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STATISTICAL COMPARISON OF MEAN AREAL PRECIPITATION ESTIMATES FROM WSR-88D, OPERATIONAL AND HISTORICAL GAGE NETWORKS

Dahong Wang*, Michael B. Smith, Ziya Zhang, Seann Reed, Victor I. Koren
Hydrologic Research Laboratory, National Weather Service, NOAA, Silver Spring, Maryland

1. INTRODUCTION

The National Weather Service River Forecast System (NWSRFS) is a comprehensive set of models and hydrologic techniques used by the National Weather Service (NWS) River Forecast Centers (RFC) to conduct hydrologic forecasting. The Sacramento Soil Moisture Accounting (SAC-SMA) model (Burnash et al.,1973), which uses mean areal precipitation (MAP) input and outputs runoff, is an important component of the prediction program in the NWSRFS (Fread et al, 1995).

The MAP estimates can be generated using precipitation data from three types of observations. The RFC operates the Weather Surveillance Radar 1988-Doppler (WSR88-D) to produce high resolution gridded precipitation estimates at a 4X4 km^2 spatial scale and a 1-hr time step. The RFC also operates a rain gage network to (Hudlow, 1988) produce observed precipitation in 6-hr time step. National Climatic Data Center (NCDC) operates a recording rain gage network to provide historic precipitation data in a 1–hr time step. This paper describes a detailed analysis of model input MAPs from the WSR88-D radar data (MAPX), RFC's operational rain gage data (MAPO) and NCDC's historic rain gage data (MAPH), as well as effect of these MAPs on model performance.

Smith et al. (1999) have discussed the SAC-SMA model performance using both the radar MAPX and MAP data over the Arkansas-Red Basin. The model runoff output showed that the MAPX-forced simulations performed better than the gage-forced simulations. Similar research has been done by Borga et al. (1998) on statistical analysis of radar rainfall and runoff simulation on six flood events for two medium size watersheds in northern Italy, and the radar rainfall was found to preclude the more accurate simulation of runoff.

This work is aimed at providing insight for evaluating the SAC-SMA model performance when it is used to simulate river runoff with radar-based MAPX and gage MAPO and MAPH estimates. Insights gained from this study might be useful in developing tools and procedures to enable River Forecasting Center (RFC) personnel to more effectively use the NEXRAD data for short-term hydrologic forecasting.

2. STUDY BASINS AND DATA

Eight basins in the region near the Oklahoma-Arkansas-Missouri state boundaries, shown in Figure 1, are selected for this study. The basins in the study are generally in the foothills of the Ozark mountains of NW Arkansas and SW Missouri. Rolling hills predominate with elevations, generally ranging from 800 feet to 1500 feet. The highest elevations occur in the eastern most areas. Land use cover is a mix of forests and grasslands used for grazing, with forests increasing in amount as one moves to the east. The basins are generally rural in character with little in the way of any towns more than 2500 people. Rainfall is generally distributed well throughout the year with a slight maximum in the spring. Average annual rainfall is 40 to 45 inches. The rain gages used to compute the operational MAP data and radar locations are also shown in Figure 1.

This region is analyzed because of its dense gage network, six overlapping radar umbrellas, and one of the longest available periods of archived NEXRAD radar products in the United States. The study period is from June 1, 1993 to December 31, 1997. The 6-hr operational MAPO data, 1-hr historic MAPH data and 1-hr radar-based MAPX data for all eight basins are used during this period, which are archived at the NWS Hydrologic Research Laboratory (HRL).

* *Corresponding author address:* David Wang, Hydrologic Research Laboratory, 1325 East-west Hwy, Suite 8300, Silver Spring, MD20910; e-mail: david.wang@noaa.gov

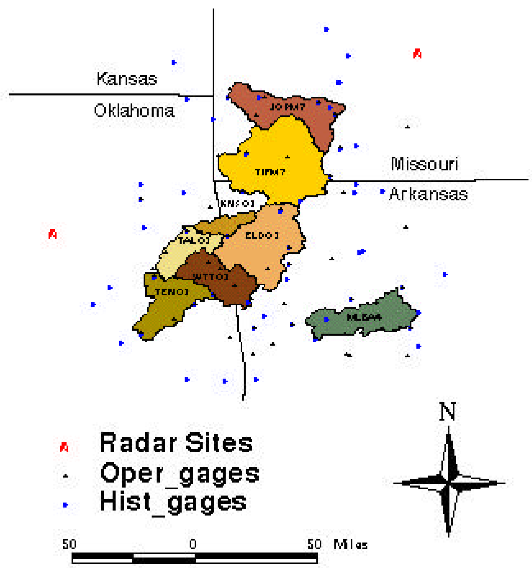


Figure 1. The study basins with the radar, operational and historic gage location.

