THE EFFECTS OF RAINFALL NETWORK DENSITY ON RIVER FORECASTS – A CASE STUDY IN THE ST. JOHNS BASIN

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Abstract. A hydrometeorological study is conducted for large and small sub-basins of the lower St. Johns River in Florida during September 2001. A gauge-only precipitation data set and a gauge+radar merged precipitation data set each are inserted into the River Forecast Center's (RFC's) Interactive Forecast Program (IFP) hydrologic model to compare Mean Areal Precipitation (MAP) and simulated streamflows from the two precipitation products. Two different gauge densities also are tested to show the dependence on gauge quantity.

Two watersheds are examined – Geneva (2035 mi^2) and Wekiva River (~210 mi^2). Although the two basins differ in size and river response, the results from each clearly reveal the advantage of having a dense gauge network. However, blending gauge-derived precipitation data with radar-derived data does not necessarily produce the best-simulated streamflow.

INTRODUCTION

Accurate information about the distribution of precipitation over a basin is vital to successful hydrologic forecasting. Gauges are the traditional data source for this purpose; however, it is very difficult to maintain a gauge network that will adequately sample rainfall. Radar remote sensing has a distinct advantage in this regard (e.g., Stellman et al. 2000). The National Weather Service River Forecast Centers (RFCs) recently implemented the Multisensor Precipitation Estimator (or MPE), which combines radar-derived estimates with rain gauges. MPE produces hourly rainfall estimates on a 4x4 km grid.

This paper describes rainfall and streamflow from gauges and from MPE during September 2001, when Tropical Storm Gabrielle produced intense precipitation over the St. Johns basin of Florida, leading to a major rise in the river. We investigate the potential for improvements in river forecasting from using dense gauge networks and the MPE method.

METHODOLOGY

Hourly gauge and radar data for September 2001 were input to the MPE algorithm. The St. Johns Water Management District and the South Florida Water Management District provided the dense gauge network (Fig. 1), a total of 456 gauges (~ one gauge every 15 km). The Southeast RFC provided 130 gauges in Florida, the sparse network (Fig. 1). Quality Control procedures were applied to each data set.

The Multi-sensor mosaicked precipitation array (MMOSAIC) is the final product of the MPE algorithm. MMOSAIC merges gauge data with a bias corrected radar field using an optimal estimation procedure. Specifically, the value at a particular grid cell is determined by weighting the gauge and radar values in the vicinity of that cell. Gauge observations are considered to be "ground truth". Heavy weight from a gauge amount is placed on grid cells near that gauge. The weight assigned to the bias corrected radar estimate increases as a function of its distance from the nearest gauge (Breidenbach et al. 2001). The Theissen Polygon method (PMOSAIC) is the gauge-only procedure that we tested against MMOSAIC. The closest available gauge exclusively determines each 4x4 km grid coordinate's precipitation value.

The National Weather Service River Forecast System (NWSRFS) is a collection of hydrologic models that processes the precipitation data and calibrated parameters (e.g., Unit Hydrographs and Sacramento Soil Moisture Accounting model – SACSMA) to simulate river flows and stages (Hydrology Laboratory 2002). Pre-processing allows the NWSRFS user to convert the hourly 4x4 km precipitation files into 1-hourly lumped basin Mean Areal Precipitation (MAP). Output from the Operational Forecast System (OFS) short-term river forecast modeling portion of the NWSRFS consists of 6-hourly simulated streamflows, which are driven by 6-hourly MAP and calibrated model parameters.

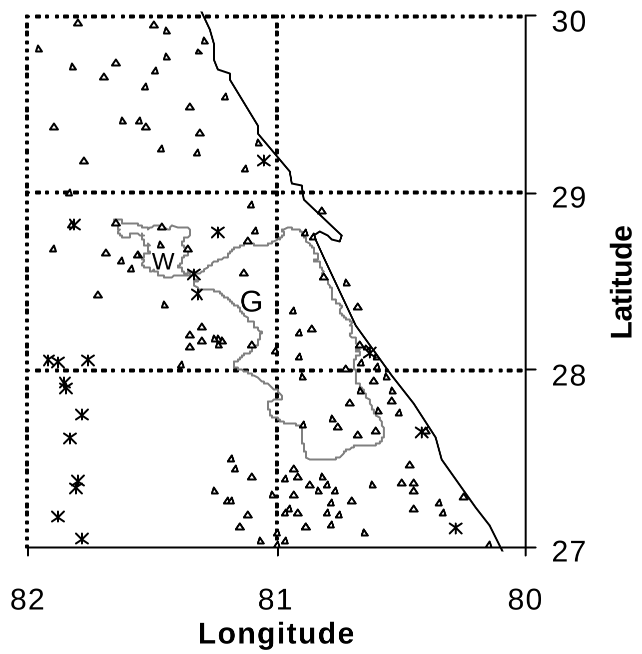

Figure 1. Wekiva River (W) and Geneva (G) basins are outlined. The dense network (WMD gauges) is shown as triangles, and sparse network is shown as asterisks.

