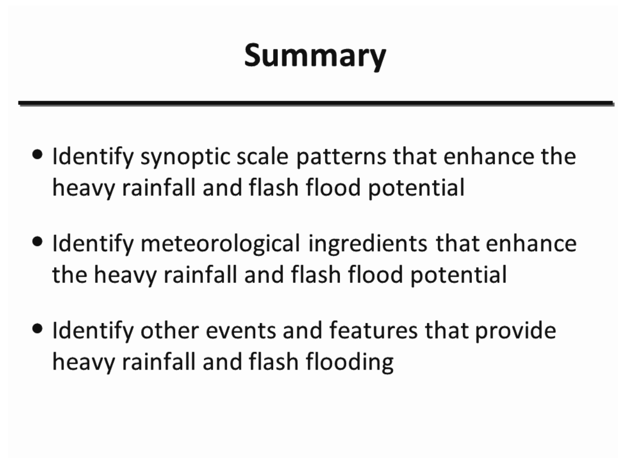

32. Don’t Forget About Your Hydrologic Factors

Instructor Notes: Identifying the flash flood potential for an event is more than just recognizing patterns and meteorological ingredients. Recall the following statement shown here from Doswell et al. (1996). Even though this module addressed the meteorological components of flash floods, it is only half of the equation. Other training modules are available that focus on the hydrologic-based factors that impact the flash flood potential.

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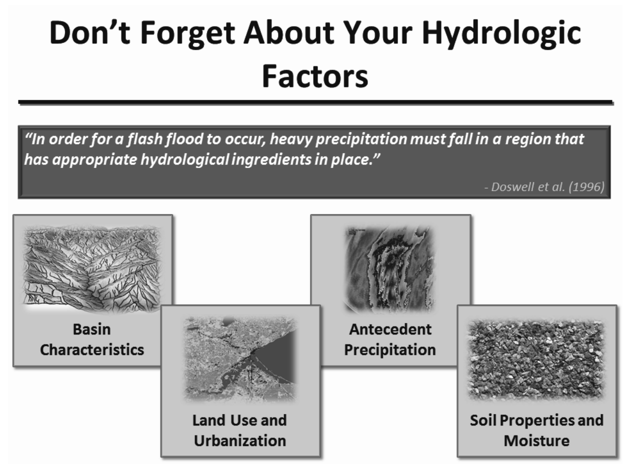
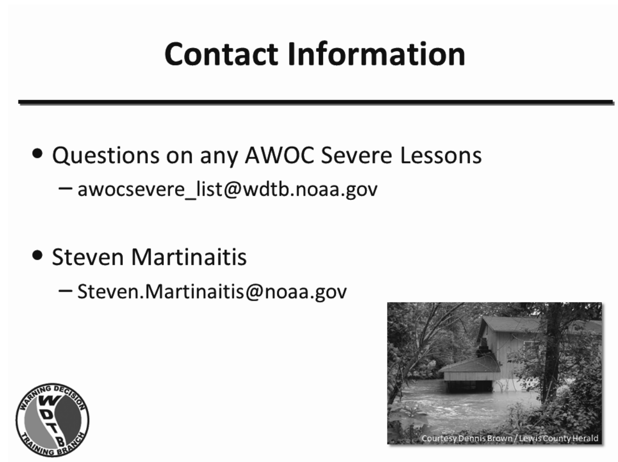


33. Contact Information

Instructor Notes: If you have any questions or issues regarding this module or the AWOC course, you can contact us at the AWOC Severe List email address. You can also contact me directly at Steven.Martinaitis@noaa.gov.

Student Notes:



1. Anticipating Extreme Rainfall with Standardized Anomalies and EnsemblesPart I - On the Value of Anomalies

Instructor Notes: Hello, and welcome to the module on Recognizing High Impact Hydro Events. The first part of this module is on anticipating extreme rainfall with standardized anomalies and ensembles. In this part I will specifically talk about anomalies. I'm Richard Grumm, and I'm the SOO at the National Weather Service Forecast Office in State College, PA.

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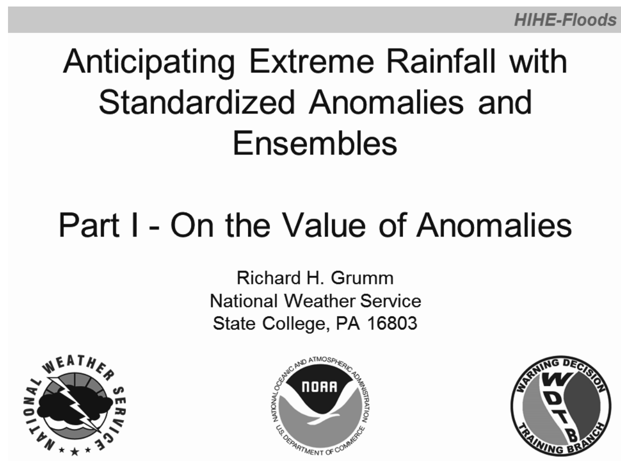

2. Motivation

Instructor Notes: This training evolved out of the Service Assessments of the Southeast US Floods and the Nashville Floods of 1-4 May 2010 and is related to several other significant flood events over the past few years. Our goal here is to aid in recognizing the potential of high end events using standardized anomalies to improve situational awareness. Improved Situational awareness should help users of our forecasts make better decisions and aid us in improving our products and services.

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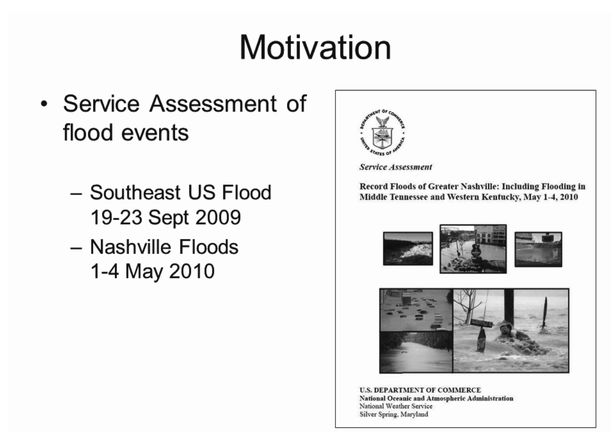

3. Objectives

Instructor Notes: These are our primary objectives: Never under estimate the value of knowing antecedent conditions prior to any rainfall event. Standardized anomalies often provide strong signals in the larger scale flooding events and may aid in distinguishing meteorological significant events from ordinary events. There are limits to standardized anomalies, especially with more mesoscale events. Finally, and in a separate lesson we will apply these concepts to models and ensembles. You will be amazed how one cannot distinguish an observed anomaly from a forecast anomaly!

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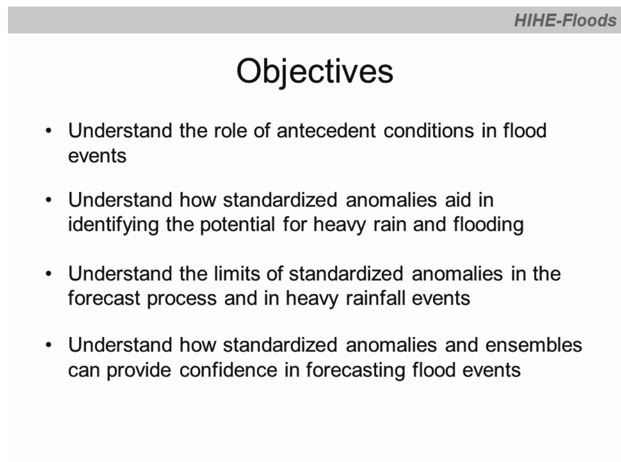

4. Role of Antecedent Conditions

Instructor Notes: It is very important before the onset of a heavy rain event to know the antecedent conditions. During prolonged periods of dry weather we all know rivers and streams have low flows and can generally handle more water. During wet conditions flows are often higher to begin with so the response can be faster and less rainfall may be required to produce flooding. Terrain and land use and changes in land use can play a significant role here too. Cold season events add the problems with ice and water in the snow pack!

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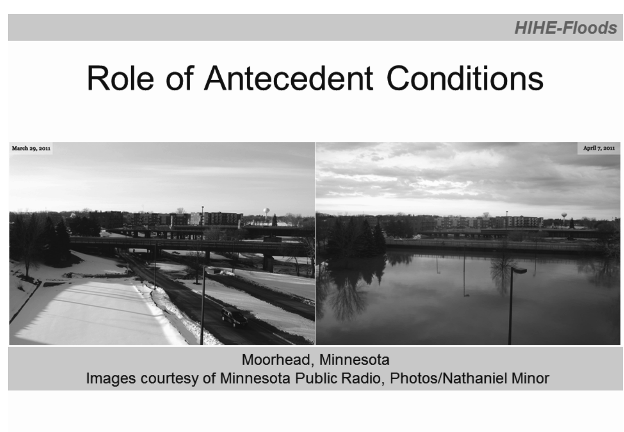


5. Antecedent Conditions Impact Response to Heavy Rainfall

Instructor Notes: This simple list shows some historic events. Hurricane Connie primed the pump to put Diane in the record books despite similar rainfall amounts from both systems. The January 1996 snowmelt floods were associated with about a top 20 rainfall event for the month of January. Despite this it is one of the top 1 to 3 flood events of record at many sites in the Mid-Atlantic and northeastern US. And the historic Pakistani floods of 2010 were triggered by a single event which was actually the 4th heavy rainfall event in about 21 days. Many historic events involved a significant pattern and ideal antecedent conditions for a disaster.

Student Notes:

HIHE-Floods

Antecedent Conditions Impact Response to Heavy Rainfall

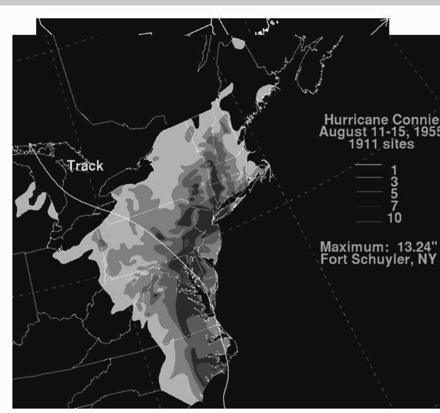
- 1955: 11-15 August Hurricane Connie and Hurricane Diane 15-19 August 1955
  - Both produced heavy rainfall
  - Diane produced record floods
- January 1996: Snow melt floods
  - Warmth produced snowmelt with 3-5 inches of rain
  - Record floods
- Pakistan July 2010
  - Four successive heavy rainfall events
  - 4th one was devastating in late July

6. Connie and Diane Rainfall

Instructor Notes: Here is the rainfall for Connie and Diane, two tropical cyclones, flooding the heart-land. Hard to believe Connie produced so little flooding.

Student Notes:

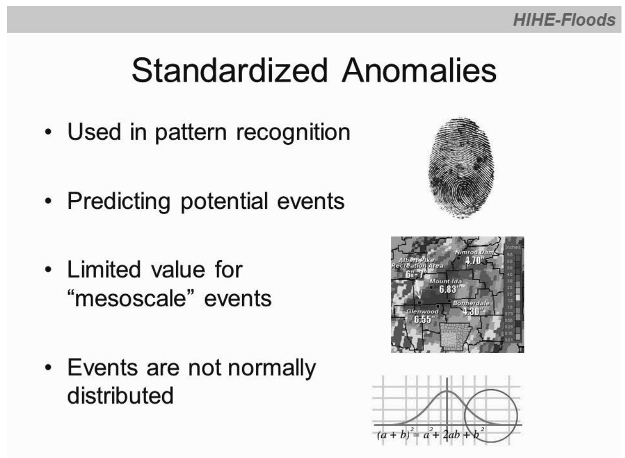
HIHE-Floods



7. Standardized Anomalies

Instructor Notes: Standardized anomalies can be used to identify the pattern or “finger print” of extreme weather events. They can be used with re-analysis data to learn from past events or with forecast data to aid in predicting potential events. The anomalies put known patterns into context. Distinguishing a significant event from a more typical event. The method is not perfect and will often be of limited value in more mesoscale forced events. Additionally, there are limits of predictability and the higher the forecast uncertainty, more difficult it is to use anomalies at longer ranges. A key point too is that these data are not truly Gaussian. Thus, it is hard to make clean estimates of the return periods but rather the potential for an extreme end event.

Student Notes:



8. Phase Space of Heavy Rainfall: A Spectrum of Events

Instructor Notes: You should be familiar with the basic patterns associated with heavy rainfall. I keep the original Maddox paper at the ready! We will use these terms associated with these patterns in this lesson but we will not review the patterns. All of the known patterns are not clean and compartmentalized. The true phase space is a spectrum of events and these events can transition and interact the key is the wind and moisture fields. The names tell it all . Tropical cyclones interactions produce either a Synoptic pattern or a Frontal pattern. Predecessor Rainfall Events (PRE) can occur ahead of TC and change antecedent conditions before TC rainfall arrives! Frontal systems can turn into Synoptic-like patterns which caused the significant New England floods of March 2010.

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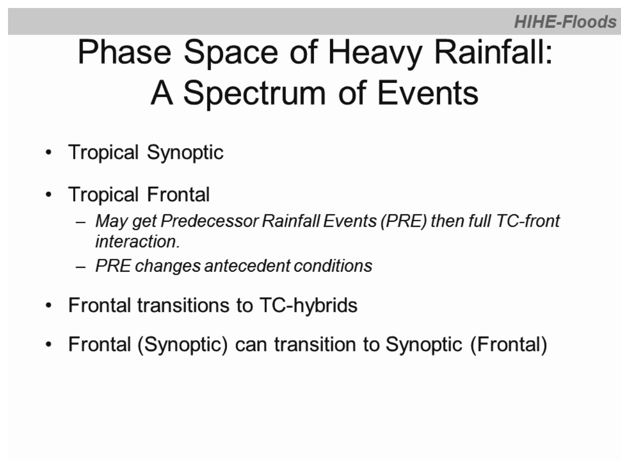
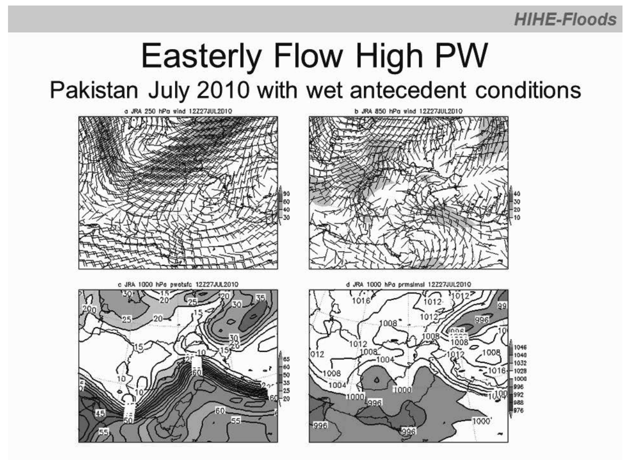


9. Easterly Flow High PW Pakistan July 2010 with wet antecedent conditions

Instructor Notes: This looks like a frontal pattern over India and Pakistan. As the pattern fades to the pattern with the anomalies, see how the anomalies add context. The mint-green PW over 60 mm is a 4-5 standard deviation PW anomaly. And those 850 mb easterlies are well above normal too!

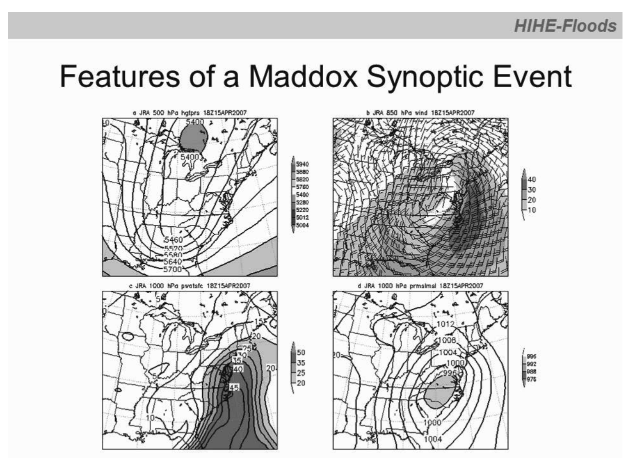
Student Notes:



10. Features of a Maddox Synoptic Event

Instructor Notes: This rare event...which was top-5 rainfall in the Mid-Atlantic region occurred in April 2007. The 30-40kt 850 mb jet is 4 sigma above normal event and the 40-45 PW are a 3 sigma above normal event. The anomalies aid in pattern recognition and seeing above normal values in key parameters associated with heavy rainfall.

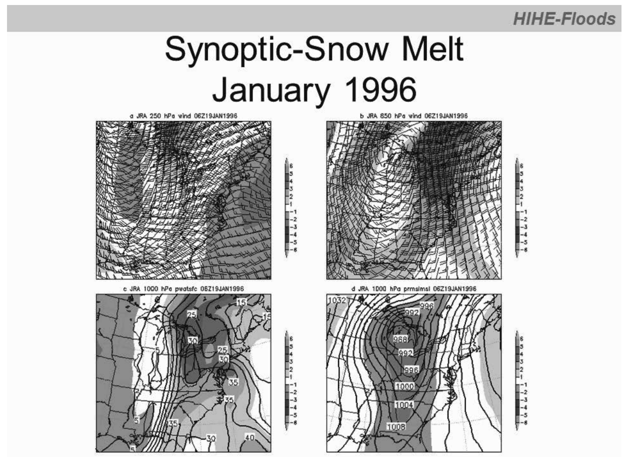
Student Notes:



11. Synoptic-Snow Melt January 1996

Instructor Notes: Another great pattern, clearly a Maddox Synoptic event...produced 2-4 inches of rain in January 1996. A good rain event but not a record maker. But, the record snow pack released a lot of water in the surge of warm air before the rainfall creating an historic flood event. Fade to anomalies and see how anomalies work well but in conjunction with knowing the antecedent conditions can work even better!

Student Notes:



12. Anomalies Pattern Recognition and Context

Instructor Notes: The overall pattern provides the event type and the anomalies provide context. We want a method to distinguish an ordinary from an extraordinary event. The right pattern with big anomalies can aid in distinguishing between an ordinary and an extraordinary event. In and of themselves, anomalies do not provide the confidence information that ensembles and probabilities accomplish and this is covered in a separate lecture (Part II). We have a method where we can help distinguish significant events and high impact events.

Student Notes:

HIHE-Floods

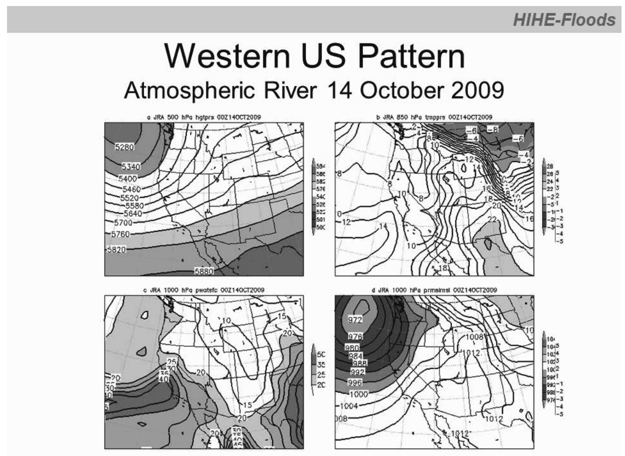
Anomalies Pattern Recognition and Context

- Pattern provides event type
- Anomalies provide context
- Distinguishes Ordinary from Extraordinary
- Not Confidence Information

13. Western US Pattern Atmospheric River 14 October 2009

Instructor Notes: Note the high heights to the south and east indicating a strong ridge and the low heights to the northwest...the trough. The strong flow between these two systems produces the high PW surge seen in the lower left panel. Western US events are often well defined by PW plumes or atmospheric “rivers” into the terrain of the western US. As we fade from the pattern to the pattern with the anomalies the PW anomaly simply jumps out of the page at you! This was an incredible event from many perspectives. But the anomalies provided context.

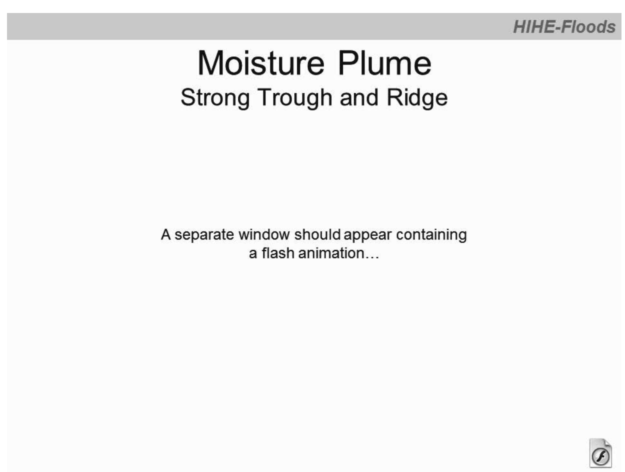
Student Notes:



14. Moisture Plume Strong Trough and Ridge

Instructor Notes: This loop shows the evolution of this impressive and historic storm from a pattern and anomaly perspective. Watch the evolution of the strong PW plume, the deep trough and strong winds into the western United States. Not to mention the anomalous surface cyclone.

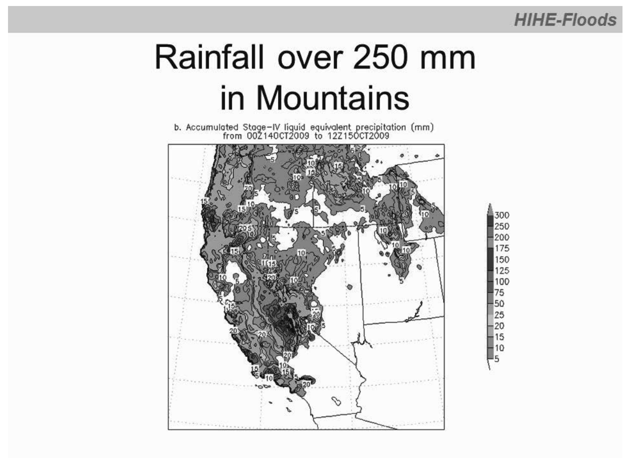
Student Notes:



15. Rainfall over 250 mm in Mountains

Instructor Notes: And here is the rainfall. Other parameters with this event could include wind damage, severe weather, and record low pressure. It was an amazing event. The Western Region of the NWS did exceptionally well predicting this event using anomalies produced at Salt Lake City Office. Randy Graham is the WR and AR expert on anomalies and how to employ them to forecast record events.

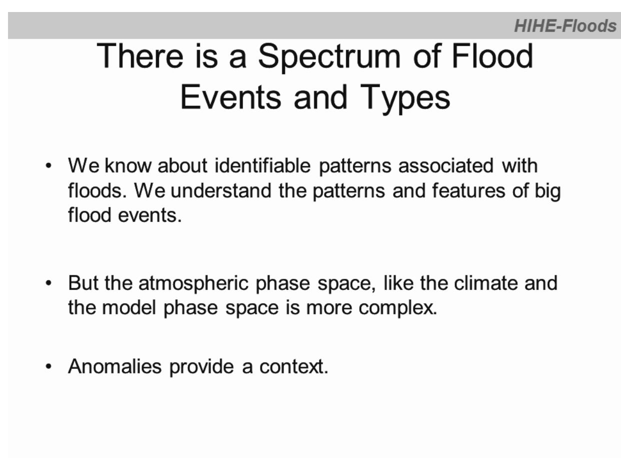
Student Notes:



16. There is a Spectrum of Flood Events and Types

Instructor Notes: Take a minute to read this slide. The key point is… There is a spectrum of flood events and event types out there. Standardized anomalies can aid in identifying them and provide a context with which we can better predict high end weather events.

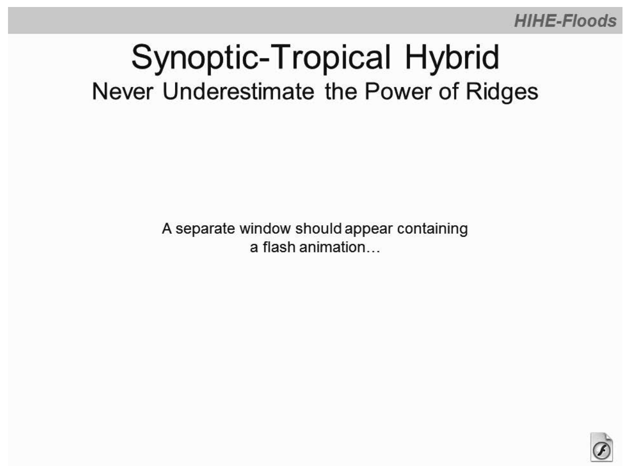
Student Notes:



17. Synoptic-Tropical Hybrid Never Underestimate the Power of Ridges

Instructor Notes: Here is another historic rain and flood event. We changed projection to see over the Atlantic for the trough-ridge interaction. It is always advantageous to know the pattern both up and down stream. The flow about anticyclones is often a key player in evolving PW plumes. Atmospheric rivers or moisture plumes come about ridges. As stated in Bodner et al (2011), many heavy rainfall events involve an anomalous upstream trough and an anomalous downstream ridge. The big picture is critical, the old Snellman funnel is always of value before you drill down.

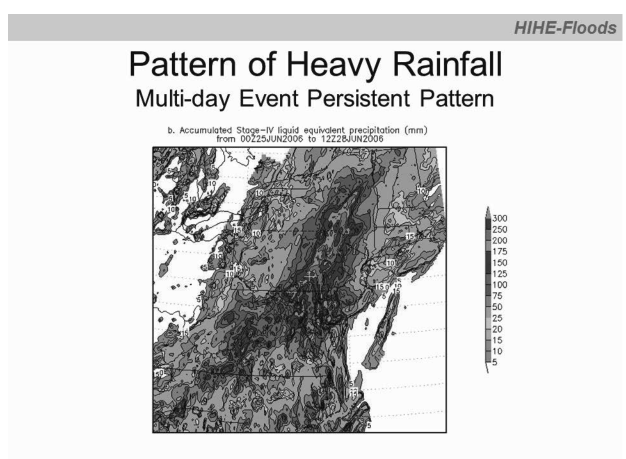
Student Notes:



18. Pattern of Heavy Rainfall Multi-day Event Persistent Pattern

Instructor Notes: The pattern from the previous slide produced a record multi-day rain event and significant flooding. Note how focused the axis of heavy rainfall was.

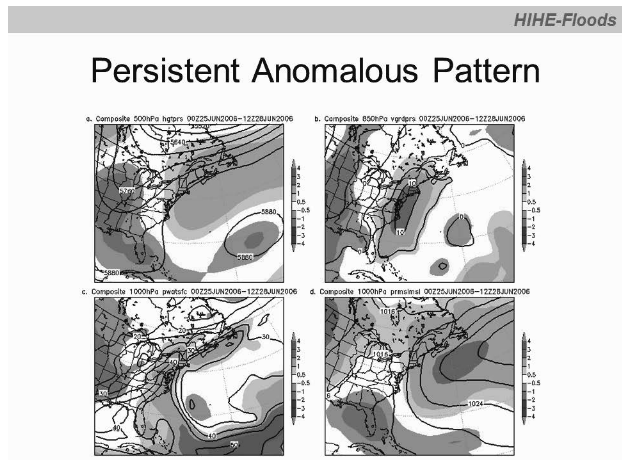
Student Notes:



19. Persistent Anomalous Pattern

Instructor Notes: For long duration events, it is useful to look at the pattern and anomalies for periods of 12,24 and sometimes 72 hours. It is important to know if you are facing a long duration event. This image shows the pattern and anomalies over 3.5 days. This long duration pattern shows the strong subtropical connection of the moisture plume. We need forecast tools like this!

Student Notes:



20. The Simple Anomaly Context

Instructor Notes: Take a minute to read this slide… Okay ten seconds was all you needed. Surges of high PW air with strong southerly flow typically produce many of the high end rain events. Easterly wind events can also produce heavy rainfall. Moisture and strong low-level winds are critical. The larger the anomalies, the higher potential for a record or near record event. This implies the value of moisture flux in association with heavy rainfall events.

