RECOGNIZING HIGH IMPACT HYDRO EVENTS

CASE EXERCISE #2

6 SEPTEMBER 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

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- 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.
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- 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:

- Major flooding along the Susquehanna River in the town of Wilkes Barre, PA during the historic floods of September 7-8, 2011. This image is courtesy of DIS Boards user disneymarie.

Ed Mahoney, Chief

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

Version	Date	Description
1.0	December 23, 2011	Initial Release

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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 State College, PA. 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 #2:

WFO Office -- State College, PA

Case Date/Time -- 06 September 2011 - 0500 UTC

Performance Objective #1 -- Antecedent Conditions

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.

During the month of August, areas of the mid-Atlantic region and the northeast received two record rainfall events. The first event occurred during 14-16 August, where localized areas of 6-10 inches fell over southern New Jersey and Long Island. Two weeks later, Hurricane Irene dumped 5-15 inches of rain from coastal North Carolina to Vermont during 27-28 August. Preliminary USGS data shows that over 80 stream gauges set new peaks of record in ten states during Irene, including the Schuykill River at Norristown, PA.

Evaluation Criteria 1.1 - Provided in Figures 1-3 are the precipitation totals for the month of August, the departure from normal, and the percentage of normal precipitation. Based on these maps, how much rain has fallen across the mid-Atlantic coast, especially in eastern Pennsylvania during this period? What is the departure from the normal August rainfall (in inches) and the percentage of normal?

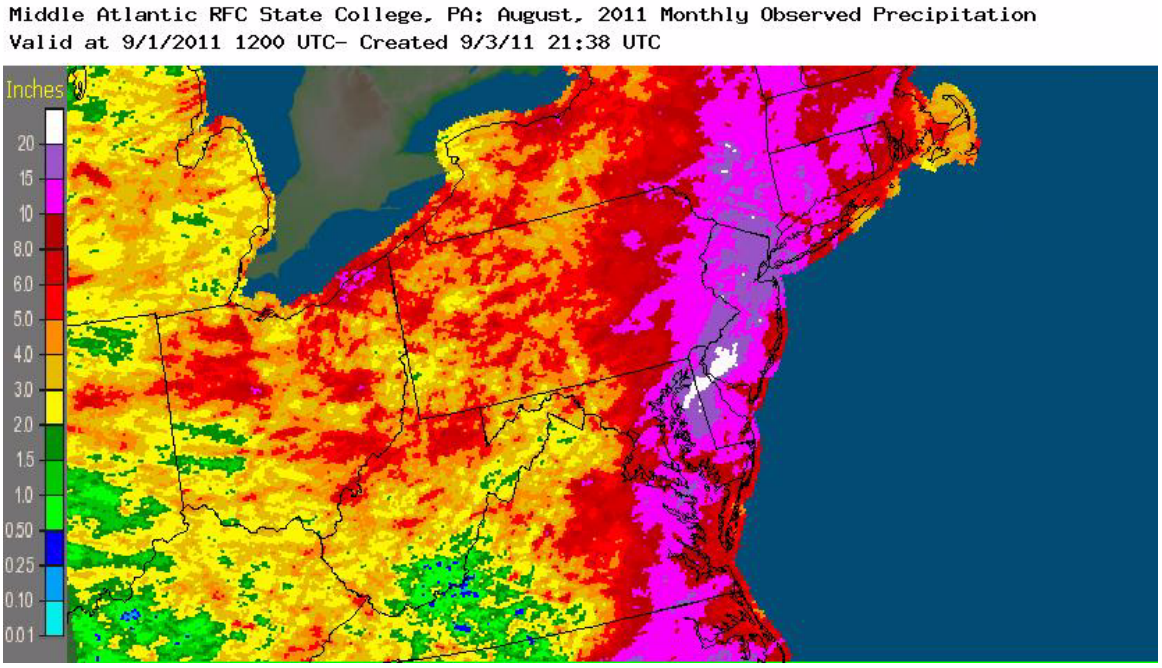

Figure 1: Multisensor Precipitation Estimator (MPE) totals (in inches) over the Middle Atlantic River Forecast Center (RFC) coverage area during the month of August.