LARGE HEADWATER BASIN – GENEVA

Cumulative sums of MAP in the Geneva headwater were computed from each precipitation product (Fig. 2a) at 6-h intervals between 12 UTC September 10 and 12 UTC September 27, 2001. Most precipitation occurs between Sept. 12 and 16 because of Tropical Storm Gabrielle coupled with onshore easterly flow in advance of Gabrielle. Some individual gauges register up to 10 in. of total rainfall during the 4-day period. Total MAP accumulations over the 17-day period exceed 7 in. for the sparse PMOSAIC method and half that with the sparse MMOSAIC method. When the dense WMD gauge information is used, differences in MAP from PMOSAIC and MMOSAIC are less than 1 in. during the entire period. Rainfall timing generally is similar among the data sources. However, close examination near Sept. 12 reveals some differences.

The resulting simulated streamflows in the Geneva watershed (Fig. 2b) exhibit large differences among the different MAP inputs. The observed peak stage is 8.6 ft. Peak simulated river stages range from 7.3 ft for MMOSAIC's sparse network to 10.0 ft for PMOSAIC's sparse network.

The peak stage from PMOSAIC's dense network matches the observed peak; however, all simulated stages underestimate the observed stage by 0.5 ft on Sept. 10. It is important to note that precipitation from Stage III data (Breidenbach et al. 1998) was input to NWSRFS prior to Sept. 10 to compute the initial simulated stages shown. SACSMA simulations are based primarily on layered soil moistures, and not enough tension water exists throughout the simulations to produce streamflow forecasts that resemble the observed. Similar underestimates have been found in operational streamflow forecasting for the Geneva watershed.

Considering the initial difference between simulated and observed stages, it appears that the dense gauge PMOSAIC and MMOSAIC are the best performers. MMOSAIC simulations may exhibit slight underestimates attributed to truncation errors in the PPS algorithm (Hydrology Laboratory 2000). The underestimation is reduced with the use of the dense gauge network, but minor underestimates can still exist even with abundant gauges, especially where the radar does not detect precipitation.

It should be noted that sparse gauge data alone were used to determine the unit hydrographs and SACSMA parameters before OFS was run. Calibration using MMOSAIC and a dense gauge network may provide better results. This calibration likely would change the results in Fig. 2b. A long record of MMOSAIC data will be required to calibrate NWSRFS parameters using MMOSAIC data.

SMALL HEADWATER BASIN – WEKIVA RIVER

Cumulative sums of MAP in the Wekiva River headwater (Fig. 3a) were computed at 6-h intervals between 12 UTC Sept. 10 and 12 UTC Sept. 27. Greatest precipitation again occurs between Sept. 12 and 16. Total accumulations over the 17-day period are similar to MAP accumulations for the Geneva watershed, ranging from 4 in. for MMOSAIC's sparse network to 7.5 in. for PMOSAIC's sparse network. One should note the large MAP increase on Sept. 22 when RFC gauges are used for PMOSAIC. An isolated thunderstorm produced over 1 in. of rain at a single gauge location. As a result of very few gauges near the Wekiva River watershed, MAP calculations were almost totally dependent on this one gauge with a copious rain amount. MMOSAIC's sparse network does not show that same spike because MMOSAIC uses gauge corrected radar data throughout the basin.

Simulations for the Wekiva River (Fig. 3b) show that all four forecast stages differ by less than 1 ft. This is mainly attributed to the small area of the watershed. The MMOSAIC sparse and dense networks slightly underestimate the peak, with the dense network providing the better results. Again, radar truncation errors could be the cause of these underestimates. The PMOSAIC dense network over-estimates the peak observed river response by ~ 0.5 ft. Although the PMOSAIC sparse network surprisingly produces the best simulation for Gabrielle's uniform rain event, simulated stages rise erroneously due to the large MAP on Sept. 22. Excluding PMOSAIC sparse, all simulations show similar recessions to that of the observed response beyond Sept. 17. All simulated stages recede slightly quicker than the observed stages, probably because the unit hydrograph was based on historical data dominated by Florida convection, whereas this event was primarily stratiform. Again, calibration using MMOSAIC (and not gauges) might eliminate some of the differences between MMOSAIC simulated and observed streamflow.