Student Notes:

HIHE-Floods

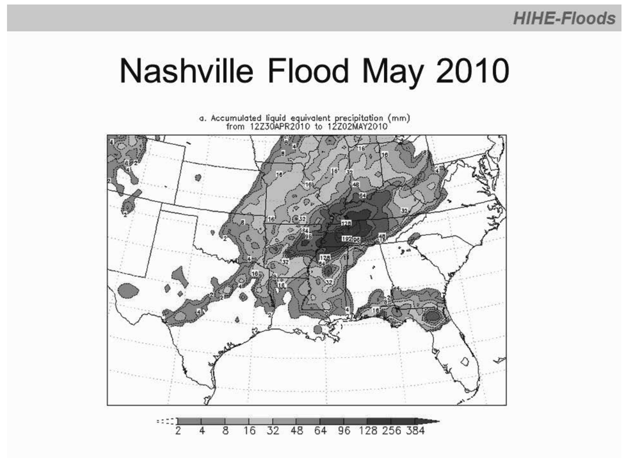
The Simple Anomaly Context

Pattern	Event Type	Anomalies
Moisture plumes ("Atmospheric Rivers")	High end heavy rain	2 to 4σ PW
Strong poleward flow	Synoptic	3-5σ v-wind
Strong easterly flow	TC or Frontal	3-5σ u-wind
Simplistically high moisture/High wind	Big rainfall	2 to 4σ Moisture Flux

21. Nashville Flood May 2010

Instructor Notes: Now we will look at the historic Nashville flood rainfall pattern over 48 hours. This was an impressive and enduring rainfall event over the Mid Mississippi Valley.

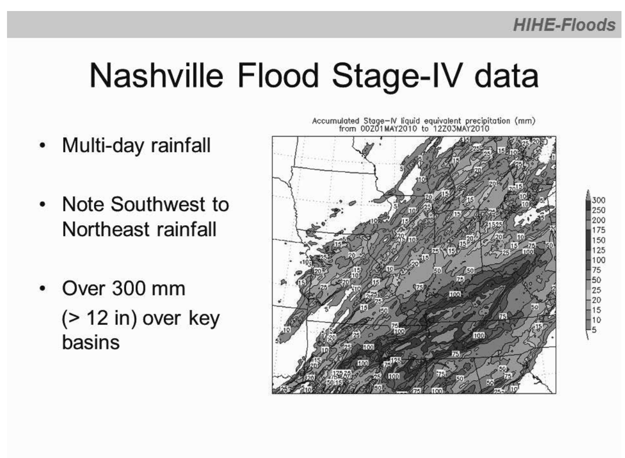
Student Notes:



22. Nashville Flood Stage-IV data

Instructor Notes: Here is a zoomed view of the rainfall. Those blue colors show over 250 mm or 10 inches of rainfall. And those grays, like my hair, show over 300 mm or 12 inches of rainfall. This was an impressive rainfall event.

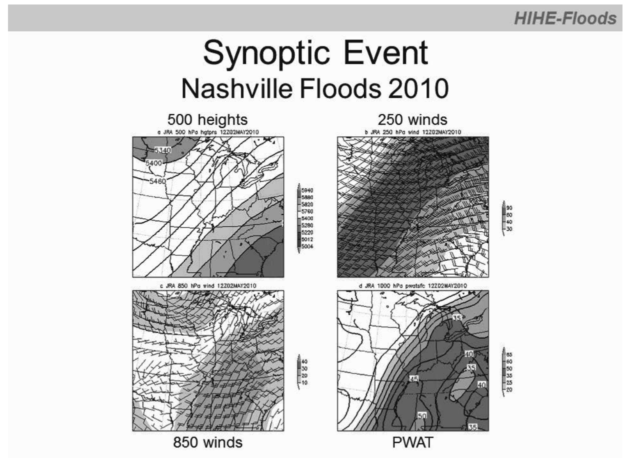
Student Notes:



23. Synoptic Event Nashville Floods 2010

Instructor Notes: Here is the pattern over the region defined by the 500 heights, 250 winds, 850 winds and precipitable water. As we fade to the anomalies... The anomalies of this event provide context of the known heavy rainfall pattern. We will look a bit more at this…..

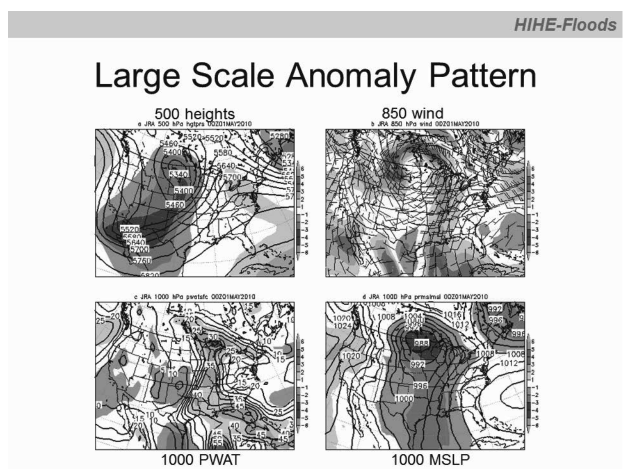
Student Notes:



24. Large Scale Anomaly Pattern

Instructor Notes: Watch the evolution of the large scale pattern over the United States during the event. Note the evolution of the deep trough to the west and the strong ridge to the east. This impacts both the low-level winds and surge of high PW air. Once we know the large scale pattern we can drill down to the local scale.

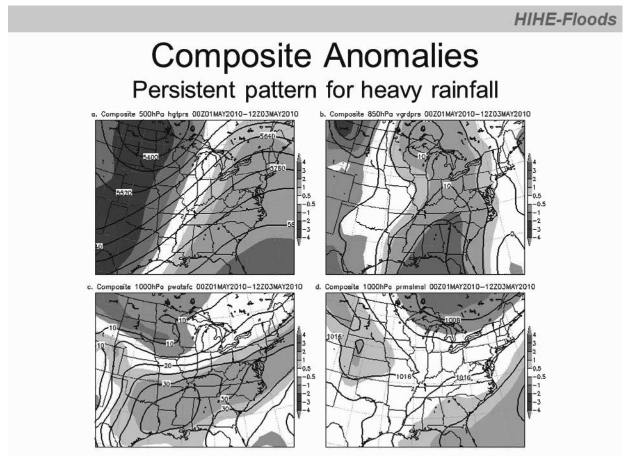
Student Notes:



25. Composite Anomalies Persistent pattern for heavy rainfall

Instructor Notes: This is the composite pattern from the data used on the previous slide during the heavy rainfall associated with the Nashville flood. Not the persistent plume of moisture and winds into the region over the 2.5 day long period. Beware of persistent or lingering anomalies in patterns associated with heavy rainfall. They tend to be associated with many record or near record events.

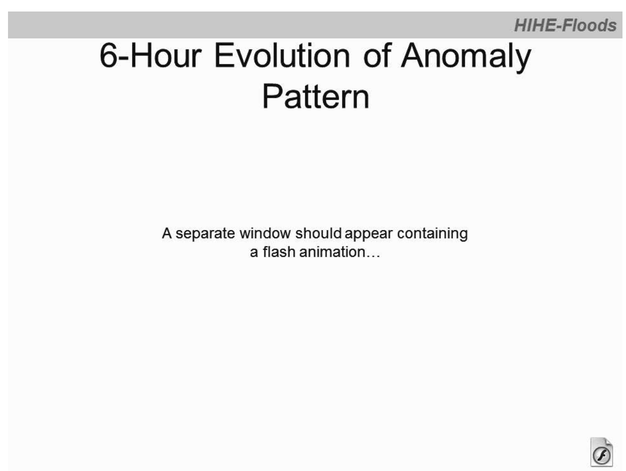
Student Notes:



26. 6-Hour Evolution of Anomaly Pattern

Instructor Notes: The composite showed the persistence of the pattern. This loop shows the evolution of the pattern in 6-hour time steps. The ridge over the Atlantic strengthened, the PW plume surged south-to-north several times, and there were surges of strong south-southwest winds into the Mid-Mississippi Valley. An ideal set up lasting for several days.

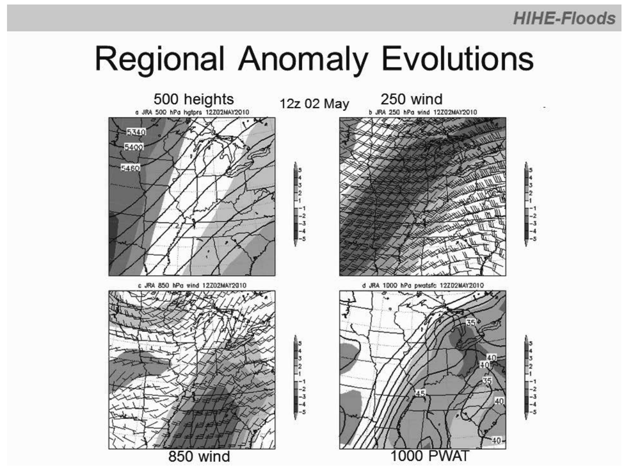
Student Notes:



27. Regional Anomaly Evolutions

Instructor Notes: This slide shows the evolution of the pattern in slower time steps. Play the slide over to visualize the PW plume or the strong low-level jet. The key is the multiple surges and persistence of anomalous conditions over the Mid-Mississippi Valley.

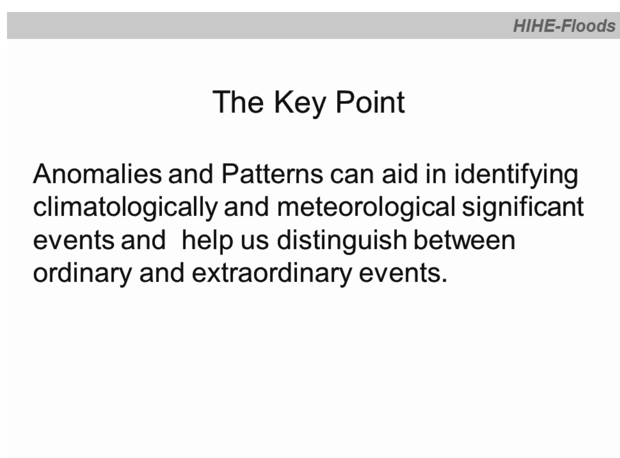
Student Notes:



28. Forecast Methodology

Instructor Notes: Our examples and experiences suggest a simple forecast method. 1. Know the large scale set up. 2. Then focus on the regional scale. Know the large scale pattern and sources of moisture. The pattern matters (Bodner et al 2011 is a good read with references to other good papers). Drill down and find the region likely most highly impacted by the pattern. Finally, the model QPF and ensemble QPF probabilities can be of great value. The key point so far is Anomalies and Patterns can aid in identifying climatologically and meteorological significant events and help us distinguish between ordinary and meteorologically significant events .

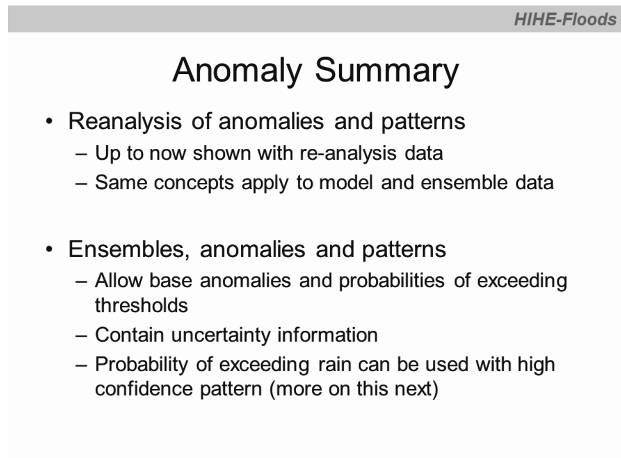
Student Notes:



29. Anomaly Summary

Instructor Notes: We are almost to the goal line.. We showed re-analysis data here to reconstruct the pattern and the anomalies. All of these concepts apply to forecast output too! The same concepts apply to single model forecasts from the GFS and NAM and ensemble output. You can use re-analysis data to reconstruct historic events in your region. Building your expertise! The ensembles provide probabilities and the all important confidence information. More on ensembles follows in the next module.

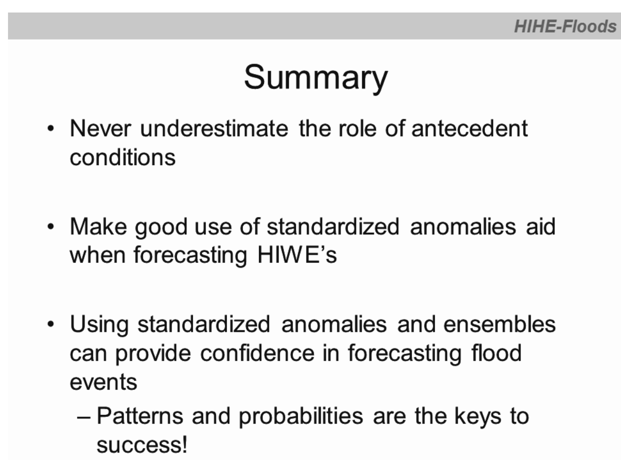
Student Notes:



30. Summary

Instructor Notes: Hopefully this module reinforced your knowledge on the patterns associated with heavy rainfall and the value of knowing the antecedent conditions prior to the onset a high impact weather event. Anomalies are a powerful tool in providing quick pattern recognition and putting that pattern into context. All of these concepts can and should be used in forecasting. They should aid in helping you better identify and provide more confidence in predicting future HIW flood and heavy rainfall events in your not to distant future. Thanks!

Student Notes:



31. Acknowledgements

Instructor Notes:

Student Notes:

HIHE-Floods

Acknowledgements

- Randy Graham Western Region for collaboration on cases and events
- WDTB staff for assistance in this module and providing the opportunity to include Brad Grant and Steve Martinaitis
- The Pennsylvania State University data access

32. References

Instructor Notes:

Student Notes:

HIHE-Floods

References

Bodner, M.J., N.W Junker, R.H. Grumm and R.S Schumacher 2011: Comparison of Atmospheric Circulation Patterns during the 2008 and 1993 Historic Midwest floods. Accepted NWA Digest March 2011.

Junker, N.W., R.H. Grumm, R.H. Hart, L.F Bosart, K.M. Bell, and F.J. Pereira, 2008: Use of normalized anomaly fields to anticipate extreme rainfall in the mountains of northern California. *Wea. Forecasting*, **23**,336-356.

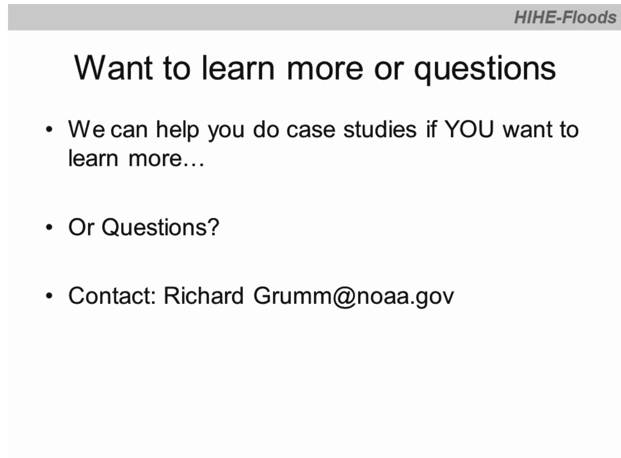
--------, M.J. Brennan, F. Pereira, M.J. Bodner, and R.H. Grumm, 2009: Assessing the Potential for Rare Precipitation Events with Standardized Anomalies and Ensemble Guidance at the Hydrometeorological Prediction Center. *Bull. Amer. Meteor. Soc.*, **90**, 445–453.

Maddox,R.A., C.F Chappell, and L.R. Hoxit. 1979: Synoptic and meso-alpha aspects of flash flood events. *Bull. Amer. Meteor. Soc.*, **60,** 115-123.

33. Want to learn more or questions

Instructor Notes: If you have any questions, please contact Richard Grumm using the email address provided.

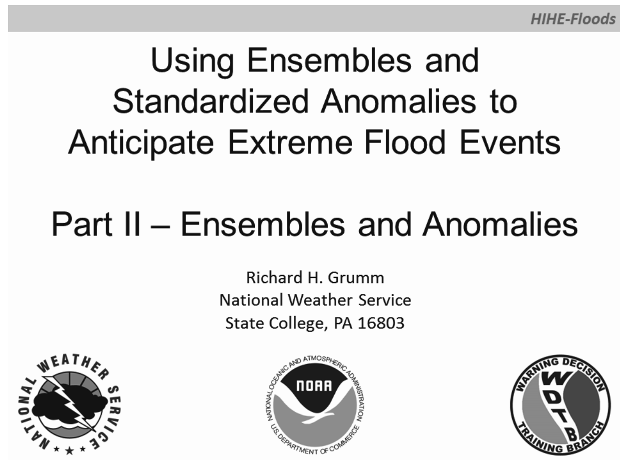
Student Notes:



1. Using Ensembles and Standardized Anomalies to Anticipate Extreme Flood Events Part II – Ensembles and Anomalies

Instructor Notes: Hello! I am Richard Grumm, the SOO at the NWS office in State College, PA. Welcome back! This is part-II of the module on recognizing High Impact hydro events. Our goal is to use ensembles and standardized anomalies to anticipate extreme rainfall events.

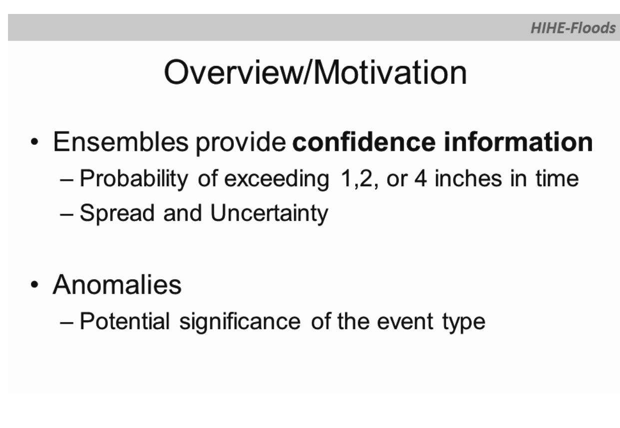
Student Notes:



2. Overview/Motivation

Instructor Notes: Ensembles will provide us with confidence information and good probabilistic information, such as the probability of exceeding 1,2 or 4 inches in a specified period of time. They can provide spread and uncertainty with regards to storm tracks and intensity of features of interest and could be used for more issues. The anomalies can be computed from models and ensembles to gage the potential significance of the event type being predicted. We could use EPS guidance to produce probabilities of anomalies and the persistence of anomalous features. We cannot cover all of this here over the next 30 minutes!

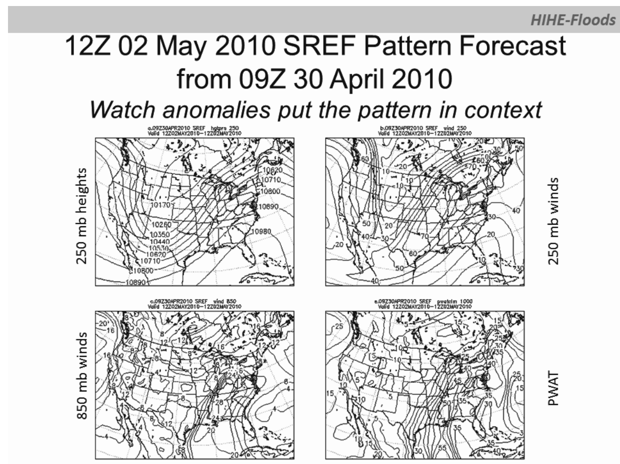
Student Notes:



3. 12Z 02 May 2010 SREF Pattern Forecast from 09Z 30 April 2010

Instructor Notes: This image is the SREF ensemble mean pattern over the United States valid at 12Z 02 May 2010. Interesting pattern but if we apply the anomalies the features of note jump out at us. The upstream trough and down stream ridge along with the strong jet between these systems and the low-level jet and the associated plume of high PW air into the Mid-Mississippi Valley. Now we can see a classic heavy rainfall pattern and one associated with significant anomalies.

Student Notes:



4. Anomalies and Patterns

Instructor Notes: The anomalies and the known patterns aid in distinguishing an ordinary from a potentially extraordinary event. A known pattern with large anomalies may provide confidence in the potential for a high impact event. Ensembles add the confidence information related to predictability. Ensembles provide things we often use like the probability of exceeding 2, 3, or 4 inches of QPF. They can show spread and areas of high and low predictability.

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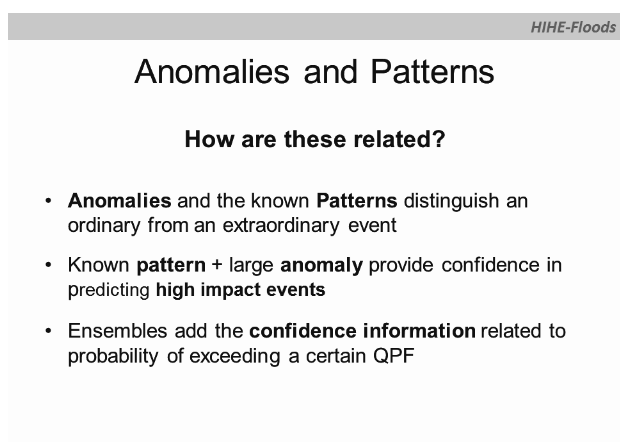
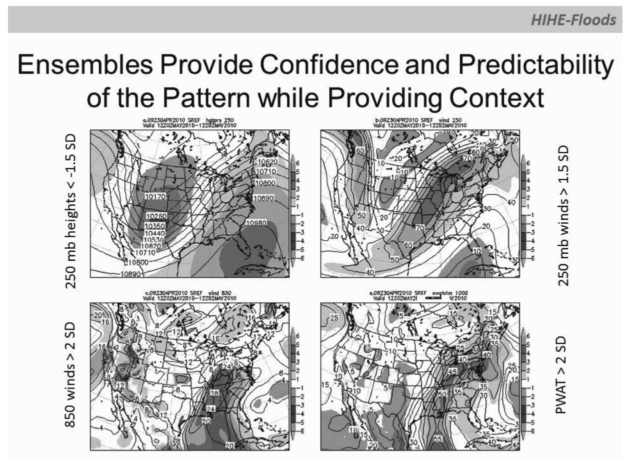


5. Ensembles can provide confidence and predictability of the pattern while providing context

Instructor Notes: The first image shows the pattern with the anomalies. A pattern often associated with heavy rainfall. The fade in image shows the probability of key anomalies as forecast by the SREF. We have confidence in the anomalous trough and the +2 sigma 850 hPa low-level jet and +2 sigma PW plume. We could also derive images for the probability of exceeding 50 mm of PW or 25 kts of wind at 850 hPa. Ensembles provide confidence in the pattern and thus the predictability of the system.

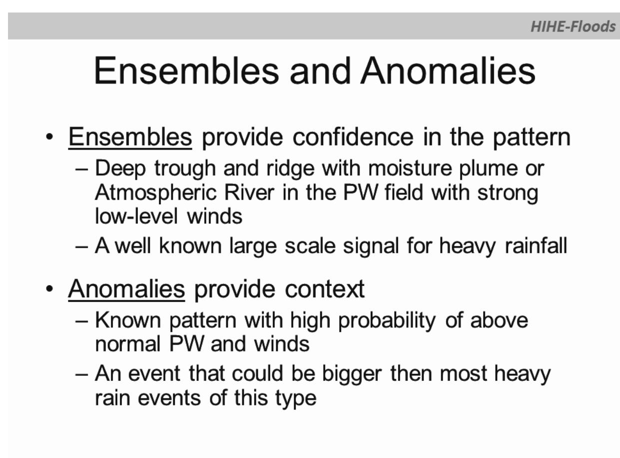
Student Notes:



6. Ensembles and Anomalies

Instructor Notes: This slide is a summary of the points on the previous slide. Take a minute to read the key points. The ensembles can provide us with confidence and the anomalies with the context of the event type.

Student Notes:



7. A Word on Confidence vs. Uncertainty

Instructor Notes: And now a word about confidence.... Uncertainty is a word used as a scientific term. The general public often confuses it with knowing or not knowing. Thus, outside of our community we should always refer to how confident we are in the forecast or the potential outcome. We want users to know if we have high or low confidence in our forecasts and not perceive us as being unsure. So be mindful of highly uncertain and low probability forecasts especially at longer ranges as these forecasts typically change. Finally, uncertainty is a reason to act not a reason not to act.

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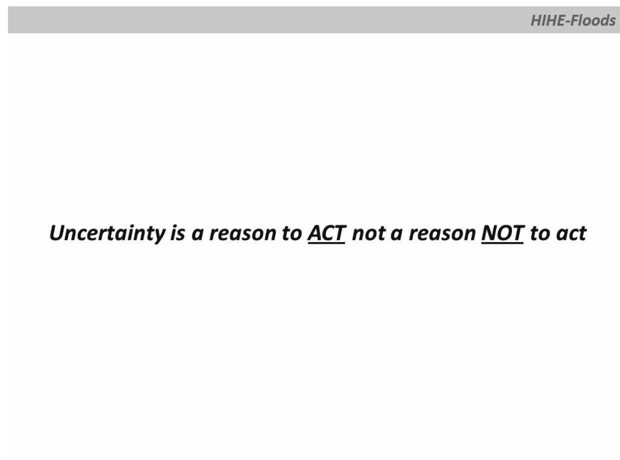
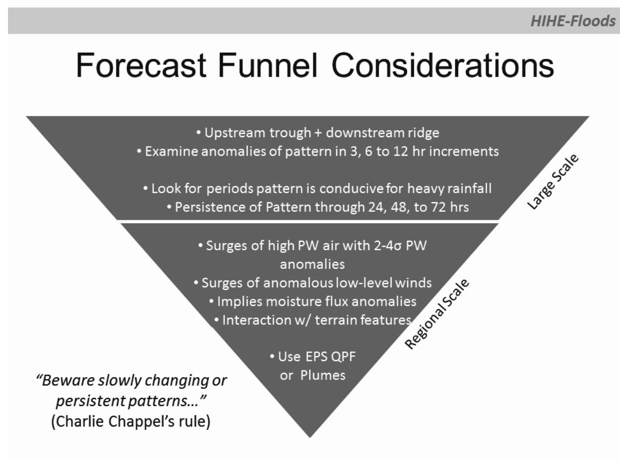


8. Forecast Funnel Considerations

Instructor Notes: Whenever making a forecast...always start from the large scale and work your way down. Heavy rain events, Bodner 2011 again, often have an upstream trough and a downstream ridge. This opens the United States up to subtropical moisture plumes and can enhance the upper and thus low-level jet. Beware slowly changing or persistent patterns as Charlie Chappell's rule states... It rains the most where it rains the hardest the longest...often applies in these conditions. Forecasts of patterns and anomalies over 12,24 and 48 hours can be of value for enduring events. Drill down to the more regional scale to refine your forecast. Surges of high PW and strong low-level winds can focus heavy rainfall and interact with known terrain features. Moisture flux as well as PW and winds may help along with QPFs especially ensemble probabilities of QPF or Plume Diagrams showing the QPF PDF.

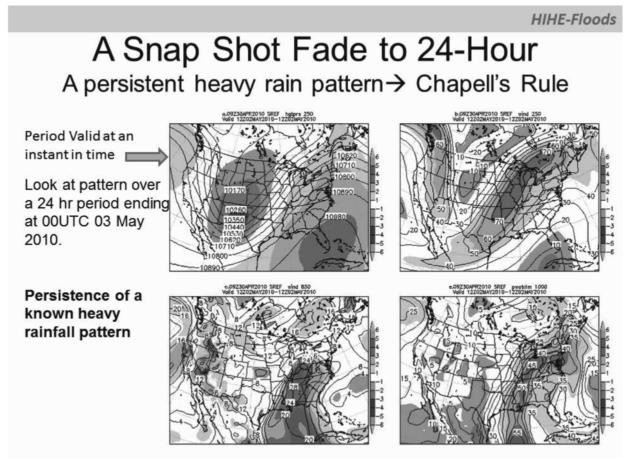
Student Notes:



9. A Snap Shot Fade to 24-Hour

Instructor Notes: The traditional way to view forecast data is at an instant in time as in this image. It shows the strong pattern often associated with heavy rainfall and explained earlier. The second image shows the pattern and anomalies as forecast over the 24 hour period. This implies that the pattern was enduring and lasting somewhat ensuring a prolonged period of rainfall. Images of 12, 24, 48 and even 72 hours could be value in enduring rainfall and heat events.

