RECOGNIZING HIGH IMPACT HYDRO EVENTS

CASE EXERCISE #1

23 APRIL 2011

Presented by:
The Warning Decision Training Branch

Course Page:
http://www.wdtb.noaa.gov/courses/hydro/index.html

Case Exercise Interface:
http://www.wdtb.noaa.gov/courses/hydro/exercises/index.html

Acknowledgments

Special thanks to the following people for their time and assistance with this series of course modules and case exercises:

- Richard Gumm (SOO) from the State College, PA Weather Forecast Office for helping with the case analysis, identifying performance objectives, and review of the exercises. WDTB would also like to thank Richard Grumm for coming to Norman, OK to work with us on the Recognizing High Impact Hydro Events course.
- Ron Murphy (IT Specialist) from the Binghamton, NY Weather Forecast Office for providing the AWIPS data for Case Exercise #2. WDTB greatly appreciates Ron's efforts to help us with gathering cases while the office and town were greatly impacted by these flood events.
- Pat Spoden (SOO) and Ken Ludington (ITO) from the Paducah, KY Weather Forecast Office for providing us with the AWIPS data for Case Exercise #1. WDTB would also like to thank Pat for reviewing the case exercises.
- Wendy Abshire and Matt Kelsch from COMET for their input and review of the Recognizing High Impact Hydro Events course.

Cover image is of the following:

- Significant flooding in the town of Poplar Bluff, MO during the flood event of April 23-26, 2011. This aerial image is courtesy of the Missouri state government.

Ed Mahoney, Chief

Warning Decision Training Branch
Training Division, OCWWS
December 23, 2011

Version	Date	Description
1.0	December 23, 2011	Initial Release

To provide feedback, comments, or ideas related to this document, please visit our web site at: http://www.wdtb.noaa.gov

Instructions

There are four main learning goals to this case exercise for the Recognizing High Impact Hydro Events course:

1. You should be able to identify the antecedent hydrometeorological conditions that are present when determining the potential for a heavy rainfall event.
2. Using model data generated from within an AWIPS environment, you should be able to correctly identify the heavy rainfall pattern and the characteristics associated with it.
3. You should be able to use standardized anomalies to place the heavy rainfall pattern into context. These anomalies should aid you in determining if this is a meteorologically and climatologically significant event.
4. Finally, you should be able to tie in Quantitative Precipitation Forecasts (QPFs) from the GFS, SREF, and Hydrometeorological Prediction Center (HPC) to gain confidence in your prediction of the event and the potential impacts.

For this case, you are located at the National Weather Service (NWS) Weather Forecast Office (WFO) in Paducah, KY. Using the data provided in the case exercise interface, answer the questions provided in the following performance objectives regarding the analysis and short-term forecast (F00 to F72 hours) of this event. In the end, you will answer questions regarding your confidence level of a heavy rainfall event impacting your county warning area (CWA) and the potential impacts.

Use This Case Exercise Interface:

http://www.wdtb.noaa.gov/courses/hydro/exercises/index.html

Additional information regarding hydrometeorological concepts or reviewing case data is provided using the information icon.

Estimated Completion Time: 40 minutes

Case Exercise #1:

WFO Office -- Paducah, KY

Case Date/Time -- 23 April 2011 - 1700 UTC

Performance Objective #1 -- Synoptic Scale Setup

Use the antecedent conditions presented in the case to understand their impact on various hydrologic factors, including soil moisture and river/stream levels. With this knowledge, anticipate the potential impacts these conditions would have on a heavy rainfall event in the area.

Evaluation Criteria 1.1 - One of the main factors that influence the hydrologic conditions in the area is previous precipitation events. Figure 1 shows the accumulated precipitation over the region from 0000 UTC 15 March to 1200 UTC 23 April. Figure 2 shows the accumulated precipitation that has occurred in the month of April up to this point (i.e., accumulation from 0000 UTC 1 April to 1200 UTC 23 April). How much rain has fallen during these time periods in southeastern Missouri, southern Illinois, and western Kentucky? What can you infer about when the majority of the rain fell?

Table 1 provides a list of stations, the precipitation that fell from 11 April to 22 April, the normal precipitation for each station, the departure from normal, and the percentage of normal. Figure 3 is a map of the stations that are used in these tables. Analyze the values for each site from these two time periods. For April, the majority of the rain fell in the most recent 12 days with all sites having above normal rainfall (i.e., rainfall was about two inches above normal, which is approximately 220% of the normal rainfall.

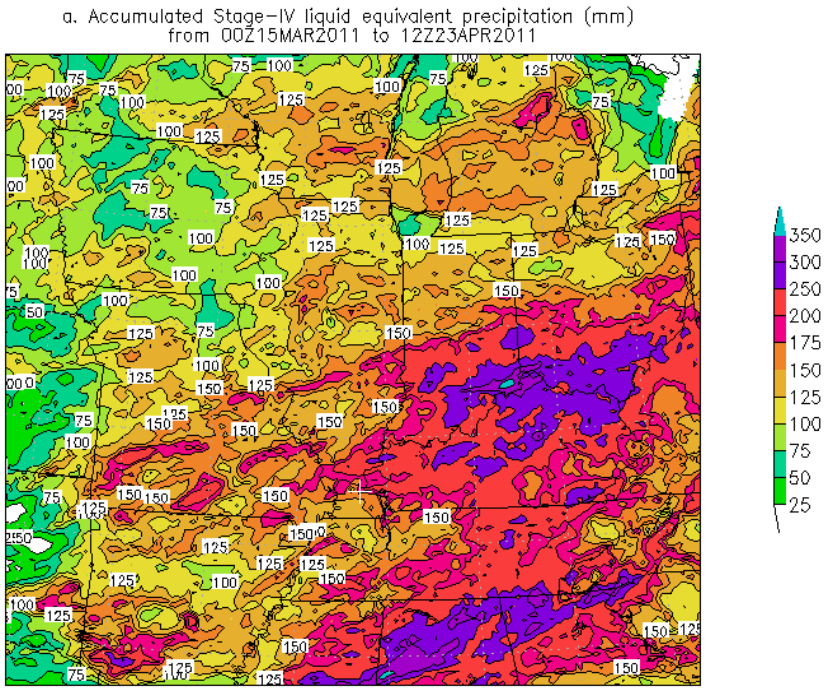

Figure 1: Accumulated Stage-IV liquid equivalent precipitation (in mm) from 0000 UTC 15 March to 1200 UTC 23 April.

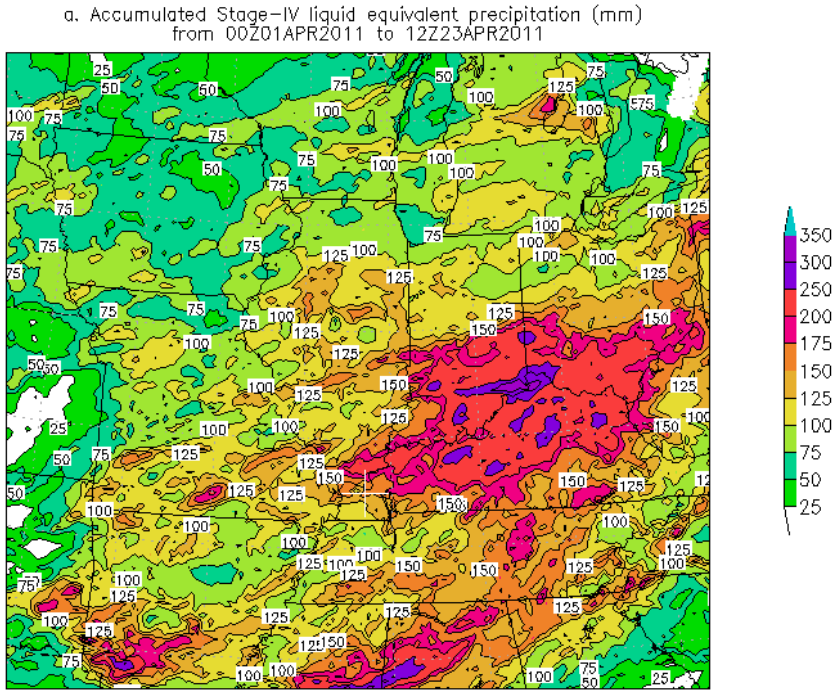

Figure 2: Same as Figure 1 except from 0000 UTC 1 April to 1200 UTC 23 April.

