Quantitative Precipitation Forecast
Its Generation and Verification at the Southeast River Forecast Center

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Abstract. In a typical year, flooding is the number one cause of weather related deaths in the United States. The National Hurricane Center recently reported that inland flooding now surpasses coastal storm surge as the leading cause of hurricane related deaths (Rappaport et al., 1998). Hurricane Mitch of October, 1998, was responsible for upwards of 10,000 people losing their lives in inland flooding and mud flows in Central America.

Although the National Weather Service has produced river and flooding forecasts since 1890, it wasn't until the mid 1990s that the Southeast River Forecast Center (SERFC) incorporated Quantitative Precipitation Forecasts (QPF) into its river models throughout the southeastern United States. With the southeastern United States receiving more annual precipitation than anywhere else in the country, and with threats of hurricanes and other tropical type weather, it is imperative that an accurate QPF forecast be made and entered into the SERFC river models.

Verification of the QPF has been an important undertaking at the SERFC over the last two years. This paper will discuss QPF verification findings for 1998 and the impact of QPF on the accuracy of hydrologic models.

INTRODUCTION

In the late 1980s, the National Weather Service (NWS) launched its ten year, 4.5 billion dollar Modernization and Restructuring (MAR) program to take advantage of rapidly advancing scientific and computer technologies. The implementation of MAR is nearly complete and has succeeded in modernizing the meteorological and hydrological operations of the NWS.

As a result of MAR, all 13 River Forecast Centers (RFC) across the U.S. restructured their operations and upgraded computer technology. The RFCs have extended their hours into the evening and nearly doubled their staff, which included the hiring of three meteorologists at each RFC. These meteorologists became part of a new function at RFCs, known as the Hydrometeorological Analysis and Support (HAS) program, to manage the greatly increased flow of meteorological data for input into the hydrological models. The two greatest responsibilities of the HAS forecaster are the comparison and quality control of radar and rain gage data, and the assimilation of the QPF.

The SERFC, with a responsibility for river and flood forecasting for the Southeastern United States and Puerto Rico, has been incorporating 24-hour QPF from the Carolinas and Virginia since the late 1980s, and from the rest of the Southeast since 1995. Prior to this, river models were computed with only observed rain and were very inaccurate during ongoing rain events.

Presently, HAS forecasters assimilate QPF forecasts from all 18 of the Weather Forecast Offices (WFOs) in the SERFC area of responsibility, including Puerto Rico. QPF forecasts are prepared twice a day by WFO meteorologists using a graphical MS Windows program known as WinQPF, developed by Mark Fenbers, Senior HAS of the Ohio River Forecast Center (OHRFC), and are then sent to the RFC. The HAS forecaster may make modifications to the overall QPF forecast in case of inconsistencies among the WFOs' forecasts, and inputs them into the hydrologic model.

MEAN AREAL PRECIPITATION

The Quantitative Precipitation Forecast is future or forecast Mean Areal Precipitation (MAP). Mean Areal

Precipitation is the amount of precipitation in inches that occurs if spread out over a river basin. It is also called Basin Average Precipitation (BAP). This MAP is transformed into runoff in the river model by using the Sacramento Soil Moisture Accounting Model within the National Weather Service Forecast System (NWSRFS).

In the SERFC area of responsibility, there are 349 such basins which are defined by river segments. Most segments are defined by the location of a river gage.

Currently the SERFC interrogates 1313 rain gages by various methods, such as by satellite, manual observation, telephone, etc. To compute MAP, the SERFC uses the Thiessen Polygon method. This method computes rain gage areas and then determines a weight for each rain gage. Rain gages inside each basin, as well as those bordering the basin, are used (Larson et al., 1976).

The Thiessen method for determining MAP is adequate for most basins. However, a few basins, particularly in south Florida, have a limited number of rain gages and may cause unrepresentative MAP computations, especially during convective type rain events where heavy precipitation is scattered.

In the near future, the SERFC will be using a procedure to compute MAP for each basin using WSR-88D radar-derived rainfall. Currently the NWS is developing a "Stage 3" or three step process nationwide to calibrate 1-hour radar precipitation amounts with rain gages. The SERFC is in the testing phase of a Unix based graphical software package known as Stage 3. The radar-rain gage derived product is input into the Stage 3 computer program and manually quality controlled by the HAS forecaster at each RFC. Erroneous radar and rain gage data can be observed by the forecaster and corrected or deleted. These MAPX (mean areal precipitation derived from radar) values will be the output and will be entered into the river model. The theory is that the higher the temporal and spatial resolution in the rainfall input, the more accurate the river forecast (Stellman, Fuelberg and Garza et al., 1998).