Student Notes:



10. High Impact Weather Forecast Methodology ? Heavy rainfall

Instructor Notes: Below is a simple method to predict heavy rainfall. 1. Start with the large scale pattern. 2. Move downscale. 3. Know the antecedent conditions. Put the larger scale pattern into context to be aware of persistent patterns and features with large anomalies. Move down scale to tie in the more regional sensible weather. Probabilities might include: Quantitative precipitation such as exceeding 2 and 4 inches in 12 or 24 hours CAPE exceeding 1200 JKg-1 or PW exceeding 2 inches or +2 sigma. Your high impact weather problem dictates key probabilities to focus on. Anomalies may aid in confidently predicting a high end rainfall events. Finally, always checked antecedent conditions. Recent rainfall may have lowered amount of rain requried to get flooding or flash flooding.

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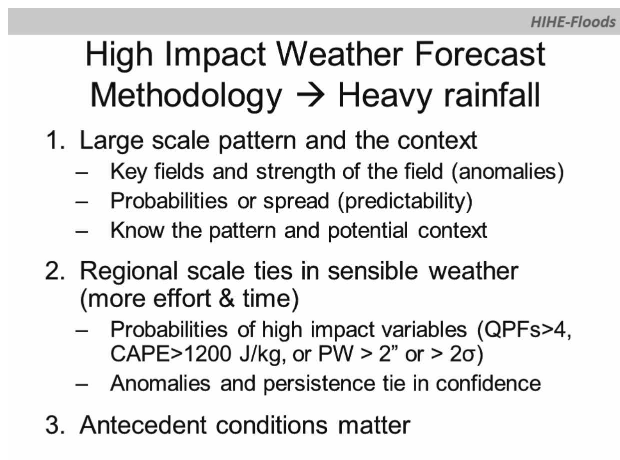
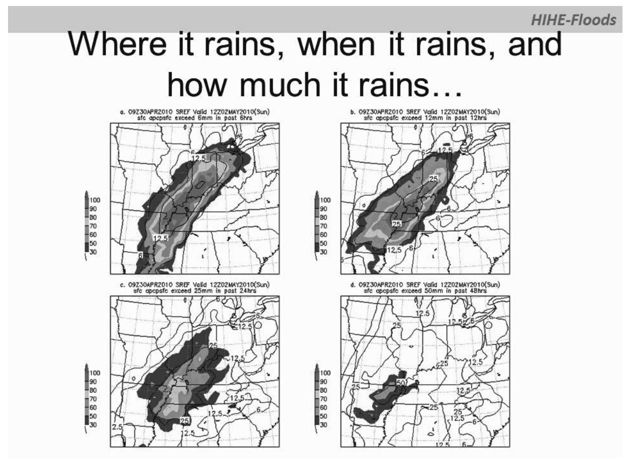


11. Where it rains, when it rains, and how much it rains…

Instructor Notes: Where it rains, when it rains, and how much it rains...is critical decision making information.... Example of high probability of rainfall four panel format: 6 mm (~0.25 in) 6 hours where its raining 12 mm (~0.5 in) 12 hours of recent moderate rainfall 25 mm (1 in) 24 hours of area large rainfall 50 mm (2 in) 48 hours of heavy rainfall We need to know confidence where it will rain and when it will rain and relate this to an established favorable large scale pattern.

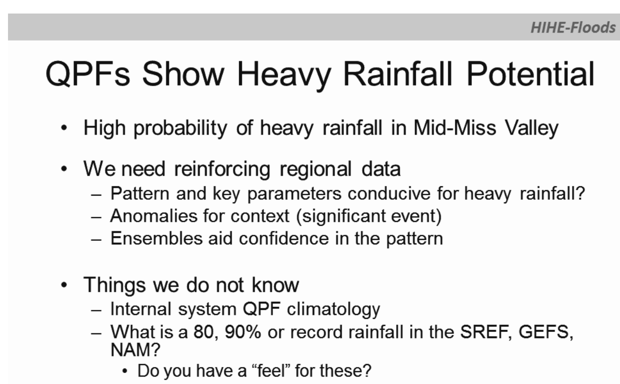
Student Notes:



12. Previous QPFs Show Heavy Rainfall Potential

Instructor Notes: The previous slide's QPFs showed the heavy rainfall potential. They showed a high probability of rainfall in the mid-Mississippi valley. We could probably use other thresholds. We need reinforcing regional data. The pattern and the key parameters conducive to heavy rainfall… were they present? The anomalies may help add context for the potential of a significant event. Ensembles could also add confidence in the pattern. There are things we do not know. We don't know the internal QPF of the model ensembles. It would be interesting to know what the 80% or 90% or a record rainfall event is in the SREF, GEFS, or NAM. Do you have a "feel" for these in your area?

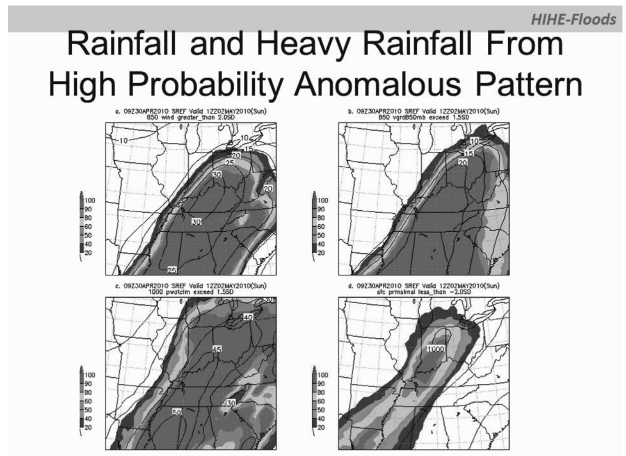
Student Notes:



13. Rainfall and heavy rainfall from high Probability Anomalous Pattern

Instructor Notes: This SREF images show the pattern of some key fields associated with heavy rainfall using the ensemble mean. The probabilities show the confidence based on the 21-SREF members of a strong 850 hPa LLJ using the wind and the v-winds along with the PW and MSLP. The persistent high PW plume with the low-level jet is a known signature for heavy rainfall. The next slide shows how this evolves…..

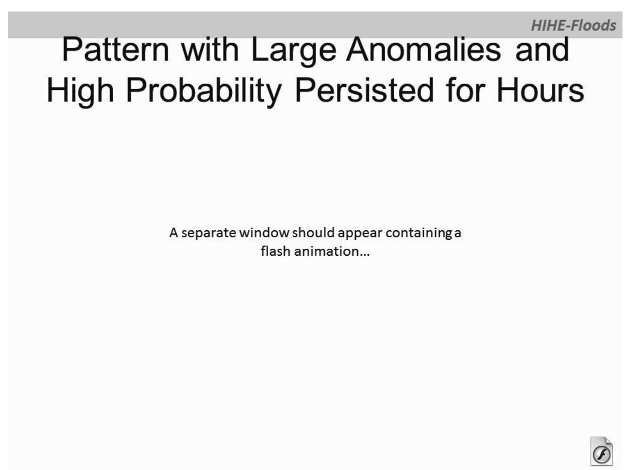
Student Notes:



14. Pattern with large anomalies and high probability persisted for hours

Instructor Notes: This loop shows the surge of a high PW with about 100% chance of PW being in excess of 1.5 sigma above normal into the MMV and Ohio Valleys over a pro-longed period of time. This PW surge is accompanied by a strong LLJ at 850 hPa.

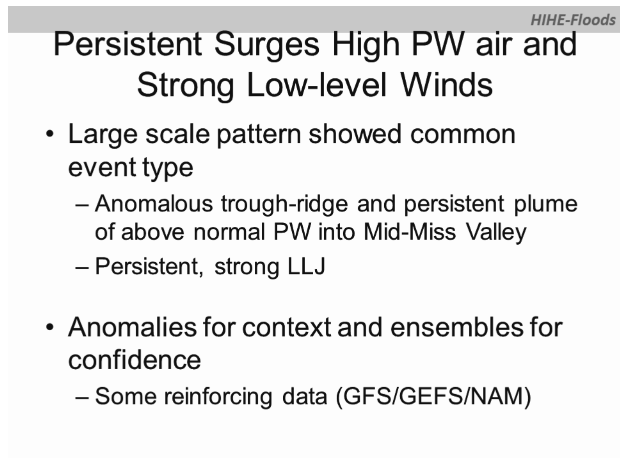
Student Notes:



15. Persistent surges high PW air and strong low-level winds

Instructor Notes: Our loop showed high confidence, based on probabilities, of a persistent plume of above normal PW into the Mid-Mississippi Valley. The loop showed a persistent and strong low-level jet into the same region Here the anomalies were displayed in probabilistic form, giving us confidence in the predictability of the pattern. We tied in anomalies for context and ensembles for predictability and thus confidence in the forecasts.

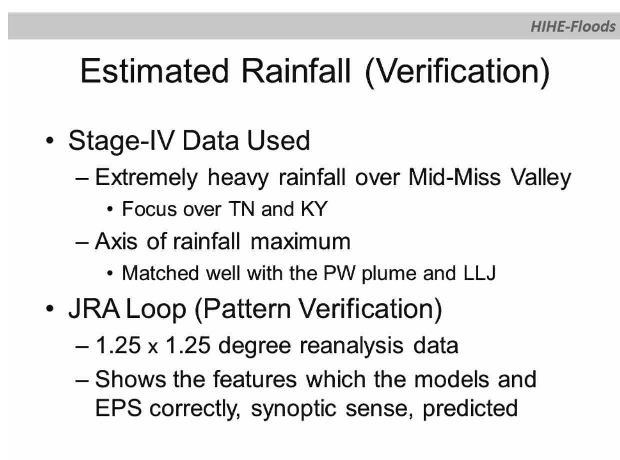
Student Notes:



16. Estimate Rainfall (Verification)

Instructor Notes: Now we will look at what happened... We will see where it rained and how much over the period. Then we will look at the pattern from an independent data set. The pattern match was rather good.

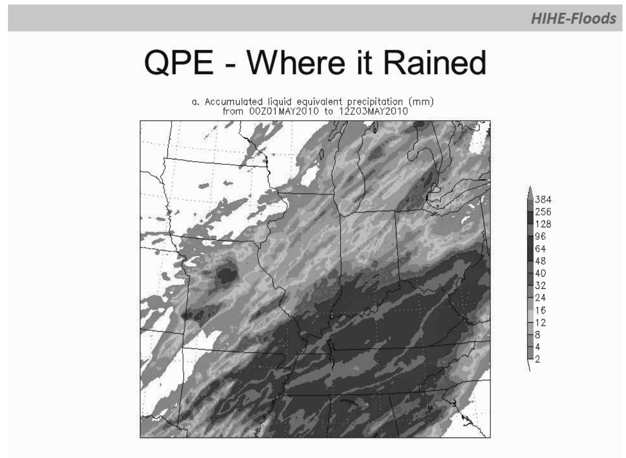
Student Notes:



17. QPE - Where it Rained

Instructor Notes: Stage-IV rainfall for the period from 0000 UTC 1 May through 1200 UTC 3 May 2010 is shown. These data show the extreme rainfall...in this gridded data set... over TN and KY. Dark blues are up to 256 mm or 10 inches of rainfall. The purple 48 mm about 2 inches covers most of the MMV and Ohio Valleys.

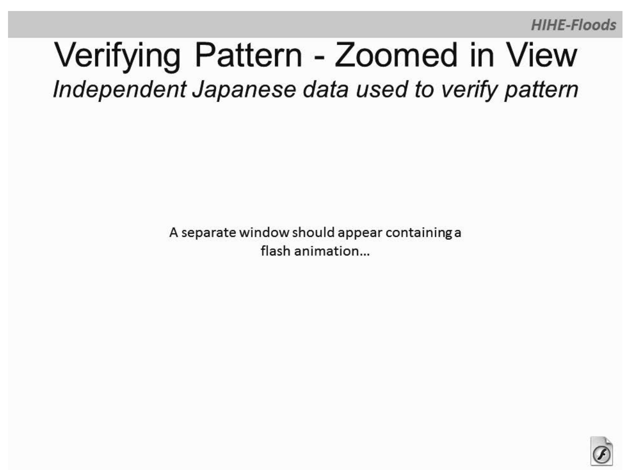
Student Notes:



18. Verifying Pattern - Zoomed in View

Instructor Notes: This is a loop of the JRA 1.25 x 1.25 degree data. It shows our moisture plume and strong LLJ as predicted by the NCEP SREF. Note the SREF at 32km resolution is much finer than the JRA. But these data independently show we got the pattern right.

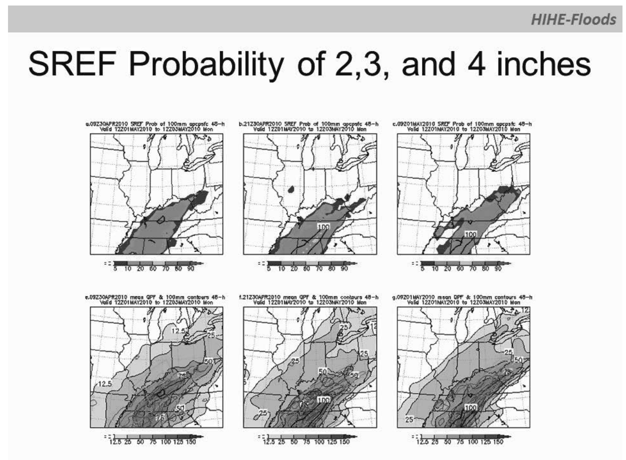
Student Notes:



19. SREF Probability of 2,3, and 4 inches

Instructor Notes: Here we included 3 runs of the SREF to show the probability of over 50 mm or 2 inches of rainfall. All forecasts are valid ending at 12Z 03 May 2010. The lower panel shows the mean QPF and each member 2 inch contour. The key point is our pattern with persistent anomalies was causing the 21-member SREF to predict a large area of high QPF. We will now look at 75 mm or 3 inches… and 100 mm or 4 inches of QPF. We get positive feed back from the SREF probabilities of heavy rain in a pattern conducive for heavy rainfall and a pattern with significant anomalies.

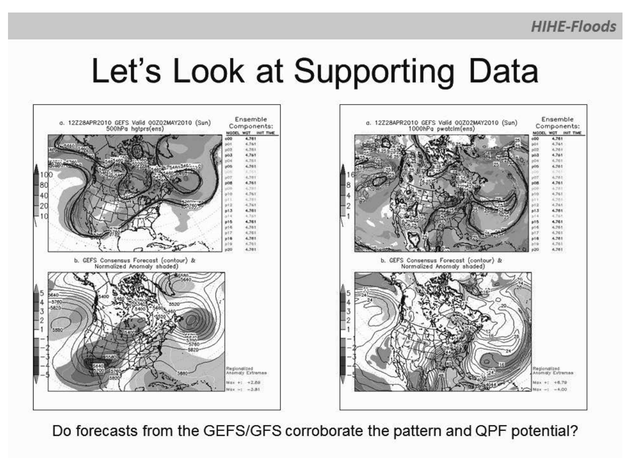
Student Notes:



20. Supporting Data

Instructor Notes: So, the SREF predicted heavy rain and showed pattern we associated with heavy rain. Now we will look at the GEFS and its component model the GFS. Do forecasts from these systems corroborate the pattern and QPF potential? A Funnel approach for pattern recognition and a tie back into model and ensemble system QPFs will aid in confidently predicting heavy rainfall.

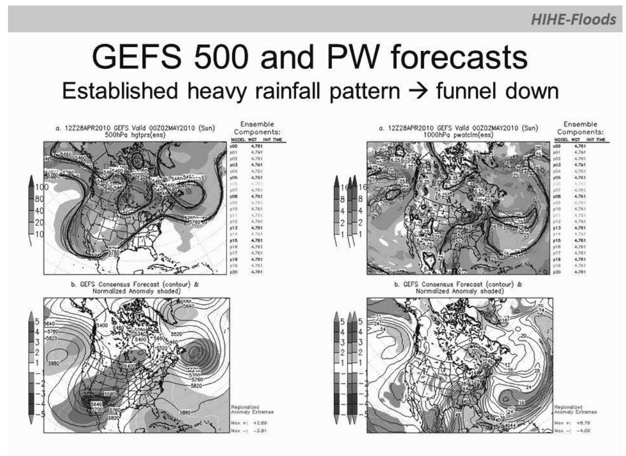
Student Notes:



21. GEFS 500 and PW forecasts Established heavy rainfall pattern

Instructor Notes: GEFS forecasts of the large scale 500 mb heights on the left..and PW pattern...right...are included to provide uncertainty information. We can zoom in and see closer to our threat area how this pattern looks... and finally zoom in over the Ohio Valley where the rain will hit the proverbial road. Similar to the SREF....these data show high confidence in the pattern in the GEFS and a surge of high PW air into the MMV!

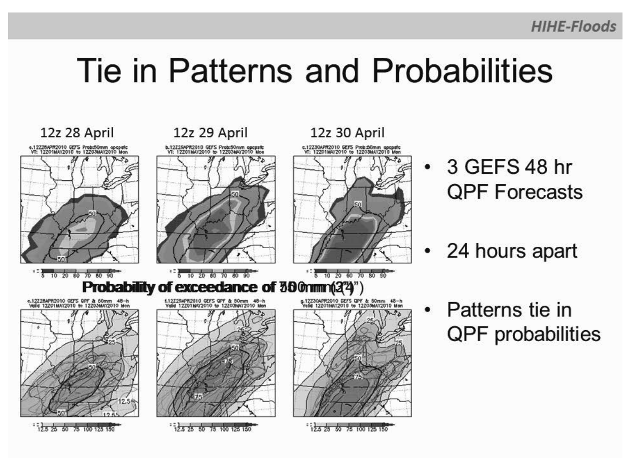
Student Notes:



22. Tie in Patterns and Probabilities

Instructor Notes: Using the same concept we used from the SREF we will look at 3 GEFS forecasts of QPF.... The resulting GEFS QPF probabilities show significant rainfall in the region our pattern would imply it would be. Patterns tie in the QPF probabilities. We showed the pattern for one cycle but here show 3 GEFS runs and their QPFs for critical thresholds.

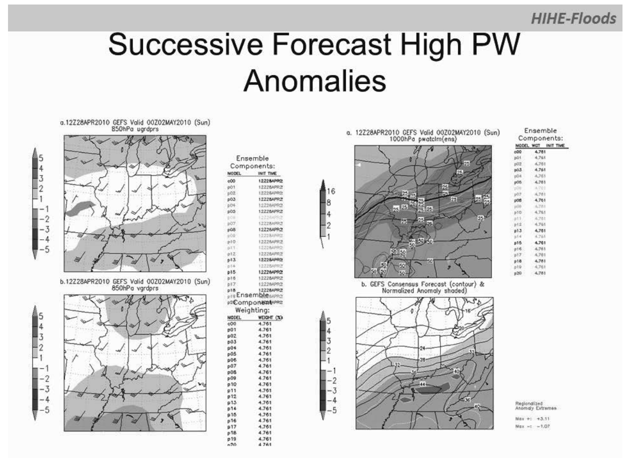
Student Notes:



23. Successive Forecast High high PW air and strong low-level winds

Instructor Notes: We will now look at the regional pattern of 850 winds and PW anomalies from the GEFS. Similar to the SREF the GEFS too had the strong winds and the high PW anomalies with high confidence in the region of higher PW and PW anomalies.

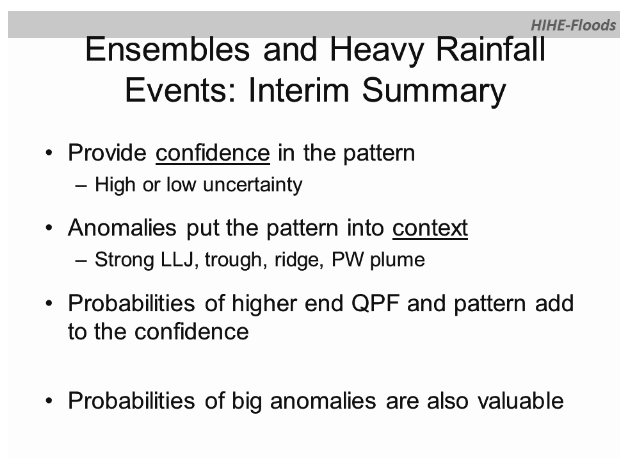
Student Notes:



24. Ensembles and Heavy Rainfall Events

Instructor Notes: From a forecast perspective the ensembles provide both the confidence in the pattern and the context when viewed with anomalies. The probabilities of the higher end QPF and the pattern add to the confidence. Of course, probabilities of big anomalies are also of great value in this process. NCEP is working on a new 1981 to 2010 climatology and products showing exceedance of key thresholds from the GEFS and NAEFS.

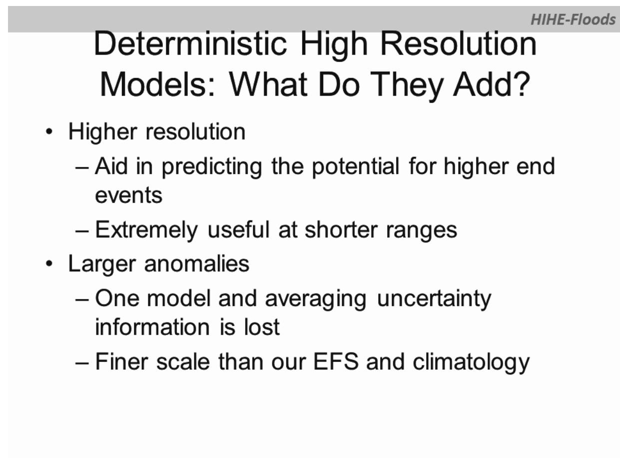
Student Notes:



25. Deterministic High Resolution Models

Instructor Notes: Deterministic models are very useful at all ranges and more so at shorter ranges. They are of higher resolution than our ensemble forecast systems and we need to take advantage of this. They typically show larger anomalies at longer ranges especially when there is high uncertainty as there is no averaging. The impacts of averaging often limit high and lower end values in EFS data relative to the single model.

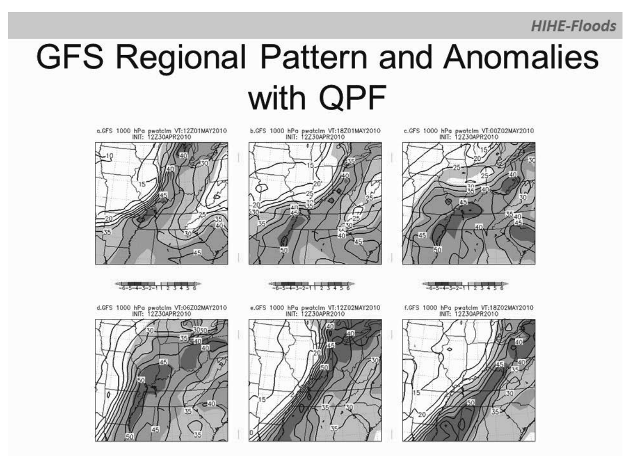
Student Notes:



26. GFS Regional Pattern and Anomalies with QPF

Instructor Notes: These data show GFS forecasts initialized at 12Z 30 April 2010 in 6-hour increments beginning at 12Z 01 May 2010. The GFS like the SREF and GEFS shows the surge of high PW air with large anomalies in the six periods shown. The winds in the ~27km GFS are nearly 5 sigma above normal at times. This produces large moisture flux anomalies. And thus heavy rainfall in the GFS at the forecast intervals shown.

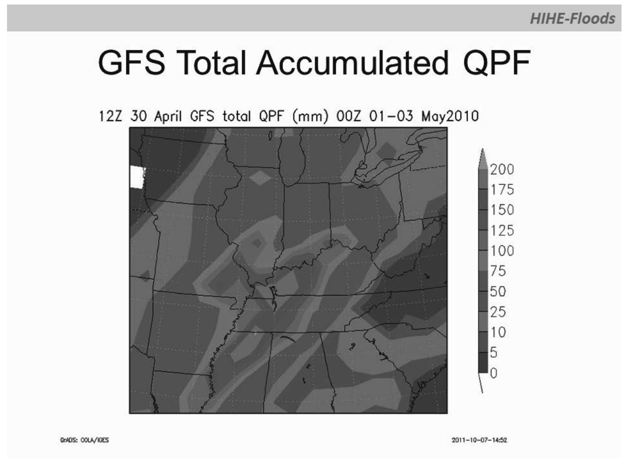
Student Notes:



27. GFS Total Accumulated QPF

Instructor Notes: And here is the total QPF produced by the GFS! Not surprisingly the GFS puts out quite a lot of QPF, over 200 mm in places a bit too far to the west relative to observed though verification is not shown here.

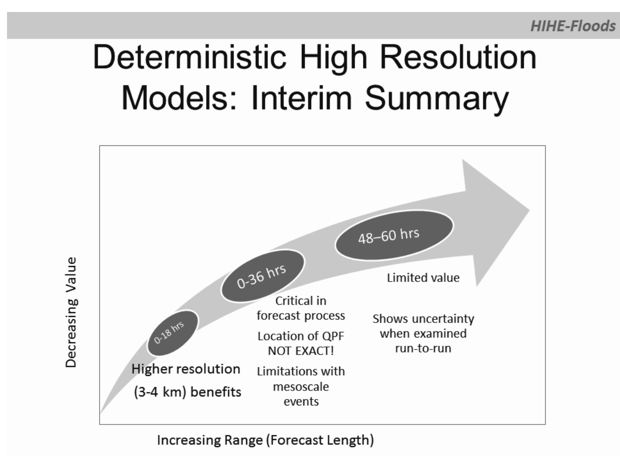
Student Notes:



28. Deterministic High Resolution Models

Instructor Notes: This slide sums up so key aspects of our higher resolution models. Take a minute to read this slide. Only comparing them run-to-run can one see the uncertainty. But higher resolution pays off at shorter ranges and they are critical in our forecast process in the 0-36 hour period if you realize and accept the fact that the location of the QPF will not be EXACT! Resolution pays of in the 0-18 hour period We need higher resolution for QPF! Now some practical limits...

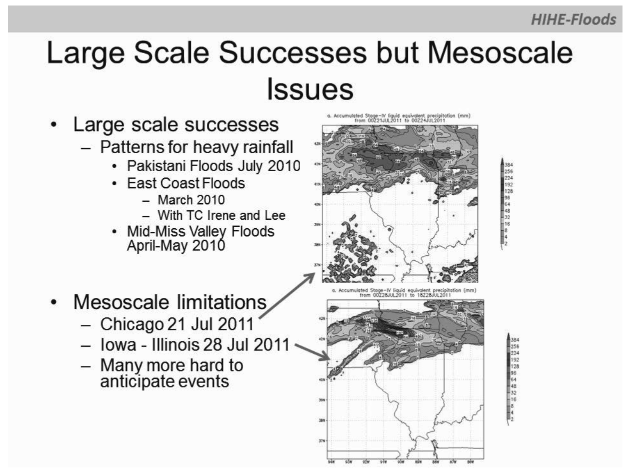
Student Notes:



29. Large Scale Successes but Mesoscale Issues

Instructor Notes: Our example thus far was a strongly forced larger scale event. We did not go into the details of the meteorology. The Nashville event had lots of convection and mesoscale rainfall issues. A list of some strongly forced and relatively successful flood events is provided. Now we briefly look at some mesoscale events with weaker synoptic forcing and signals. These events produced heavy rainfall, but due to the more local scale forcing, the convective nature were not so predictable. It happens.