SUMMARY

Two gauge densities were used in the MPE algorithm to compute precipitation estimates for MMOSAIC and PMOSAIC. Their results were input into NWSRFS to compare MAP and simulated streamflow for two different basin sizes. Dense network simulations typically performed better than those of the sparse network. However, based on these two sets of simulations, and considering calibration complications, it is unclear whether MMOSAIC based on dense gauges produces superior streamflows compared to dense PMOSAIC alone. MMOSAIC may encounter problems as a result of slight radar truncation errors. Additional cases must be studied. Also, as the MMOSAIC database is expanded, the models should be calibrated using MMOSAIC.

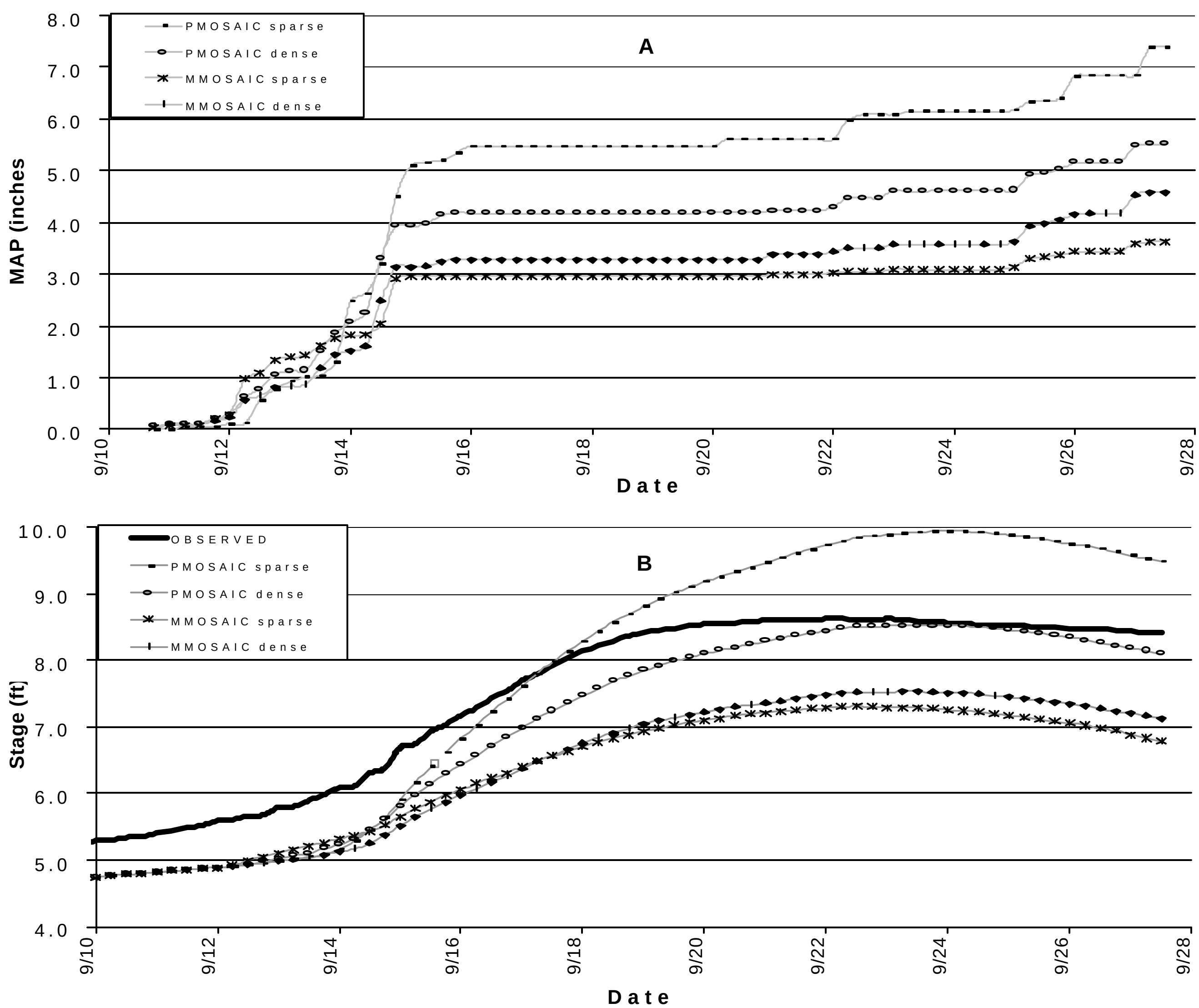

Figure 2. Geneva headwater A) accumulated MAP and B) simulated stage during September 2001.