MAP data are computed by the MAP operational preprocessor in the HRL. The details of this operational procedure can be found in the NW S (NWSRFC User's Manual, 1976).

MAPO data are derived from an operational network of precipitation gages, in which gages report at a variety of time steps, most commonly 1, 3, 6, and 24 hours. Rainfall reports from different gages are accumulated to derive daily totals. Missing data are estimated from surrounding gages using $1/d^2$ weighting method. A daily MAP is computed by using Thiessen polygon method, then distributed into 6 hour periods based on the precipitation values of the recording gage closest to the centroid of the basin in each of 4 quadrants.

The radar-based MAPX estimates are generated from the radar data processed using two algorithms: Stage III or Process 1 (P1). Both methods use the same basic input: the hourly digital precipitation product (HDP) computed by each radar within the ABRFC's area, and hourly rain gauge reports. The MAPX estimates before June 15, 1996 are derived from the Stage III, and those thereafter are derived from either the Stage III or P1. Stage III was created by the HRL. It is a merged radar-gage precipitation field design to provide the spatial resolution of radar data while preserving the precipitation accumulations measured by gages (Seo et al., 1995; Finnerty et al., 1997). In this process, the raw reflectivity data produced from the radar sites is transformed into precipitation estimates by using a standard Z-R power law relationship (Fulton, et al., 1998). The gage measurements assumed as "ground truth" are then utilized to remove a mean field bias in the radar precipitation estimates. The overlapping radar fields are merged in a gridded system known as Hydrologic Rainfall Analysis Project (HRAP) to generate the Stage III products (Greene and Hudlow, 1982). P1 is developed from the US Army Corps of Engineers (COE)'s Rain program. It has many of the same features of Stage III, including editing or removing the bad gages, inserting pseudo gages, and removing anomalous propagation. Basically P1 makes a contour map of the rainfall from reporting gages and adjusts the raw mosaiced radar field accordingly. A mosaic of all the hourly HDPs are created by combining them into one product that covers the entire ABRFC basin. Where radar fields overlap, the average value is taken. A collection of all hourly reporting rainfall amounts from gauge sites is also created. An irregular triangulated grid field is created by using the locations of the gauge sites. The radar mosaic is overlaid on this triangulated grid and a bias field is created based on the difference between the radar field value and the gauge field value. Where there is no gauge site, a bias is computed using the triangular grid and the distance from the nearest gauge sites. The resultant bias field is then used to create the final precipitation product. P1 works well when there are numerous gauge sites available, otherwise the fields tend to get spread out too much based on the large triangular grids created.

MAPH data are derived from a historic network of precipitation gages which is operated by the NCDC. Totally 63 rain gages over the study region are used to compute MAPH by using Thiessen polygon method. Quality control procedures are applied not only to the raw data but also at various stages of calculation process. The most important check is the effects of man-made changes to the station, such as relocation of station, equipment changes. Effects of these man-made changes are reduced by the implementation of a graphical interactive procedure called the Interactive Double Mass Analysis (IDMA).

In this study, the 1-hr MAPX and 1-hr MAPH are summed to derive a 6-hr MAPX and MAPH so that three MAPs are in the same time step. Analyses are conducted based on these 6-hr MAP and MAPX values. For the comparison analyses of MAPX, MAPO and MAPH, the missing data as well as their matched mates are removed.

3. RESULT AND ANALYSIS

In general, the radar-based MAPX are in good agreement with the gauged MAPO for most of the basins. This is borne out by analyzing the long-term average ratios of MAPX value to MAPO and value, which are listed in Table 1. The overall ratio of MAPX to MAPO for all eight basins is 1.004. The basin KNSO2 had cumulative MAPX values that were slightly higher than the MAPO value, while the cumulative MAPX values over the basin TIFM7, WTTO2, and MLBA4 are in good agreement with the MAPO values over the study period. The reminder of the basins have MAPX values being lower than MAPO values at a range of 3~6%.

Table 1. Overall averaged 6-hr MAP estimates (mm) for radar, operational and historic observations

BASIN	Average 6-hr Precipitation (mm)		
	MAPX	MAPO	MAPH
JOPM7	0.759	0.803	0.773
TIFM7	0.844	0.848	0.809
KNSO2	0.743	0.666	0.773
ELDO2	0.814	0.882	0.803
TALO2	0.764	0.803	0.780
WTTO2	0.760	0.751	0.772
TENO2	0.826	0.878	0.793
MLBA4	0.860	0.837	0.800
Average	0.796	0.809	0.788

The long-term MAPH values is lower than MAPO, its average ratio over eight basins is 0.974. The KNSO2 and WTTO2 are only basins with high MAPH values. Table 1 also reveals that MAPX is lower than MAPO but higher than MAPH.