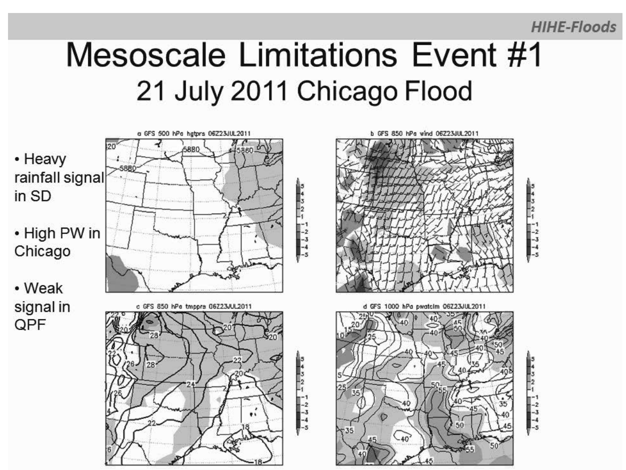
Student Notes:



30. GFS Heavy Signal Rainfall

Instructor Notes: These data are not as descript as the Nashville case and there was not a lot of rain forecast over the Chicago area. Yes, the heavy rain was there and Chicago set a new 24-hour rainfall record, in a few hours at that. These forecasts are not that impressive for Chicago. We still need to know this and we still need to deal with this.

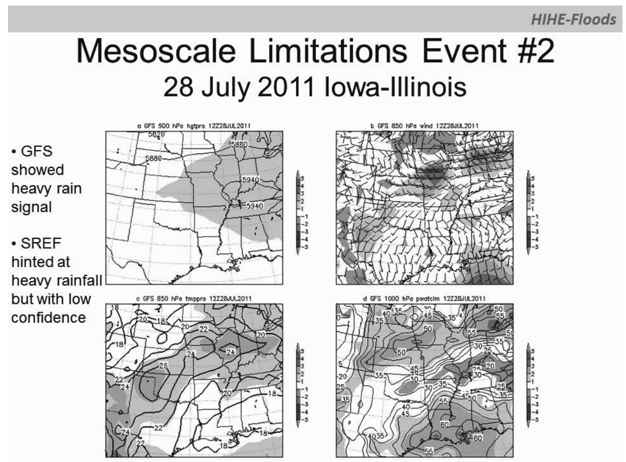
Student Notes:



31. GFS shows heavy rain signal SREF hints Heavy rainfall but low confidence

Instructor Notes: Another mesocale rainfall and flood event. This time over western IL and IA. This event had some stronger signals relative to the Chicago event but was still not well predicted. Mesoscale systems are still tough. Perhaps in some cases 3-4km models and storm scale ensembles will help at times. These events require high Situational Awareness and monitoring in the short-term.

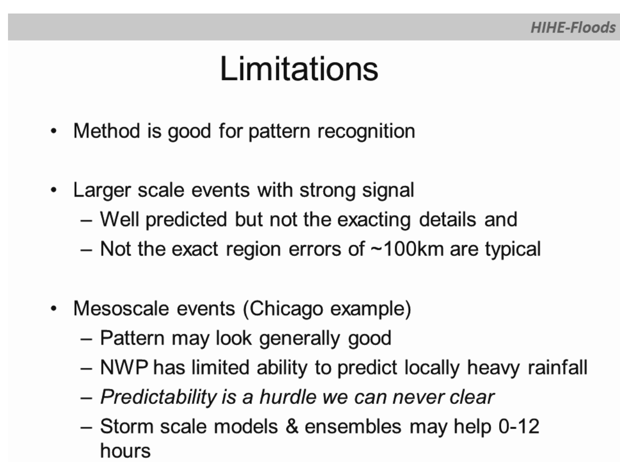
Student Notes:



32. Limitations

Instructor Notes: The method we showed is for pattern recognition and works well for the larger scale and strongly forced events. It has its limits...related to the limits of predictability. Mesoscale forced events are tough nuts to crack. As high resolution models and storm scale ensembles develop we may get a little better at these events. View this Problem as hard to deal with and a form job security as long as your are situationally aware and vigilant!

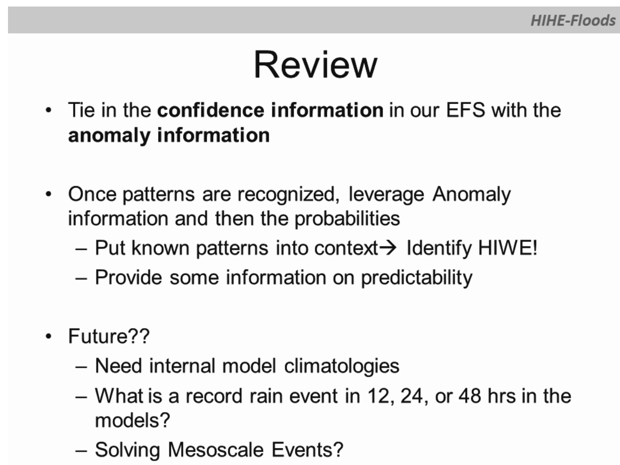
Student Notes:



33. Review

Instructor Notes: This lecture was all about Patterns and Probabilities aiding in better anticipating HIWEs. We need to tie the confidence information in our EFS with the anomaly information. If we can recognize a pattern, tie in the anomalies and then the probabilities, in this case of heavy rainfall, we can more confidently anticipate high end rainfall and thus flood events. Internal model climatologies would be of value. What is a record rain event in 12, 24 or 48 hours in the GEFS, SREF, GFS or NAM? We may never solve the more subtle mesoscale events….

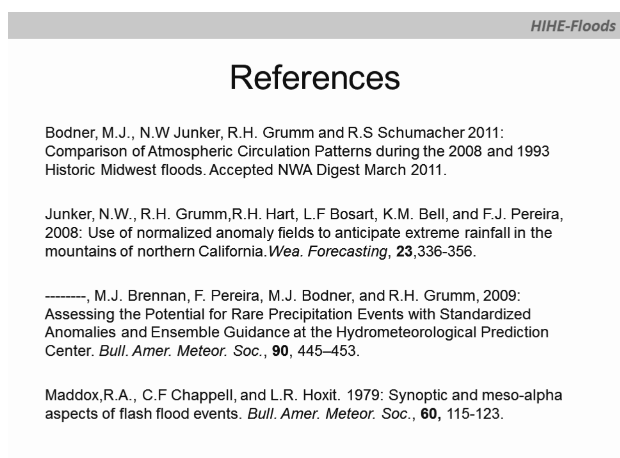
Student Notes:



34. References

Instructor Notes: These are all available from the WDTB Recognizing High Impact Hydro Events course webpage.

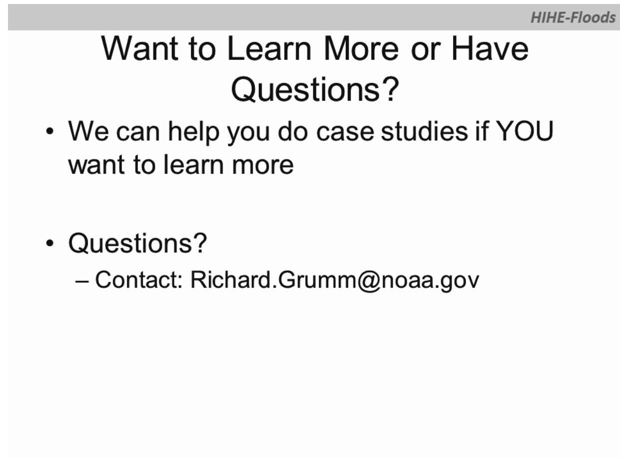
Student Notes:



35. Want to Learn More or Have Questions?

Instructor Notes: If you have any questions, please contact Richard Grumm using the email address provided.

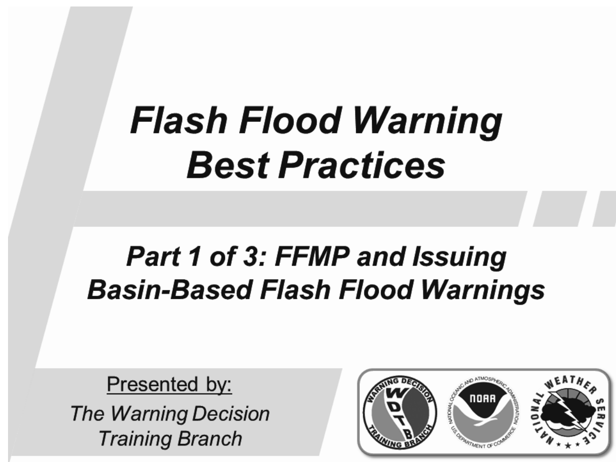
Student Notes:



1. Flash Flood Warning Best Practices - Part 1: FFMP and Issuing Basin-Based Flash Flood Warnings

Instructor Notes: Welcome to the Warning Decision Training Branch's Flash Flood Warning Best Practices. This is Part 1 of 3 lessons that make up the FFW best practices course. This lesson will show best practices for using FFMP and for issuing basin based flash flood warnings.

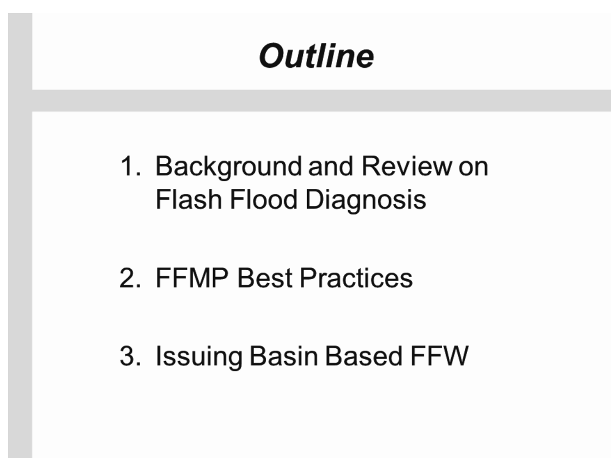
Student Notes:



2. Outline

Instructor Notes: The lesson is broken up into 3 parts. First, I'll provide a quick review on the important parts of Flash Flood diagnosis. Part 2 will be on the best ways to incorporate FFMP into your decision making. Finally, part three will examine the issues associated with basin based flash flood warnings.

Student Notes:



3. Learning Objectives

Instructor Notes: Here are the learning objectives tied to this lesson. Upon completion of this lesson, hopefully you will understand how to effectively use FFMP-A to diagnose flash flooding potential at the basin level. Second, to be able to identify best practices for issuing basin-based flash flood warnings.

Student Notes:

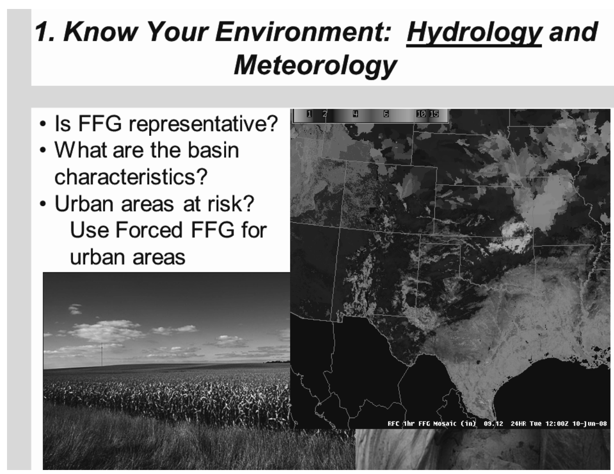
Learning Objectives

- Understand how to effectively use FFMP to diagnose flash flooding potential at the basin level
- Identify best practices for issuing basin-based flash flood warnings

4. Part 1: Know Your Environment

Instructor Notes: Let's begin with a review of flash flood forecasting. There are two equally important parts to any flash flood event: The hydrology and meteorology. It is crucial to examine flash flood guidance from the River Forecast Center across your CWA prior to any warning decision analysis to see if it is representative for the areas with the biggest threat. If there are areas where FFG is clearly not representative and if time permits, it may be very useful to adjust the flash flood guidance in those areas using the Forced Flash Flood Guidance program. Local knowledge of the basin characteristics is important because it allows you to understand what the basin response will be to heavy rainfall. For example on one extreme, out west if you are familiar with a certain basin with a stream channel consisting of a narrow canyon of slickrock, you'll know it takes very little upstream rainfall to flash flood. On the other extreme a very flat area with fields of growing corn would take an extraordinary amount of rainfall to cause a flash flood. Hopefully your flash flood guidance is representative in these two extremes, but it may not be. Also important are urban areas because they tend to have poor drainage systems and quickly convert rainfall to runoff. Check with your RFC or hydro focal point to see whether or not FFG needs to be tweaked lower in your urban areas.

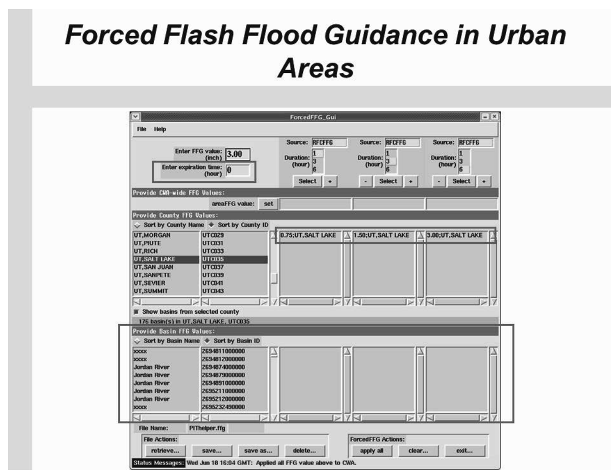
Student Notes:



5. Forced FFG in Urban Areas

Instructor Notes: Since we are in review mode, I wanted to briefly refresh your memory on how to use forced FFG in urban areas. Many urban areas cover entire counties. In that case, you could just apply a FFG value with a 0 expiration time to that entire county. In this example, even though Salt Lake county is not entirely urban, for the sake of an example I have applied 0.75 inch in 1 hour, 1.50 inches in 3 hr, and 3 inches in 6 hrs to every basin inside of Salt Lake County. By setting the expiration time to zero I am ensuring that these values are input to FFMP-A at all times, until I delete the file this is saved to. If your urban areas only cover half the county, it is probably best to apply the urban FFG values to those basins which actually reside in the urban area. This is much more time consuming because you have to identify those basins by Basin ID in arcview or D-2D, then individually select those from this GUI. Consequently this is also a great tool for burn scars, again provided your local RFC hasn't already accounted for them in the raw flash flood guidance you receive over the SBN.

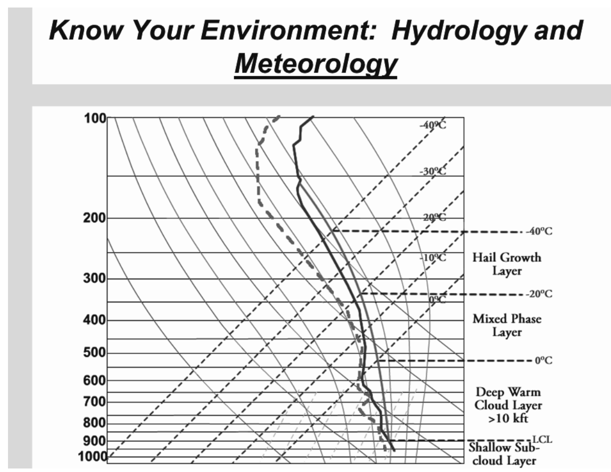
Student Notes:



6. Know Your Environment: Meteorology

Instructor Notes: In terms of meteorology factors here is a composite skew-T showing favorable ingredients for heavy rainfall under weak synoptic forcing and weak but non-zero vertical wind shear. All of the characteristics of this sounding are hopefully well-recognized, and the point of this slide is that as a forecaster prior to thinking about a warning decision, it is important to a have a solid conceptual model of the near storm environment as it pertains to the production of heavy rainfall. Thus, it is vital that prior to a warning decision you have to the best of your understanding, a handle on the specific hydrology and meteorology ingredients for flash flooding across your warning sector.

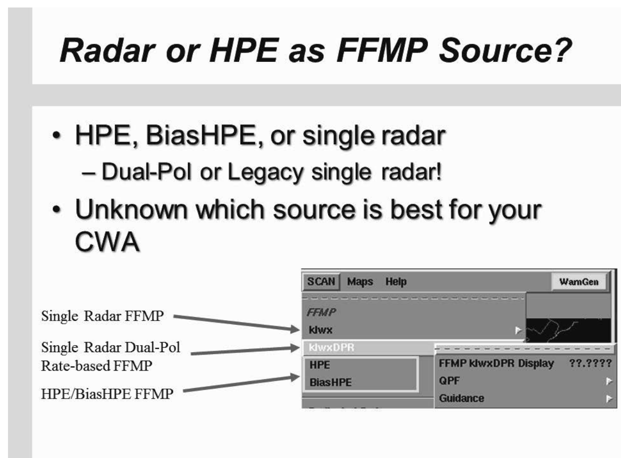
Student Notes:



7. Radar or HPE as FFMP Source?

Instructor Notes: Radar only or HPE as the source for FFMP analysis? Radars will soon have dual-pol rates to use in FFMP as well, further adding to the debate on which source to utilize in FFMP. Once you are upgraded to dual-pol you can use High-Resolution Precipitation Estimator (HPE), biasHPE, single radar legacy rates, and single radar dual-pol rates. Studies have not been done that show which source is better, and it will probably vary from CWA to CWA. I've included a menu graphic showing the options to load FFMP after the upgrade to dual-pol. In regions with poor radar coverage and/or beam blockage, HPE or BHPE should be better than a single radar as input to FFMP because it incorporates information from multiple radars. BiasHPE has a possible benefit of incorporating a bias supplied from MPE…but as always keep in mind that errors can creep into HPE and BiasHPE.

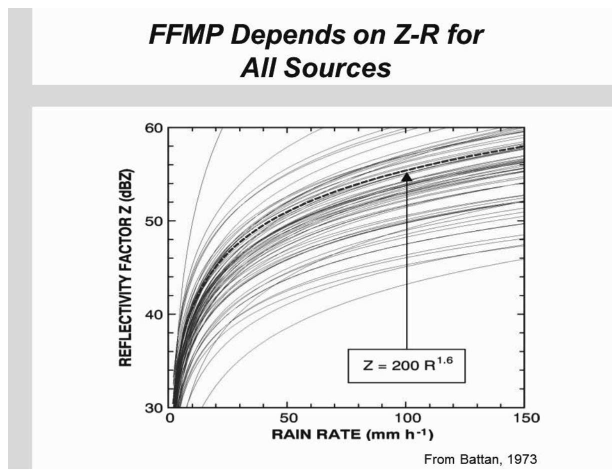
Student Notes:



8. FFMP-A Depends on Z-R

Instructor Notes: Regardless of FFMP source you choose, rainfall estimations will be limited because of the imperfections of radar rainfall estimation. The dual-pol source is by far the least dependent on Z-R relationships, and when HPE and BiasHPE incorporate dual-pol rainfall estimation, they too will improve in this area. This graphic shows the spread of reflectivity to rain rates given the potential drop size distributions. The one in thick dashed blue is the Marshall-Palmer relationship for a general stratiform rainfall event. Adding a bias to the estimation for biasHPE doesn't necessarily solve the problem because the bias is applied universally to the grid points, and different storms on the same day near the same location can have vastly different drop size distributions and thus rain rates. With dual-pol rainfall estimation, differing drop size distributions on the same day are much less of an issue than with a single Z-R applied everywhere. Overall, the caveat to always keep in mind when using FFMP is that it is only as good as the radar estimated or multi-sensor biased precipitation estimation it receives as input.

Student Notes:



9. Part 2: FFMP-A Best Practices

Instructor Notes: We will now move onto Part 2. The next several slides will examine best practices for using FFMP-A as a decision aid for flash flood diagnosis. From this point forward in this presentation, assume I have loaded FFMP-A using whichever source I feel best represents the situation and/or the County Warning Area. These topics will be covered in depth and in this order on the following slides.

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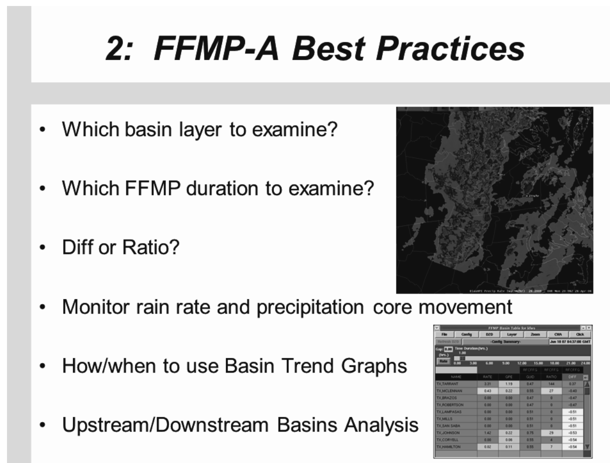
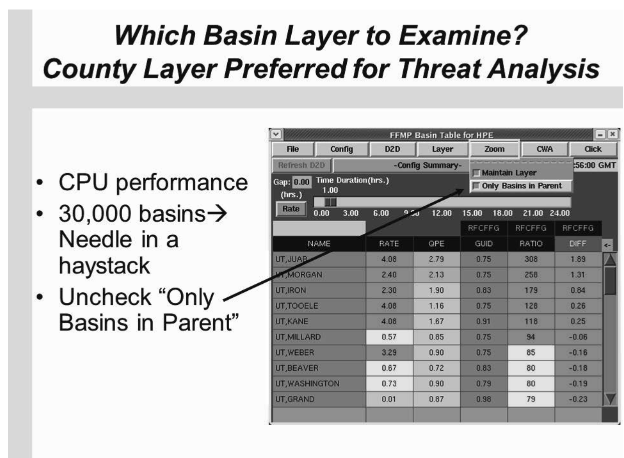


10. County Layer as Default

Instructor Notes: Let’s begin with which basin layer is most useful. Recall that the basin layer to view both in the D-2D pane and the Basin table is accessible via the layer button shown in this red box. Though the end goal is a basin based flash flood warning, it is still a good idea to have the County layer displayed for several reasons. First, many WFOs will have over 30,000 small basins ingested into FFMP-advanced, thus using the “Any and Only Basins” Layer for threat analysis can hinder cpu performance even when loading the recommended 1 frame at a time. Second, also because of 30,000+ small basins, it is unlikely that you know off the top of your head where many of those basins are and thus you lose any potential familiarity you may have with regards to specific hydrologic characteristics. Starting from the County layer with worst case display turned on, you have a better chance of knowing the hydrologic characteristics of that basin and to comprehend where those basins might affect the general public. In most flash flood events, the scale of the heaviest rainfall is quite small in areal coverage, thus the flash flooding occurs in small basins. Using this configuration, it is quick and easy to zoom into the county and evaluate those at great risk by left clicking on the county name and having the basin table list only those small basins in the County. It is recommended that if you use the County level, make sure “Only Basins in Parent” is unchecked. This feature is accessible via the zoom button, and leaving it unchecked allows you to view in the D-2D pane all small basins in surrounding counties that could potentially have a flash flood threat.

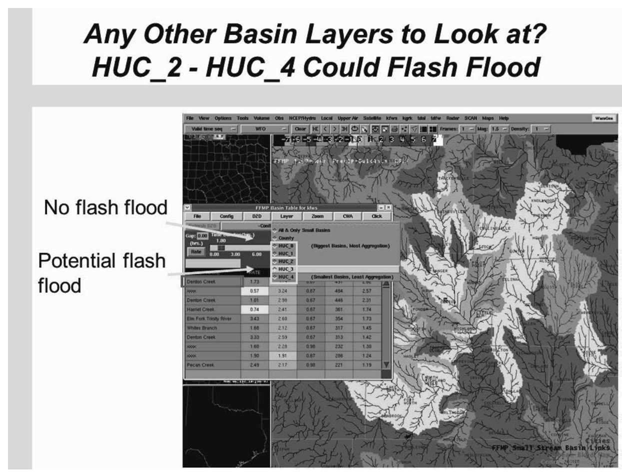
Student Notes:



11. HUC_2 - HUC_4 Could Flash Flood

Instructor Notes: Some of the Hydrologic Unit Code Levels may also be useful if you are familiar with where they are and if meteorology conditions favor flash flooding of larger basins. Here are the HUC_1 layers for the Fort Worth CWA. Notice that they cover entire counties in some cases. HUC_0 and HUC_1 layers are essentially impossible to cause flash flooding because the scale of the heaviest rainfall is vastly smaller than the size of those large aggregated basins. HUC layers 2 through 4 are small enough such that they could potentially flash flood, especially for long duration events such as cell training, upwind propagation, or stalled tropical systems. You can still zoom in on the smallest basins by left clicking on the HUC name shown inside the red box in this graphic. One important thing to keep in mind when using these HUC levels is that the names of the HUC_0-4 basins listed in the table are not always given the name of the primary stream or river as you might expect. Also note that you cannot do Basin Trend graphs on any of the larger HUC layers, only on the small basins.

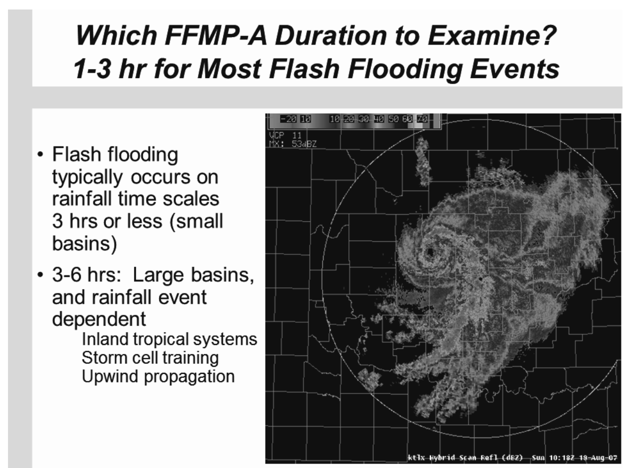
Student Notes:



12. 1-3 hr for Most Flash Flooding Events

Instructor Notes: The majority of flash flood events take place in basins smaller than 25 square miles. This is because the scale of the heaviest rainfall for most heavy rainfall events is also less than 25 square miles. The smallest basins can become inundated by flash flooding from less than an hour of heavy rainfall because of the quick basin response to the rainfall. Most small basins across the U.S. will flash flood for rain event durations of 3 hrs or less. It is thus suggested you focus on the 1 to 3 hour duration from the FFMP basin table for most events and monitor those values in between; the duration slider bar feature in FFMP-A 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 like this one from August 2007 or 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 hr duration, it would be wise to also check out the 6 hr duration statistics from the basin table. Let’s now examine which FFMP-A basin table column to monitor: Diff or Ratio?

Student Notes:



13. Diff vs. Ratio

Instructor Notes: The difference column in the FFMP basin table is far more useful than the ratio column. Let’s use an example to illustrate why. Let’s take a hypothetical basin Boulder Creek that has a basin-averaged rainfall of 3.00 inches in one hour, and the flash flood guidance is 1.50 inches in one hour. Thus, the diff value would be 1.50 inches while the ratio would be 200%. Now imagine that for a different rainfall event in Boulder Creek, it receives 1.00 inch of rain in an hour but the flash flood guidance had been reduced to 0.50 inches. The ratio is still 200%, which could lead you to believe a significant flash flood was possible. However, comparing the two difference values, it is crystal clear that the 1st event would have much more significant flash flooding given that flash flood guidance was exceeded by 1.50 in the first event and only 0.50 inches during a different event. Though the ratios were the same, only the diff value gives information on the potential magnitude of the flash flooding. Outside of this crude example, it can be said that the ratio is fundamentally flawed in that it provides no information about the potential magnitude of flash flooding. However, Ratio can be used to get a quick look at basins that are close to or already exceeded flash flood guidance, or as another way to quickly monitor temporal trends for basins at risk.