QPF VERIFICATION METHODS

QPF Generation

The SERFC updates all river forecasts by 11:00 a.m. ET each day using the 12z observed data in the river model run. During heavy rain events the SERFC increases its operation from 18 hours to 24 hours. River Mean Absolute QPF Error (MAE) forecast updates can be issued, every six hours, after new data is incorporated into the river model.

Each of the 18 WFOs issues a QPF forecast of four six-hourly periods for its respective hydrological service area (HSA), or area of hydrologic responsibility (Figure 1), by 1130z each morning then again by 2330z each evening. The HAS forecaster may request additional QPF forecasts from the WFO as needed. The HAS forecaster checks each QPF, and may coordinate with WFO forecasters and/or revise the forecast before it is entered into the river model. QPF forecasts may extend beyond 24 hours to produce contingency river forecasts during flood events.

In the near future, the SERFC will be using a Unix based graphical program known as HASQPF, developed at the OHRFC by Mark Fenbers, to mosaic all 18 QPF forecasts. This will also allow the HAS forecaster to check for inconsistencies among forecasts and revise each QPF by drawing isohytes.

Water Watcher

Water Watcher is an MS Windows based Visual Basic compiled program developed at the SERFC by the author in July of 1997. This program downloads the QPF and observed MAP files stored in the SERFC Unix server and computes a QPF error for each basin. Errors are averaged for each HSA (Figure 1) and can be viewed in both text and graphical format. Many of the graphics produced are available online and are updated each day. The SERFC web site address can be found at the end of this paper.

Statistics produced by the program are Root Mean Square Error (RMSE), Average Error, Mean Absolute Error, Heidke Skill Score, and an R-Score (equations. 1 to 5). The R-score is used to compare the RMSEs of different WFOs. RMSE is proportional to the amount of average MAP a WFO's HSA receives in a given time. Therefore, by dividing the WFO's RMSE by its respective average MAP, a comparison among the WFOs' RMSEs can be made with differing amounts of MAP.

Mean QPF Error = (1)

= (2)

Root Mean Square Error (RMSE)

= (3)

where,
QFP = Quantitative Precipitation Forecast for a particular basin
MAP= Mean Areal Precipitation for a particular basin
N = Number of basins in the WFO’s HSA.

(4)

where,
MAP is the average MAP across a WFO’s HSA
RMSE is the Root Mean Square Error for the WFO’s HSA

Heidke Skill Score (HSS) (NWS, 1982) is the fraction of possible improvement over chance afforded by a set of forecasts from a contingency table of categorical forecasts (columns) versus observations (rows). Row and column totals are denoted with subscript q.

(5)

where,
the number correct (NC):

(6)

where,
i is the index for row and column
m is number of rows or columns

the total number of cases analyzed (T):

(7)

where, q is the total number of rows and columns in the contingency table

the expected value (E):

(8)

where,
i is the index for row and column
q is the total number of rows and columns
m is number of rows or columns

Also produced, and shown in Table 1, are the percentage of basins in a WFO HSA that are correctly forecast, under-forecast, and over-forecast. A basin accurately forecast is defined as one that is within 20 percent of its actual MAP amount. These statistics and graphical products are uploaded to the SERFC Web Site.

FINDINGS

QPF verification statistics have only been computed at the SERFC since July 1997. Therefore, the findings are inconclusive at this point. However, some unexpected trends have been noted over the past year, under different weather systems.