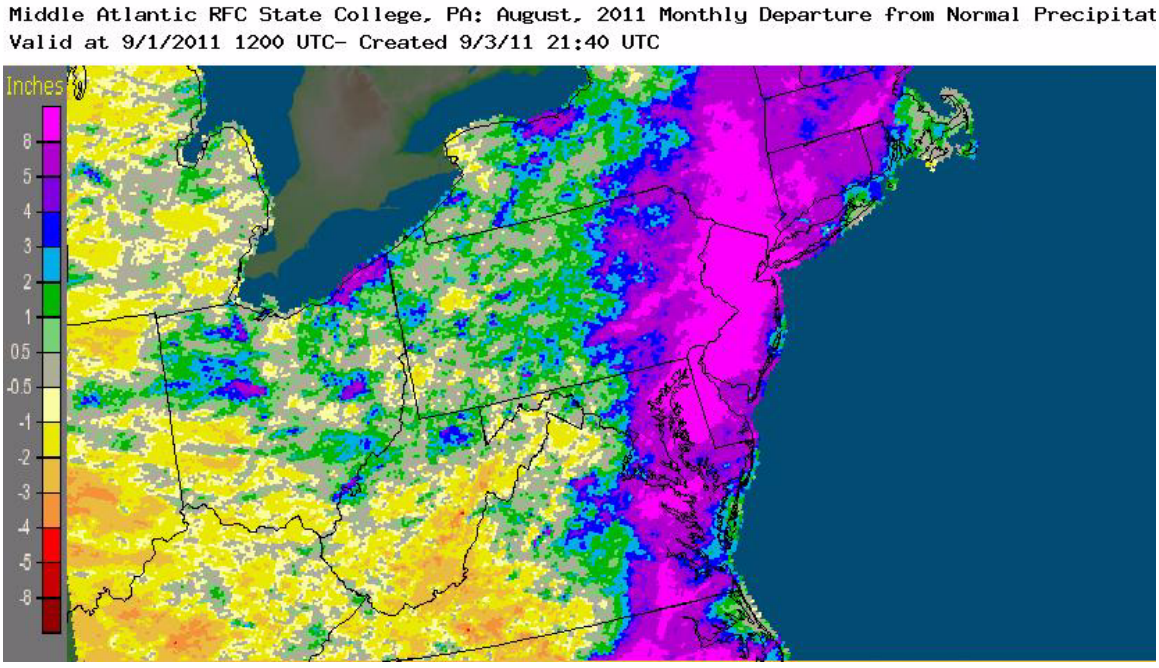

Figure 2: Departure from normal (in inches) of the Multisensor Precipitation Estimator (MPE) totals over the Middle Atlantic River Forecast Center (RFC) coverage area during the month of August.

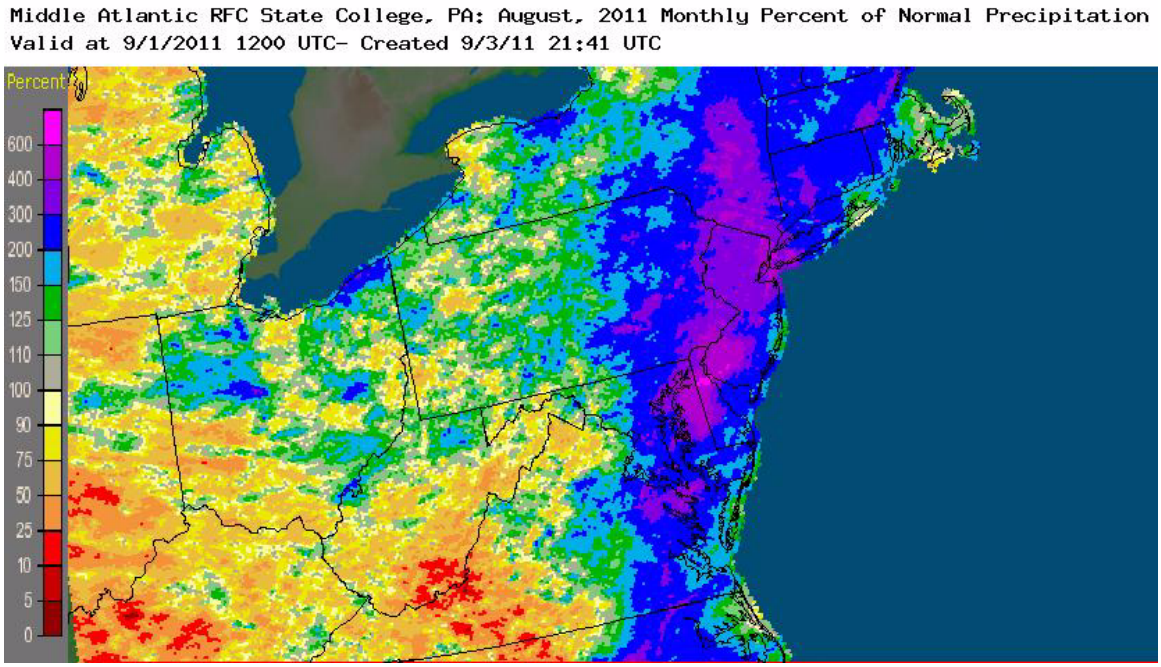

Figure 3: Departure from normal (percentage) of the Multisensor Precipitation Estimator (MPE) totals over the Middle Atlantic River Forecast Center (RFC) coverage area during the month of August.

Evaluation Criteria 1.2 - The calculated soil moisture ranking percentiles for the dates of 4 August 2011 and 4 September 2011 are displayed in Figures 4-5, respectively. The period of record for these ranking percentiles are from 1932-2000. Describe the changes in the soil moisture percentiles over this one month period for the northeastern U.S. and then specifically for the State College, PA county warning area (CWA).