Student Notes:

Diff vs. Ratio

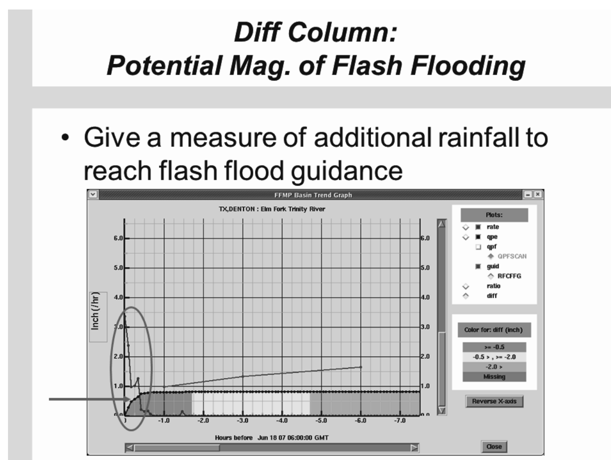
Boulder Creek 1-hr QPE & FFG	Diff	Ratio
QPE: 3.00 in FFG: 1.50 in	+ 1.50 in	200%
QPE: 1.00 in FFG: 0.50 in	+0.50 in	200%

→ Same Ratio, but different flash flood magnitude

14. Diff Column: Potential Magnitude of Flash Flooding

Instructor Notes: We just saw how the Diff column is far more useful than the ratio column. It can also give you a “heads-up” estimate on how much additional rainfall is needed to exceed flash flood guidance provided you have been monitoring rainfall trends. For example, examine this basin table scrolled down to one of this basins that make up the Elm Fork of the Trinity River. Recall from Lesson 2 that the blue line is rainfall rate, the purple line is flash flood guidance, the black line is rainfall accumulation, and the shaded colors are the difference field. The diff column in the basin table implies that this basin is 0.20” away from exceeding 1-hr flash flood guidance, and the current rain-rate is intense with 3.36 in/hr. As a warning forecaster, I would like to know when within the last hour 0.80 inch of QPE fell, so I left clicked on the basin to load a basin trend graph shown here. All the rain has fallen over the last 30 min, so 0.20” over the next 30 minutes would result in 1-hr flash flood guidance being exceeded. Studying the radar trends I am confident 1-2 inches of rain is likely in the next hour, and much of that will fall in the next 30 minutes. My confidence in a potentially significant flash flood increases for this basin given that I expect the 1-hr flash flood guidance to be exceeded by at least an inch in the next half hour, and the 3-hr flash flood guidance by as much as 2 inches in the next hour.

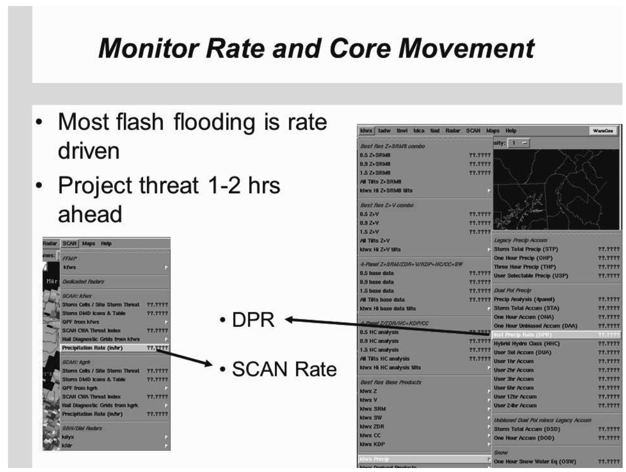
Student Notes:



15. Monitor Rate and Core Movement

Instructor Notes: Throughout the entire threat analysis and warning decision, it is vital to keep tabs on where the heaviest rain is occurring and where the heaviest rain is moving. High rain rates are a primary cause of flash floods, especially in the Western United States or in urban areas. Being aware of where those high rates are moving is also important to project where flash flooding may occur in the next hour or two. There are a variety of ways to monitor rain rates and the movement of the heavy rain cores. The SCAN Precipitation Rate product and Dual-pol DPR, which is a the dual-pol rainfall rate product (once available), are nice ways to monitor rainfall movement and intensity. I like to keep SCAN rate and DPR looping and zoomed out to keep situational awareness.

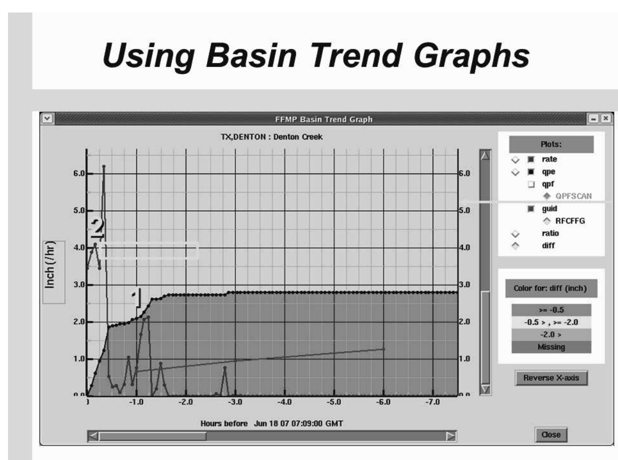
Student Notes:



16. Using Basin Trend Graphs

Instructor Notes: By this point you have zeroed in on the primary threat areas using the Diff column and by monitoring rainrates. Though basin trend graphs in FFMP may be a bit awkward at first, using them can be beneficial to evaluating the flash flood threat for particular basins. Recall from Lesson 2 that you can only load them by right clicking on a small basin name from the basin table; setting the click button option in the top right of the basin table set “Basin Trend”, then going to the D-2D pane with FFMP and making the Table display editable, you could right click on any basin in the D-2D display to load a basin trend. Because there could be over 30,000 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 have the greatest current or projected threat; or perhaps those basins that might significantly impact the general public like urban basins; or 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. Of particular importance for this basin trend for Denton Creek are the two peaks of heavy rainfall within the last 90 minutes. The first burst of heavy rain likely filled the creek to near bank-full with about 6 tenths of an inch in 20 minutes, followed closely by a 2nd, heavier burst of rain which has lasted for nearly a half hour leading up to the current time. This easily accessible and important information, notably the 2nd heavy burst coming on the heels of the first and amounting to about 2 additional inches of rain, could be included in a follow-up flash flood statement indicating the likelihood of significant life-threatening flash flooding in the next 30 min for Denton Creek.

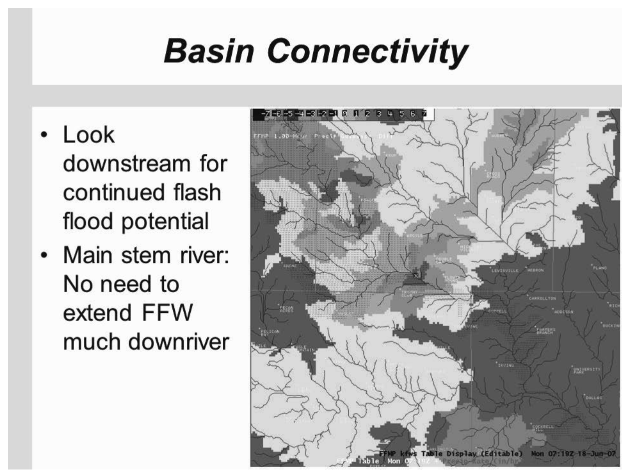
Student Notes:



17. Basin Connectivity

Instructor Notes: This slide will only detail basin connectivity as it pertains to FFMP-A, although there are impressive basin connectivity things you can do using arcview if you are skilled at using it. For basin connectivity, as warning forecasters we are interested at looking at the downstream basins from the ones that are currently under a high threat of flash flooding. 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. Additionally, major main stem rivers typically don't flash flood, so using the upstream and downstream connectivity to help identify them can be useful. Of course, the service hydrologist and/or hydro focal point at your office can probably tell you which main stem rivers are large enough that they would have a hard time experiencing flash flooding. A great way to help visualize downstream flow is by overlaying the FFMP stream links from the map menu in D-2D. I made them blue in this graphic.

Student Notes:



18. Part 3: Issuing Basin Based FFW

Instructor Notes: We looked at best practices for using FFMP in a operational setting. Now let's focus on issuing basin based flash flood warnings. This section won't repeat material from the FY08 storm based warnings training course, if you recall that covered the issues surrounding basin based flash flood warnings pretty well. Here is a link to that lesson if you wish to review it. In this part, the focus will be on polygon size, and warning duration.

Student Notes:

3. Issuing Basin Based Flash Flood Warnings

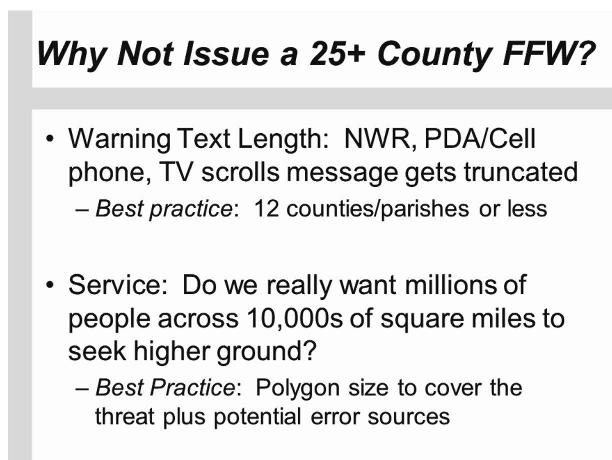
- Discuss basics of polygon size and warning duration

http://www.wdtb.noaa.gov/modules/SBW/lessons/FF1-flashFlooding/player.html

19. Why Not Issue a 25+ County FFW?

Instructor Notes: In recent years several flash flood warnings were issued that covered over 25 counties in a single warning. There are two primary issues with this type of warning that highlight a potential disservice to our customers. First, the text listing of 25 counties or parishes becomes so long that the warning basis statement and other important information in the warning text gets truncated. This has occurred with NOAA weather radio listeners, PDA or cell phone text subscribers, and with the scrolls on TV screens. Additionally, with warning text so long, it can become difficult for our customers to hear and understand the pertinent details of the threat. There is discussion at the regional level to modify Directive 10-922 such that 12 counties or parishes or less in each flash flood warning would be a best practice. This modification to the directive would alleviate the concerns over length of text. Another issue is one of service: When we paint such a huge area (at times an entire CWA), are we really wanting millions of people living across 10,000s of square miles to seek higher ground? Depending on the size of the counties in your CWA, especially in the WR, an overly large polygon could be reached by including just 1 or 2 counties, so it’s not just an issue of 12 counties or less, it’s really an issue of the shear size of the polygon. As a best practice for basin based flash flood warnings, if you have a very large threat area for flash flooding, break it up into manageable warnings and be sure to include a significant buffer to account for uncertainty inherently part of radar or gridded rainfall estimation.

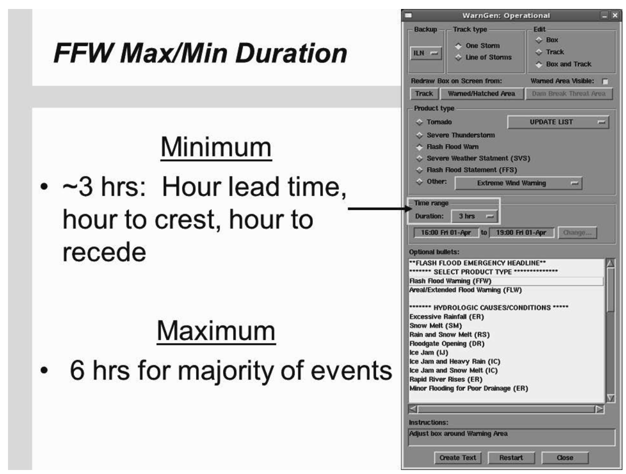
Student Notes:



20. FFW Max/Min Duration

Instructor Notes: In most flash flood events it is a good idea to issue a flash flood warning for a minimum of 3 hours. The reasoning is that you will ideally want to get about an hour lead time before the onset of flash flooding, then give about an hour for the flood to crest, then another hour for the flood waters to recede. If you don't already have it set up as the default in your WARNGEN template, it may be a good time to ask your WARNGEN focal point or ITO to set the default duration for a FFW to 3 hrs, because it is extremely easy to do. Warnings longer than 3 hours are needed if you expect the flash flooding to continue for several hours, say from repeated cores of heavy rain. Exceeding 6 hrs for a flash flood warning might be done for very rare events like the one around Atlanta in September 2009 which led to a service assessment. Events with long-term excessive rainfall where life threatening flash flooding continues well after 6 hours would be cases when you'd want to extend a FFW longer than 6 hrs. There are other product options to consider for flooding events not quite as severe and rare that last 6 hrs or more, and we'll look at that next.

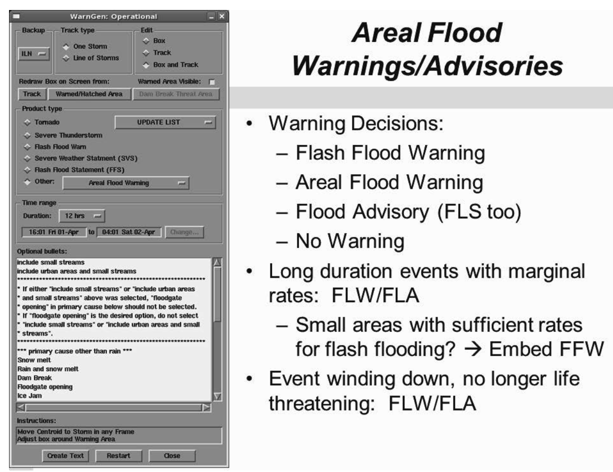
Student Notes:



21. Areal Flood Warnings/Advisories

Instructor Notes: During a warning decision, forecasters can decide between the following flood products to issue or not issue, in order of severity: Flash flood warning, areal flood warning, flood advisory (which would include the urban and small stream advisory), or no warning. Many heavy rainfall events last a long time but may not contain the exceptional rates that cause true life-threatening flash flooding. This is particularly the case in flatter, agricultural regions of the Plains and Midwest states. An example of when to check out longer duration accumulations is with events that have rainrates less than an half inch per hour in which would not normally lead to flash flooding, but let’s say those rates are projected to last for 6 to 24 hrs, causing serious but non-life threatening flooding. In that case, a 6 to 24-hr areal flood warning or advisory would be an effective product to issue. Let’s take it a step further: In those long duration events with marginal rain rates for flash flooding, let’s say small areas of localized heavy rates occur that could lead to life-threatening flash flooding. It would be important to then embed flash flood warnings in areas already under a areal flood warning. Additionally, areal flood warnings or advisories could be used after a flash flood warnings expire for events where drainages are not expected to rise any further and/or are starting to recede but general flooding is still expected to continue.

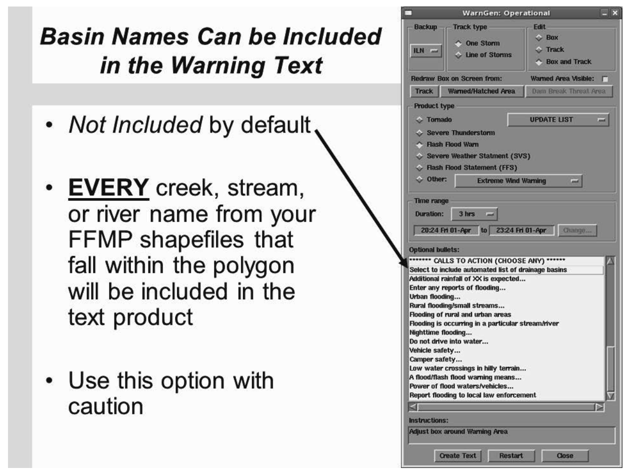
Student Notes:



22. Basin Names Can be Included in the Warning Text

Instructor Notes: Basin names can be automatically inserted into flash flood warnings by clicking the “automated list of drainages” option under the Calls to Action shown here. What this does is include every single basin/stream name as labeled in your wwa_basins localization files that fall within the warning polygon. It of course removes any duplicate entries and any unnamed basins. With potentially 100s to 1000s of basins inside a given polygon depending on how large or small you draw it, this option can lead to un-needed and unwanted text in your warning, thus use caution when clicking this option. Let's check out two examples.

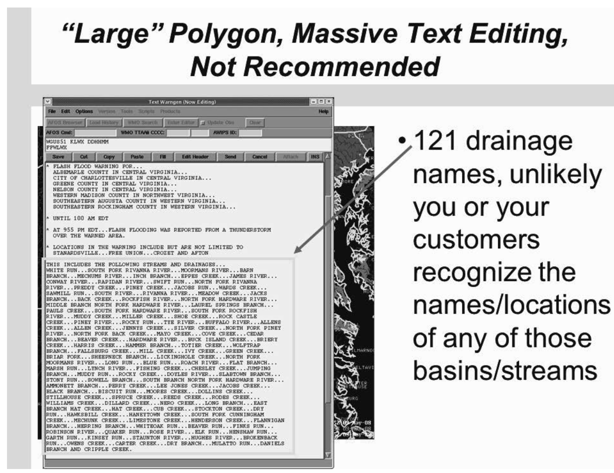
Student Notes:



23. “Large” Polygon

Instructor Notes: Let’s examine a hypothetical flash flood warning from the Sterling, VA WFO. I will be drawing a “large“ polygon. Let me qualify “large” to be about the size of 4 normal-size counties. Be aware that a 4 county flash flood warning in the Sterling CWA would still be well within the recommended polygon size discussed earlier in this lesson. In this graphic, I have it zoomed out to show the entire LWX CWA, and the flash flood warning polygon I drew covers parts of 6 counties. I enabled automated list of Drainages and the result was this text product. I actually counted how many drainage names were included and it came out to be 121. It is highly unlikely that you or your customers recognize the names or locations of those basins and streams. It also does not say which city or county these drainages are in, making it a near certainty that the customers who read this warning would have no clue as to where the flash flood threat might be. Using the automated drainage names option even for a polygon like this that is probably a little smaller than average is not recommended because of the massive amounts of text editing that would be required and problems with dissemination. Let’s check out a much smaller polygon for a very localized flash flood to see what the text may look like.

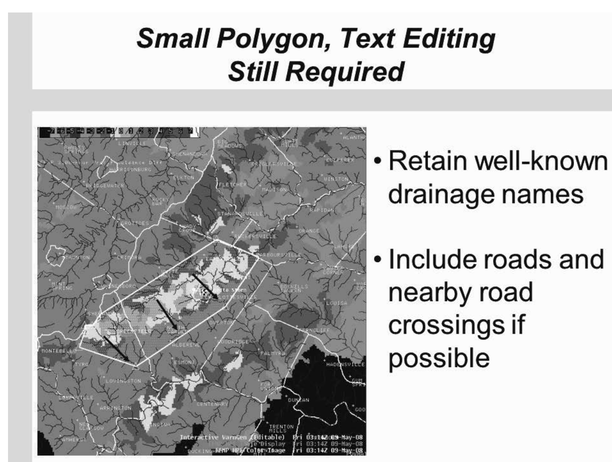
Student Notes:



24. Small Polygon

Instructor Notes: In cases where flash flooding conditions cover a relatively small area, say the size of one or two counties or smaller, the automated list of basins option might be useful. Here is another example polygon from the Sterling office. Let's say there is very slow storm motion training from WSW to ENE over the same areas in yellow and orange, which are differences of -1 inch up to + 1 inch. This polygon contains hilly terrain and an urban area of Charlottesville. Let's discuss the reasoning for this polygon shape and size, as it's a good example of how to issue a basin-based flash flood warning. I drew the polygon to include the areas that have already exceeded 1 hr and 3 hr flash flood guidance, as well as those areas I felt exceed flash flood guidance the next 1-2 hours. I extended the warning to the south and south east to cover 2 important things: uncertainty in the actual location of the rainfall and 2. the potential for flooding of down-stream basins. The corresponding text would look like this. In this product there are only 20 drainage names included. I would still need to hand edit or many of these drainage names, especially all the different forks of the Hardware River. I would only keep the drainage names of the creeks under the biggest threat and those well-known to the average customer and/or those creeks and rivers that are well identified by signage for travelers to the area, if that information is indeed known. I would try to reduce the number of names down to about 7-8 prior to hitting the send button. I would also type in some road crossings that would be affected by flash flooding since the general public and media would recognize those even better than most creek names, of course including this information is contingent on the fact that I have knowledge of those roads and creeks, or I might ask the resident local hydro expert in the office about them.

Student Notes:



25. Summary

Instructor Notes: You are now complete with this lesson, part 1. Feel free to move onto parts 2 and 3 of the flash flood warnings best practices course. After you complete all 3 parts and the WES exercise, there will be a 20 questions exam in the LMS that once passed, completes your training for the course. If you have any questions, feel free to email Brad Grant or Steve Martinaitis.

Student Notes:

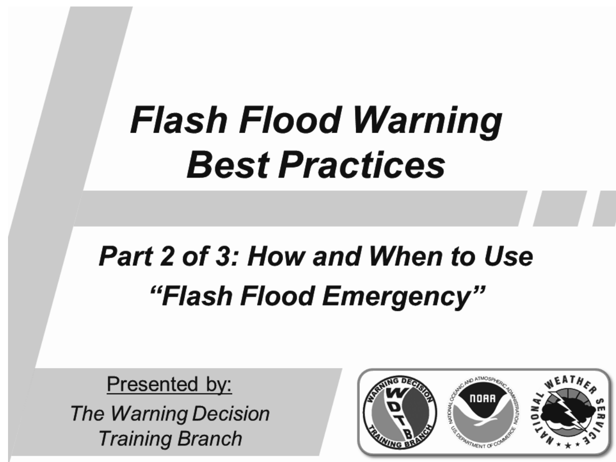
Summary

- Move onto Parts 2 and 3 of Flash Flood Warnings Best Practices Course
- Exam after parts 2 and 3, and the WES exercise
- Questions?
  - Bradford.N.Grant@noaa.gov or
  - Steven.Martinaitis@noaa.gov

1. Flash Flood Warning Best Practices Part 2: How and When to Use “Flash Flood Emergency”

Instructor Notes: Welcome to Flash Flood Warning Best Practices. This is another in a series of online courses from WDTB on Warning Best Practices. This instructional component is on how and when to use “flash flood emergency” in the context of issuing flash flood warnings and statements. My name is Brad Grant and this lesson consists of about 30 minutes of instruction. This is part 2 of a 3-part course.

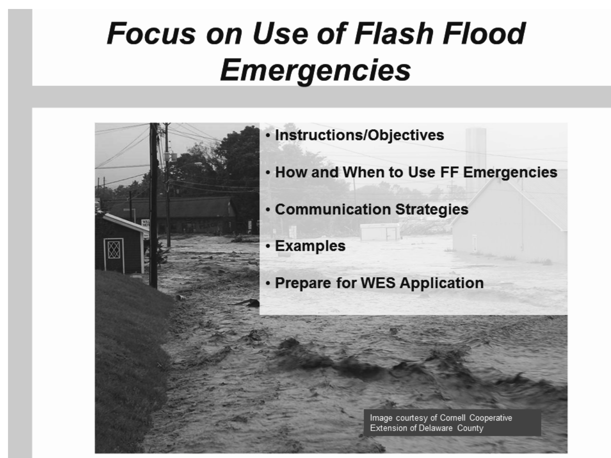
Student Notes:



2. Focus on Use of Flash Flood Emergencies

Instructor Notes: The main emphasis in this lesson is on how and when to use flash flood emergencies, a term used to describe a rare situation where lives are threatened due to the expected or occurring impacts of a flash flood event. As you look at this image of a flash flood event from June 27, 2006 in southern New York, most of us without knowing the details of the event would say that this event most likely would constitute an actual flash flood emergency for this area. However, the policy directive establishing the authority and responsibility for the action had not yet been implemented, so we can only hypothesize. In this lesson, we will focus specifically on the use of flash flood emergency and the steps to get to that decision. We will start out with a brief look at the course requirements, so you'll have clear instructions on how to complete the course. Plus, we will define the learning objectives. Then, we will get into how and when you can use flash flood emergencies or flash flood emergencies, with attention to the official hydrologic products. We will show some examples of communication strategies, examples of specific flash flood emergencies, and then talk about the application of the concepts via a WES exercise, where, in the simulation environment, you will get an opportunity to practice issuing a flash flood emergency using an actual event.

Student Notes:



3. What are the Course Completion Requirements?

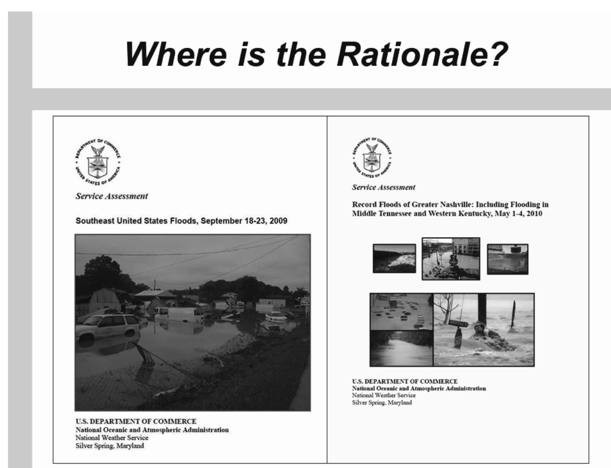
Instructor Notes: Here are the Course completion requirements as shown on the Flash Flood Warning Best Practices web site. We have designed four complimentary parts, each addressing unique learning objectives. Since this Course builds upon fundamental knowledge from related storm-based warning training and the science of standardized anomalies, we are recommending some pre-course instruction that will help grasp the full concepts of the Course. First is the Tornado and Severe Thunderstorm Warning Best Practices Course, which was developed in 2010. This is a series of five short lessons on basic and advanced issues with issuing storm-based warnings, such as overlapping and using smaller polygons. The second task is to review the standardized anomaly approach used in AWOC Winter IC 4.2. This review will help you to better understand methods and products displayed in Part 3. The various parts of the Flash Flood Warning Best Practices Course are: Part 1) FFMP and Issuing Basin Based Flash Flood Warnings, which is an updated version of the module first developed in 2008. Part 2) How and When to Use Flash Flood Emergency Part 3) The Meteorology Behind Extreme Rainfall Events, and then Application via the WES Simulation. The course is located in the NWS Learning Center using an exact search for “FFE”. As far as order of completion, do Parts 1-4 in order from the LMS. For the WES simulation, A DVD containing the simulation has been mailed to your office. The end of course test contains specific learning objectives from this presentation and objectives evaluated via the WES simulation.

Student Notes:

4. Where is the Rationale?

Instructor Notes: Two of the most recent NWS service assessments: Southeast U.S. Floods of September 18-23, 2009, and the TN and KY Flooding of April 30-May 4, 2010, found that the fatalities which occurred during the assessment events were attributed to flash flooding and/or longer duration flooding. Many deaths were a result of people driving vehicles across flooded roads in poor visibility, such as blinding rain. Both events were typified by consecutive days of heavy rain which produced major flooding on many creeks and rivers in the area. In addition, periodic, very intense rainfall episodes occurred within the longer duration flood events producing flash flood conditions. Some fatalities occurred beyond six hours of the causative flash flood event. Thus, the dangers to the general public due to lack of knowledge of these extended flash flood events pose a tremendous challenge to our forecasters' understanding of the current suite of products. Despite timely flash flood and flood warnings, people still died. One aspect that this lesson will address is communication of the severity of the threat. Recognition of an extreme nature of an event is paramount to being able to convey a life-threatening situation. Use of strongly worded language, such as "flash flood emergency", in the context of a flash flood warning or statement, can be important in conveying the severity of a situation which can help residents validate the threat and produce a behavioral response that minimizes risk. One last aspect of this lesson, again based on NWS operations and particularly, from these two service assessments, is the issue that flash flood storm-based warnings need to encompass the area truly impacted. The use of both meteorological assessment and hydrological response tools can help forecasters better predict the onset of rapid floods and convey warning information graphically to partners and the public.