The effect of applying P1 algorithm for MAPX processing is noted from a time series analysis. It caused overestimation of annual averaged 6-hr MAPX for most of the basins since June 15, 1996. The 6-hr MAPX and MAPO analysis, including mean, standard deviation, coefficient of variation, and bias, before and after the P1 algorithm was applied, are studied. The MAPX values before June 15, 1996 over most of the basins were underestimated and the only exception existed in the basin KNSO2. The relative bias for KNSO2 is positive, 6.59%, while they are negative for all other basins, varying from –2.03 to –14.12%. The relative mean bias became positive for all basins but TANO2 after June 15, 1996.

In order further to evaluate MAPX performance in time series, 12-month moving average monthly biases over the eight study basins are studied in moving time series, the plot over ELDO2 is shown in Figure 2. These monthly biases are calculated by averaging the previous 12-month monthly biases. Therefore, the bias in 11/1994 is calculated by averaging monthly bias in a period of 12/1993 to 11/1994. Figure 2 also reveals that a systemic underestimation of MAPX values existed over ELDO2 before summer 1996, thereafter MAPX values were overestimated.

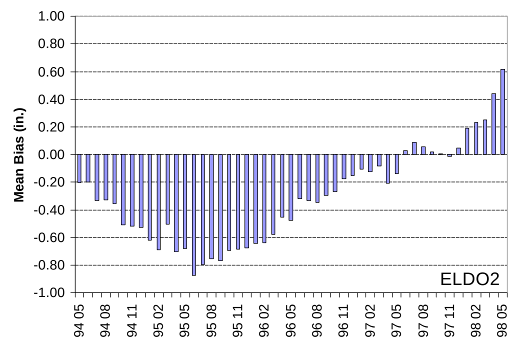


Figure 2. 12-month moving average monthly bias in time series over ELDO2.

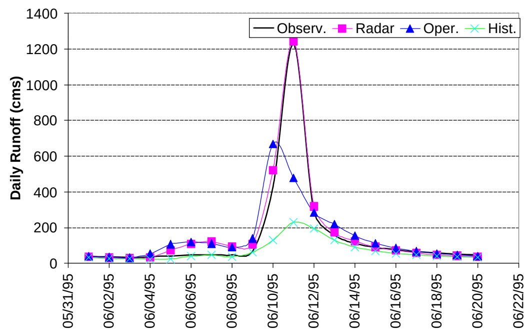
The time series analysis has revealed that the basin KNSO2 is an exception with a positive bias when using the stage III algorithm. The possible reasons include the "ground truth" gage density and Biscan Maximization (BM) procedure (Seo et al., 1995).

In order to evaluate the hydrological effects of the three MAPs, streasmflow simulations were performed using SAC-SMA model for TIFM7. The SAC-SMA is a conceptual model consisting of several tension water and free water reservoirs representing the active portion of the soil. Unit hydrographs are used to transform runoff volumes to discharges. Parameters for the SAC-SMA were derived through manual calibration using historic gage-derived MAP time series and observed mean-daily flow from the US Geological Survey.

The plot of the observed and discharge hydrographs for an event in June, 1995 in Figure 3 reveals that the MAPX-forced simulation produced a perfect match with the observation,

Figure 3. Simulated and observed hydrograph for event of June 1995.

and it is far better than both MAPO and MAPH-



forced simulation. For this case, some parts of the basin only might receive little precipitation so that gage observation misrepresented the event. Statistical analysis of three simulations vs observation reveals that percent bias of MAPX simulation is -9.98%, while MAPO and MAPH simulations are -14.72% and -17.73 respectively.

4 CONCLUSIONS

The radar-based MAPX values are in very good agreement with the gauged MAPs for most of the study basins. The overall ratio of MAPX to MAPO for all eight basins is 1.004. The long-term MAPH values is lower than MAPO, its average ratio over eight basins is 0.974. Time series analysis has revealed that MAPX estimates are strongly affected by processing algorithms. The Stage III tends to underestimate MAPX while a mixed use of P1 and Stage III tends to overestimate them. The MAPX-forced simulation to produce runoff is far better than both MAPO and MAPH-forced simulation. The MAPX, MAPO and MAPH-forced simulations are with percent bias of -9.98%, -14.72% and -17.73.

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