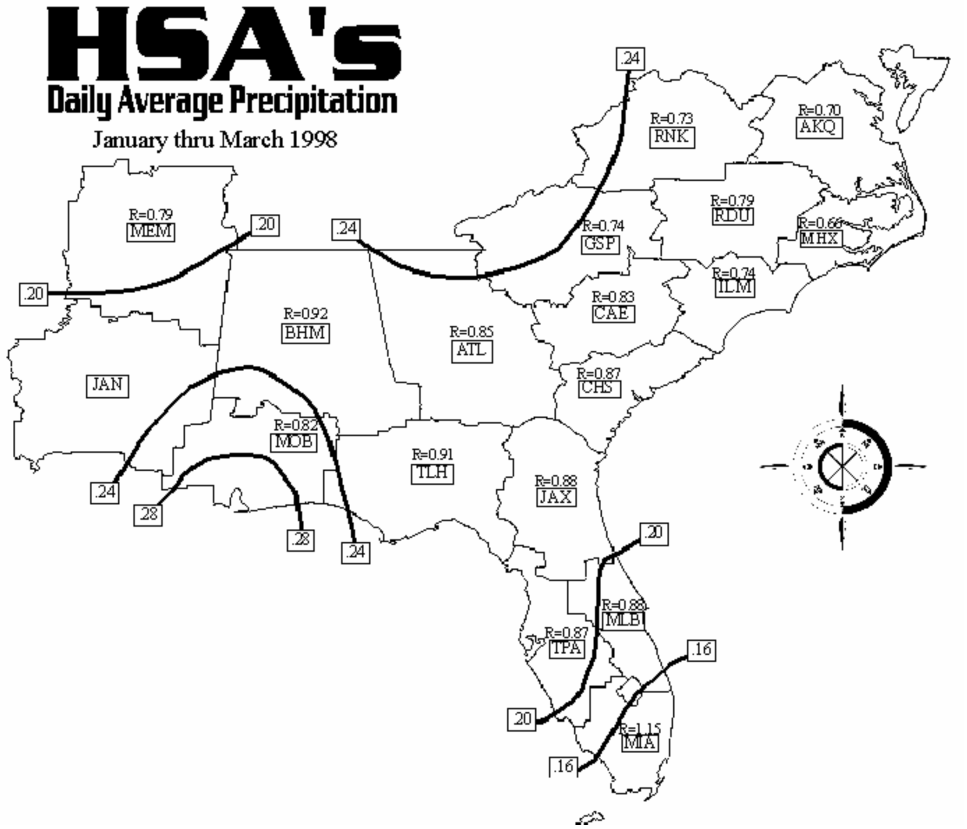
Weather Discussion

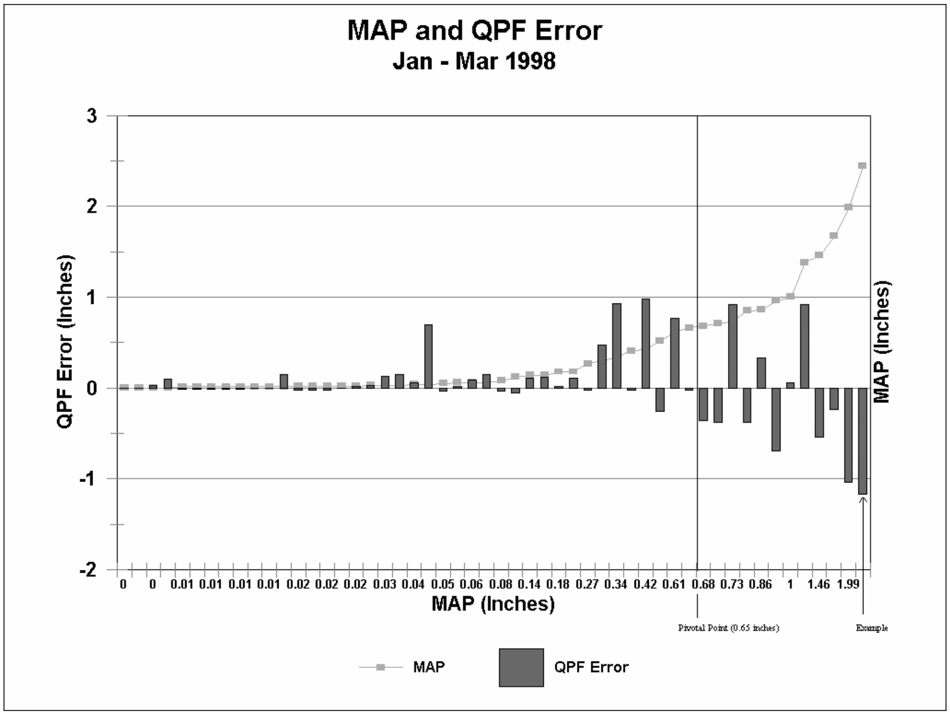
The climate in the Southeastern United States proved to be a highly variable one during 1998. Weather conditions ranged from extremely wet during the winter, due to the effects of El Niño, to drought conditions in spring and early summer. Late summer and early fall brought tropical weather and hurricanes into the Southeast U.S., and late fall brought drought conditions once again.

In the winter of 1998, El Niño was responsible for a very active southern jet stream. The southern branch of the jet stream had mostly a zonal and rapid flow from the Pacific through Mexico to the Gulf of Mexico. From the Gulf it veered northeast, focusing energy over the Gulf and Southeastern United States. Repeated cyclogenesis in the Gulf brought a progressive series of low pressure systems into the southeast. These low

Table 1. QPF Verification for the WFOs in the SERFC Area of Responsibility for 1998. Shown is the Heidke Skill Score (HSS), the percentage of basins accurately forecast, under-forecast, and over-forecast, the Mean Absolute Error (MAE), the Root Mean Square Error, and the Zero QPF Root Mean Square Error.

WFO		AVG MAP	AVG QPF	# OF BASINS	HSS	% QPF HITS	% QPF UNDER	% QPF OVER	MAE	RMSE	ZERO QPF RMSE
Wakefield, VA	AKQ	0.13	0.11	5	0.62	69.64	14.96	15.4	0.1	0.11	0.14
Atlanta, GA	ATL	0.15	0.15	37	0.44	65.94	12.9	21.15	0.12	0.15	0.19
Birmingham, AL	BHM	0.15	0.18	40	0.45	65.57	11.99	22.44	0.14	0.17	0.19
Columbia, SC	CAE	0.14	0.14	24	0.53	72.88	12.26	14.86	0.11	0.13	0.16
Charleston, SC	CHS	0.15	0.16	10	0.51	66.05	12.22	21.73	0.14	0.16	0.17
Greenville, SC	GSP	0.16	0.14	22	0.46	68.66	16.12	15.22	0.12	0.16	0.19
Wilmington, NC	ILM	0.15	0.16	16	0.5	66.02	12.41	21.6	0.13	0.15	0.18
Jacksonville, FL	JAX	0.15	0.16	12	0.48	63.22	11.89	24.88	0.15	0.18	0.19
Memphis, TN	MEM	0.15	0.18	21	0.52	64.76	12.9	22.34	0.14	0.16	0.17
Newport, NC	MHX	0.15	0.17	5	0.52	63.29	14.41	22.3	0.14	0.15	0.16
Miami, FL	MIA	0.16	0.23	12	0.37	56.32	12.44	31.23	0.2	0.23	0.19
Melbourne, FL	MLB	0.14	0.19	10	0.39	60.16	11.64	28.19	0.15	0.18	0.17
Mobile, AL	MOB	0.19	0.21	18	0.46	64.44	14.25	21.31	0.16	0.19	0.23
Raleigh, NC	RDU	0.14	0.15	29	0.45	66.76	13.63	19.6	0.13	0.16	0.17
Roanoke, VA	RNK	0.13	0.12	20	0.44	66.74	13.79	19.47	0.11	0.13	0.16
Tampa, FL	TBW	0.15	0.19	20	0.44	61.4	10.48	28.12	0.15	0.18	0.18
Tallahassee, FL	TLH	0.16	0.15	35	0.47	67.02	13.41	19.57	0.14	0.18	0.21





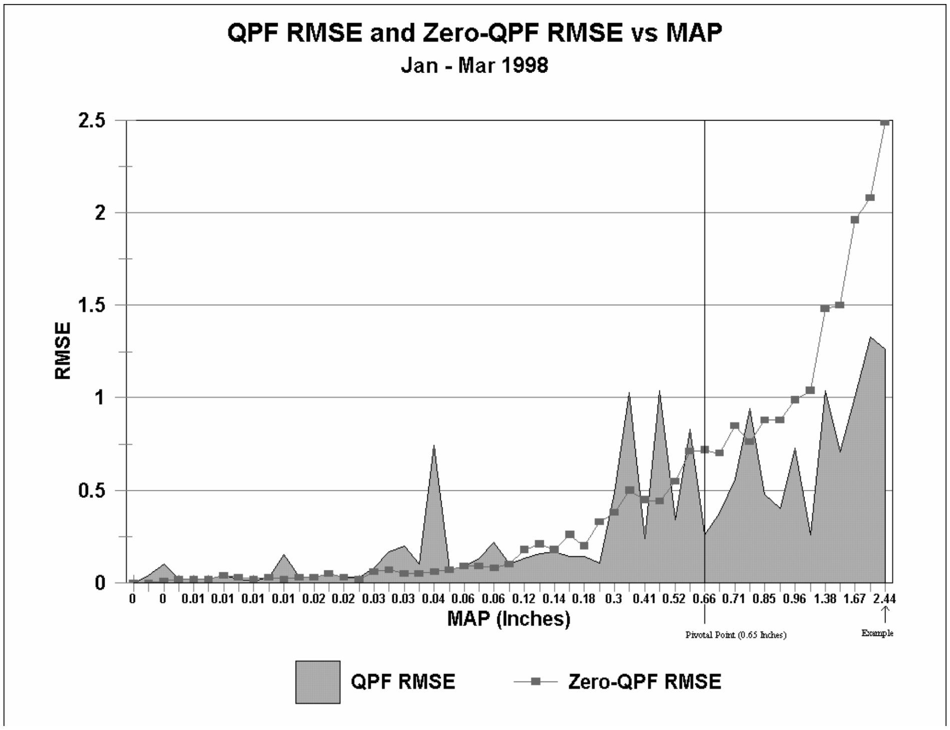


Figure 1. Average daily MAP in the Southeastern United States and R-Score (R) for each WFO.

Figure 2. Daily MAP and QPF Error averaged over all 37 basins in the WFO Atlanta HSA.

Figure 3. Daily QPF Root Mean Square Error versus Zero-QPF Root Mean Square Error averaged for all 37 basins in the WFO Atlanta HSA.

pressure systems tended to move from the Gulf of Mexico into the gulf coast near Mobile, Alabama, then finally up the Atlantic East Coast. Each system brought very heavy rainfall to the gulf coast and Appalachian Mountain areas and severe weather to Florida. At one point over 80 percent of the river forecast points in the SERFC area of responsibility were in flood. This weather pattern began in late December and ended abruptly in April when drought conditions began to develop.

QPF Verification Findings

Figure 1 depicts the average daily MAP and the R-Score for each WFO HSA. Figures 2 and 3 show QPF verification, averaged over all 37 basins in the WFO Atlanta HSA, from January 1 to March 31, 1998. The x-axis is sorted by daily average MAP. It was noted in nearly all cases that there was an over-forecasting of QPF in light rain events and an under-forecasting in heavy rain events (Figure 2). For the Atlanta WFO area (ATL), the pivotal point was around an average observed MAP value of 0.65 inches. At this value of rain, events producing an average MAP of less than 0.65 inches had been over-forecast and rain events bringing an average MAP of more than 0.65 inches had been under-forecast. In general, light rain events occur more often than heavy rain events. Therefore, it has been found through 1998 that QPF was overestimated by most of the WFOs.

Figure 3 tries to prove that streamflow forecasts are better off with QPF added by comparing daily QPF RMSE for the WFO Atlanta HSA and the RMSE (Zero-QPF RMSE) for the same area with the QPF entered as zero. The x-axis is sorted by daily average MAP. The shaded areas of QPF RMSE above the Zero-QPF RMSE line show a "busted" forecast, since a more accurate forecast would have been one with the QPF entered as zero on that day. Shaded areas above the zero QPF RMSE line is an over-forecast rain event. These "busted forecasts" most often happened when the MAP was less than the "pivotal point" of 0.65 inches. The rain events producing more than 0.65 inches of MAP had mostly lower QPF RMSE than the respective Zero-QPF forecast. For example, the highest average MAP for the WFO Atlanta basins was 2.44 inches, which fell between 12z on February 3rd and 12z on February 4th. WFO Atlanta issued an average QPF for its HSA at 12z on February 3rd of 1.27 inches. This resulted in an under-forecast QPF for its HSA by 1.17 inches (Figure 2, last plotted point on right). Looking at Figure 3, last plotted point on the right, the WFO Atlanta's QPF RMSE was 1.26. If WFO Atlanta had entered all zeros for its QPF or had not done a QPF at all, the RMSE (Zero-QPF RMSE) would have been 2.49, which is higher than its actual QPF RMSE. Thus proving that, on that day, the use of QPF added value to the streamflow forecast.

High QPF skill is most needed during heavier rain events. During these heavier rain events, river forecasts based on QPF are clearly better than those based on zero QPF.

For other areas across the Southeast U.S., the "pivotal points" were variable and ranged anywhere from 0.15 to 0.7 inches of average daily MAP, depending on season and predominant weather in that season.

Table 1 shows statistics used for each WFO's QPF verification for 1998. It is better to have an overall QPF RMSE less than its Zero-QPF RMSE. In most cases for 1998 this was true; however, in areas where convection was the predominant weather throughout the year, the QPF RMSE tended to be higher, such as central and south Florida. In fact, during the seasons when convection was the primary rain maker, the QPF RMSE was higher across the entire Southeast U.S. All of the QPF RMSEs were lower during the very wet winter than in the dry spring or summer.

Higher RMSEs for convective weather events are the result of the wide variability in rain amounts from basin to basin. It is extremely difficult for a meteorologist to determine the exact basins for which heavy precipitation is going to occur during typical afternoon type convection. The forecaster can only make a general estimate of where convection is likely to occur and will usually broad brush the area with an estimated average. Weather forecast accuracy decreases with time, however, it was noted that the worst QPF errors were not in the latest six-hour period, as a meteorologist would naturally assume, but in the second six-hour period, from 18z to 00z, when the most afternoon convection occurs.

In addition, the RMSE method also penalizes the convective rain events because it causes badly missed basins to stand out more. It is common for almost all basins to be correctly forecast and one or two to be missed badly in a convective situation. Those missed basins would have more of an effect on QPF RMSE than if the absolute of the error rate was simply averaged. This is shown in Figure 2 on the Zero-QPF RMSE line. The mean absolute error would just equal the average MAP. However, the line does not increase steadily. The peaks are the result of higher variability in MAP amounts across the basins.

Figure 1 is a winter map analyzed for average MAP and the R-Score displayed by its respective WFO. The heaviest amount of rain fell around the Mobile Bay area (0.28 in.) and the lightest fell across south Florida and northern Mississippi. R-Scores were the best in the Carolinas and worst in Florida. Stratiform precipitation, mainly over-running situations, predominated in the Carolinas, with MAP being uniformly distributed across the basins, and thus was easier to forecast. Convective type precipitation, due mostly to thunderstorms and squally type weather, predominated in Florida.

Another interesting observation in day-to-day QPF verification is the overemphasis on areal coverage. In many heavy rain events, it was common to see amounts under-forecast where the heaviest rain fell, and bordering areas over-forecast. This happened mostly with hurricanes or strong low pressure systems, where the heaviest rain tended to be tightly packed in an area. An example of this is shown in Figure 1. During the winter, the heaviest total seasonal precipitation was centered in WFO Mobile's HSA, due to the continuous onslaught of low pressure systems moving northeast into that area from the Gulf of Mexico. WFO Mobile's R-score was 0.82, while bordering WFOs Birmingham and Tallahassee had a higher R-Score (higher error rate) of 0.92 and 0.91, respectively. The higher error rate was due to the overextending of the heavy rain forecast.

RECOMMENDATIONS AND CONCLUSIONS

For 1998, QPF verification statistics show over-forecasting of convective and sea-breeze type weather across most WFOs. It is hard for forecasters to lower QPF amounts across their area when they see isolated heavy rain amounts occurring. However, it is recommended for forecasters to see a comparison of the their QPF and what actually occurred each day. Such a page exists at the SERFC Web Site and is updated each day. Seasonal QPF verification statistics are also uploaded soon after the season ends. Forecasters should make note of their "pivotal point" and adjust their QPF accordingly, i.e., lower their QPF forecast when they expect values to be lower than their "pivotal point." Another "rule of thumb," to reduce QPF for convective weather events, is to multiply the maximum amount of rain expected out of showers and thunderstorms by the probability of precipitation, thereby lowering their QPF (Amburn et al., 1993).

QPF = (Probability of Precipitation) * (Precipitation Rate in Inches per Hour) * (Duration in Hours)

Tighter QPF gradients also need to be used for tropical storm type weather. This is difficult until a forecaster knows where the heaviest rain is going to occur. Therefore, more frequently updated QPF forecasts (every six hours) should be issued during heavy rain events. Many variables can affect the WFO's verification results in different ways, such as number of basins considered, predominate weather, season, accuracy of the computed MAP, etc. Therefore, in assessing a forecaster's skill, only surrounding WFO verification results should be used. Better yet, forecasters should compare their own WFO's results over time to measure their performance.

SERFC INTERNET WEB SITE

www.nwsserfc.noaa.gov

For specific Internet addresses, please e-mail, jack.bushong@noaa.gov.

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