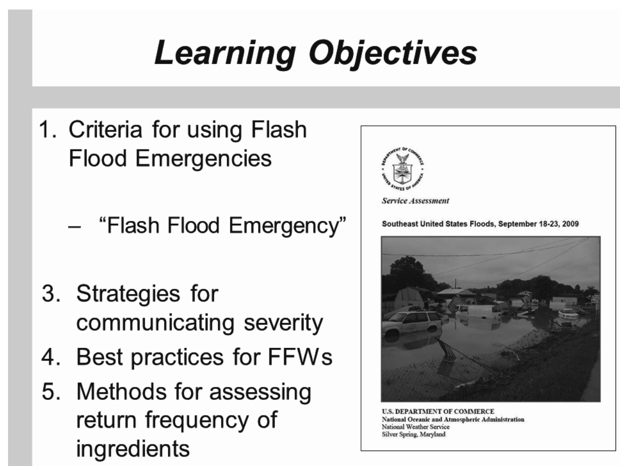
Student Notes:



5. Learning Objectives

Instructor Notes: The learning objectives for this training are based in part on recommendations taken from the NWS Service Assessment for the Southeast U.S. Floods of September 18-23, 2009. We've added one objective (#5) that involves aspects of the ingredients-based forecast methodology that could help lead to the decision for declaring a potential flash flood emergency in a flash flood warning or statement. The learning objectives are: Identify criteria for using declaring a flash flood emergency in a FFW or FFS. Identify warning language that is as specific as possible in conveying the severity of impact (both the area impacted and the severity, such as the use of flash flood emergency, life-threatening, and so forth. Identify strategies for communicating severity in statements. Identify best practices for issuing basin-based Flash Flood Warnings (FFWs), such as drawing the polygons with as many vertices as possible to encompass area truly affected and not just the entire county unless the entire county is affected (note this objective is addressed in Part 1 of the course). Identify some of the methods for assessing return frequency of heavy rain contributing factors. Again, remember that the test questions cover all of these learning objectives.

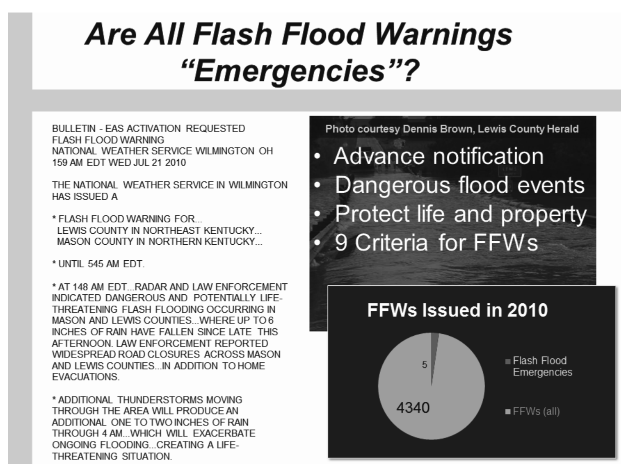
Student Notes:



6. Are All Flash Flood Warnings “Emergencies”?

Instructor Notes: NWS Instruction 10-922 defines the criteria for issuing a flash flood warning the following way: “Flash flood warnings are issued when flooding is imminent or likely. This product will be reserved for those short-term events which require immediate action to protect life and property, such as dangerous small stream or urban flooding and dam or levee failures. The geographic area covered, which is defined by a polygon, may be all or a portion of one or more counties, a river/stream basin, or any other type of definable area (e.g., a specific valley).” By definition, all flash floods can be life-threatening. So, do all flash flood warnings constitute usage of enhanced wording? The answer is “no”. But, in analyzing many of the flash flood warning events issued over the past three years, many of them, based on the Instruction Document, could have used enhanced wording to convey the severity of the situation. Flash flood warnings help us meet the NWS mission by providing advance notification of dangerous, short-fused flood events. This lead time allows users to take immediate mitigation actions such as evacuation to higher ground, thus helping to protect life and property. There are nine different criteria options for issuing a flash flood warning. While still rare overall, the opportunities for situations that call for a flash flood warning far outnumber circumstances where “flash flood emergencies” might be issued. For instance, there has been almost 13,000 flash flood warnings issued since storm-based warning verification stats started in Oct. of 2007. Last year alone, there were 4,340 warnings, but only 5 contained flash flood emergency wording. This lesson will identify situations that might warrant the use of flash flood emergency based on policy but also with an eye toward the subjective interpretation of how forecasters might interpret them.

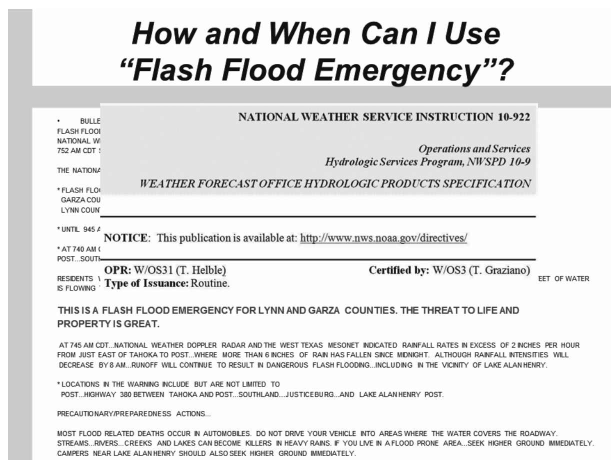
Student Notes:



7. How and When Can I Use FF Emergency?

Instructor Notes: According to NWS Instruction 10-922, which addresses weather forecast office hydrologic products specification, in a Flash Flood Warning, in exceedingly rare situations, when a severe threat to human life and catastrophic damage from a flash flood is imminent or ongoing, the phrase “This is a flash flood emergency” can be used for a specific geographical location. A special call to action may be included immediately following the emergency statement. Please note the correct format of the enhanced wording in this example from WFO Lubbock. The text should be included at the end of 3rd bullet which contains the basis statement and expected impacts. The instruction goes on to state that this enhanced wording should only be used when reliable sources have provided clear evidence that rapidly rising flood waters are placing or will place people in life-threatening situations, such as in this photograph taken from an individual who was trapped inside a mobile home at a recreation park along Logan Fork (a tributary to Kinniconick Creek) during the flash flood event in Lewis County Kentucky on July 21, 2010.

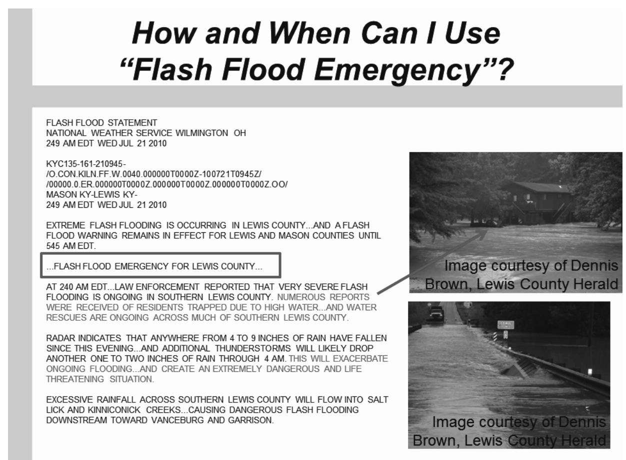
Student Notes:



8. How and When Can I Use FF Emergency?

Instructor Notes: You can also use Flash Flood Emergency language in a Flash Flood Statement, like in this example from WFO Wilmington from the night of July 20, 2010. One of the key communication cues provided in this product are the words highlighted in red: “NUMEROUS REPORTS WERE RECEIVED OF RESIDENTS TRAPPED DUE TO HIGH WATER...AND WATER RESCUES ARE ONGOING ACROSS MUCH OF SOUTHERN LEWIS COUNTY, ” and the words used in the section containing the current hydromet situation and expected impact section, “THIS WILL EXACERBATE ONGOING FLOODING AND CREATE AN EXTREMELY DANGEROUS AND LIFE THREATENING SITUATION. “ When you use these words to convey urgency and exceptional life-threatening situations in this part of the product, they will help to qualify and enhance the flash flood warning message.

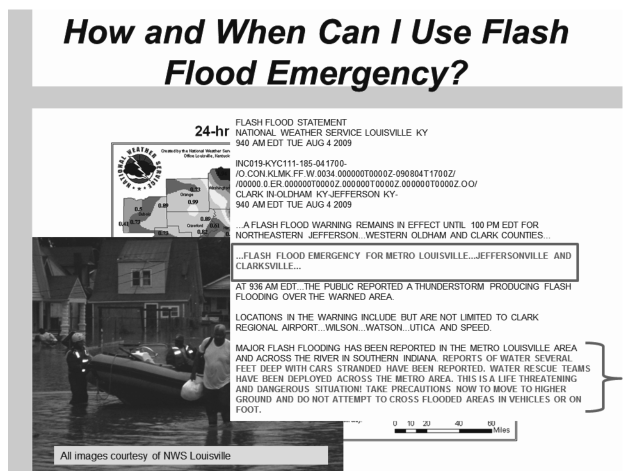
Student Notes:



9. How and When Can I Use FF Emergency?

Instructor Notes: Another example of a situation which prompted a Flash Flood Emergency headline in the Flash Flood Statement was from the record-breaking rains that fell in Jefferson County, Kentucky as well as Floyd and Clark Counties in Indiana, on August 4, 2009. Note the 7.04 inch bulls-eye which was reported in downtown Louisville. During this event, up to 6 inches of rain fell in a three-hour period in central Louisville, with five inches of rain in 1.5 hours, and rainfall rates up to 8.8 inches per hour reported on the morning of August 4. In Louisville, nearly 200 people were rescued by emergency workers from the tops of cars and houses. 50 people were rescued by a boat from a University of Louisville office building. In Jeffersonville and New Albany, many cars were stranded and water entered homes and businesses. Amazingly, no fatalities or injuries were reported. You can see the correct placement of the Flash Flood Emergency in this modified Flash Flood Statement. Note in the current situation and expected impact statements, the words effectively describe extremely dangerous, life-threatening conditions that were reported in the warning area. Again, another example of how and when to use a flash flood emergency.

Student Notes:



10. It is a Whole Lot About Communication

Instructor Notes: When you talk about conveying risk such as an emergency with weather, it's a whole lot about communication and trying to express urgency for a potential life-threatening situation. There are often specific words that are used that can elicit a unique response. For example, consider this movie clip from the movie, "Jaws".

Student Notes:

11. Ready, Set, Go!

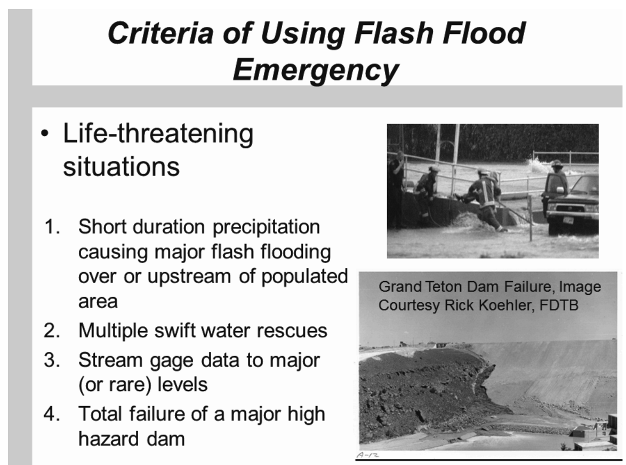
Instructor Notes: While we certainly do not want the usage of flash flood emergency to invoke a panic, it is important to note that the use of this terminology is one of the final acts in the integrated warning process that elicits a desired response, that is we want people to change their behavior. We reiterate that the flash flood emergency indicates a situation that is a severe threat to human life and catastrophic damage (either imminent or ongoing), and you want people's behavior to change as a result of that message. And, it is important to state that you don't usually just get to the point of issuing a flash flood emergency without a chain of events that occur within the warning methodology process. The forecast and warning process is very holistic and involves many facets of data analysis and synthesis on many scales, monitoring and constant information gathering. Thus, as is addressed in Part 3 of the course on meteorological ingredients, the assessment process is an important step in anticipating these types of exceedingly rare events.

Student Notes:

12. Criteria of Using Flash Flood Emergency

Instructor Notes: Flash flood emergencies can be issued in situations where reliable sources have provided clear evidence that rapidly rising flood waters are placing or will place people in life-threatening situations. Examples of specific situations which could be considered flash flood emergencies include the following: Short duration (1 to 6 hour) precipitation of equal or greater magnitude than an amount known to be able to cause major flash flooding has been detected or is occurring over or upstream of a populated area. Threshold amounts, such as one-tenth of one percent chance of occurring in a given year can be estimated by using the precipitation frequency data server. Multiple, swift water rescues are being deployed in response to a flash flood of an exceptional magnitude. Stream gages, where available, indicate flood waters have risen rapidly to at least major levels or if gages are not available, flood waters have risen to levels rarely if ever seen. Total failure of a major high hazard dam that would have a catastrophic impact on the downstream communities. We are going to give some examples of each of these criteria.

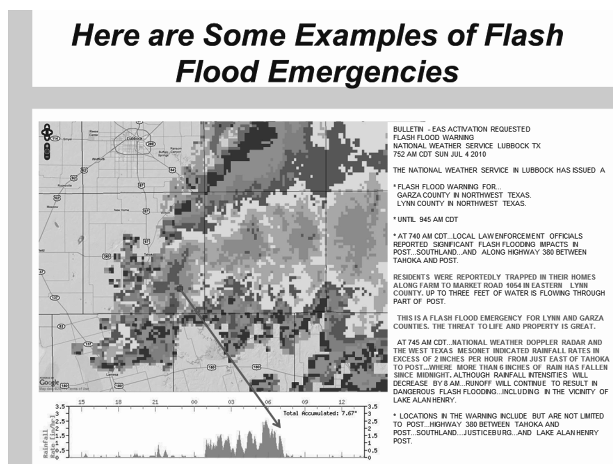
Student Notes:



13. Here are Some Examples of FF Emergencies

Instructor Notes: Here is our first example showing criteria for issuing a flash flood emergency. This is an example of one of the most common criteria of intense, short duration precipitation. This an event from WFO Lubbock's CWA from the evening of July 3 and the early morning of July 4th , 2010. In this example, deep, tropical moisture interacting with multiple, slow-moving upper level waves led to several rounds of widespread heavy rainfall over portions of the Rolling Plains and southeastern South Plains of West Texas. Rainfall totals of 2 to 5 inches were common for the first two days of July. Then, on the evening of July 3, an intense area of rainfall, enhanced in part by a mesoscale convective vortex, led to an additional 6 inches of rain in Lynn and Garza counties, which are just south and east of Lubbock. Then, a last burst of precipitation with rainfall rates of 2 inches per hour (note West Texas Mesonet) occurred around Post and Tahoka, Texas between 6 and 7 am. This led to a very dangerous situation with residents trapped in their homes and many roads under water. While it is not uncommon that intense, short duration precipitation will cause flash flooding, it is the rare situation as in this event whereby multiple bursts of high-rate rainfall within a 6 hour interval lead to saturated ground conditions, excessive runoff and a flash flood emergency type of situation that occurred here.

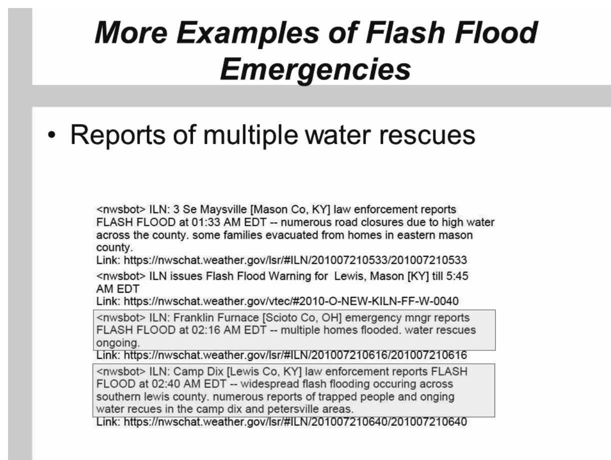
Student Notes:



14. More Examples of FF Emergencies

Instructor Notes: Another example which could be considered a situation where it is appropriate to issue a flash flood emergency occurs when multiple water rescues are being deployed in response to a flash flood of an exceptional magnitude. We have seen this in just about every flash flood emergency issued in the NWS over the past 3 years. This is a segment of a a NWSChat log from WFO Wilmington and the Weather Event Simulation from July 20-21, 2010 that is used in this Course. Images and a warning product from this event were shown previously on slides 6 and 7. One of the pieces of information which led to the issuance of the flash flood emergency by the warning forecaster in this event were the reports from emergency managers and law enforcement of multiple water rescues commencing in the flooded areas. This information, conveyed through NWSChat can quickly be inserted into the text of the warning to convey the extremity of the situation.

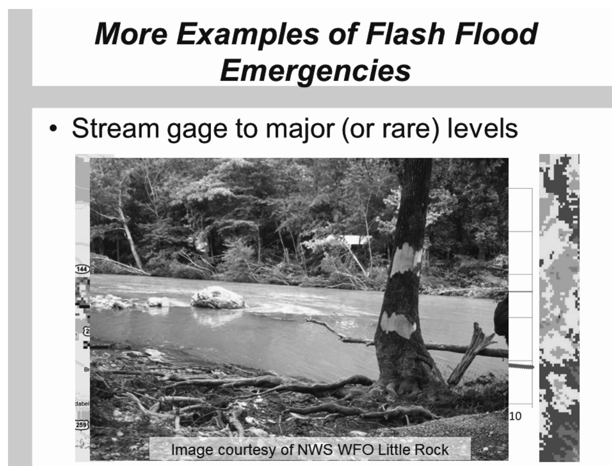
Student Notes:



15. More Examples of FF Emergencies

Instructor Notes: Another criterion that can necessitate a flash flood emergency is the rapid rise as measured by a stream gage. In this case, we are showing a modified hydrograph from the Little Missouri River, which lies in the Ouachita National Forest in southwest Arkansas. In the overnight hours of June 11, 2010, torrential rains of approximately 6 inches fell near the headwaters of the Little Missouri River producing a rise of 20 feet in about three and half hours. The River swelled rapidly and crested to over 23 feet, which was 10 feet over the previous record stage. You can see the Flash Flood Warning in green opaque area overlaying the half-degree reflectivity at 2:00 am, which is about the time an initial warning was issued by WFO Little Rock. In the Albert Pike Recreation Area (Montgomery Co.), where there was no NOAA radio coverage, the flood waters inundated much of the campground areas during the early morning hours of June 11 and 20 people were killed and 24 others were injured. The force of the water mowed down trees and left travel trailers deposited in the tops of trees.

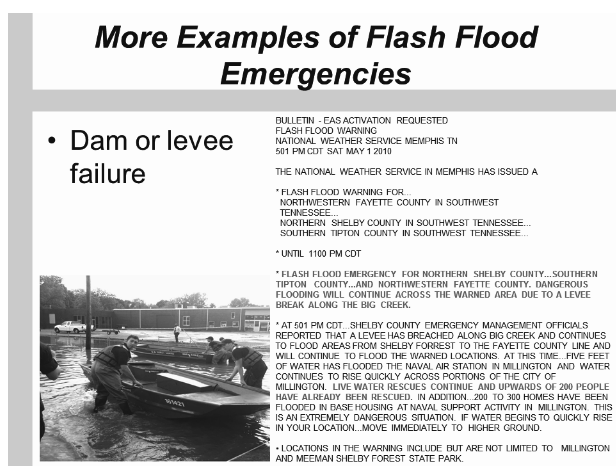
Student Notes:



16. More Examples of FF Emergencies

Instructor Notes: Another example that constitutes a legitimate rationale to issue a flash flood emergency is when there a total failure of a major high hazard dam that would have a catastrophic impact on the downstream communities. Our next example here comes from the Memphis, Tennessee area from May 1, 2010. A stalled frontal boundary that coupled with very moist air from the Gulf allowed repeated intense, convective precipitation episodes to occur over portions of western and middle Tennessee. Multiple hazards (including flash flooding, damaging winds, and tornadoes) impacted the Memphis WFO over a two-day period into May 2. Approximately 10 inches of rain fell over the area in less than 48 hours, which according to the Precipitation Frequency Data Server was a once per 1000 year rainfall event. On May 1st, heavy rain started to fall over the area in the early morning hours with a strong line of thunderstorms. Behind the line, and all through the day into the late afternoon, numerous bands of intense thunderstorms produced rainfall rates of 1 to 2 inches per hour for over 4 hours in and around the Memphis vicinity. The WFO extended the original Flash Flood Warning issued at around 5 am to last all the way to almost 5 pm for a large part of the CWA. Storms continued to redevelop over the area in the late afternoon and were generating an additional 1 to 3 inches of rainfall per hour over portions of northwest MS and western TN, especially around Memphis metro area. The first Flash Flood Emergency was issued in the morning. Water started overtopping a levee on Big Creek around 4:45 pm and started flooding the Naval Air Station at Millington which is just north of Memphis in Shelby County. At least 1,500 residents were evacuated throughout the area as flood waters of 5 feet deep poured into the base. Approximately 250 people were evacuated from the Base and another 500 people were evacuated elsewhere in Millington. Note the wording describing the flash flood emergency impacts placed directly in the text of the Flash Flood Warning. The Flash Flood Emergency language was repeatedly used in warning and statements throughout the entire Flash Flood Event, which lasted over 24 hours.

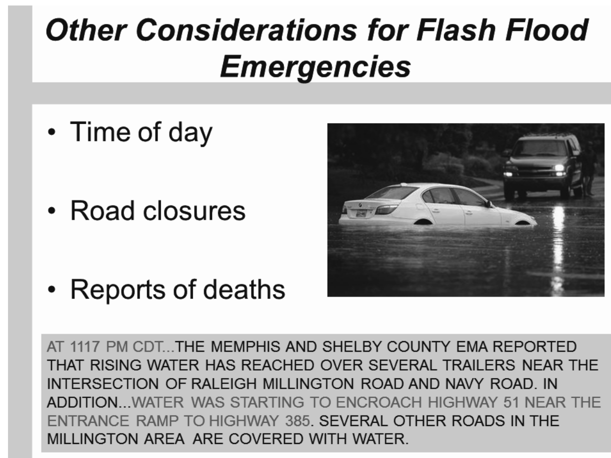
Student Notes:



17. Other Considerations for FFE

Instructor Notes: Some of the other considerations in determining to use flash flood emergency are time of day and road closures such as in this image from the May 1 , 2010 flash flood in Memphis. Note the text that was inserted into the Flash Flood Statement included current flood impacts on major roads. Other considerations are reports of deaths, soil moisture content way above normal prior to the event, and of course, rarity levels in the flash flood ingredients and precipitation rates or amounts.

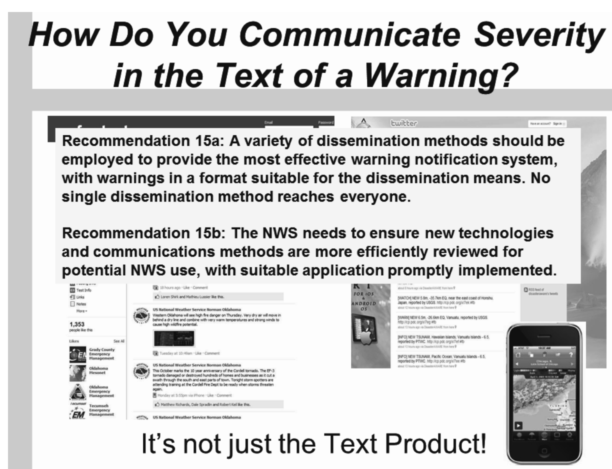
Student Notes:



18. How Do You Communicate Severity in the Text of a Warning?

Instructor Notes: Based on some recommendations in the Southeastern U.S. Flood Service Assessment, NWS offices should incorporate changes in text watch/warning product paradigm to serve customers more effectively, including possible separate "public" and "emergency professional" products, and products in a concise format for Smartphones. New methods and technology for warning dissemination must be considered, including Common Alerting Protocol (CAP), and Extensible Markup Language (XML) feeds. Facebook and Twitter now are extensively used to communicate and receive weather impact information. An example of some variety in dissemination occurred in March with the tsunami threat spawned by the earthquake in Japan. The Pacific Tsunami Warning Center (PTWC) in Honolulu issued a Pacific Ocean-wide Tsunami Watch and Warning. As the tsunami waves spread across the ocean basin, the Pacific Disaster Center (PDC) went into emergency operations support mode. Within minutes, the tsunami alert was pushed to emergency managers using various PDC applications and was announced to the public through the PDC web site, the Disaster Alert app for mobile phone users, and social media channels on Facebook and Twitter. Meanwhile, analysts began working with international and regional agencies and volunteers to prepare assessments and map products for potentially impacted areas. To help large numbers of internet users understand when the tsunami might impact their areas, a Tsunami Travel Time map was produced and posted to PDC's main web page, along with the latest advisories and Hawaii evacuation maps. The site received more than 4 million hits and served more than one million requests for Hawaii tsunami evacuation maps.

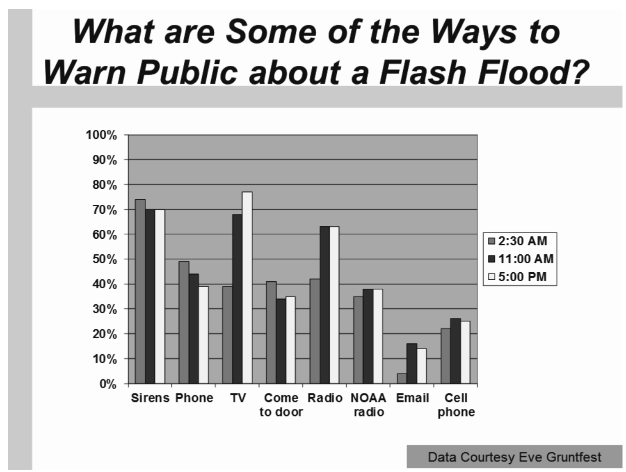
Student Notes:



19. What are Some of the Ways to Warn Public about a Flash Flood?

Instructor Notes: While not explicitly tied to the requirement for using flash flood emergency language, it is nevertheless important to evaluate some of the ways we communicate with the public. This question was part of a survey used in a NSF research project developed in 2003-07 by the social scientist , Eve Gruntfest. The survey questions were aimed at helping to find out how people in two large metropolitan areas (Austin, TX and Denver, CO) perceived flash flood risks including what sources of information they use. One of the findings as shown here in the graph recognizes that the NWS and emergency managers may need to use different strategies to reach people at different times of the day. People said they liked sirens but there is a divided expert opinion regarding the effectiveness of sirens since so many people live in sprawling cities, sirens may not be heard indoors over air conditioning or other noises. Also, the sources of weather information likely has changed over the past 4-5 years due the technological advances in communication services, such as Smart Phones.

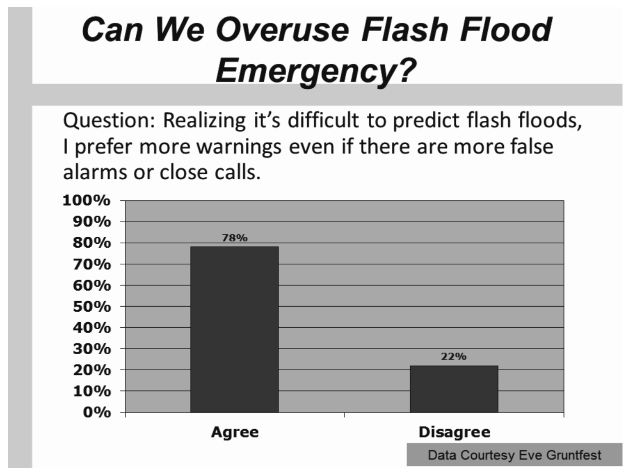
Student Notes:



20. Can We Overuse Flash Flood Emergency?

Instructor Notes: I do not know the answer to the question, “Can we overuse flash flood emergency?” I suspect that there are limits to the effectiveness of the use of the wording, since it is by definition only to be used in exceptional cases. But, with regard to the misconceptions of over-warning and subsequent inflated false alarm rates, I do not think there will be a problem as a large majority of people say that they disagree with officials that are too sensitive to the possibility of flash flooding. To reiterate , people are not that concerned about over-warning. So, since people are willing to accept a higher number of flash flood warnings even with false alarms, it suggests that the NWS should be issuing more warnings containing flash flood emergency usage.