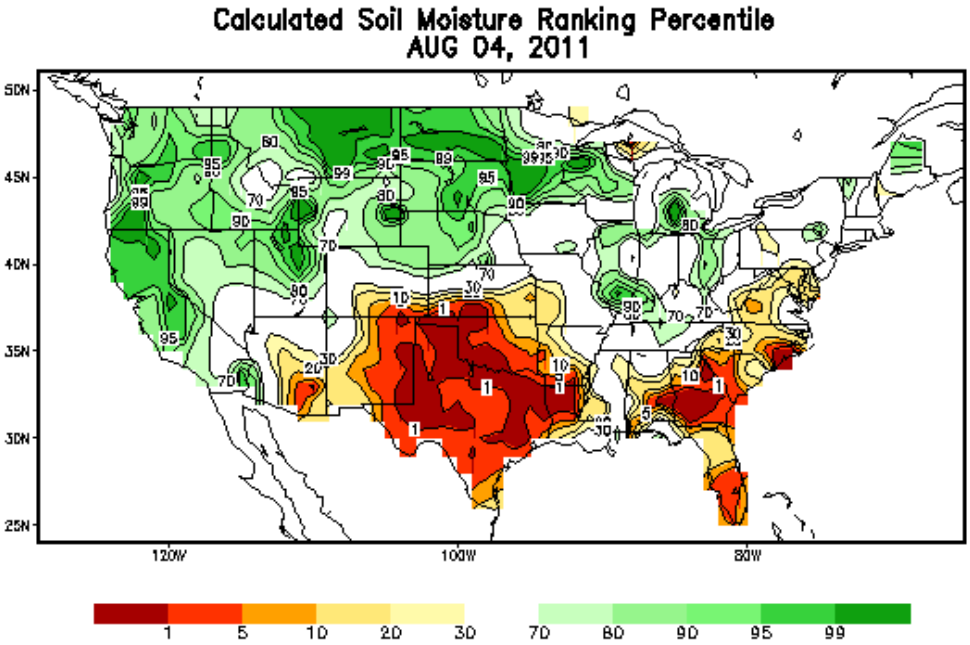

Figure 4: Calculated soil moisture ranking percentile for 4 August 2011. The ranking percentile is calculated by the NWS Climate Prediction Center (CPC) using a soil moisture content database from the period 1932 to 2000. Soil moisture data can be found at the following CPC page: http://www.cpc.ncep.noaa.gov/soilmst/w.shtml

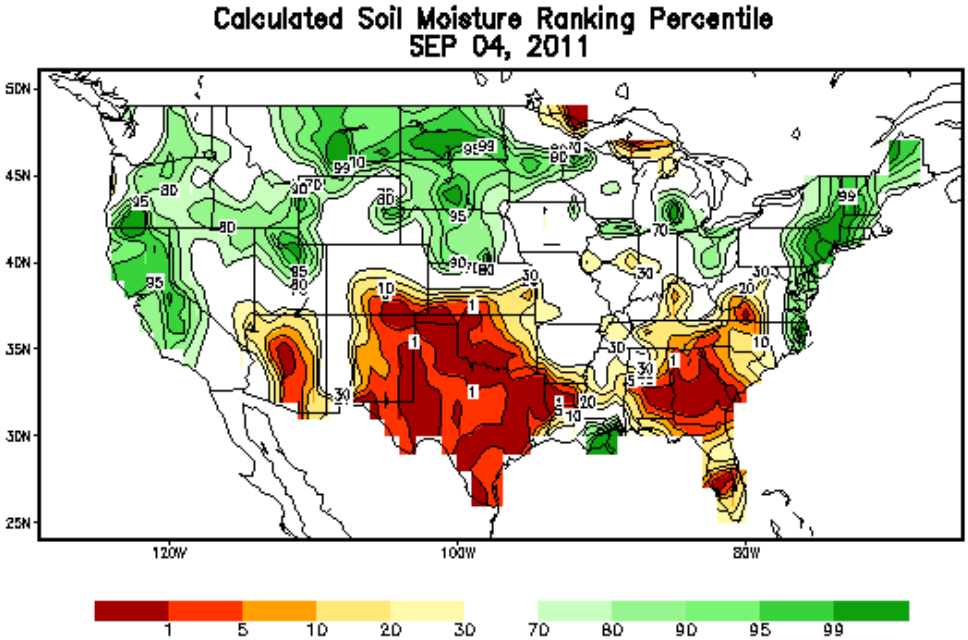

Figure 5: Same as Figure 4 except for 4 September 2011.

Evaluation Criteria 1.3 - Approximately 50-100 mm (2-4 inches) of rain has fallen over the area during the past few days and is continuing to fall at this time. Figure 6 shows the precipitation totals from 1200 UTC 1 September to 1200 UTC 6 September. 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 State College, PA CWA. The average three-hour FFG value is 1.75 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.

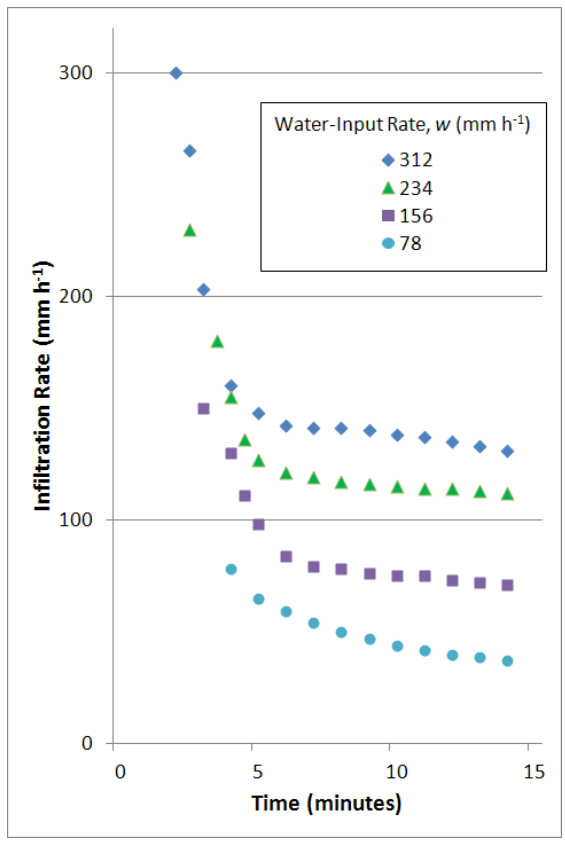

Figure A: Infiltration rate of grass covered loam surface at a slope of 16% using artificial rainstorms of 15-min duration. After Nassif and Wilson (1975).

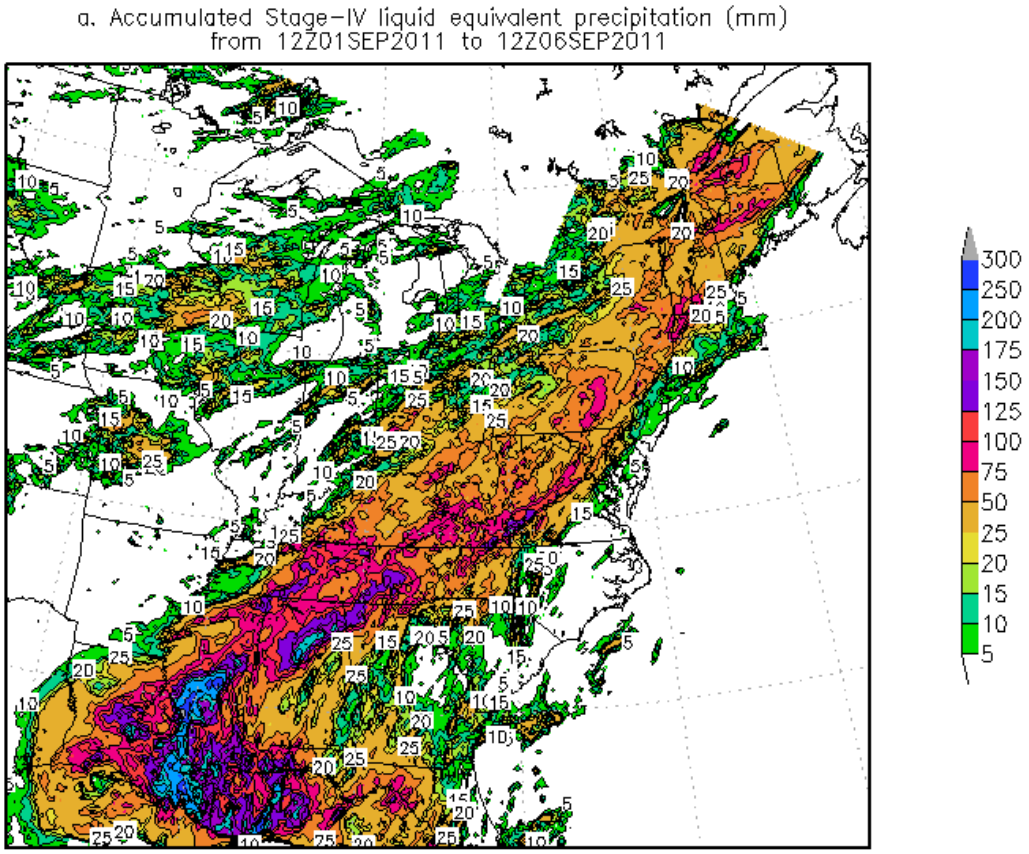

Figure 6: Precipitation totals (in mm) over the eastern U.S. from 1200 UTC 1 September 2011 to 1200 UTC 6 September 2011.

With the current 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?

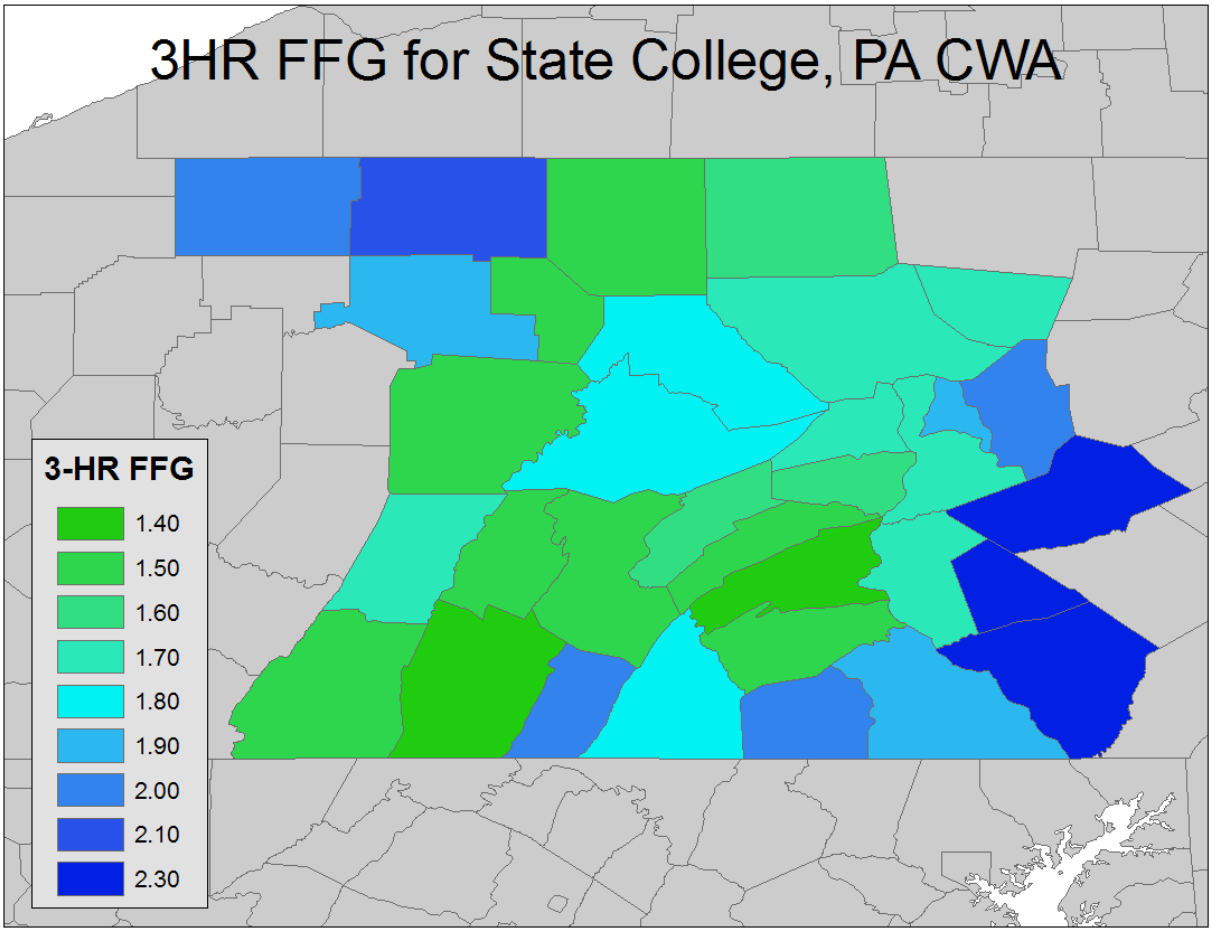

Figure 7: Three-hour county-average flash flood guidance (FFG) for the State College, PA CWA.

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 0000 UTC 6 September 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. Identify the two large scale features that are contributing to the location of the jet entrance region over New England at F00.

It is very important to look at both the upstream and downstream systems. Common heavy rainfall events usually have a large ridge to the east and a low/trough to the west that can allow certain ingredients for heavy rainfall events, such as favorable jet entrance/exit regions, to persist over the same area. Remember that patterns are never static and can transition over time.

Now select the GFS CONUS scale 500 mb Wind/Temp/Height model data. You should be able to identify the same synoptic scale features as you did in the 300 mb analysis. Scroll through the F00 to F72 forecast data to see how the upper-level features evolve. Describe what happens with the trough and the 5720 m low that is located over Tennessee at F00 (the remnants of Tropical Storm Lee) over the next 72 hours?

Now view the CONUS scale surface data (Wind/Temp/SLP and PW/Dewpoint). What happens with the surface low associated with the remnants of Tropical Storm Lee and its moisture return?

Evaluation Criteria 2.2 - We will now perform a regional analysis over the mid-Atlantic states that will focus on the low-level winds, precipitable water, and moisture transport associated with the remnants of Tropical Storm Lee. For the first step of the evaluation criteria, perform an analysis of the 850 mb Wind/Temp/Height of the 0000 UTC 6 September GFS model run for the forecast period F18-F30. Include in your analysis any frontal boundaries, associated low-level wind patterns, and the location of the remnants of Lee.

Now perform the same analysis for the F42-F54 forecast period. Describe any significant changes over Pennsylvania with regards to any low-level wind shifts and any boundaries that may play a role in forcing over the region.

Switch to the 0300 UTC 6 September SREF 850 mb analysis. Is the SREF model run generally consistent with that of the latest GFS model run?

Return back to the 0000 UTC 6 September GFS model and analyze both the 850 mb moisture flux parameter and precipitable water values. You can easily identify the location of the WSW-ENE boundary in both fields during the forecast period F00-F18. When does the moisture begin to surge into Pennsylvania based on the moisture transport vectors and precipitable water values? Describe the characteristics and duration of this moisture transport and precipitable water content into Pennsylvania?

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.

Through your analysis of the GFS model data, you were able to see how Post Tropical Storm Lee influenced the southerly flow and the low-level moisture transport into the region. We saw how this moisture and the strong 850 mb winds lifting over the E-W oriented frontal boundary could created a long-duration rainfall event over the CWA. However, Post Tropical Storm Lee is not the only tropical system that could influence the precipitation over the State College, PA CWA. Recall from the Case Introduction page within the Case Exercise interface that Hurricane Katia is currently located 450 miles south of Bermuda.

Select the GFS model and analyze the following data: Precipitable Water, 925 mb Winds and Moisture Flux, 850 mb Winds and Moisture Flux, and Surface Winds. Are there any potential moisture influences from Hurricane Katia?

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 your CWA. From your analysis in Evaluation Criteria 2.1 and 2.2, what is the most representative Maddox heavy rainfall pattern from F00-F30 (0000 UTC 6 September to 0600 UTC 7 September) over the mid-Atlantic states?

Briefly describe how the surface and low-level winds support the Maddox heavy rainfall pattern that is in place from F00-F30.

What Maddox typology would be best associated with the potential heavy rainfall pattern during the latter part of the forecast period (i.e., beyond F36)? Describe any influences that Lee would have on the setup and Maddox pattern.

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 synoptic pattern. Begin with the 250 mb anomalies for the u- and v-wind components. What do the anomalies tell you about the jet over New England and the southerly flow at 250 mb during the forecast period?

Select the 500 mb height anomalies. Recall that the two key features we saw in our analysis was the ridge over the western Atlantic and the trough/low combination over the southern United States. What are the minimum/maximum anomaly values for these two features respectively and at what time? What is the 500 mb height anomaly trend for the remnants of Tropical Storm Lee?

Evaluation Criteria 3.2 - We will now focus on the 850 mb analysis using both the GEFS and SREF anomaly data. Start by loading the GEFS 850 mb wind anomalies for both the u- and v-components. Recall in your model analysis that the 850 mb winds over Pennsylvania are from the east and are on the cool (north) side of a frontal zone. Use the u-wind anomalies to describe the location and strength of the easterly jet during the entire forecast period.

Now analyze the v-wind anomalies at the 850 mb level. Recall that Lee is forecast to move northward, so strong southerly flow will approach the mid-Atlantic region and your CWA. Use the standardized anomalies to describe the strength of this southerly jet associated with Lee during the forecast period.

The strong southerly flow into the region coincides with a significant moisture return and surge in precipitable water values. (We will further discuss the precipitable water anomalies in Evaluation Criteria 3.3). Select the 850 mb moisture flux anomalies for the GEFS. Describe the 850 mb moisture flux anomalies during the entire forecast period.

Now select the SREF 850 mb wind and moisture flux anomaly data. What general differences do you see between the GEFS and SREF model output in the wind and moisture flux anomalies?

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

Table 1 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 interface). 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 1: Maximum Forecasted Precipitable Water Values

Site	Max PW	Valid Forecast Time	Percentile
KALY	1.91 in.	0000 UTC 9 September	
KIAD	2.28 in.	0000 UTC 8 September	
KMHX	2.24 in.	0000 UTC 6 September	
KOKX	2.23 in.	0600 UTC 6 September	
KPIT	1.77 in.	0600 UTC 7 September	
KWAL	2.26 in.	1200 UTC 6 September	

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 0300 UTC 6 September 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? Also note the location of the greatest probabilities, especially if it impacts the 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? Where are these maximum values located? 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 8 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.

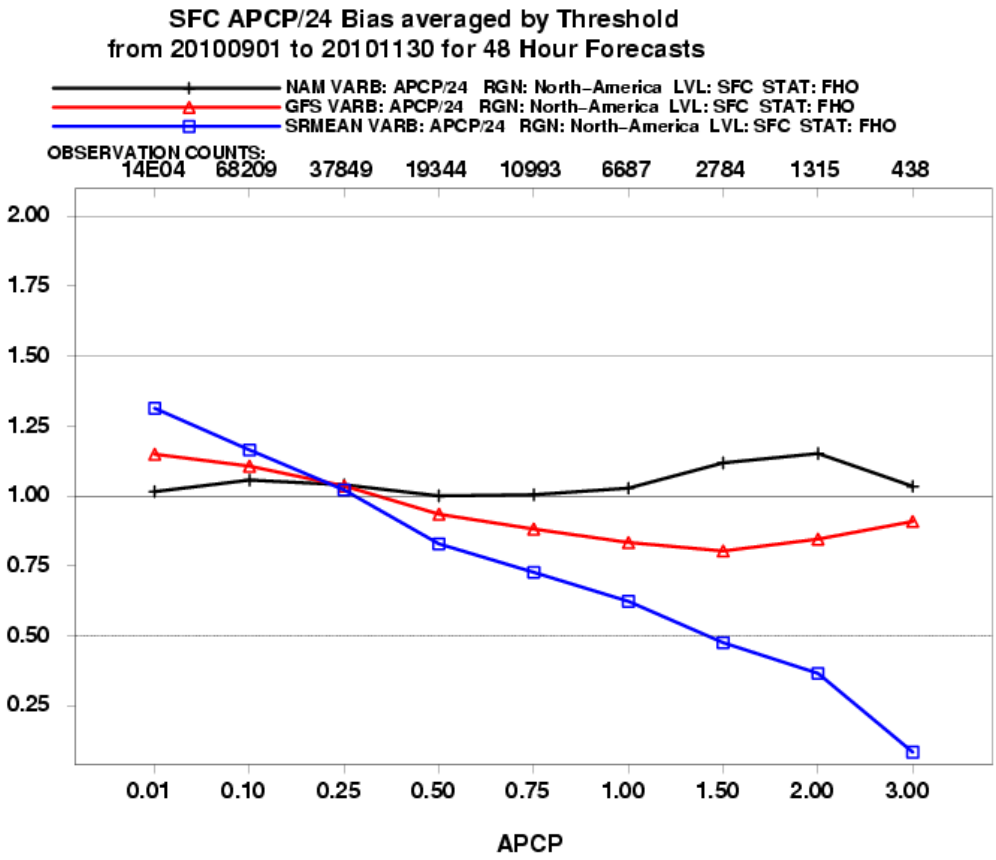

Figure 8: Comparison of 24-hour precipitation bias over North America at the forecast hour F48 for the NAM (black line), GFS (red line), and SREF (blue line) models from 1 September 2010 to 30 November 2010. The x-axis represents the average precipitation (APCP) and the y-axis is the model bias. This 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 9 depicts the individual members of the WDTB WRF ensemble for State College, PA at 0000 UTC 7 September (the model run for 0000 UTC 6 September is unavailable). Here you can see how each member accumulates precipitation over a 48-hour period.

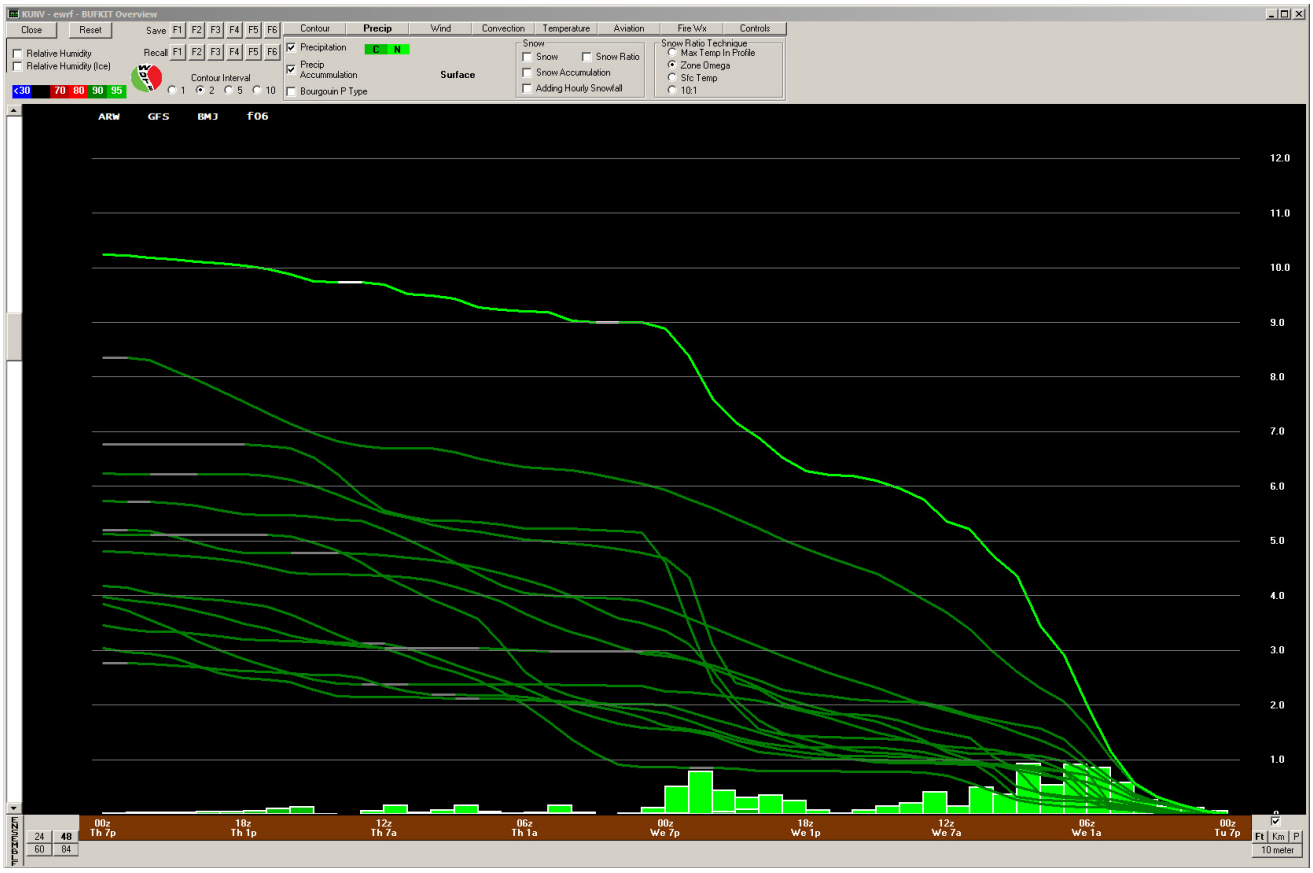

Figure 9: WDTB WRF precipitation output for each ensemble member for 0000 UTC 7 September at State College, PA. The bars represent hourly precipitation and the lines represent precipitation accumulation.

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

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). Mouse over the forecast period and observe the trends in the six-hour accumulations over the 72-hour period. When and where does the greatest forecast six-hour precipitation accumulations occur over Pennsylvania? Use Figure 10 to assist in your analysis.

Recall that the model data showed a change in low-level wind orientation from a Maddox frontal pattern (E-W orientation) to more of a Maddox synoptic pattern (N-S orientation) over Pennsylvania. Is this evident in the GFS and SREF QPF products? Use the GFS output in Figure 10 to help in this analysis.

The GFS accumulates up to 11.31 inches of rain in south-central Pennsylvania by F54 (0600 UTC 8 September) and 12.69 inches of rain by F72 (0000 UTC 9 September). Compared to the SREF QPF values, do you think the GFS QPF better represents the precipitation potential over the area?

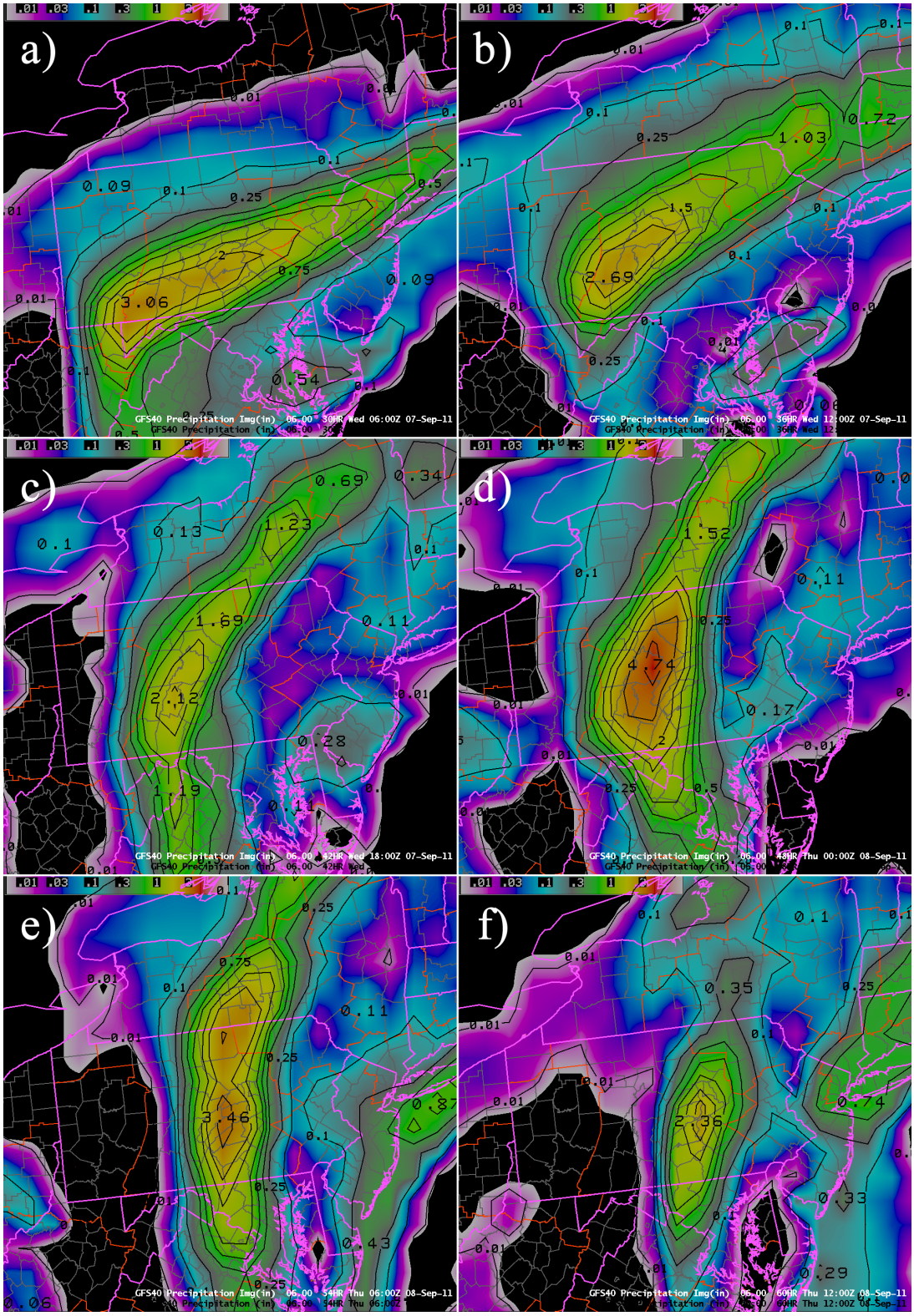

Figure 10: GFS six-hour forecast precipitation accumulations (black contours and shaded) for a) 0600 UTC 7 September (F30), b) 1200 UTC 7 September (F36), c) 1800 UTC 7 September (F42), d) 0000 UTC 8 September (F48), e) 0600 UTC 8 September (F54), and f) 1200 UTC 8 September (F60).

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 0000 UTC 6 September. Please note that the text products (e.g., the Quantitative Precipitation Forecast Discussion or Excessive Rainfall Discussions) are not available through this exercise.

Table 2 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 2: 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	0000 UTC 6 September - 0000 UTC 9 September		
120-Hour	0000 UTC 6 September - 0000 UTC 11 September		

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

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 State College, PA 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 #2

Now that you have analyzed this case for the State College, PA 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