Table 1: Precipitation Analysis from Regional Sites from 11 April to 22 April

ID	Location	Observed Precip	Normal Precip	Departure From Normal	Percentage of Normal
A	Harrison, AR	3.50 in.	1.80 in.	1.70 in.	194%
B	Jonesboro, AR	2.31 in.	1.97 in.	0.34 in.	117%
C	Evansville, IN	3.93 in.	1.75 in.	2.18 in.	225%
D	Paducah, KY	4.82 in.	1.93 in.	2.89 in.	250%
E	Cape Girardeau, MO	4.97 in.	1.71 in.	3.26 in.	291%
F	Popular Bluff, MO	3.44 in.	1.92 in.	1.52 in.	179%
G	Rolla, MO	2.89 in.	1.69 in.	1.20 in.	171%
H	St. Louis, MO	4.04 in.	1.46 in.	2.58 in.	277%
I	West Plains, MO	6.41 in.	1.76 in.	4.65 in.	364%
J	Jackson, TN	2.48 in.	1.94 in.	0.54 in.	128%
	AVERAGE	**3.88 in.**	**1.79 in.**	**2.09 in.**	**220%**

** Use Figure 3 for a map of the locations.*

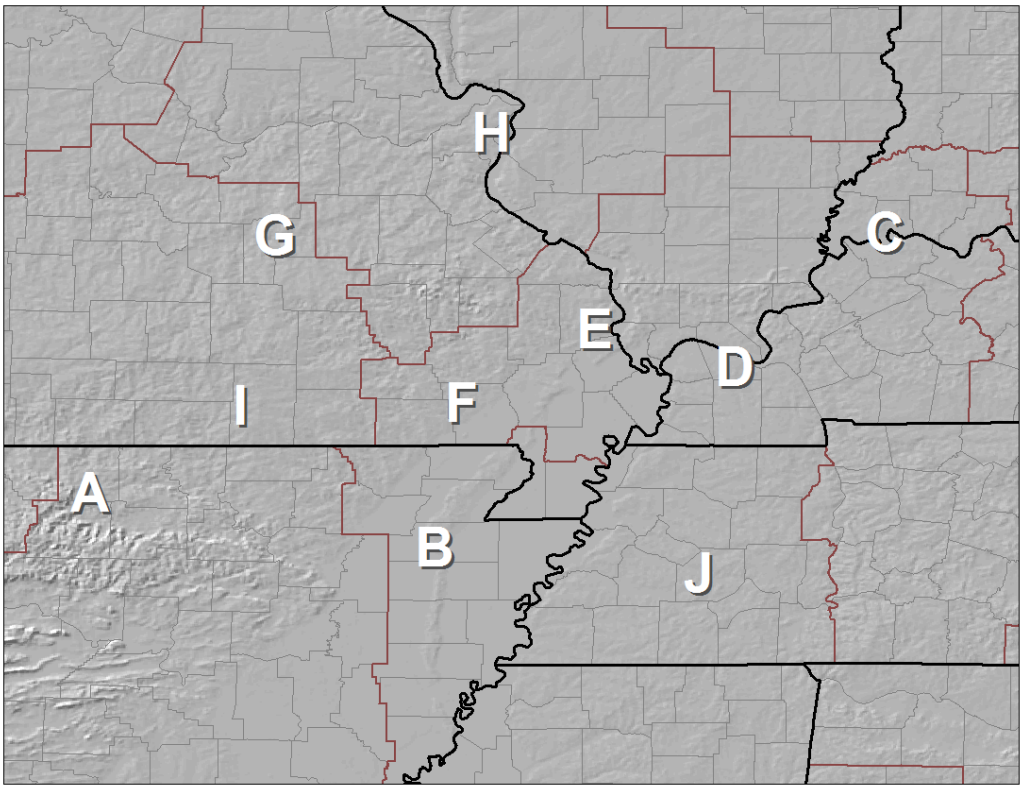

Figure 3: *Locations identified by Site ID for the stations listed in Table 1.*

Evaluation Criteria 1.2 - Next, we will analyze the soil moisture content of the area. The long-term Palmer Drought Severity Index as of 16 April is shown in Figure 4. The soil moisture anomalies and the soil moisture ranking percentiles at the beginning of April 2011 are shown in Figures 5-6. The period of record for these soil moisture anomalies and ranking percentiles are from 1932-2000. Describe the overall dryness and soil moisture content in the region.

The Palmer Drought Severity Index (PDSI) calculates the dryness through a formula that includes temperature and precipitation and is standardized to local climates. The PDSI is most effective in determining long-term droughts but can also reflect excess rainfall. However, it is not useful for short-term forecasts.

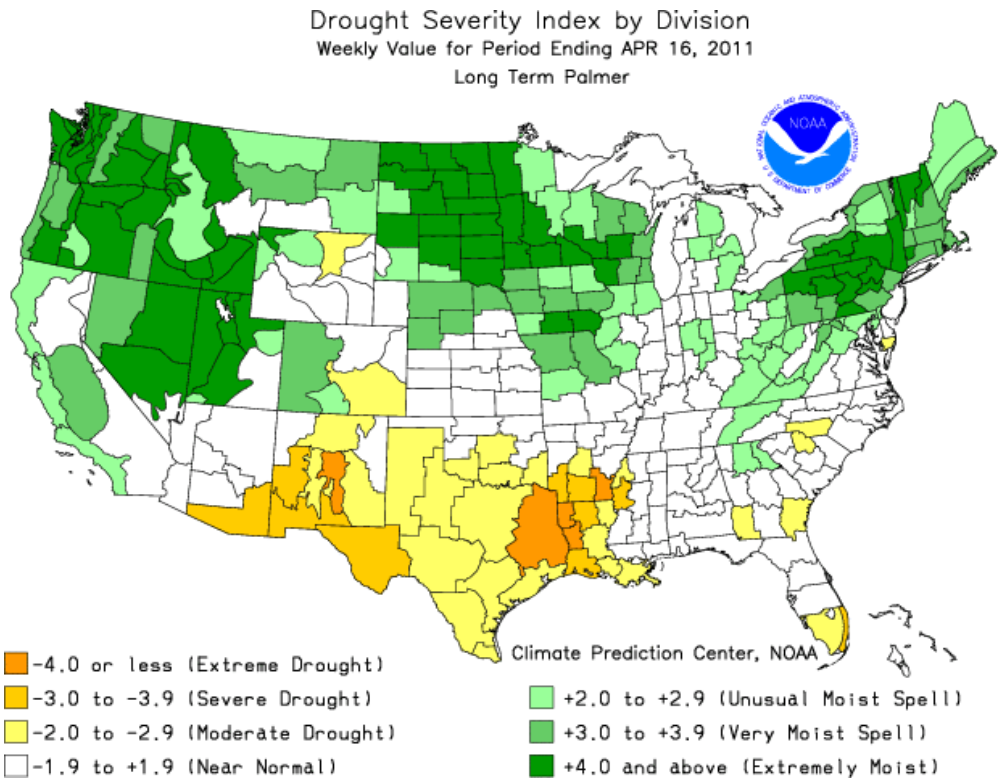

Figure 4: Long-term Palmer Drought Severity Index for period ending 16 April. Data regarding the Palmer Drought Severity Index and other drought monitoring indices can be found at the following NWS Climate Prediction Center (CPC) web page: http://www.cpc.ncep.noaa.gov/products/monitoring_and_data/drought.shtml