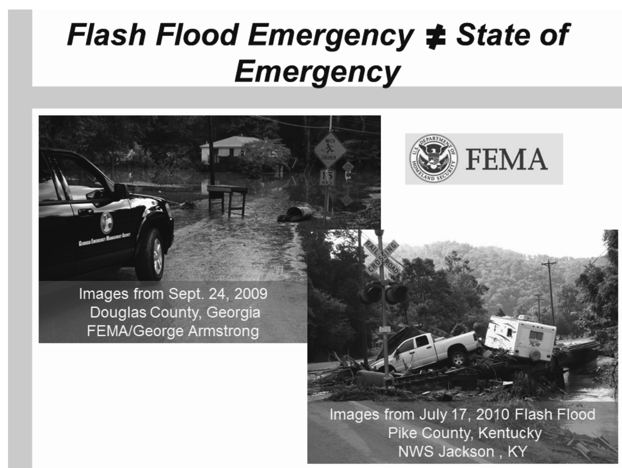
Student Notes:



21. State of Emergency

Instructor Notes: It is important that we distinguish between using flash flood emergency wording in warnings with a State of Emergency. Elected officials in government, such as a President, governor or a local mayor can only issue or declare a “state of emergency” due to weather events. Typically, a state of emergency empowers the executive branches of government to name coordinating agencies such as FEMA to deal with the emergency relief efforts and to alleviate the hardship and suffering caused by the emergency on the population and to provide assistance for required emergency measures. So, for the NWS and purposes of this training, to avoid confusion, the act of issuing a flash flood emergency should never be confused with official declarations of a state of emergency. However, for a unique situation which might call for a flash flood emergency, coordination of efforts between the federal government and state and local counterparts will certainly result in improved services. And to emphasize the coordination aspect, with instant communication capabilities, it is very important to always share weather impact information and intelligence with our partners on a potential, life-threatening event so each group can then be better prepared to assist and respond.

Student Notes:



22. Preamble to WES Exercise

Instructor Notes: To practice and apply the concepts of flash flood forecasting and evaluate recommended criteria for issuing a flash flood emergency, we have designed a short WES simulation on a recent event in the OH/KY area. The simulation is intended to run about two hours total and each participant will have an opportunity to systematically perform various tasks such as: Analyze the synoptic and mesoscale environment including assessing the meteorological and hydrological ingredients. Analyze observed and model-derived Skew-T diagrams Analyze radar observations and trends Analyze FFMP data and trends Issue flash flood warnings and statements

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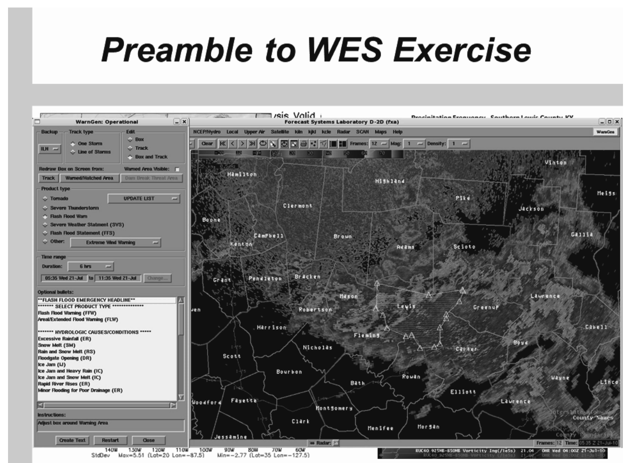

23. Conclusion

Instructor Notes: In conclusion, let's revisit some of the key points that we made in the lesson. Although there are many official criteria available for issuing a flash flood warning, there are special situations reserved when you should consider using enhanced wording, such as flash flood emergency. These are reserved for rare, life-threatening situations. Criteria are: Short duration precipitation causing major flash flooding over or upstream of populated area Multiple water rescues Stream gage data to major (or rare) levels, and Total failure of a major high hazard dam (or levee). We showed examples of each of these as well as some the language used. Make sure you can identify these situations and be able to correctly insert the enhanced wording to convey the severity of the situation via a flash flood warning and associated statements. This module was about communication and how critical special language is used to convey the message and elicit the desired warning response. There should be a variety of ways NWS and associated decision makers get the warning message out. There is a need to issue more flash flood emergencies in warnings as that language can be a signal to users that the event is causing (or could cause) catastrophic damage and/or loss of lives. The increase in flash flood emergencies, as with any flash flood warning, will not be detrimental in terms of the public's acceptance.

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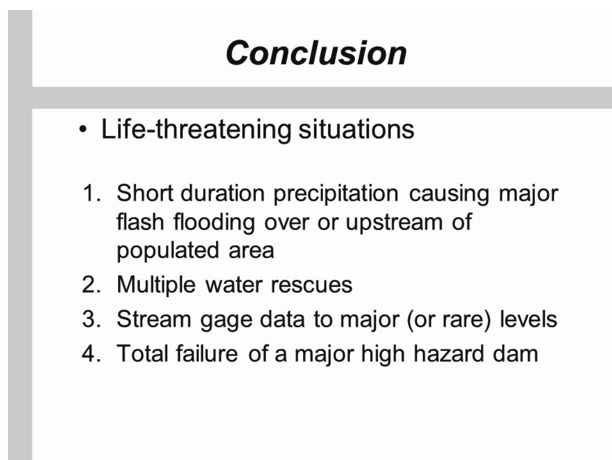

24. Learning Interaction

Instructor Notes:

Student Notes:

25. For Help

Instructor Notes: A reference page is available on the flash flood warning best practices web site, where you can get more information about the training. Make sure you are logged into the NWS Learning Center to take the test and survey to complete this lesson. Also, remember, you must complete the WES simulation to get a course completion certificate. If you have any questions regarding the Flash Flood Warning Best Practices training, please feel free to email the point-of-contacts from the Warning Decision Training Branch listed here.

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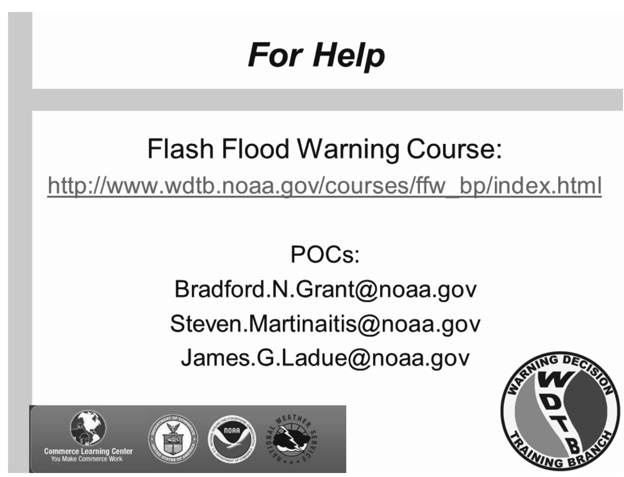

1. Flash Flood Warning Best Practices Part 3: The Meteorology Behind Extreme Rain Events

Instructor Notes: Welcome to Flash Flood Warning Best Practices. This lesson is about the meteorology behind extreme rain events. This is Jim LaDue and for the next 40 minutes I'll walk you through this lesson.

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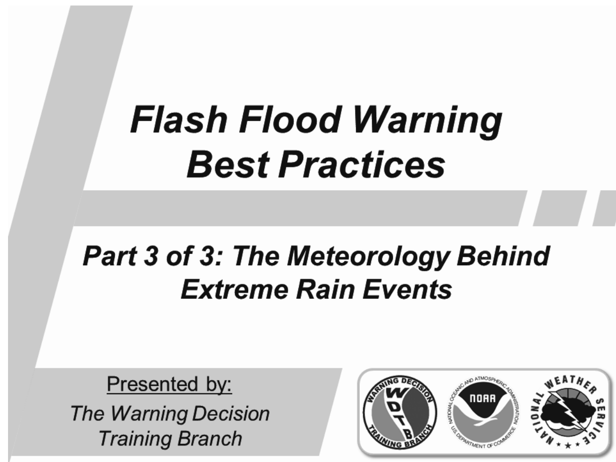

2. Strategies to Anticipate Severe Flash Floods

Instructor Notes: This lesson will address the meteorological influences of a great majority of flash floods. That is when a particular small drainage basin is subjected to abnormally heavy rainfall in a relatively short amount of time. To anticipate whether or not this will happen requires us to draw upon some kind of methodology to anticipate this event. The strategy we choose to pursue in this lesson starts off with attempting to gauge whether or not the basic ingredients for heavy, persistent rainfall are going to be present and anomalously strong. So this lesson will have you understand the meteorological ingredients involved in extreme rainfall and the how to estimate the rarity of those ingredients. In many cases of flash flood producing rainfall, we may find that the contributing ingredients match a conceptual model drafted by someone who's studied similar events. We will have you understand some common conceptual models with extreme rainfall events. Finally, you may find it important to relate the QPF, or the current QPE in some climatological context. This is because our building patterns become tuned to deal effectively with a certain common frequency of rainfall events. When a abnormal situation presents itself, then that's when we find that we're with a potential flash flood for which we have little memory of how to deal with it. Thus the final objective is to have you go through where and how to put the QPF and QPE into the context of climatological rarity.

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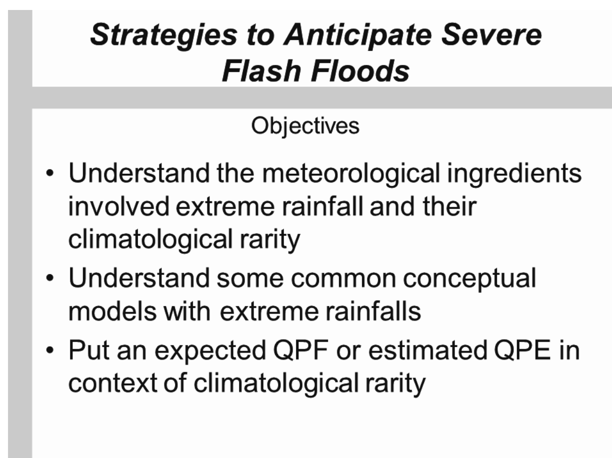

3. Ingredients-based Flash Flood Threat Assessment

Instructor Notes: When it comes to flash flood ingredients, we refer to three key aspects that flash floods share, rain rate, rain duration, and the hydrological response. Just to set the tone of this meteorological discussion in the right path, I'll be referring to these ingredients again and again and so I'll make sure to elaborate on them here up front. We'll be focusing on the meteorological aspects to extreme short-term rainfall where short-term means 6 hours or less. Rain rate is a big contributor to initiating a flash flood but it has to last long enough to get a significant volume of water onto the ground. In it's most simple form, rain rate is really a function of how strong the upward moisture flux happens to be over a certain area and then how much of that comes back down as rain (efficiency). It's really hard to figure out if a rainfall event is efficient because we have to time integrate all of the total volume of water ascending and then the fraction that resulted in precipitation reaching the ground. However, there are a few queues amongst the contributing ingredients that we agree help create a high efficiency event. Rain duration is also a key ingredient. In this case, we're really talking about how long the favorable rain rate ingredients persist over any one geographical location. So it's not a matter of looking at different fundamental parameters contributing to rain rate but how long they stay there. To meet a criteria for longer than normal duration, we need either a large rain producing system and/or slow movement. So the motion of the system, or its forcing, the size of the system, and the shape of the system, or orientation are big contributors. For now, let's dive into the rain rate issue a little more.

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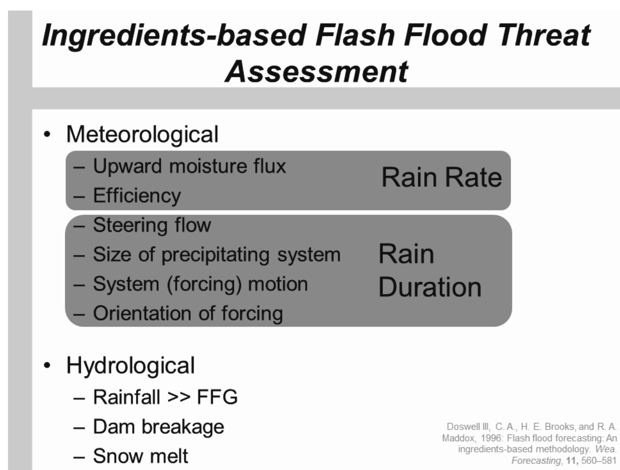

4. Ingredients-based Flash Flood Threat Assessment

Instructor Notes: As we mentioned, upward moisture flux and efficiency to convert that moisture to precipitation contribute to rain rate. Upward moisture flux is dependent on how much moisture is there (mixing ratio) and the strength of the updraft. So I include PW in here because it's a common proxy for assessing the moisture of an atmosphere for which we have a long climatological track record. However, mixing ratio is the best parameter to assess because it's the one parameter that's most easily converted to the upward moisture flux when you multiply it by the updraft strength. What's also important is how much horizontal moisture flux is coming in to replace the moisture lost due to precipitation. This may be more important in precipitation duration, however. Meanwhile precipitation efficiency determines the fraction of the ascending moisture that falls down to the ground. While we cannot measure precipitation efficiency in an operation setting, we do know that precipitation systems become more efficient as dry air entrainment decreases and so we want a higher mean RH throughout a large depth. We also want to maximize the rate of precipitation production through cold phases such as seeding an updraft with ice (interstorm seeding), and through warm phases such as maximizing the depth of collision coalescence. In this two-dimensional spectrum, we have precipitating systems that have wildly different combinations of upward moisture flux and precipitation efficiency and yet may yield the same rain rates. A typical midlatitude baroclinic system supercell may have enormous upward moisture flux but the isolated nature of its updraft, strong shear may limit interstorm, or intrastorm seeding putting the breaks on rainfall rate. Yet the rainfall rate would still be adequate to produce flash flooding should the storm motion be small. On the other end of the spectrum, orographic rain, or typical tropical-like convection with slow updrafts often exist in environments supporting very efficient precipitating systems and thus similar rainfall rates may result. Typically these systems cover a relatively wide area or are slow moving and so long rainfall durations are likely.

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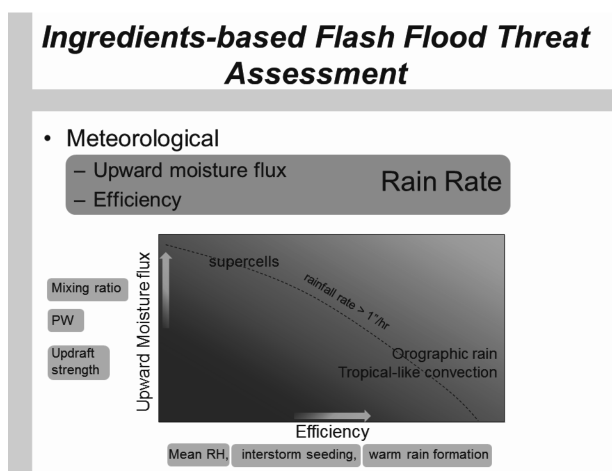

5. Putting Flash Flood Ingredients into Climatological Context: PW

Instructor Notes: While precipitable water is not really the most relevant parameter when discussing potential upward moisture flux, it's got a long track record for which we're used to viewing. And there's some relationship to the maximum mixing ratio found in a sounding primarily because the greatest contributor to PW is the moisture in the boundary layer where updrafts draw in the highest mixing ratios. The values drawn in this plot here were created by WFO Rapid City and it helps to determine the relative rarity of the PW you may question. The climatology is displayed as a seasonal trend in a ranked distribution by showing the curves for the minimum, maximum, 25th, 50th, 75th and 99th percentiles. In addition, a curve is shown for PWs 2 standard deviations above the mean. If you're confronted with a situation where your forecasted PW is above this value, you are looking at strong anomalies. The common wisdom is that the more anomalously high the PW value is, the more likely flash flood producing rains. Certainly this wisdom makes sense when you consider that an anomalously high PW may suggest an anomalously high upward moisture flux and subsequent rainfall. Perhaps the drainage basins, not being used to receiving such a rainfall, may easily flood. This PW climatology is from Tucson, AZ. We can overlay an estimated PW from a recent heavy rain event on 2010 January 21 and we find it is near the 99 % level. One would think this is exceptionally rare. It's certainly well above normal but consider that normal is quite dry in the western US, especially Arizona. So we don't know how rare this PW happens to be. Let's take a more detailed look at standardized anomalies next, this time for low-level specific humidity.

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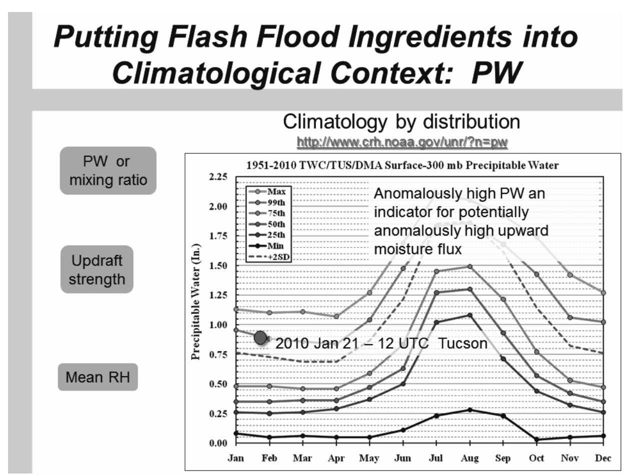

6. More on Climatological Context: Moisture Standardized Anomalies

Instructor Notes: Speaking of PW being 2 standard deviations above the norm, this represents a normalized anomaly. If you take the PW in question (call it f) and subtract it from the mean PW (m), and divide by the standard deviation, a normalized anomaly is the output. Any parameter can fit the term f. In this case, let's take a look at 850 mb specific humidity (mixing ratios). The specific humidity normalized anomalies can be represented as a map such as this example for a west coast winter storm that shows values up to four standard deviations above normal in northern Arizona. So that means that the 7 g/kg observed here in this NARR analysis is definitely above normal. But how above normal is it, or how significant is the anomaly? Well, one useful way to quantify this question is to convert that significance in terms of our living memory. We can do this using the gridded climatology of the NARR to create a plot of the return intervals of any parameter, this time mixing ratio, as a function of the normalized anomaly value. For this event, the Western Region of the NWS created a site showing such return intervals given a maximum value over their domain, including Arizona (search for return intervals in http://www.wrh.noaa.gov/slc/projects/anomalies/index.htm). Note that it is most common to have some anomalies somewhere in a region like here out west. To have no anomalies anywhere in a geographical region is quite rare. Likewise very high negative and positive anomalies become increasingly rare. Notice that in this case, a +4 normalized anomaly has a return interval of about once per month in the western half of the US. Very rare specific humidity anomalies would need to be up toward 100 month return periods where very few cases reside. So this means that while the moisture was above normal, it was not excessively rare. In addition, many of the highest anomalies may be an artifact of the 850 mb layer being below ground level. The anomalies near Phoenix, AZ, directly upwind of the Mogollon Rim, were even lower. Note the study by Graham and Grumm, 2010. Graham, Randall A., Richard H. Grumm, 2010: Utilizing Normalized Anomalies to Assess Synoptic-Scale Weather Events in the Western United States. Wea. Forecasting, 25, 428–445.

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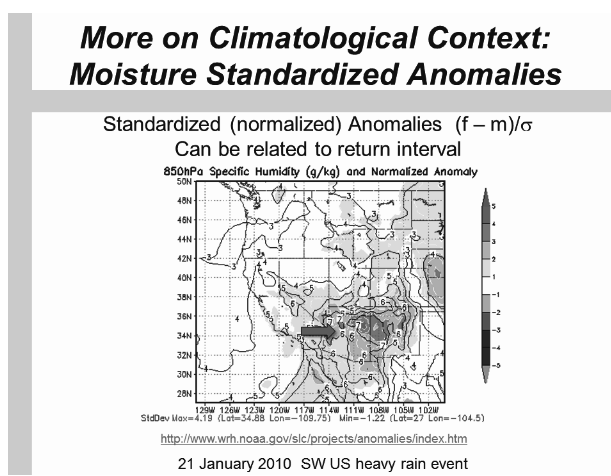

7. Standardized Anomalies Applied to Other Ingredients: Upslope Ascent

Instructor Notes: If the 850 mb specific humidity anomalies were not excessively large, there is still the horizontal flow and updraft potential that contribute to the upward moisture flux. This being a west coast winter storm, the strength of the vertical moisture flux will also be highly dependent on the strength of orographic upslope after the moisture supply has been considered. This storm had an unusually deep central pressure breaking low pressure records all across southern Arizona, Nevada and much of California and also creating perhaps the largest -5 standard deviation normalized anomaly seen in the Pacific Southwest. The strength of the resulting low-level jet within the warm sector of the low produced V-wind normalized anomalies in excess of +5 standard deviations. The orientation of the low-level jet was nearly perpendicular to the Mogollon Rim and the subsequent upslope was also likely to be quite strong. Meanwhile a narrow cold frontal convective band likely supplemented the upslope. The return period of this V-wind anomaly was much longer than for the 850 mb specific humidity, on the order of several years. Thus it was quite likely the vertical motions along upwind of the rim were similarly rare.

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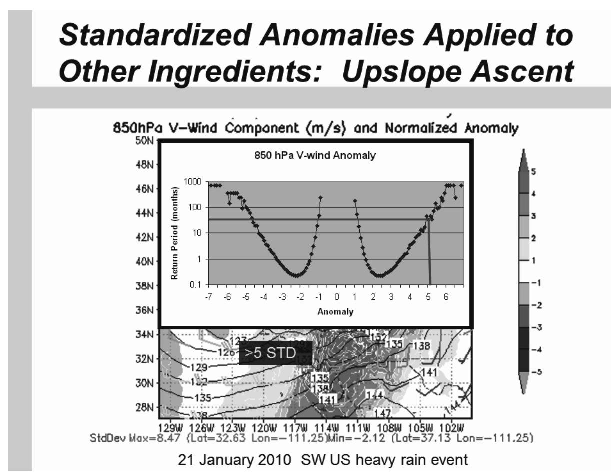

8. Moisture Flux Ingredients Put Together 21 January 2010

Instructor Notes: So what we had here was above average moisture multiplied by significantly above average orographic upslope that contributed to the potential for climatologically rare cool season rainfall rates, at least below the melting level. The corresponding flash flood potential could also be unusually high for this time of year. The horizontal moisture flux is a big parameter out west in determining heavy rain potential as Junker et al. 2008 found out with several California rainfall events. Because of the upslope strength, and the narrow cold frontal rainband, 3 hourly rainfall rates exceeded two inches north of Phoenix according to the gauge adjusted radar data. Already flash flooding was reported that closed highway 74 near Carefree north of Phoenix just before 00 UTC on the 22nd of January. Total rainfall amounts were in excess of 8” in the 2000 – 4000’ elevation range southwest of the rim. However, none of this rain could be said to produce the kind of flash flooding that would normally be expected because the area was in a long-term drought. See the paper by Junker, N. W., R. H. Grumm, R. Hart, L. F. Bosart, K. M. Bell, F. J. Pereira, 2008: Use of Normalized Anomaly Fields to Anticipate Extreme Rainfall in the Mountains of Northern California. Wea. Forecasting, 23, 336–356.

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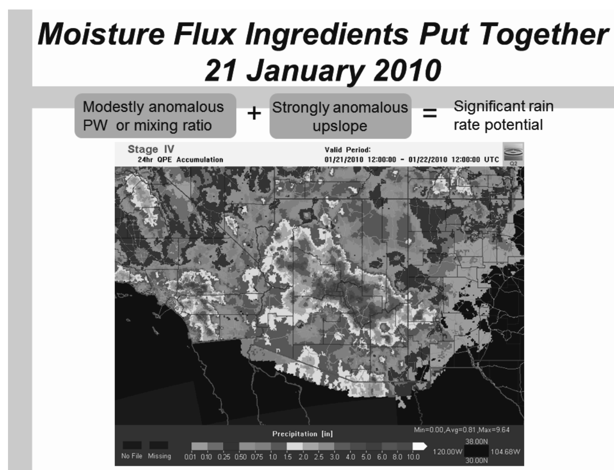

9. Conceptual Model: Atmospheric River

Instructor Notes: The setup for these ingredients has been studied before and there's a well established conceptual model developed as an explanation. This January 2010 event fit very well with the atmospheric river conceptual model highlighted in recent research such as this display from a CALJET experiment. The strong horizontal low-level moisture flux courtesy of the low-level flow already has some ascent to moisten a deep layer. This layer impacts the terrain to generate stronger ascent and healthy precipitation rates. The deep saturation and long-term ascent of the atmospheric column serves to assist in generating heavy rainfall rates by minimizing dry air entrainment into localized updrafts, and also to create a moist-neutral vertical lapse rate that allows the air to ascend upslope unimpeded. These conditions were met in the Arizona case on 21 January 2010 but enhanced due to the highly anomalous strength of the low-level flow impinging on the Mogollon Rim.

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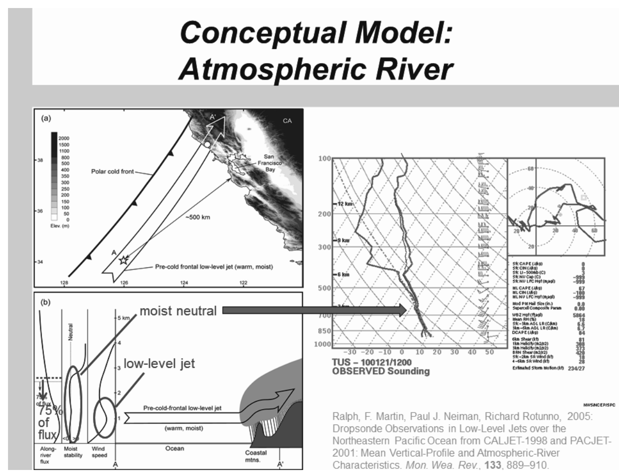

10. Standardized Anomalies

Instructor Notes: Going back to standardized anomalies, they are quite useful in helping you anticipate highly anomalous ingredients that contribute to enhancing precipitation rate. They have a tie to quantifying the potential climatological rarity of an event through the return intervals. But there are some cautions too. Sometimes these ingredients may be the norm for a given location and time of year. Consider the average Gulf-return flow in the late spring or summer. Other ingredients also relate to rainfall intensity like the mean RH in the atmosphere that don't lend themselves well to the current suite of standardized (normalized) parameter anomalies. And we have yet to discuss what influences rainfall duration. Certainly with the Arizona case, the extreme anomaly in the low-level flow would need to reside in an area for an adequate length of time. They did but was it an adequate length? Finally, we haven't considered the hydrologic factors. Being that Arizona was in a long-term drought, the duration or rain rate ingredients would need to remain fixed for an even longer time, then the stage could be set for more severe flash flooding upon a renewed surge in precipitation rates. Conversely, a burn scar would be much more sensitive to rainfall rates derived from more modest values of the contributing parameters that may not show up well in the standardized anomalies.

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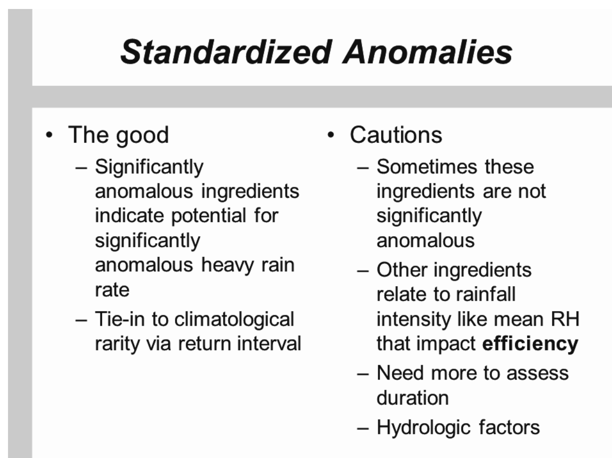

11. Putting Flash flood Ingredients into Climatological Context: Mean RH

Instructor Notes: Let’s consider one of the ingredients to enhancing rainfall rates through improving efficiency. That is the mean RH in a vertical column. This parameter can also be represented by how close to a saturation 1000-500mb thickness your current atmosphere happens to be. The maximum PW is limited by the thickness value. Thus in the warm season, high relative thicknesses permit higher PW values. Notice that many famous flash flood events fall into the regime where the atmosphere was relatively close to the saturation thickness, at least at the 70% RH level. Many of these case are warm season convective and tropical cyclone events. But notice there are a few events from the cool season sprinkled around including the California/Arizona event from 2010 January 20-22. Funk, Theodore W., 1991: Forecasting Techniques Utilized by the Forecast Branch of the National Meteorological Center During a Major Convective Rainfall Event. Wea. Forecasting, 6, 548–564. ean RH in the atmosphere.