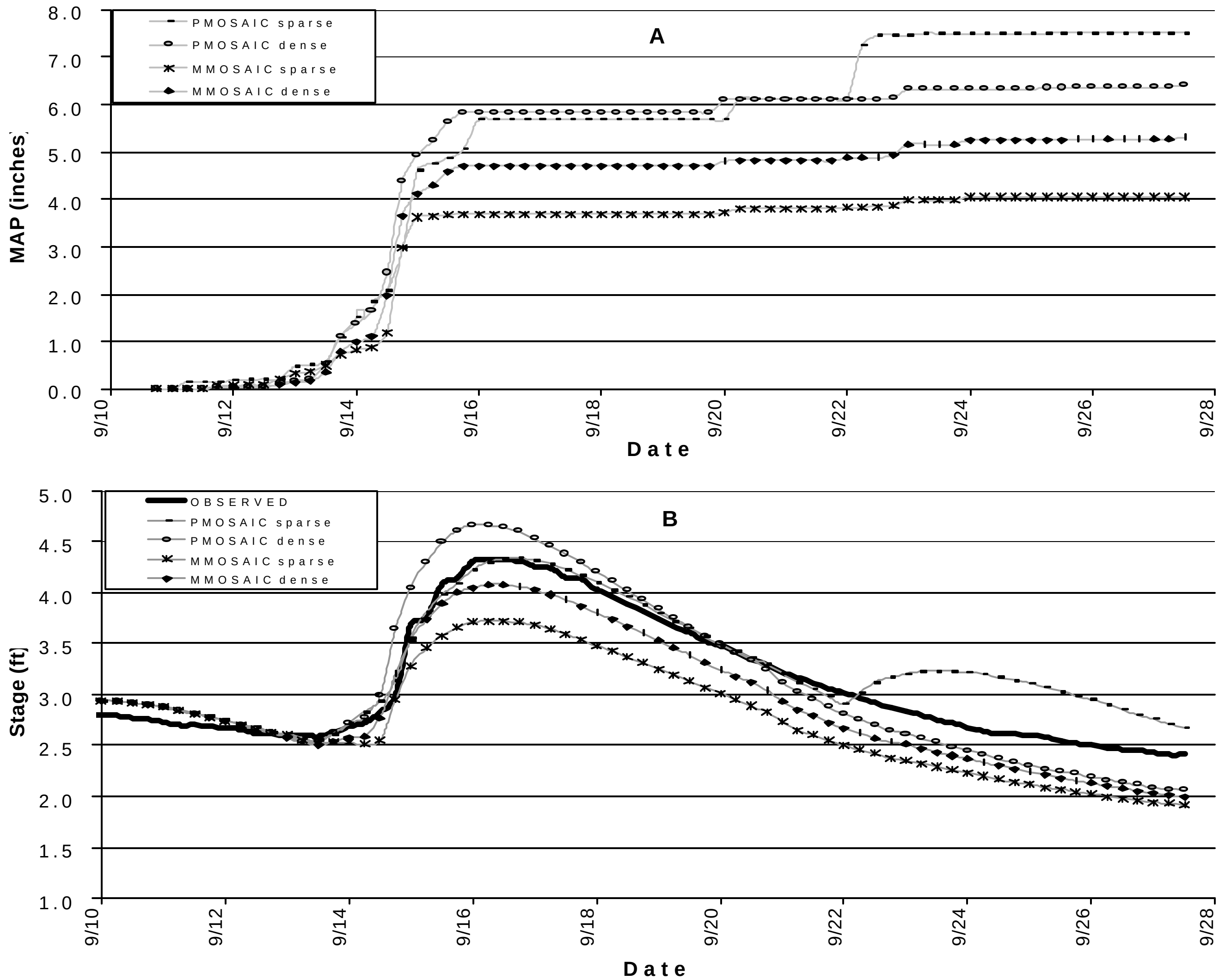

Figure 3. Wekiva River headwater A) accumulated MAP and B) simulated stage during September 2001.

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