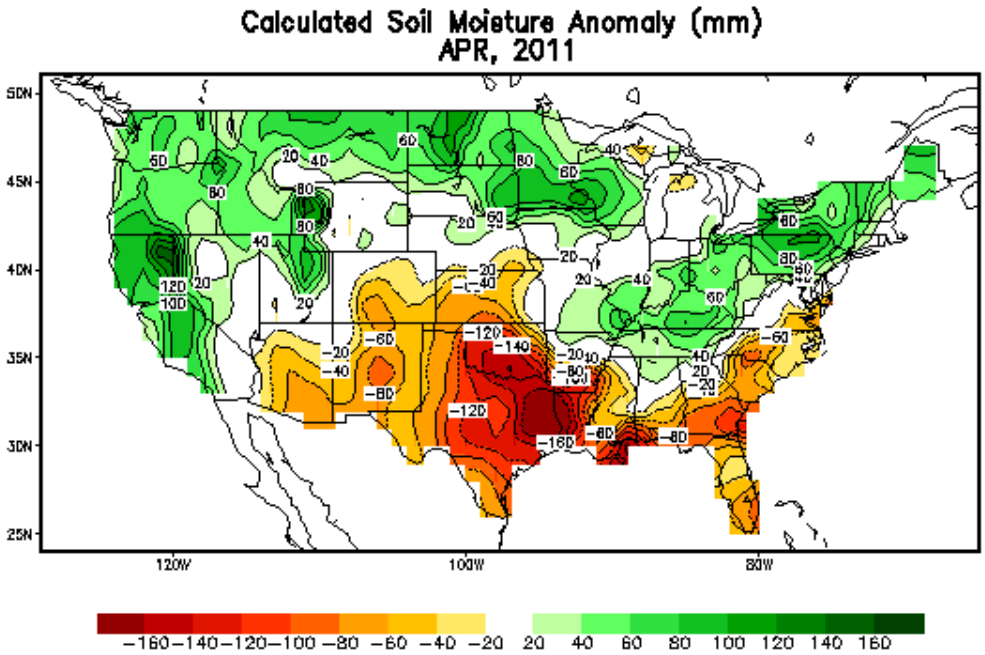

Figure 5: Calculated soil moisture anomaly (in mm.) for April 2011. The anomalies are calculated by the NWS CPC using a soil moisture content database from the period 1932 to 2000. Soil moisture data can be found at the following CPC page: http://www.cpc.ncep.noaa.gov/soilmst/w.shtml

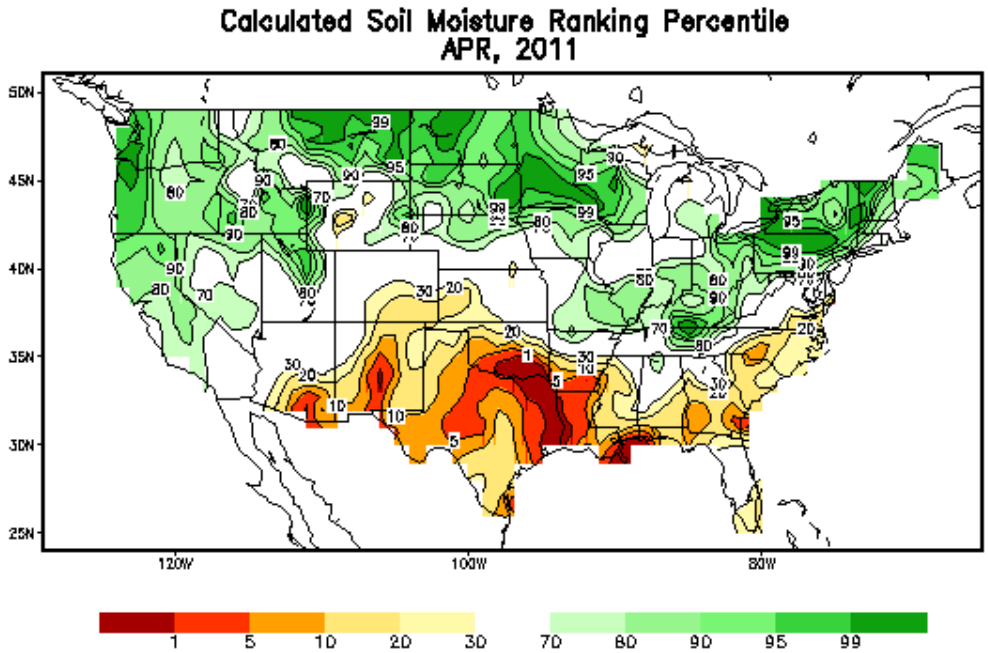

Figure 6: Same as Figure 5 except for the soil moisture ranking percentile.

Evaluation Criteria 1.3 - Approximately 0.50-1.50 inches of rain has fallen over the area during the past few days. It is also important to note that the majority of USGS river gauges are measuring above average streamflow.

Figure 7 shows the three-hour county-average flash flood guidance (FFG) for the Paducah, KY CWA. The average three-hour FFG value is 2.00 inches. Remember that FFG is comprised of a number of hydrologic and geologic factors, which includes terrain slope, soil moisture, and soil infiltration. Use the informational bullet below to learn how precipitation impacts the infiltration rate during an event.

A study by Nassif and Wilson (1975) quantitatively showed the change in the soil infiltration rate during a rain event at various ground slopes. In their study, they used different 15-minute artificial rainfall rates to calculate the infiltration rate of various soil compositions. Their laboratory results showed high infiltration rates at the beginning of the event, followed by a rapid decline and asymptotic approach to a near constant value (see Figure A). Rainfall and the subsequent ground infiltration is based on the concept of saturation from above. In a case that leads to ponding of water,

$$H(t) > 0,\ f(t) = f^*(t) \leq w(t)$$

where $H(t)$ is the depth of ponding, $f(t)$ is the infiltration rate, $f^*(t)$ is the maximum infiltration rate, and $w(t)$ is the water-input rate. Basically, when the infiltration rate becomes less than the water input rate, then ponding and runoff occurs. The greater the difference between the infiltration rate and water input, the more water runoff that is created.

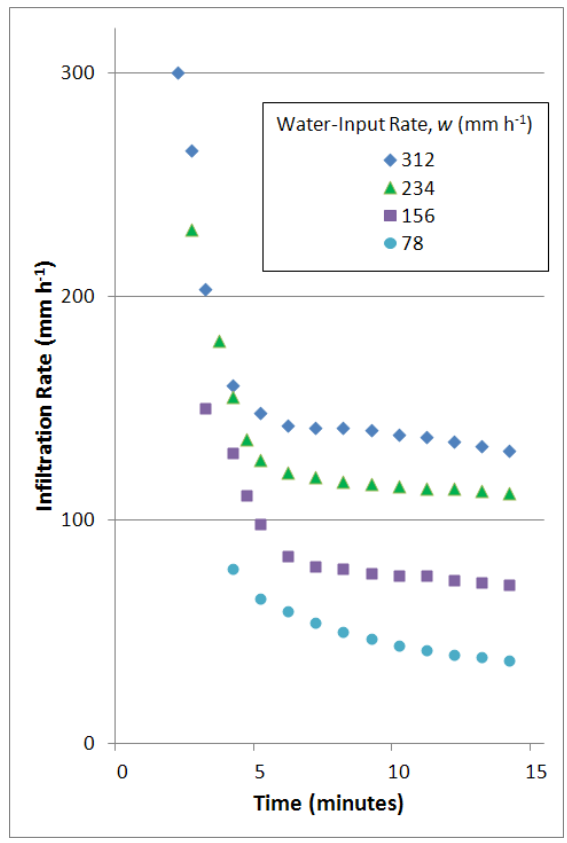

Figure A: Infiltration rate of grass covered loam surface at a slope of 16% using artificial rainstorms of 15-min duration. After Nassif and Wilson (1975).

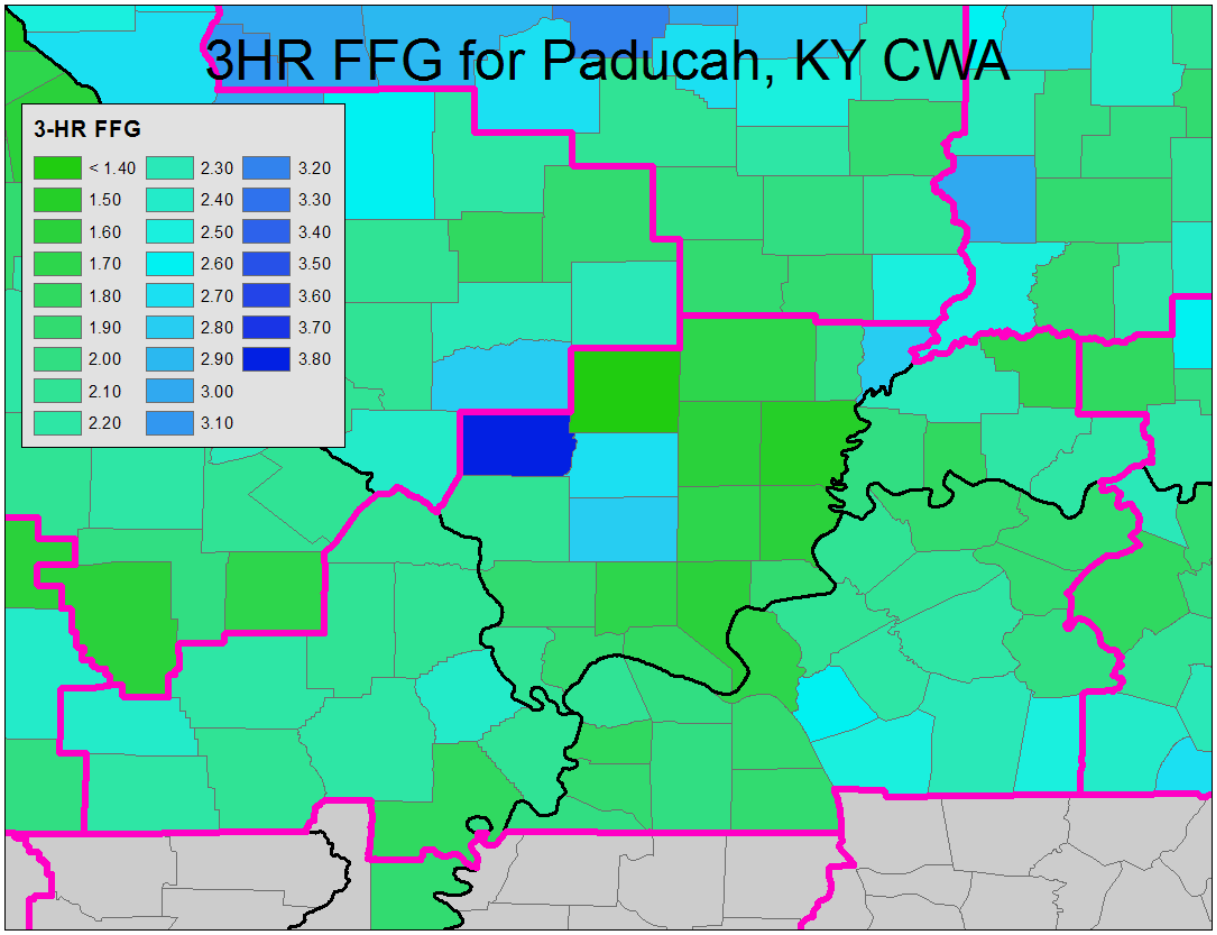

Figure 7: Three-hour county-average flash flood guidance (FFG) for the Paducah, KY CWA.

With the very recent precipitation combined with the state of the local streams/rivers and the soil moisture content, what kind of impact would you see in your local FFG? If additional rain were to fall over this region, what would become of this rainfall?

Performance Objective #2 -- Pattern Identification

Data from the latest Global Forecast System (GFS) and Short Range Ensemble Forecasting (SREF) models are presented to you in the case exercise web interface. The forecast data is provided in six-hour intervals up to the 72-hour forecast period. Use this data to analyze the current synoptic setup and identify the Maddox heavy rainfall pattern(s) that develops during the forecast period.

For the first part of this Performance Objective, we will use the 1200 UTC 23 April model run of the GFS. After selecting the model, there will be a set of CONUS and regional scale data. The Evaluation Criteria will outline which model and parameters you should use to answer each question.

Evaluation Criteria 2.1 - We will first evaluate the current large scale upper-level pattern. Select the CONUS scale 300 mb Wind/Temp/Height GFS model data, if it is not already selected. Describe the general flow and pattern during the forecast period. Are there any key jet stream features near the Paducah, KY CWA during this period?

Common heavy rainfall patterns usually have a large ridge to the east and a trough/low to the west. This can allow for ingredients such as favorable jet entrance/exit regions to persist over a general area. Identify the location of the ridge complex and trough that are influencing the jet stream.

Select the CONUS scale 500 mb Wind/Temp/Height GFS model data. Analysis of the 500 mb synoptic feature is similar to that of the 300 mb. Figure 8 highlights the key features at the 500 mb level at F42 (0600 UTC 25 April).

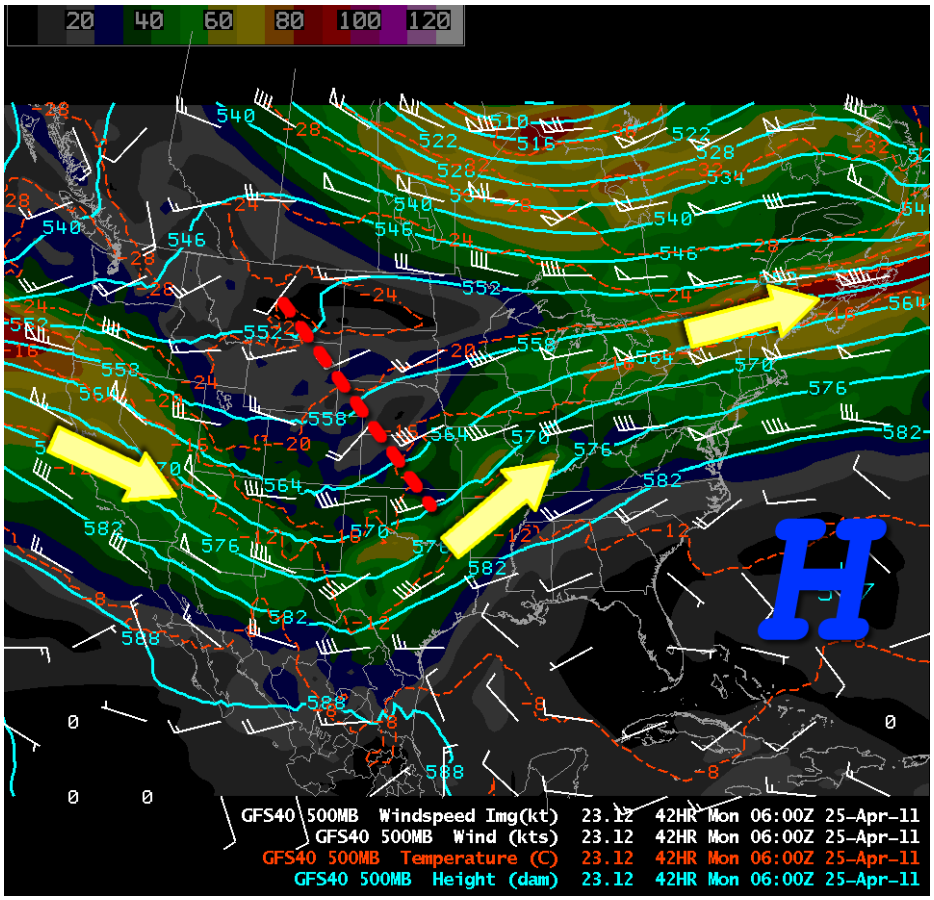

Figure 8: GFS40 500 mb heights (meters; cyan contours), temperature (Celsius; red contours) and Winds (knots; barbs and image) for F42 at 0600 UTC 25 April 2011 with annotation of the key synoptic features.

Finally, we will analyze the CONUS scale surface parameters. Start with the Wind/Temp/SLP products. What are the general direction and magnitude of the surface winds in your area? What is influencing these surface winds? Describe the winds when the forecast low develops (as seen in previous analysis).

Next, let's take a look at the CONUS scale precipitable water and dew point parameters from the GFS. What are the general values for both parameters over the area? Also describe the precipitable water plume over your region. Note that we will look at the precipitable water values and their anomalies in more detail within Performance Objective #3.

Evaluation Criteria 2.2 - We will now perform a regional analysis over the mid-Mississippi Valley that will focus on the low-level parameters, moisture transport, and surface boundaries. For the first step of the evaluation criteria, perform an analysis of the regional 850 mb Wind/Temp/Height of the 1200 UTC 23 April GFS model data for the entire forecast period. Describe in your analysis the characteristics of the low-level jet, boundary locations, and any developing lows.

Next, select the GFS regional 850 mb Moisture Flux parameter. Describe the overall pattern and the strength of the moisture transport in this region. Put this pattern into context with the CONUS and regional analysis you have performed, including how the developing low influences the moisture transport.

You can also perform the same analysis for the 925 mb pressure level. You should be able to better seen the cyclogenesis of the low pressure system over KS and MO and the associated increase in moisture transport into the area, especially from F48 (1200 UTC 25 April) to F60 (0000 UTC 26 April). This 925 mb analysis further solidifies the increased moisture content and the persistence of this moisture surge over the Paducah, KY CWA, which is a key ingredient in forecasting a significant rainfall and flooding event.

To help with identifying boundaries, you can use the GFS 925-850 mb Frontogenesis/Divergence/Moisture Flux model data. You will be able to see the combination of moisture transport vectors with areas of frontogenesis and convergence, which is generally where the more convective precipiation can occur. Of course, this is dependent upon the direction of the flow with respect to the boundary orientation. Note that some frontal features can be quite shallow and can reside below the 925 mb level.

The orientation of the forcing (e.g., frontal boundary) will play a significant role in precipitation accumulation. When the forcing and precipitation orientation changes, the pivot point of this change is where the greatest storm total accumulation usually occurs.

Finally, select the regional GFS surface Wind/Temp/SLP data. Describe the location of the surface boundary as seen through the surface parameters shown and the winds associated with it. Also describe the location of the surface low forecasted to develop and its influence on the pattern.

Evaluation Criteria 2.3 - After performing the model data analysis, we can determine what type of pattern(s) exist that could support a heavy rainfall event in the Paducah, KY CWA. From your analysis in Evaluation Criteria 2.1 and 2.2, what is the most representative Maddox heavy rainfall pattern from F00-F48 (1200 UTC 23 April to 1200 UTC 25 April)?

With the development of the surface low to the northwest of the Paducah, KY CWA, what Maddox heavy rainfall pattern best describes the conditions seen around F60-F66?

Performance Objective #3 -- Standardized Anomalies

Anomalies aid in pattern recognition and in distinguishing the ordinary and "extreme" events. Large anomalies will assist in identifying events that may be meteorologically and climatologically significant. Anomalies can also provide context to the overall pattern and confidence in predicting high impact weather events. Here, we will analyze the anomalies for this event in order to better understand how standardized anomalies can help in distinguishing a potentially high impact event.

The standardized anomalies in this exercise were derived from the NCEP/NCAR reanalysis data. The means and standard deviations created from this dataset are described by Hart and Grumm (2001). The standardized anomalies shown here are computed using the following equation:

$$SD = (F - M)/\sigma$$

Here, F is the value from the mode data at each grid point, M is the mean for the specific date and time at each grid point, and σ is the value of one standard deviation at each grid point.

Evaluation Criteria 3.1 - The first part of our analysis will start with the Global Ensemble Forecast System (GEFS) anomalies, which has 21 members versus the single member GFS. This evaluation criteria will focus on the anomalies of the large scale synoptic pattern at the 250 mb and 500 mb levels. Evaluation Criteria 3.2 will focus on the low-level winds and moisture flux. Begin with the 250 mb anomalies for the u- and v-wind components. What do the anomalies tell you about the jet streak over the Great Lakes region? Also describe the anomalies as the 250 mb wind field evolves during the 72-hour forecast period.

Select the GEFS 500 mb height anomalies. Recall that the two key features we saw in our analysis was the ridge complex over the western Atlantic and the forecasted trough/low combination over the western United States developing at F24-F30. What are the minimum/maximum anomaly values for these two features respectively and at what time?

Evaluation Criteria 3.2 - We will now focus on the 850 mb analysis using both the GEFS and SREF anomaly data. Load the GEFS 850 mb wind anomalies. Analyze the u-wind and v-wind components and describe the anomalies associated with the low-level jet in the mid-Mississippi Valley.

When are the wind anomalies at their greatest near the Paducah, KY CWA?

Now select the GEFS 850 mb moisture flux ensemble and anomaly data. Describe the anomalies and variability of the ensemble members from F00-F42 (prior to cyclogenesis) and from F48-F72. When are the anomalies at their greatest for each time period over the Paducah, KY CWA?

Now select the SREF 850 mb wind and moisture flux anomaly data. What, if any, differences do you see between the GEFS and SREF models in the wind and moisture flux anomalies? Remember that there is a three hour difference between the two models runs, so we are looking for more general differences.

Evaluation Criteria 3.3 - Finally, we will look at the precipitable water anomaly values and compare them to climatology. Analyze both the GEFS and SREF precipitable water anomaly data. Describe the anomaly values and trends throughout the forecast period.

Table 2 has a list of RAOB stations and maximum forecasted precipitable water values based on the GFS for each location over the 72-hour period. Determine the rarity of these values by comparing them to the appropriate precipitable water climatology for each site (use the Climatology link in the case exercise page). List the approximate percentile or percentile range for the given value. Also note if the value is at or above two standard deviations of normal or at the maximum value recorded.

Table 2: Maximum Forecasted Precipitable Water Values

Site	Max PW	Valid Forecast Time	Percentile
KBNA	1.20 in.	0600 UTC 24 April	
KILX	1.45 in.	0000 UTC 26 April	
KJAN	1.43 in.	1200 UTC 26 April	
KLZK	1.67 in.	0000 UTC 26 April	
KSGF	1.60 in.	0000 UTC 25 April	
KSHV	1.73 in.	0000 UTC 26 April	

Performance Objective #4 -- QPF and Impacts

With the identification of a known heavy rainfall pattern in place and the context provided by standardized anomalies, we will analyze the SREF and GFS QPF probabilities and output. Then we will introduce the HPC QPF products to gain confidence in forecasting high impact hydrometeorological events and determine potential impacts.

Evaluation Criteria 4.1 - We will start with the 1500 UTC 23 April SREF model run and select the QPF probabilities (image and contours) in the model section of the case exercise interface. What and when are the maximum probabilities for 12-HR and 24-HR accumulations greater than two inches near the Paducah, KY CWA?

Since the QPF accumulations and probabilities are created using the F00 hour of the model run, there will be a certain period where there will be no data present. This is because the model has not temporally accumulated enough precipitation to calculate any totals or probabilities (e.g., the model will need at least 12 hours to calculate data for 12 hour QPF probabilities). The table below will show when each product will become available based on the time period of the product.

Time Period	Forecast Period Data Becomes Available
6-HR	F12
12-HR	F18
24-HR	F30

We will now focus more on the flash flood time scale with the SREF model data. Analyze the SREF 6-hour QPF probabilities of > 0.50 inches and the SREF running 6-hour QPF accumulations. What and when are the maximum probabilities and accumulations over the Paducah, KY CWA? Are they co-located with the 12-hour and 24-hour maximum values?

Now select the SREF 24-hour QPF accumulations. What and when are the maximum 24-hour QPF totals? Where are the maximum value(s) located?

Knowing the different model precipitation biases can help in determining if QPF values are reaching a significant or historic level. Figure 9 shows the 24-hour precipitation bias of the GFS, NAM, and SREF 48-hour forecasts during Fall 2010 (i.e., 1 September to 30 November). From this graph, you can see that the bias of the GFS and NAM are generall around 1.00 when compared to observerd precipitation. The SREF, however, begins to underestimate the precipitation at totals above 0.50 inches and then greatly underestimates (bias < 0.50) when totals exceed 1.50 inches. Read the information bullet below on why ensemble means underestimate precipitation.

Ensemble means average out the extreme values on either end of the spectrum, which limits the model in predicting extreme events. Therefore, ensemble models generally underestimate significant precipitation values. This is why it is important to look at the individual ensemble members when forecasting precipitation.

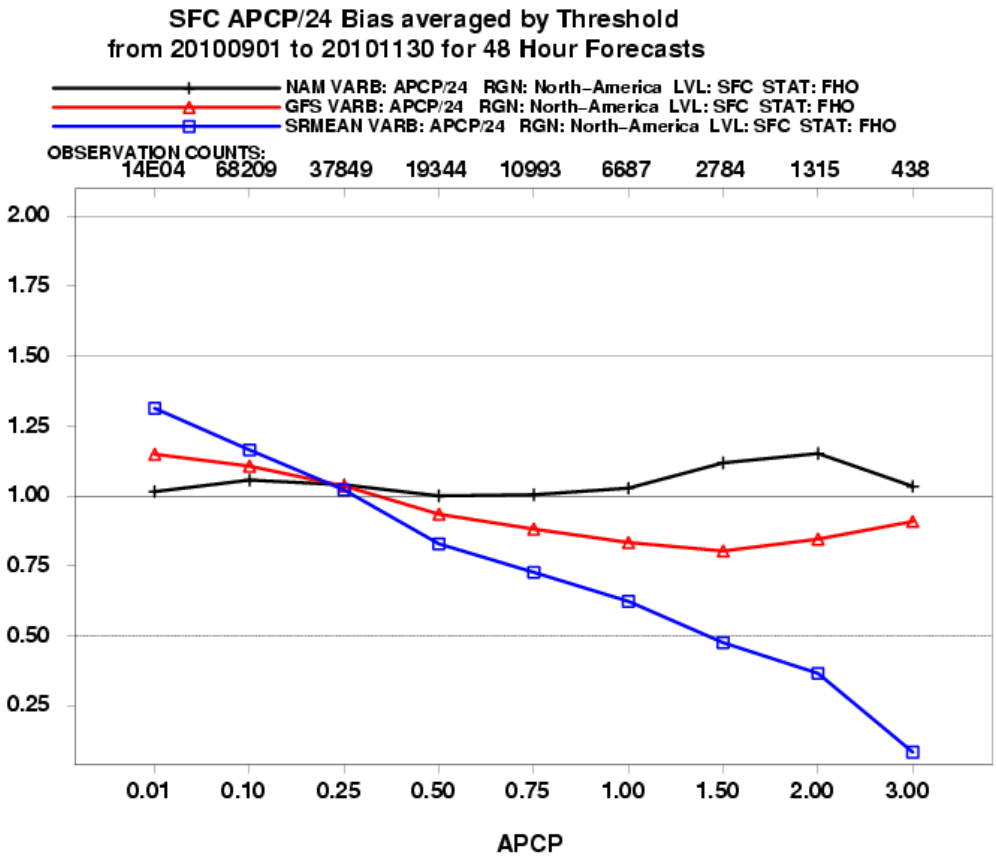

Figure 9: Comparison of 24-hour precipitation bias over North America at the forecast hour F48 for the NAM (black line), GFS (red line), and SREF (blue line) models from 1 September 2010 to 30 November 2010. The x-axis represents the average precipitation (APCP) and the y-axis is the model bias. This graph is provided by the National Weather Service Environmental Modeling Center (EMC). You can access their model bias verification by visiting the following EMC SREF verification page: http://www.emc.ncep.noaa.gov/mmb/SREF-Docs/verif/html/precip.html

Do you think the SREF mean values are consistent with that of a heavy rainfall event? Why or why not?

Unfortunately, there are limitations in AWIPS, and we cannot view the individual ensemble members of the SREF. Figure 10 depicts the individual members of the WDTB WRF ensemble for Cape Girardeau, MO at 0000 UTC 23 April. Here you can see how each member accumulates precipitation over a 48-hour period.

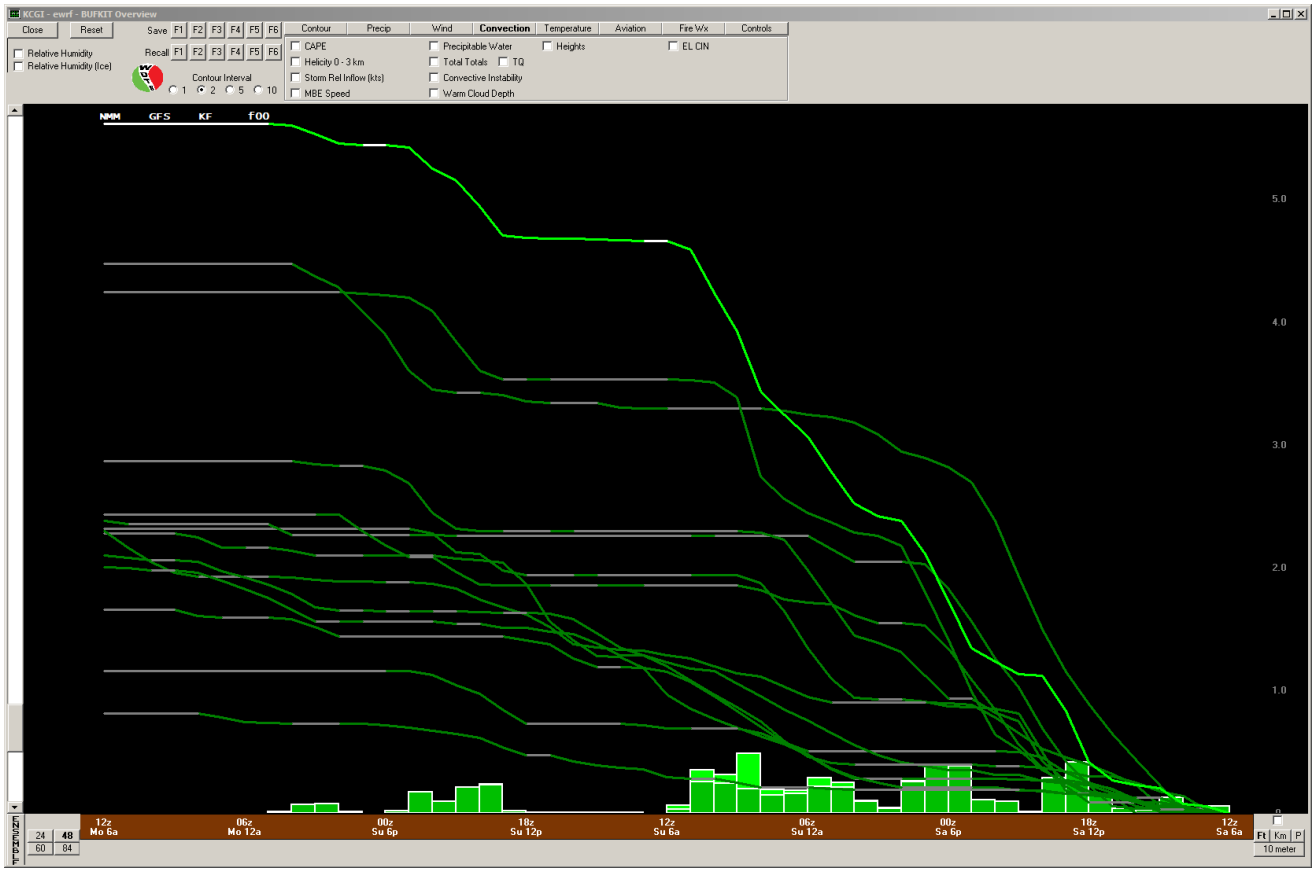

Figure 10: WDTB WRF precipitation output for each ensemble member for 0000 UTC 25 April at Cape Girardeau, MO. The bars represent hourly precipitation and the lines represent precipitation accumulation.

How many ensemble member accumulate more than five inches? What is the greatest precipitation accumulation of an ensemble member?

As you see in Figure 10, the forecast only goes out to 0000 UTC 25 April. This means that some of the model members are accumulating over five inches of rain before the next significant event that is expected from 1200 UTC 25 April to 1200 UTC 26 April. Figure 11 depicts the individual members of the WDTB WRF ensemble for Cape Girardeau, MO at 0000 UTC 25 April for a 48-hour period.

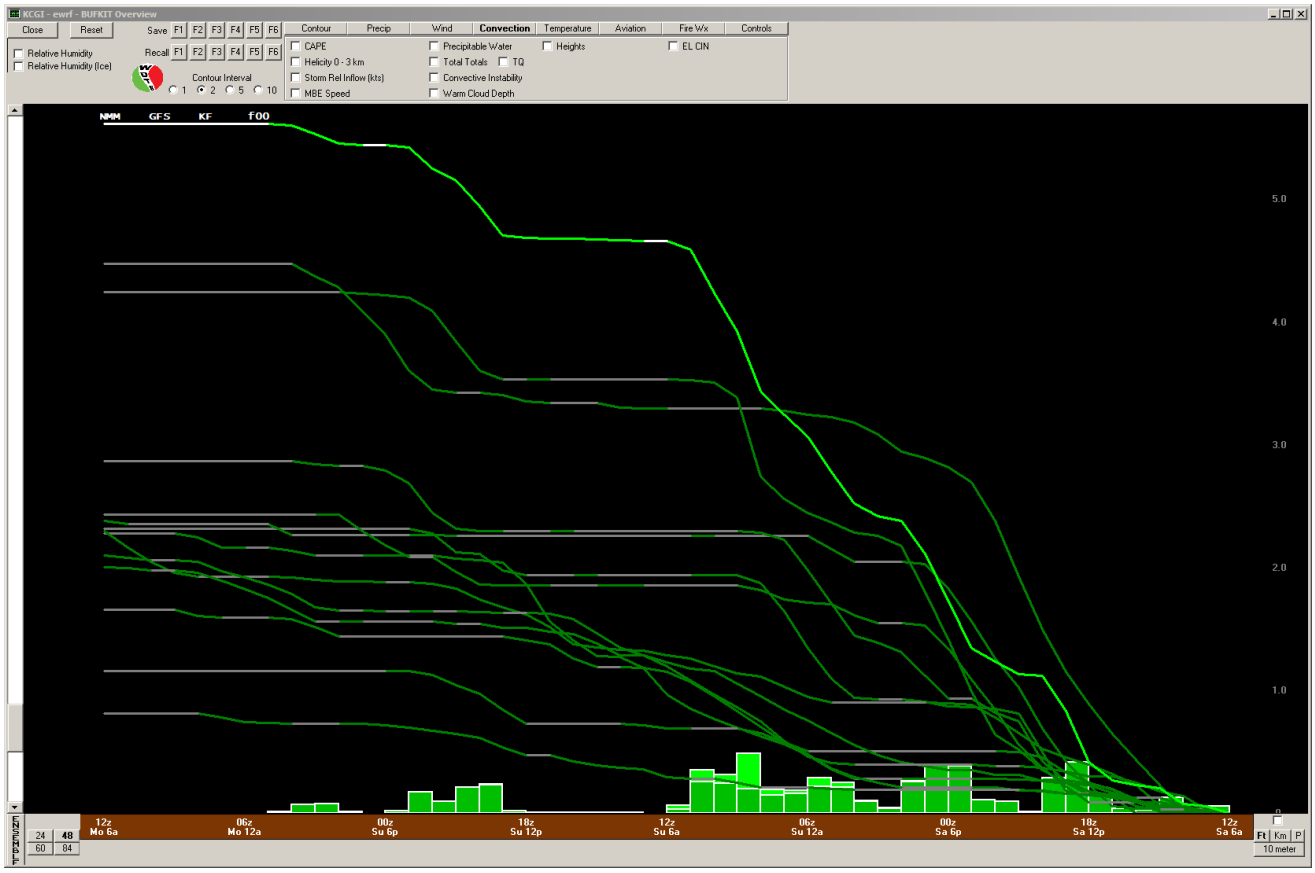

Figure 11: WDTB WRF precipitation output for each ensemble member for 0000 UTC 25 April at Cape Girardeau, MO. The bars represent hourly precipitation and the lines represent precipitation accumulation.

How many ensemble member accumulate more than three inches of precipitation? If you were to combine the model members that have the higher accumulations, what would the forecast storm total precipitation be?

Evaluation Criteria 4.2 - We will now analyze the GFS QPF output. The QPF output provided in the case exercise interface contains model run accumulation (image and white contours) and six-hour precipitation accumulation (black contours). When do the greatest six-hour totals fall over the Paducah, KY CWA? How much rain does the GFS forecast for these six-hour totals? Use Figure 12 to help in your analysis.

Using the model data provided in the case exercise interface and in Figure 12, note the trends in the precipitation orientation throughout the entire forecast period. Does the SREF and GFS QPF output match up well with your model data and anomaly analysis that you performed earlier?

The model accumulates more than six inches of rain across southern Missouri and southern Illinois. After looking at the various QPF products from both the GFS and SREF, do you think the GFS QPF better represents the precipitation potential over the area? Why?

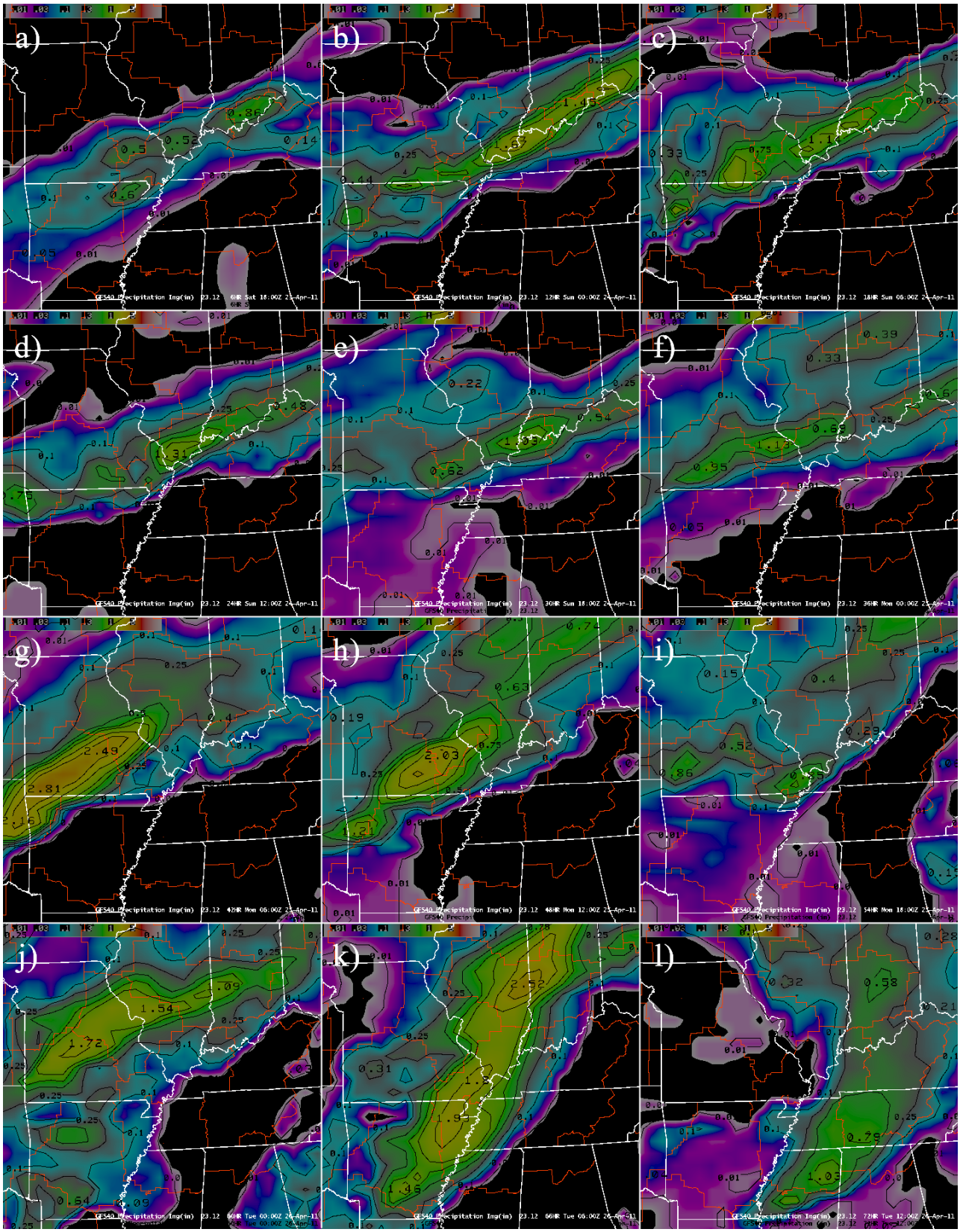

Figure 12: GFS six-hour forecast precipitation accumulations (black contours and shaded) from a) 1800 UTC 23 April (F06) to l) 1200 UTC 26 April (F72).

Evaluation Criteria 4.3 - After analyzing the QPF output from both the GFS and SREF models, it is time to look at the HPC QPF products. When you select the HPC QPF button on the case exercise interface, you can view the color-fill images for the forecast intervals ranging from 6-hours to 120-hours that are valid as of 1200 UTC 23 April. Please note that the text products (e.g., the Quantitative Precipitation Forecast Discussion or Excessive Rainfall Discussions) are not available through this exercise.

Table 3 lists the various QPF accumulation periods that are provided in the HPC QPF graphics. Fill out this table below with the time period that is forecasted to receive the greatest precipitation accumulation for each accumulation period given, the general location of the QPF maxima, and the estimated maximum precipitation total for the accumulation period. Since there is only one image given for the 72-hour and 120-hour QPF forecasts, we have already filled in the forecast period for you.

Table 3: HPC QPF Maximum Precipitation Accumulations

Accumulation Period	Forecast Period of Max Precipitation	Location of Max QPF	Estimated Max QPF
6-Hour			
12-Hour			
24-Hour			
48-Hour			
72-Hour	1200 UTC 23 April - 1200 UTC 26 April		
120-Hour	1200 UTC 23 April - 1200 UTC 28 April		

Compare the HPC QPF forecast with that of the GFS and SREF forecasts. Does the HPC QPF forecasts fit the analysis from the GFS and SREF model forecasts for your area?

In Table 3, you should notice that even though the greatest 6-hour and 12-hour totals occur within your CWA, the greatest 24-hour and 48-hour totals were not located in the same location. However, you should have recognized that the HPC QPF products have precipitation totals for the Paducah CWA that are near the maximum total you recorded (i.e., within 0.20 inches of the values shown in Table 3). Within the Paducah CWA, there is a precipitation maximum of 3.26 inches for the 24-hour period and 4.38 inches for the 48-hour period.

To focus on the flash flood scale, how many significant precipitation events do you see for the Paducah, KY CWA? When do these events occur?

Evaluation Criteria 4.4 - Now that you have analyzed the model output, the standardized anomalies for various model parameters, and QPF for your region, you should have gained confidence in forecasting the potential for a high impact rainfall event in the Paducah, KY CWA.

Describe the potential impacts from the rain expected in your area. Include in your discussion changes in soil moisture and FFG (recall Performance Objective #1), any expected time period(s) for the greatest threat of flash flooding, and thoughts on main stem river flooding.

Conclusion of Case Exercise #1

Now that you have analyzed this case for the Paducah, KY CWA and answered the questions presented here in this document, you are now ready to begin the debriefing process.

There is a Debrief tab located on the case exercise web interface. Click on this tab (seen below) to begin. Inside this debrief page is a link to a short presentation regarding this event and a PDF document containing the answers to this case exercise.

Materials referenced in this document can be found on the course Reference Page: http://www.wdtb.noaa.gov/courses/hydro/references.html