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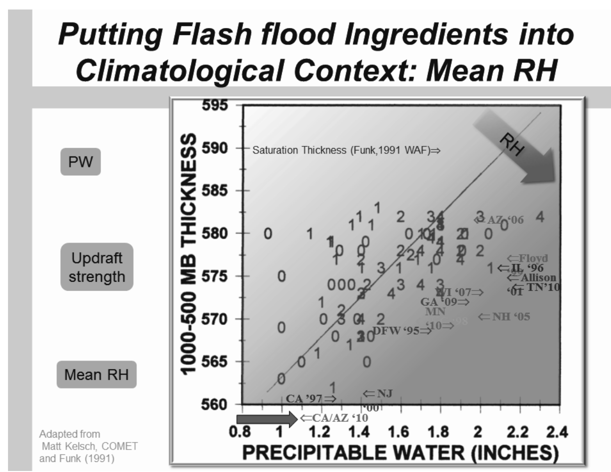


12. Quiz

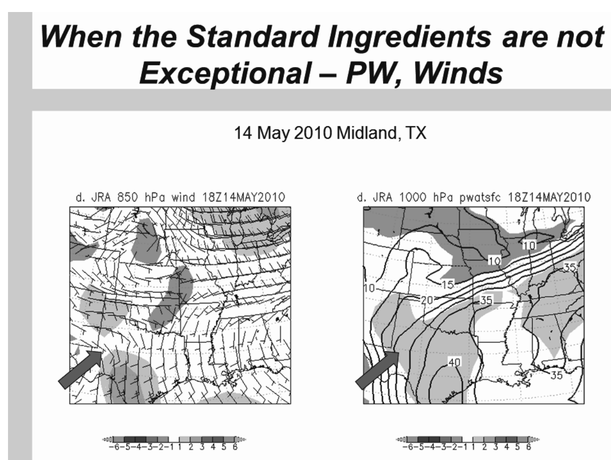
Instructor Notes:

Student Notes:

13. When the Standard Ingredients are not Exceptional – PW, Winds

Instructor Notes: Here's another case that show decent positive normalized anomalies in PW for west Texas, though not exceptional. The 850 mb wind magnitude normalized anomalies were also not exceptional, all based on the NARR reanalysis data for 18 UTC on 2010 May 14.

Student Notes:



14. PW Climatology - Midland, TX

Instructor Notes: Comparing the PW climatology via rankings, we see that the Midland CWA values were relatively modestly above normal, between the 75th and 99th percentiles. Certainly these values don't represent an historically moist day and they are less prominent than the Arizona case.

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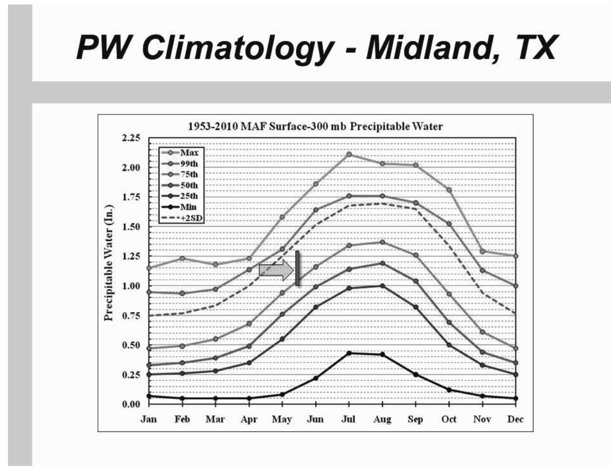

15. When the Standard Ingredients are not Exceptional – Mean RH

Instructor Notes: Even if the PWs were not exceptional, the mean RH in the atmosphere over this general area was relatively high. I depicted a broad swath in this area due to the strong gradients in both PW and 1000-500 mb thickness in the area. Notice, however that this swath is a bit lower than some of the other events we note here. That's not to say that for this case, the values are too low, or that there were no other flash flood events with similar combinations of thickness and PW.

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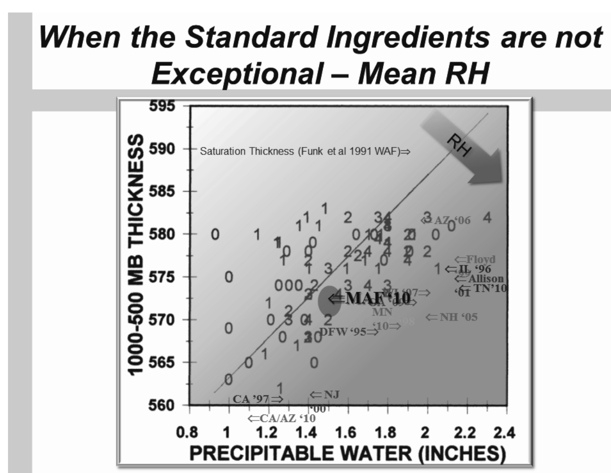

16. Upward Moisture Flux by Convective Instability vs. Others

Instructor Notes: Let's compare, however, what potential upward moisture flux we may have between the Arizona case and west TX. Upon viewing the morning sounding at Midland on 14 May, we see about 2000 j/kg of MUCAPE. Converting that to a reasonable updraft strength, not even maximum theoretical, would yield a 20-40 m/s value depending on rate of dilution through dry air entrainment, or precipitation loading. We're talking about convection and thus these areas would be relatively small. For the Arizona case, a 30 m/s low-level jet impinging on the Mogollon Rim would likely rise a total of 2 km over a horizontal run of 20 km. This would yield a rough updraft strength of 4 – 8 m/s. This is a high-end value when compared to other orographically-induced updrafts. It may be more likely it's less. However, the area of ascent is large and the near saturation of the deep layer, and the prevalence of upper-level seeding from synoptic ascent suggests precipitation efficiency will be quite high.

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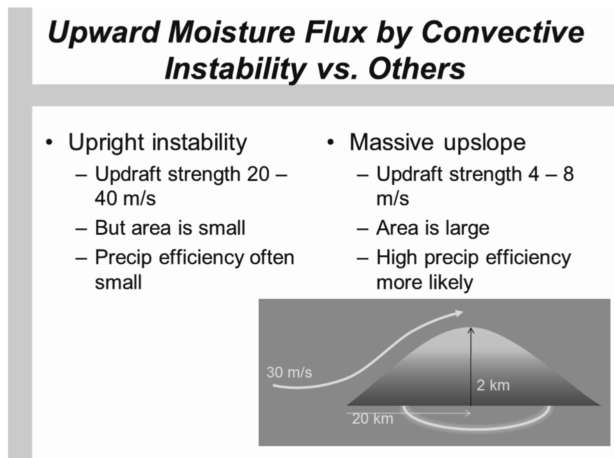

17. Upward Moisture Flux by Convective Instability vs. Others

Instructor Notes: However, also consider that the specific humidity entraining into the west TX convective updraft was 14 g/kg while the Arizona case had a more modest 7 g/kg. The maximum potential vertical moisture flux in west TX would be potentially 40 X higher. Even accounting for dry air entrainment, the vertical moisture flux would be much higher. This kind of comparison shows why for areas where thunderstorms occur, the large majority of short-duration extreme rainfall events (>50 year return interval) come from convective events as proposed by Doswell et al. 1996 and confirmed by Schumacher and Johnson (2005).

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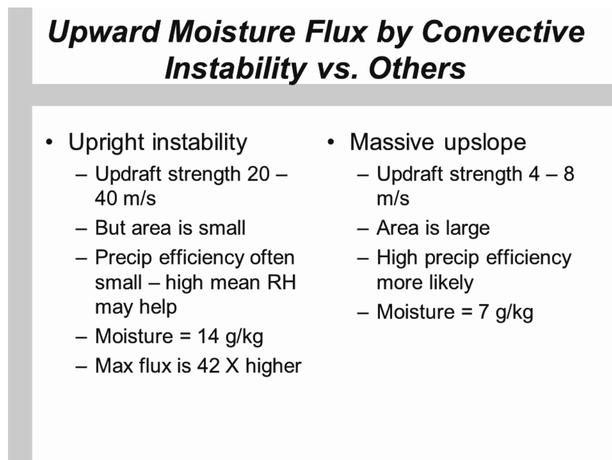

18. Moisture Flux is Higher for Convection but Duration and Efficiency is the Issue

Instructor Notes: But the problem for getting extreme rainfall from convective events is that while the rain rate is adequate, the rainfall duration is often not. It's rare to get a 3”/hr rainfall rate to persist for more than 10 minutes at any one spot. But in those few cases that it does, there was probably an unusual coincidence in those ingredients that kept the rate for an abnormally long duration. These could be the steering flow was low, the size of the precipitating system was unusually large, and most likely, the forcing mechanism was stationary or its orientation allowed cell training. In the next two slides, I walk through this Midland case in D2D discussing these ingredients for maximizing convective rain duration and how they contributed to the rain totals here.

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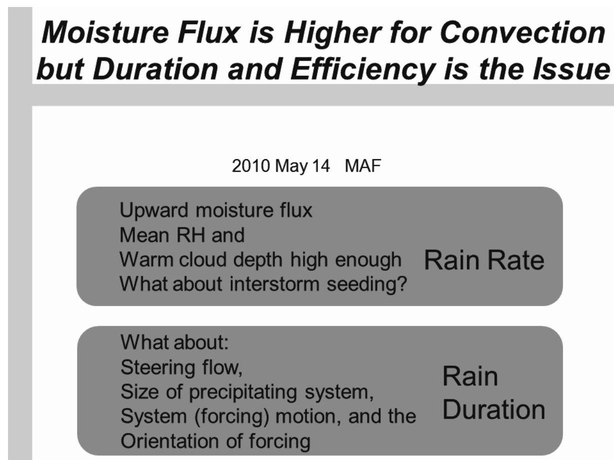

19. 2010 May 14 – Pre-storm Threat

Instructor Notes: A video window will open up. Play it for a discussion of the pre-storm flash flood threat for the May 14, 2010 case.

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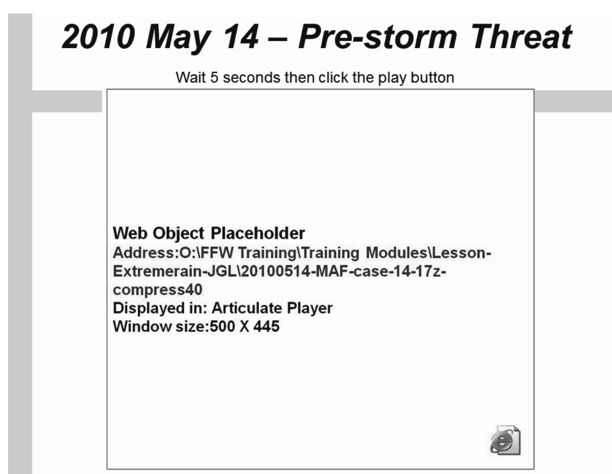
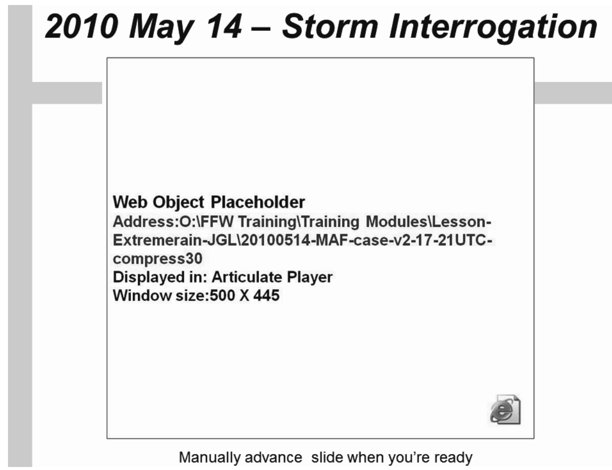


20. 2010 May 14 – Storm Interrogation

Instructor Notes:

Student Notes:



21. Moisture Flux is Higher for Convection but Duration and Efficiency is the Issue

Instructor Notes: So in review, we had the upward moisture flux potential. We had likely adequate warm cloud depth but this alone is not significant since we had eventually generated a large amount of interstorm seeding potential for boosting the efficiency of cold precipitation production processes. As for rain duration, the key for long duration heavy rain was the fact that the steering flow removed the mature cells away from the respective multicell forcing mechanisms. And these forcing mechanisms, i.e. the triple points of cumulus lines with the front, were allowed to remain nearly stationary in order to generate new cells over the same places that already were receiving heavy rain from earlier cells. The steering flow to the north also permitted the moist, unstable feed to be undisturbed.

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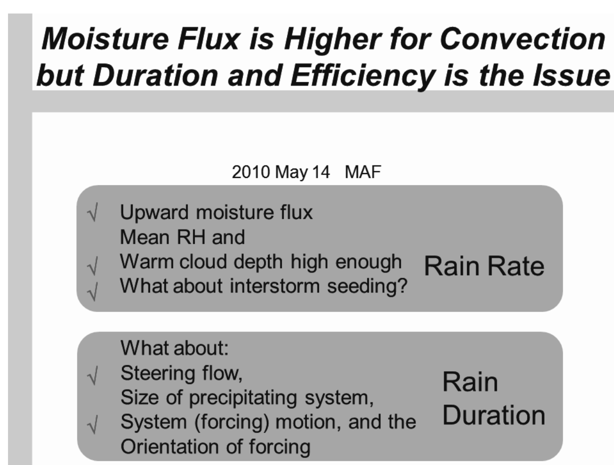

22. Pattern Recognition: Flash flood Reports vs. Storm Type

Instructor Notes: Relating the Midland case back to pattern recognition, let's take a look and see if any of the convective morphologies in this study by Gallus et al. 2008 matches what we've seen. They documented a variety of convective cell morphologies associated with flash flood reports. For each morphology type, they plotted the number of flash flood reports. Notice that the most common morphologies was the Parallel Stratiform (PS) MCS event. PS MCS events have regions of stratiform precipitation straddling a convective line, namely because the upper-level flow is parallel to the line orientation. There are similar aspects between the PS MCS conceptual model and the multicells in the Midland case. Both exhibit backbuilding as they are anchored to a particular forcing mechanism. And both have anvil debris that spreads laterally with respect to the orientation of the long axis of the convective precipitation line. There is also not much motion normal to the long axis of the line. These attributes to both partially explain the long duration of heavy rainfall rates. However the differences show as well. The multicells in the Midland case didn't have parallel stratiform precipitation flanking both sides of the long axis of the main convective cores because the anvil canopies were too small. And on a related note, the size of the multicells was much less than the PS MCS conceptual model. In fact these multicells were so small that the long axis of the heavy precipitation may not even be called a line. Perhaps the second closest morphological association to this event would be the CC (convective cluster). The CC type is small, less than 75 km, and probably represents a similar size to the multicells in the Midland case. But notice this morphology is relatively infrequently associated with flash flood reports because of size issues due to lack of reports or a greater difficulty in maintaining a long duration heavy rain rate event. Notice other common flash flood producing convective morphologies include Trailing Stratiform (TS), Broken Lines (BL), Bow Echoes (BE), and Leading Stratiform (LS) cases. It may seem surprising that flash floods are so common with bow echoes. However, bow echoes tend to produce extremely high rainfall rates which can help compensate for their limited duration. In some bow echoes, the right flank of the line may tend to become more parallel to the convective steering layer flow helping to increase the duration of extreme rain rates too. One limitation to this study was that it was limited to only the central US. Gallus, W. A., N. A. Snook, E. V. Johnson, 2008: Spring and Summer Severe Weather Reports over the Midwest as a Function of Convective Mode: A Preliminary Study. Wea. Forecasting, 23, 101–113.

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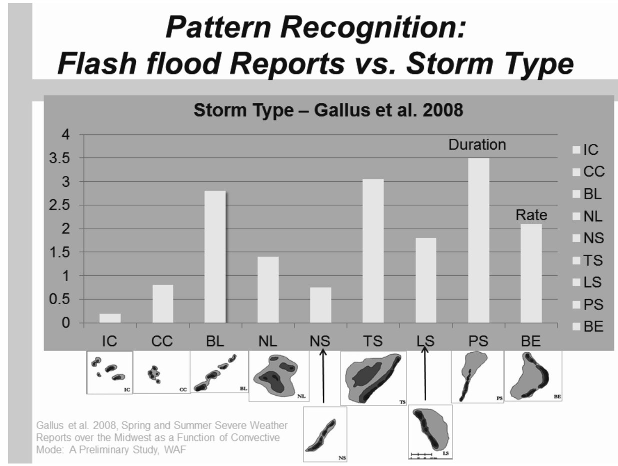

23. Most Common Convective Archetypes with 50 year 24-hr Rainfall

Instructor Notes: Instead of looking at what's causing flash flood reports, Schumacher and Johnson (2005) decided to look at what's causing climatologically rare heavy rainfalls that may occur at 50 year return intervals or more. We'll call these extreme rainfall events. They allowed their domain to include the entire CONUS and so a greater variety of climates were included. Nonetheless, they found that the greatest number of extreme rainfall events occurred with convective storms. Specifically, they found two morphologies to be commonly associated with extreme rainfall events. One was called a Training Line/Adjoining Stratiform MCS (TL/AS). These types of MCSs occur when an MCS forms north of a front or outflow boundary and then the midlevel shear and the convective layer steering flow was parallel to that front. So the forcing determined the orientation of the convective line and the front-parallel convective layer steering flow wound up causing cell training and prodigious rainfall amounts. Backward propagating multicells represented the most common other type of extreme rainfall convective events. These were harder to anticipate but they all represented cases where a local forcing mechanism was allowed to stay relatively stationary. The 2010 May 14 case probably was more similar to the Backward propagating multicell conceptual model but there were similarities to the TL/AS setup in that a stationary front was involved and the midlevel shear was front-parallel. The main difference was that the convective layer steering flow was not parallel to the front and a front-parallel line didn't develop. Instead, the point intersections between the front and various boundaries forced anchored multicells. The multicells only became unanchored when outflow formed enough convergence on their eastern flanks to start adding a forward propagation component to their overall motion. But by then the flood damage had been done.

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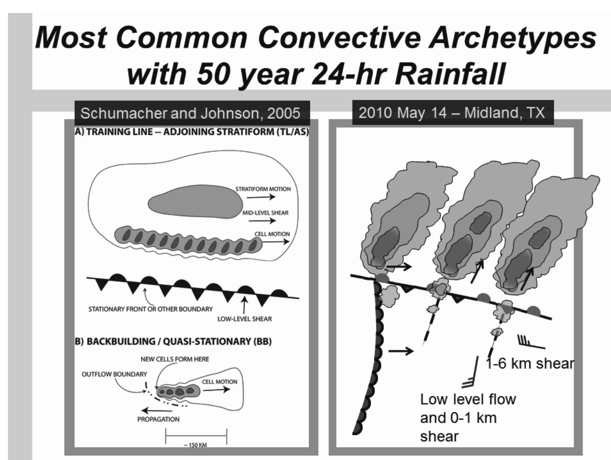
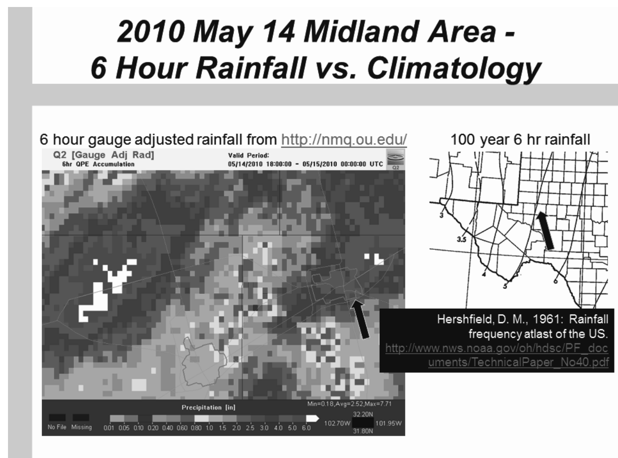


24. 2010 May 14 Midland Area - 6 Hour Rainfall vs. Climatology

Instructor Notes: Now we shift gears and take a look at the resulting rainfall. From the NMQ site at the Univeristy of Oklahoma, we see multiple areas of very heavy rain exceeding exceeding 4” focused on those areas where the anchored multicells began their lives. Zooming into the Midland area, we see two areas that exceeded 6” in this gauge adjusted radar QPE. These rainfalls occurred in the 6 hour period ending 00 UTC May 15 and you can see that the intersection of the eastern rainfall swath and the Midland area resulted in some serious flood impacts. There were numerous main roads flooded. When we compare this QPE to the 100 year 6 hour rainfall amount, we see that this flood met or exceeded the criterion of an extreme rainfall event.

Student Notes:



25. 2010 May 14 Midland Area - 1-6 hr Rainfall vs. Climatology

Instructor Notes: In fact, if we take a look at the maximum 1 hour, 3 hour and 6 hour precipitation found, all three rates are near or above the once in 50 year return period. As a forecaster, the same technique could be applied to an ensemble QPF. Our suggestion would be to assess the 90th or 95th percentile of the ensemble QPF possibilities (like this output from HPC) and then compare them to the return period of rainfall for the same valid time periods as the QPF. For storm-scale models, you may need to look over an area to account for spatial uncertainty of where convection may develop. If you see output that may exceed a long return period in the climatology, chances are that you may be facing a rare situation for which your users may have little memory. However, the models may be wrong and you may wind up with more precipitation than expected. If so, then you also can compare the QPE to climatology as done here to see how rare your event is becoming. Be mindful that we're looking at QPE and not the amount of precipitation exceeding flash flood guidance. In an urban setting, or ground that's mostly impermeable, then the amount of water here may go mostly to runoff. But in areas with changing soil permeability based on antecedant conditions, then what's important is the precip – FFG. Unfortunately at this time, we don't have a climatology of precip – FFG like we do with just precipitation alone. Also, this climatology is based on relatively old data before 1961. Our techniques have changed and we have much more data for which to update to a better climatology. In fact there is a project already underway and we'll show and example of such.

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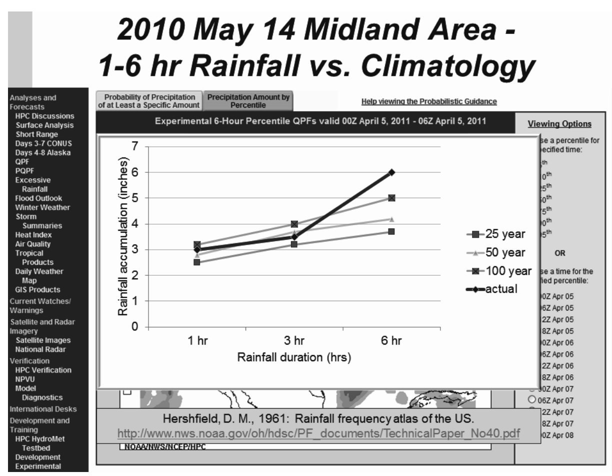

26. New Rainfall Climatology Being Developed

Instructor Notes: Here is the new extreme precipitation climatology under development by the Hydrometeorological Design Studies Center. The project isn't complete yet for Texas so we'll use the Arizona January case to illustrate its capabilities. Upon clicking on the state of AZ, we find a station north of Phoenix that was near the flooding so we'll pick near Payson. Up comes several graphs, one of which shows the amount of precipitation vs. duration for a variety return intervals. The shaded region represents all precipitation amounts exceeding the 25 year return interval. I plotted the maximum precipitation found near Payson for 1 hr, 6 hr and 24 hr durations and you can see that hourly amounts are not reaching long return periods, long enough to be called extreme. However the 6 hour amounts are reaching in excess of a 50 year return interval, and the 24 hour amount reached the 1000 year interval! The 6 hour rainfall probably represents the longest duration for a short-term event and it's bordering on being quite rare. This project will be adding more states as time goes on so keep this site in mind.

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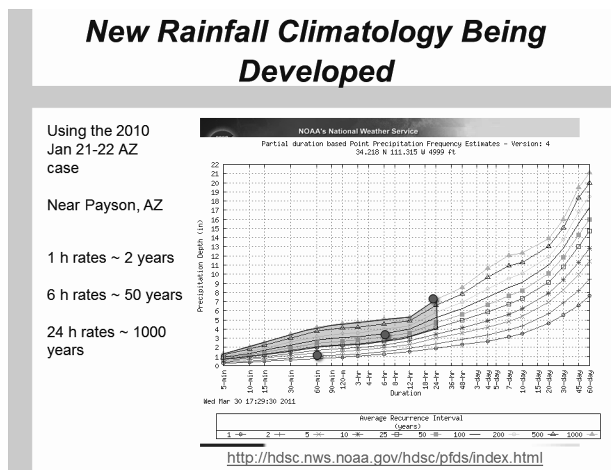

27. Quiz

Instructor Notes:

Student Notes:

28. Summary

Instructor Notes: Well, we covered quite a bit of flash flood meteorology in the context of looking for extreme rainfall events. As a forecast methodology, it's always best to look for highly anomalous heavy rainfall rate ingredients that may show up on the synoptic scale (e.g., low-level winds, specific humidity, mean RH). These will have the longest leadtime and will give you the best time to prepare. But we also want to make sure those rain rate ingredients persist for long enough to get the climatologically rare amounts in the 1 to 6 hour time frame. Many times, the ingredients that help maximize rain rate commonly exist in the atmosphere and we have to ask ourselves if a precipitating system we see will have a habit of persisting? Understanding well known conceptual models that have been studied before may help you go a long way into answering that question. I presented a few of them but by no means is that list exhaustive. And it's just a matter of getting right one to help you forecast how a future convective system will behave, or any other type of system. Finally, with an increasing availability of numerical guidance, you can make a good assessment of the distribution of QPF and come up with a plausible worst case scenario for which to compare with climatology of return periods. This step helps you forecast how the expected precipitation will fall relative to the collective memory of the users you serve. Likewise, monitoring the QPE and comparing the values to climatology of return periods will help give a short-leadtime assessment to the possible rarity of flooding with respect to the same collective memory.

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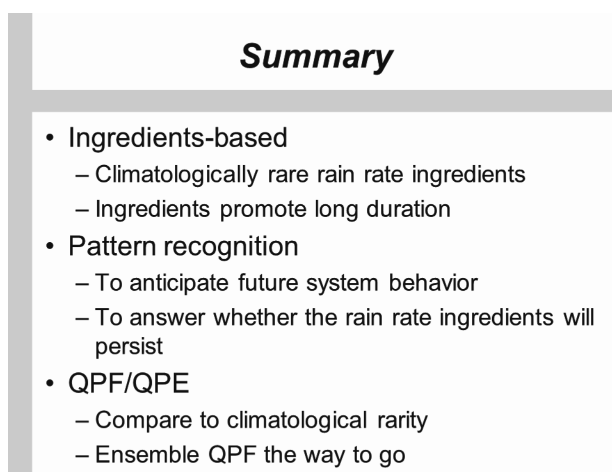
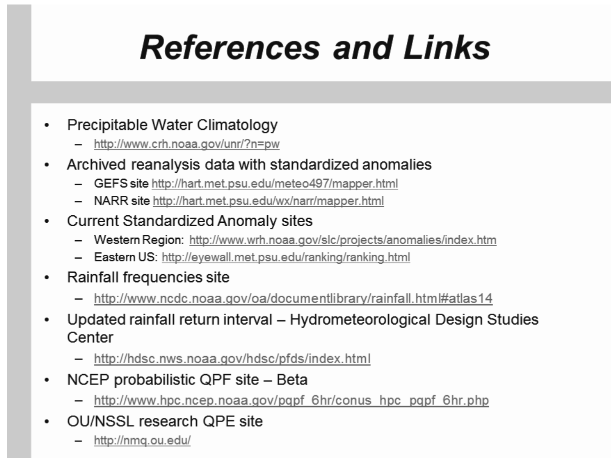


29. References and Links

Instructor Notes: Here are some of the links utilized within this lesson. Remember that some of these sites do not have an operational posture and the data availability may vary.

Student Notes:



30. Contact Information

Instructor Notes: Congratulations for finishing this lesson on anticipating extreme rainfall rates. You have completed one component to the flash flood best practices course. If you have any questions/comments, please get in touch with us.

Student Notes: