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A COMPARISON OF EVOLVING MULTISENSOR PRECIPITATION ESTIMATION METHODS BASED ON IMPACTS ON FLOW PREDICTION USING A DISTRIBUTED HYDROLOGIC MODEL

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1. INTRODUCTION

Improving both Quantitative Precipitation Estimates (QPE) and high-resolution distributed hydrologic models is critical to the National Oceanic and Atmospheric Administration's (NOAA) mission. The experiments described herein will provide a foundation for NOAA hydrometeorological service improvements for the Tar River Basin of North Carolina, and later, much of the United States. The project will provide additional benefits to NOAA program themes in the Carolinas focusing on ecosystem and water resource management, severe storm hazards, and estuary health.

This project is a joint scientific research effort that was conducted by the Office of Oceanic and Atmospheric Research National Severe Storms Laboratory (NSSL), the National Weather Service Office (NWS) of Hydrologic Development (OHD), and the National Environmental Satellite, Data, and Information Service (NESDIS) Center for Satellite Applications and Research (STAR). These organizations are working jointly to identify an optimum set of techniques and algorithms to serve as a state-of-the-science NOAA multi-sensor QPE. A key component of this collaborative research is the scientific validation of the techniques towards operational viability.

The QPE evaluation is to be conducted in three phases: first, evaluation of precipitation algorithms in post-case analysis in terms of accuracy relative to a set of reference rain gauges; second, compilation of the best algorithm elements, that afford superior performance over current operational baseline QPE products; third, evaluation in terms of impact on the quality of streamflow simulations by an advanced distributed hydrologic model.

The Tar River basin in North Carolina was identified as a testbed region for several reasons. The basin and its surrounding areas feature radar and rain gauge networks that are similar to those in many hydrologically sensitive areas of the United States (see Fig. 1). Furthermore, ongoing efforts at improving coupled hydrologic, hydraulic, and water quality models for both rivers and estuaries are already concentrated in the basin and Pamlico Sound. These include the Coastal and Inland Flood Observation and Warning (CI-FLOW) project, which seeks to leverage the multisensor QPE effort to improve river and flash flood forecasts for the Tar Basin. This project focuses on a number of problems related to precipitation-environment interactions including flooding, debris flow prediction, river-estuary interaction modeling, and water-quality prediction.

This conference paper provides a brief description of the evolution of the experimental project to date, initial project results in terms of accuracy of radar-only precipitation estimation techniques relative to reference rain gauge reports, and a preliminary assessment of the sensitivity of stream flow predictions in the headwaters of the basin to different precipitation inputs.

2. PRECIPITATION ESTIMATION ALGORITHM PACKAGES

Within NOAA, there are various algorithm packages to determine QPE. Each of these packages continues to evolve in response to user needs for accurate high-resolution QPE. The following synopses are presented to capture the unique approaches and features of each of these

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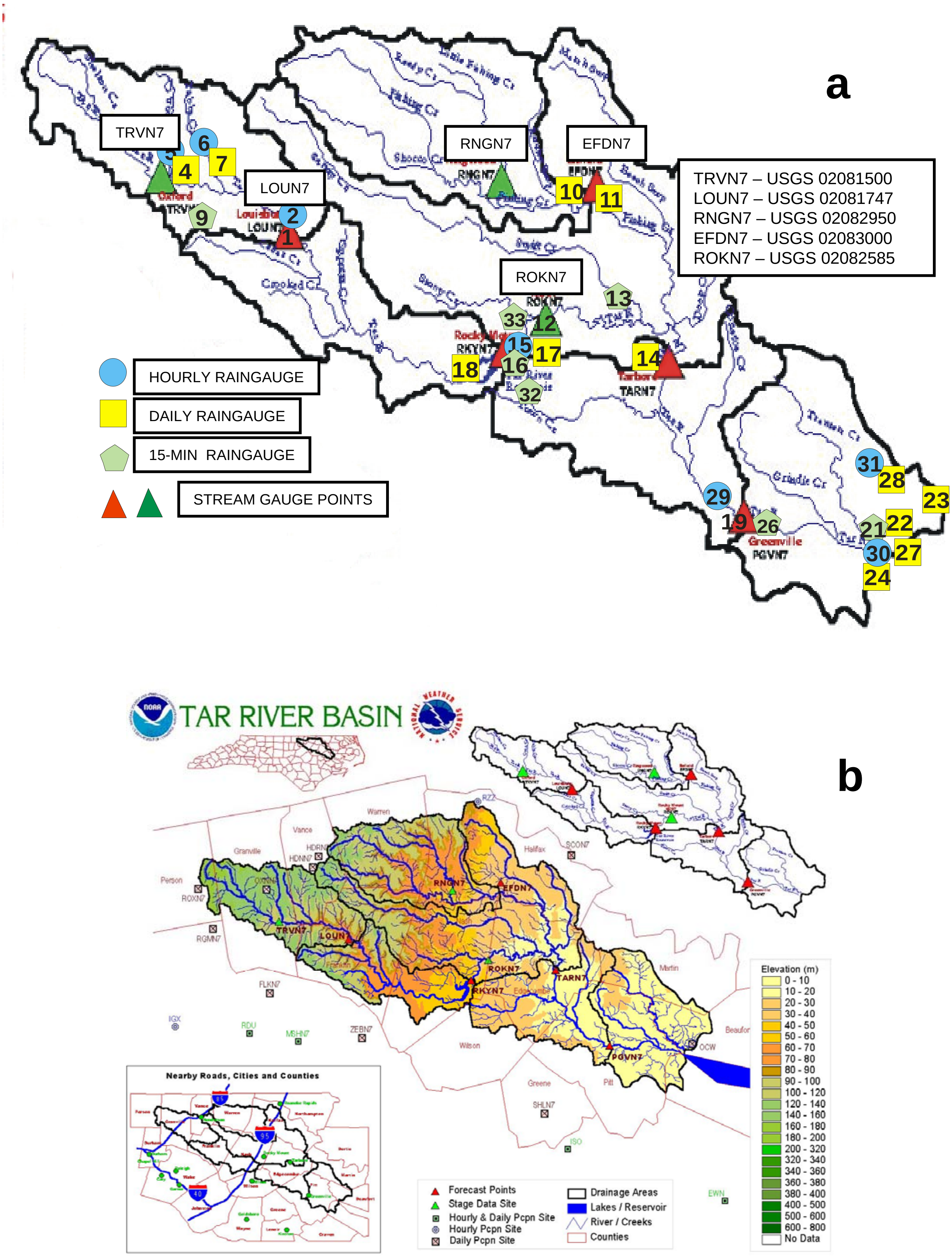


Figure 1. Tar River Basin, North Carolina (a) rain and stream gauges; (b) geography.

packages.

The ***National Mosaic and QPE (Quantitative Precipitation Estimation) (NMQ) System*** (Zhang et al, 2006; Zhang, et al; 2004; and Seo et. al., 2005) was developed from a joint initiative between the National Severe Storms Laboratory, the Federal Aviation Administration Aviation Weather Research Program, and the NOAA/ NWS /Office of Climate, Water, and Weather Services. The objective of NMQ research and development, which meets the objectives of NOAA's weather and water mission, was two fold. The first was to develop for operational utilization a seamless high-resolution national 3-D grid of radar reflectivity for data assimilation, numerical weather prediction (NWP) model verification, and aviation product development. The second was to develop fully automated multi-sensor QPE techniques at high spatial and temporal resolutions and accuracy for use in operational flash flood monitoring and prediction and water resource management.

The NMQ system is a collection of techniques and algorithms that facilitate the seamless integration of multiple radar and radar networks including WSR-88D, Terminal Doppler Weather Radar, and Canadian radar into unified 3D grid. Combining the radar 3-D grid with other remote sensing observations and model data, a suite of QPE products is produced at 1 km resolution and updates every 5 minutes. Using a combination of vertical reflectivity profiles and model analysis, the NMQ system identifies at each grid cell whether the precipitation is convective, stratiform, or tropical type and assigns appropriate Z-R relationships every five minutes to obtain a radar-based QPE product suite. Another suite of QPE products is created by applying a local gauge bias adjustment on the radar-based QPE using gauge observations. Real time QPE products for the CONUS have been available to researchers since 2007. The system is scalable and can be configured for a national implementation such as the National Centers for Environmental Prediction (NCEP) as well as regional or local offices.

Limitations: The NMQ system is a complete end-to-end system and operates independently of current NWS field-office baseline hardware and software. Though a real-time prototype is currently functional, the system is evolving and is not operational.

The ***Multisensor Precipitation Estimator (MPE)*** function within the Advanced Weather Interactive Processing System (AWIPS), which integrates rain gauge, radar, and satellite estimates into fields covering the area of responsibility for individual WFO's and RFC's. MPE includes a large suite of interactive tools for quality control (QC) of all inputs, particularly interactive and automated rain gauge QC. All rainfall estimates are interpolated to a 4-km grid and updated hourly. A new High-Resolution Precipitation Estimator (**HPE**) is under final development and undergoing field testing; HPE will create 1-km grids of precipitation rate and accumulation on a subhourly update cycle. In this experiment we have evaluated HPE radar-only estimates.

Limitations: MPE and HPE presently ingest only rainfall estimates, and do not have a capability for direct interpretation of remote sensor input (e.g. radar reflectivity, satellite radiance data). Thus improvements in MPE and HPE depend on external improvements to the algorithm output they ingest.

The ***Self-Calibrating Multivariate Precipitation Retrieval (SCaMPR) satellite algorithm:*** Satellite rainfall algorithms used for real-time operational weather forecasting at NOAA rely heavily on infrared (IR) data from geostationary satellites because forecast operations require data to be available continuously with very little delay; microwave-based rain rate estimates from polar-orbiting satellites are more accurate than estimates from IR data but are available only several times per day with a latency of several hours. The current NESDIS operational algorithm, the Hydro-Estimator (HE; Scofield and Kuligowski 2003) uses a fixed relationship between IR brightness temperatures and rainfall rates. Since this relationship in fact varies significantly among seasons, climate regimes, and storm types, an algorithm that calibrates IR data against microwave rain rates called the Self-Calibrating Multivariate Precipitation Retrieval (SCaMPR; Kuligowski 2002) has been developed at NESDIS and has been running in real time on an experimental basis since 2004. Presently, HE output is ingested by MPE, but the flexible framework of SCaMPR makes it possible to calibrate SCaMPR against MPE in regions where sufficient radar and gauge data are available, and then to apply the resulting calibration relationships in regions where only satellite data are available

Limitations: Like most passive infrared precipitation estimation techniques, SCaMPR has limited absolute accuracy, even when calibrated against a reliable source of rainfall data.

3. EXPERIMENTAL PROJECT OUTLINE

The QPE collaboration project has seen completion of several project milestones since its initiation in January 2007. These include:

1) Identification of suitable historical storm events, encompassing heavy rain events in both cold and warm seasons;
2) Creation of common radar, satellite, and rain gauge input datasets for all QPE algorithms;
3) Creation of a common set of reference rain gauge reports;
4) Execution of NMQ/Q2, MPE/HPE, and SCaMPR algorithms to produce QPEs;
5) Evaluation of precipitation algorithms in post-analysis mode, in terms of accuracy relative to the reference rain gauges;
6) Evaluation of QPE in terms of impact on the quality of streamflow simulations from an advanced distributed hydrologic model, the Research Distributed Hydrologic Model (RDHM). The RDHM (formerly HL-RMS, Koren et al. 2004)) consists of a framework integrating several components of streamflow modeling, including rainfall-runoff (Sacramento Soil Moisture Accounting), hillslope routing, and snowmelt (SNOW-17, Anderson 1976))

3.1 *Hydrometeorological events*

Three hydrometeorological events were identified during the period from 2003 to 2006, each of which featured appreciable rises in streamflow on the Tar River and its tributaries. For the initial QPE collaboration, the project focused on a cool-season period to evaluate algorithm performance outside of warm rain processes. The event selected covered the period 10 December 2004 – 15 January 2005, when several storms affected the basin. Future QPE collaboration projects are planned to evaluate QPE algorithm performance in two warm-season situations.

Input and verification data sets required by all algorithms for the cool-season case were assembled. Each case features at least one major precipitation event over a period of at least 20 days.

Selection was contingent on availability of the following data for the Tar Basin and surrounding areas:

a) Rapid Update Cycle (RUC) Model fields of surface temperature and melting level 1-hour/20-km gridded fields;

b) Level 2 Data from the following NEXRAD radars:

KRAX (NWS WFO Raleigh, NC)
KMHX (NWS WFO Morehead City, NC)
KAKQ (NWS WFO Wakefield, VA)

c) Satellite digital infrared and visible imagery (15-min/4-km data from all GOES Imager channels)
d) Meteorological in-situ data (precipitation and surface air temperature)
e) Operational MPE analyses from the Southeast River Forecast Center

3.2 *Limitations of the scope of the study*

Due to the data- and labor-intensive requirements for assessing the quality and accuracy of gauge data sets necessary for verification, it was not practical to create extensive time series of QPE grids from these algorithms for entire time period from 2003 to 2006. Rather, the project aimed to create precipitation analyses and verification datasets covering three active periods of about one month each and only for hours with precipitation over the basin. Since the first target period (a warm season event including Hurricane Isabel) was in September 2003, OHD staff executed a basic RDHM simulation was run from 1 January 2003 to 31 January 2005, using precipitation input from 1-hour operational datasets archived from the Southeast River Forecast Center's (SERFC). These datasets incorporate the MPE gauge/radar analysis with forecasters' quality control of input and output. For the selected evaluation/ comparison periods, the SERFC QPE grids were replaced with the experimental QPE grids. These simulations were then compared with time-series stream discharge observations in terms of bias, RMS error, flood peak error, and error in peak timing.

For these experiments, RDHM was configured with a 4-km polar stereographic grid mesh (the Hydrologic Research and Analysis or HRAP grid). A priori estimates of tunable parameters, such as those for the soil moisture and hillslope routing models, were used; these are based on available soil type and land-use datasets. Cell-to-cell connectivity for runoff water routing was based on evaluations of topography data from a 100-m digital elevation model.

As noted above, NMQ and MPE/HPE outputs have been created and evaluated for the cool-season case December-January 2004-2005. The results are described herein. Evaluation of the multisensor (gauge-radar and gauge-radar-satellite) products, and the SCaMPR satellite products, will follow at a later date.

4. PRECIPITATION AND TEMPERATURE INPUT FOR QPE

The NMQ and HPE algorithm packages use a common set of radar and rain gauge inputs. In addition, the NMQ requires an externally supplied estimate of freezing level, used in Z-R corrections. The inputs and processing steps are described below.

4.1 *Radar input and products:*

Radar input to NMQ and HPE QPE algorithms consisted of WSR-88D level II reflectivity (1° x 1km horizontal resolution), and multiple elevation angles, from sites KRAX (Raleigh NC), KMHX (Morehead City NC), and KAKQ (Wakefield VA). For NMQ QPE, this data was used to create 3-dimensional reflectivity grids at multiple levels, which supply input to QPE algorithms. The QPE grids are of approximately 1-km mesh spacing (0.01° latitude/longitude grid). NMQ does produce a variety of multisensor products. However, this report includes only an analysis of the basic radar-only precipitation estimates. No bias correction of the radar estimates was attempted.

For MPE/HPE, the data were input to the Open Radar Product Generator (ORPG) version OB5.2, which generated Digital Storm-total Precipitation (DSP) and Digital Precipitation Array (DPA) products, which were input to an offline copy of MPE and HPE. Precipitation accumulations used here were based on time differencing of the DSP product. As for NMQ, only the radar-based precipitation product was analyzed without gauge/radar bias correction.

The HPE output was replaced with MPE for the 2-h period ending 2300 UTC on 26 December, when a missing input radar product and time accounting error caused an erroneous rainfall accumulation.

4.2 *Rain gauge reports for QPE input and reference evaluations*

Hourly rain gauge input to the algorithms was provided from gauges located inside and outside the basin boundaries. Although the gauges well outside the boundaries of the basin have very little impact on the basin-average precipitation, they do contribute to bias corrections for the radar data, which will be considered in later phases of the study.

The gauge sites are primarily from three different networks: North Carolina Econet sites, which are logged for environmental and other purposes; NWS Automated Surface Observing System (ASOS) sites; cooperative observer sites (COOP; Datatset Identification Number 3200) whose reports were supplied by the National Climatic Data Center (NCDC); and real-time reporting sites operated by several federal and local authorities, commonly reporting through the NWS Hydrologic Automated Data System (HADS) (see Fig. 1). A total of 7 hourly-reporting sites within the Tar Basin itself, and 21 additional sites within the combined radar umbrellas, will be applied to the analyses as either input or reference data.

Another set of raingauge locations have been used to provide validation reference observations. Three hourly rain gauge sites were selected to be withheld from QPE input to serve as references: Oxford (OXFO, North Carolina Econet site), Tranters Creek (TRAN7) HADS site, and KRIW (Raleigh ASOS site). A set of fourteen daily-reporting sites, not collocated with hourly-reporting ones, was available for 24-h precipitation amount reference. These hourly and daily reference locations provided the validation data described herein.

Data were collected from NCDC, USGS, North Carolina State Climate Office, and NWS sources.

4.3 *Rain gauge report quality control*

Rain gauge input (for both multisensor analyses and reference validation sites) was quality controlled jointly by NSSL, OHD, and NCDC. As noted below, some input and verification rain gauge reports at some sites were affected by frozen precipitation at various times. Other reports were affected by equipment or communications malfunctions, leading to misleading values. All reports were inspected in turn by the NSSL, NCDC, and OHD staff. Examination included time-series, nearest-neighbor, and radar-gauge comparisons. Finally, a common set of input and validation reports was agreed upon.

Of the available set of hourly gauges, only the ASOS units were equipped to report water equivalent during frozen precipitation events. An examination of the hourly gauge time series indicated that some sites were affected by snow during the precipitation event of 14-16 December, when several inches of snow accumulated over parts of the river basin. These gauges reported little or no precipitation during the latter part of the event, but indicated precipitation under fair weather conditions during subsequent days, strongly suggesting accumulation of snow in the collecting funnel, followed by melting. These reports were deleted from that portion of the overall record and were not used for input or validation. We found that the 14 daily reports also had questionable accuracy especially with zero values. The daily reports were carefully examined and suspect gauge reports during two events were removed.

4.4 *Temperature input*

In addition to the freezing level information required by NMQ, the RDHM package requires gridded estimates of surface air temperature as input to its snowfall accumulation and melt model, SNOW-17. These were extracted from Rapid Update Cycle 2 (RUC2) hourly analyses on a 40-km grid mesh, for the December-January period. On certain days when the RUC2 was not available, analyses and forecasts from the North American Mesoscale (NAM) model were used. Frozen precipitation had little influence on the Tar basin earlier in the 2004-05 winter season, and snow effects from earlier winters have essentially no impact; therefore RDHM was run in conjunction with SNOW-17 only at the end of this study period. All precipitation was assumed to be liquid at other times.

4.5 *Operational MPE analyses from the Southeast River Forecast Center*

Gauge/radar analyses on the 4-km HRAP grid are produced operationally at the SERFC and other River Forecast Centers. The analyses consist of a merging of gauge reports and radar precipitation fields, preceded by manual quality control of the input data and sometimes post-processing adjustments. We collected these analyses for the period January 2003 – June 2006, from internal OHD archives and from Stage IV mosaic composites created by the National Centers for Environmental Prediction for use by the National Precipitation Verification Unit (Lin and Mitchell 2005).

4.6 *Stream gauge reports*

United States Geological Survey (USGS) hourly stream gauge reports for five sites along the Tar River were kindly provided by the North Carolina district office. These sites are all forecast points within the NWS river forecast system. Discharge time series from the EFDN7, LOUN7, RNGN7, TRVN7, and ROKN7 sites were used to evaluate hydrologic model output (see Fig. 1a for locations). The first four of these represent discharge from unregulated headwaters ranging in size from 430 to 1360 km^2, and form the basis for our initial conclusions. The ROKN7 site is immediately downstream of a reservoir and is subject to some regulation, and we have no reservoir simulation model available; therefore comparison of the RDHM output and observations is difficult and the simulation results are not presented here.

These stream gauge locations represent mostly the upper portion of the basin, which did not receive the heaviest rain from some of the target events. We are presently seeking stream gauge data from other unregulated headwaters at lower elevations, closer to the Tar estuary. Other basins will be added to the assessment as such data are collected.

5. EVALUATION OF NMQ AND HPE RADAR-ONLY PRECIPITATION ANALYSES FOR EVENTS FROM 10 DECEMBER 2004 TO 16 JANUARY 2005

Our experiment was initiated with the cool-season event, which represented some special challenges to the QPE systems. Portions of this period featured snow or rainfall with low freezing level heights, which lead to large uncertainties in the reflectivity/surface-rainfall relationship. As noted above, few of the hourly rain gauges were equipped to provide liquid equivalent estimates of freezing or frozen precipitation amount, which would be required for optimum bias adjustment of the radar estimates.

NMQ and HPE radar-only analyses were prepared for approximately 40 hours with precipitation over at least part of the basin. The HPE analyses employed the commonly-used convective Z-R relationship $Z=300R^{1.4}$, which appeared suitable for this case and which is commonly used throughout much of the year in the southern portion of the United States. The NMQ analysis employed a time- and space-varying Z-R relationship based upon a precipitation typing scheme. Results from gauge/radar multisensor analyses will be reported in a future paper.

Twenty-four hour precipitation totals from three sources for four of the events are presented in Fig. 2, for December 14-15, December 24-25,

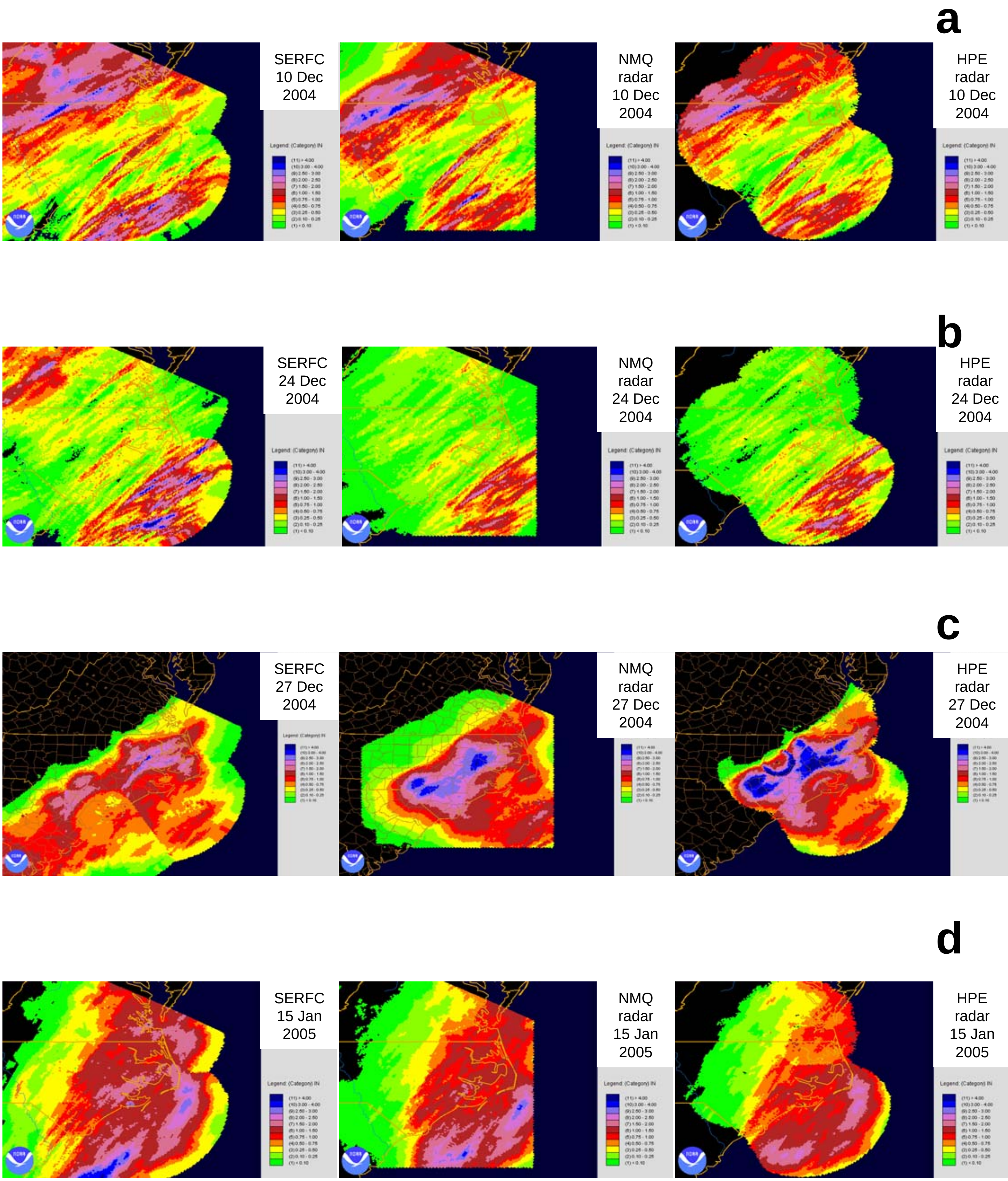


Figure 2. Total 24-h precipitation during four major events during the cool-season study period: (a) ending 1200 UTC 10 December 2004, (b) ending 1200 UTC 24 December 2004, (c) ending 0000 UTC 27 December; (d) ending 15 January 2005

December 26-27, and January 14-15. For each case, analyses are from SERFC operational estimates prepared with MPE on the left, NMQ radar-only estimates in the center, and HPE radar-only on the right. The regional rainfall patterns, such as the apparent convection storm cell track across northeastern North Carolina in the December 14-15 event, are generally similar.

However, the December 26 event (Fig. 2c) featured considerable radar overestimation relative to the SERFC analysis, which receives manual quality control and adjustment. The overestimation was evident in all radar estimates, but was most severe in the HPE analyses, where some spatial artifacts appeared such as the enhanced accumulation concentric about the KRAX radar. This type of artifact is a consequence of the construction of the digital hybrid scan reflectivity field from multiple antenna elevations. The general overestimation in central North Carolina was apparent in the NMQ, though the consequences were not as severe.

5.1 *Rain gauge evaluation*

Some of the storm events caused hourly point rain amounts of over 15 mm, and daily totals of 40 mm, as indicated by the reference rain gauge network. Both daily and 1-h totals from the NMQ and HPE analyses were evaluated in terms of overall gauge/radar bias, linear correlation between gauge and QPE grid values over the course of the events (CC), and root-mean square error (RMSE). Most of the daily-reporting reference gauges reported near 1200 UTC, with a variation of +/- 1 h. Daily totals were evaluated whenever a complete record of both NMQ and HPE data was available for a 24-h period corresponding to a gauge report, such as 1200-1200 UTC or 0500-0500 UTC (local midnight). The verification scores were calculated separately for all cases where either the gauge report or QPE grid was nonzero, and for call cases where both sources were nonzero.

Summaries for verification of 24-h amounts appear in Table 1. In general the NMQ QPE's gave the higher correlation relative to the gauge reports, and a bias value (mean radar value divided by mean gauge value) closer to unity. However, both QPE algorithms generally underestimated precipitation, as shown in Fig. 3. Particularly for the heavier gauge-registered amounts > 25 mm, both QPE algorithms appeared to underestimate, possibly a consequence of the generally cold conditions.

Our evaluation of 1-h amounts is based on reports from the TRAN7 and KRWI sites, as summarized in Table 2 and in Fig. 4. Again, both QPE sources slightly underestimated the gauge amounts, the NMQ producing a bias closer to unity. The degree of underestimation is less than for the daily gauges. The RMS error was lower for the NMQ precipitation than for HPE, as shown in Table 2 and as can be inferred from the scatter plot.

A comparison of the hourly reports from OXFO indicated reporting errors including failure to register frozen precipitation and subsequent precipitation under fair weather conditions, apparently the result of delayed melting. However we do anticipate using the OXFO reports in later evaluations of the warm-season QPEs.

These results are encouraging, in that reasonable radar estimates were produced by the algorithms during two of the three cold season precipitation events, with no attempt to adjust the output toward higher values using the available rain gauge data. However serious overestimation by the WSR-88D PPS for the December 26 event was reflected in the HPE analyses. This finding confirms the importance of real-time bias adjustment, and the potential for the dynamic Z-R selection of the NMQ package to mitigate overestimation in unusual meteorological situations.

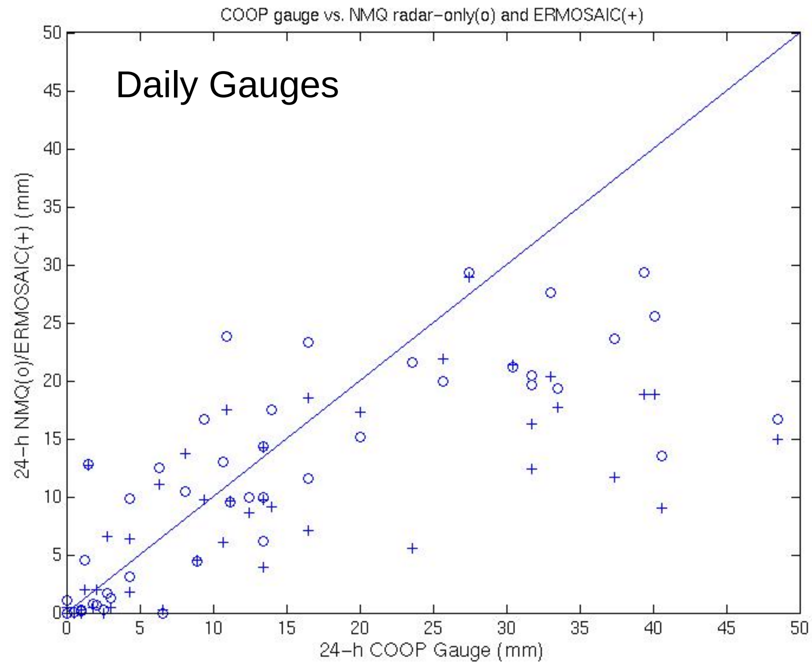
6. HYDROLOGIC MODEL SIMULATIONS

Results of hydrologic simulations and a comparison with USGS observed discharge for four headwater basins are shown in Figs. 5-8. Note that the simulation period started in January 2003, but with only SERFC MPE input. Therefore the hydrograph traces are identical up to early December 2004, and they are not illustrated here. Overall, the simulations for this “warm up” period were fairly good, especially considering that no calibration of model parameters was done. The linear correlation (R) between the modeled and observed hydrographs within the four basins was generally 0.65 or higher over the period; if the storm waves associated with the intense precipitation of Hurricane Isabel in September 2003 were excluded, the linear correlation increased to > 0.75.

In Figs. 5-8 the (a) chart shows accumulated basin-average precipitation. As noted above, the EFDN7 and RNGN7 basins were affected by radar overestimation during the 26 December rain event (Figs. 5a, 7a), and thus the precipitation traces for HPE and to some extent

Table 1.Verification scores for QPE grids relative to cooperative observer (Coop) daily 24-h total values: linear correlation coefficient (CC), root-mean squared error (RMSE).

All cases	CC	RMSE (mm)	Ratio (radar/gauge)
Coop vs. NMQ	0.80	9.0	0.79
Coop vs. HPE	0.72	11.4	0.62
Only nonzero cases			
Coop vs. NMQ	0.75	9.8	0.80
Coop vs. HPE	0.64	12.4	0.63



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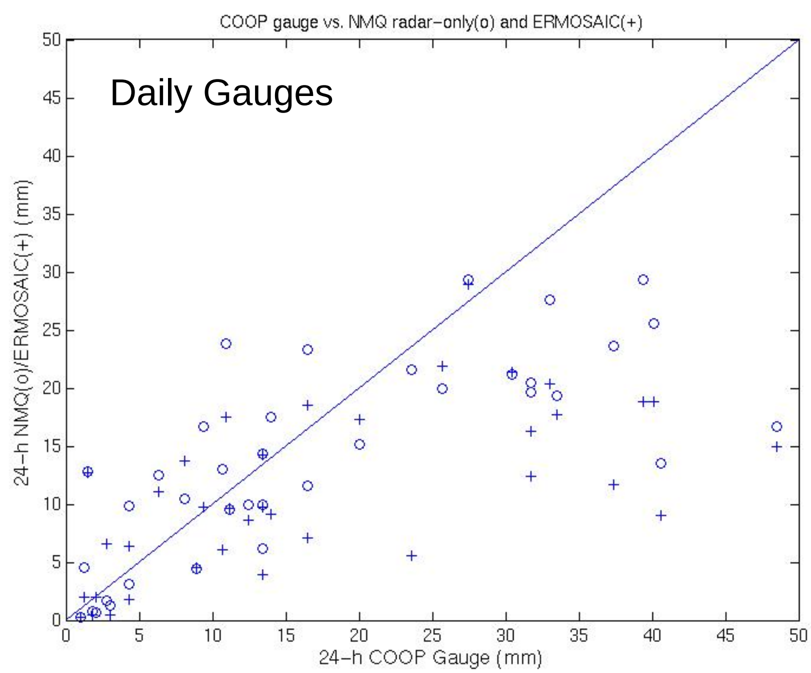

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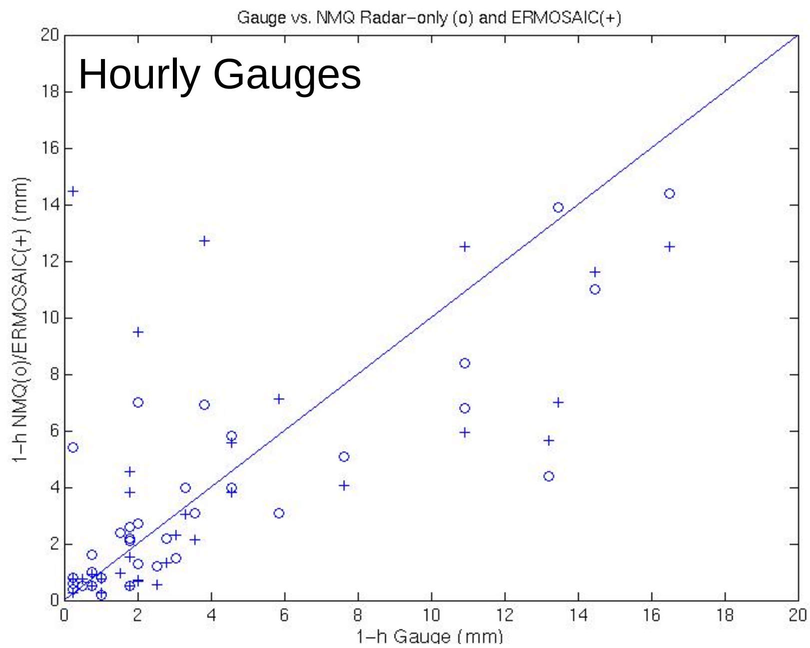
Figure 3. Distribution of gauge-radar estimates for daily 24-h amounts; circles for Q2 NMQ radar-only, Crosses for HPE radar-only. (a) shows all 47 cases with either observation nonzero, (b) shows 37 cases with both observations nonzero.

Table 2. As in Table 1, except for hourly QPEs relative to reference rain gauges.

All cases	CC	RMSE (mm)	Ratio (radar/gauge)
Gauge vs. NMQ	0.87	2.0	0.89
Gauge vs. HPE	0.68	3.3	0.92
Only nonzero cases			
Gauge vs. NMQ	0.85	2.5	0.91
Gauge vs. HPE	0.61	4.0	0.98



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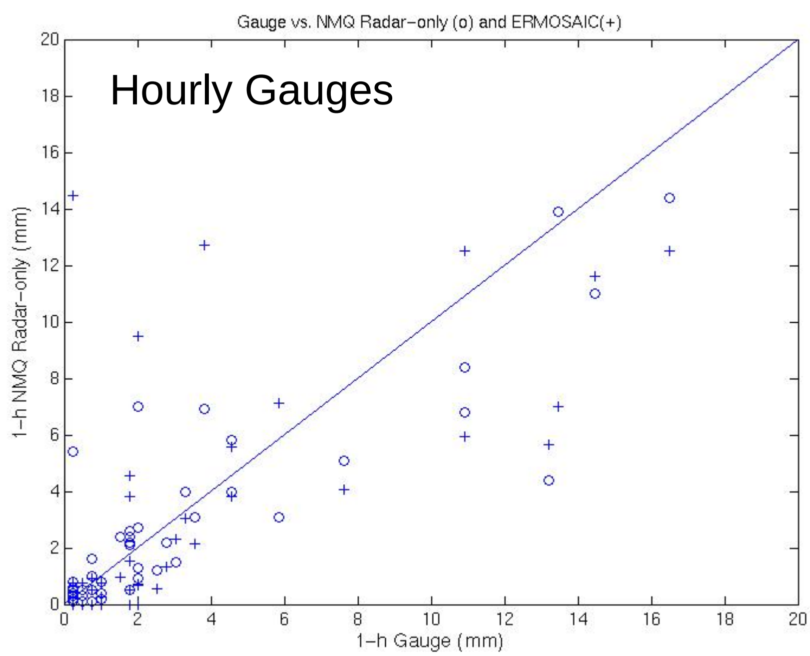

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Figure 4. Same as Fig 3, except for reports at the two reference rain gauge locations. There were 50 cases with precipitation and 36 cases with both grid and gauge nonzero.

NMQ show large jumps at that point. Overall, however, HPE underestimated precipitation relative to the SERFC analysis and NMQ.

The (b) chart in Figs. 5-8 shows observed and modeled hydrograph traces based on USGS and RDHM, respectively, where the hydrologic model was run with SERFC precipitation input. For the December – to January period shown, there is general agreement between the modeled and observed flood peaks in terms of timing, though the total flow magnitude is not modeled well. In all basins the early December event was underestimated; in EFDN7 and RNGN7 there was overestimation of the 28-31 December event. In LOUN7 and TRNVN7 the mid-January event was again underestimated, though the timing and peak magnitude were captured well for EFDN7 and RNGN7.

Because RDHM was not calibrated for these basins, our analysis of the NMQ and HPE precipitation products was focused on their ability to duplicate the manually quality-controlled SERFC precipitation analysis, and the impact of the differences in precipitation on differences in modeled discharge. Though it is possible that one of these QPE sources might yield better hydrologic simulations than did the operational precipitation analysis, we have already seen that radar-only estimates are biased low relative to rain gauge reports.

In terms of total discharge over the period, the most significant differences between NMQ and HPE are due to their different handling of the 26 December event, as shown in Figs. 5c, 7c, for EFDN7 and RNGN7 respectively. The total discharge trace for these basins was tracked closely up to that date, when both HPE and NMQ precipitation caused more discharge. The differences shown more dramatically in the time-series traces in Figs. 5d, 7d, where the HPE in particular produced a large storm wave not reflected in the SERFC-based model runs.

Within the LOUN7 and RNGN7 basins, however, the general tendency of HPE to underestimate the SERFC and NMQ precipitation is evident, with both total and time-series discharge being the lowest for HPE (Figs. 5c-d, 7c-d).

Among the four basins, total discharge volume and precipitation were correlated fairly strongly, with percentage differences among the three QPE sources produced similar percentage differences in total modeled discharge. Thus the RDHM appears to be sensitive to rather subtle differences in precipitation.

7. INITIAL CONCLUSIONS

Based on these results, it appears that our approach of combining rain gauge and hydrologic modeling analyses gives consistent results – differences in radar-based QPEs are reflected in hydrologic model output in a realistic manner. Quality control of the reference rain gauge reports has been very important in the study, and will be even more so in later phases when the reports are directly input to the QPE algorithms.

Over four precipitation events in the December 2004-January 2005 period, the NMQ radar–only QPE was generally closer to rain gauge reports and the operational SERFC analysis than was the HPE. In particular, the NMQ logic produced much less overestimation during the challenging event of 26 December, which affected the remainder of the hydrologic simulation period. This could be due to its adaptive adjustment of Z-R relationships, which is not a feature of the NEXRAD precipitation processing system or HPE.

Future analyses will concentrate on gauge-radar multisensor precipitation, testing of the impact of other features of NMQ and HPE such as gauge-radar-satellite products, and examination of SCaMPR products. We hope to expand the study to more headwater basins, particularly in the lower Tar River area. Finally, we will evaluate the algorithms' performance during warm season events.

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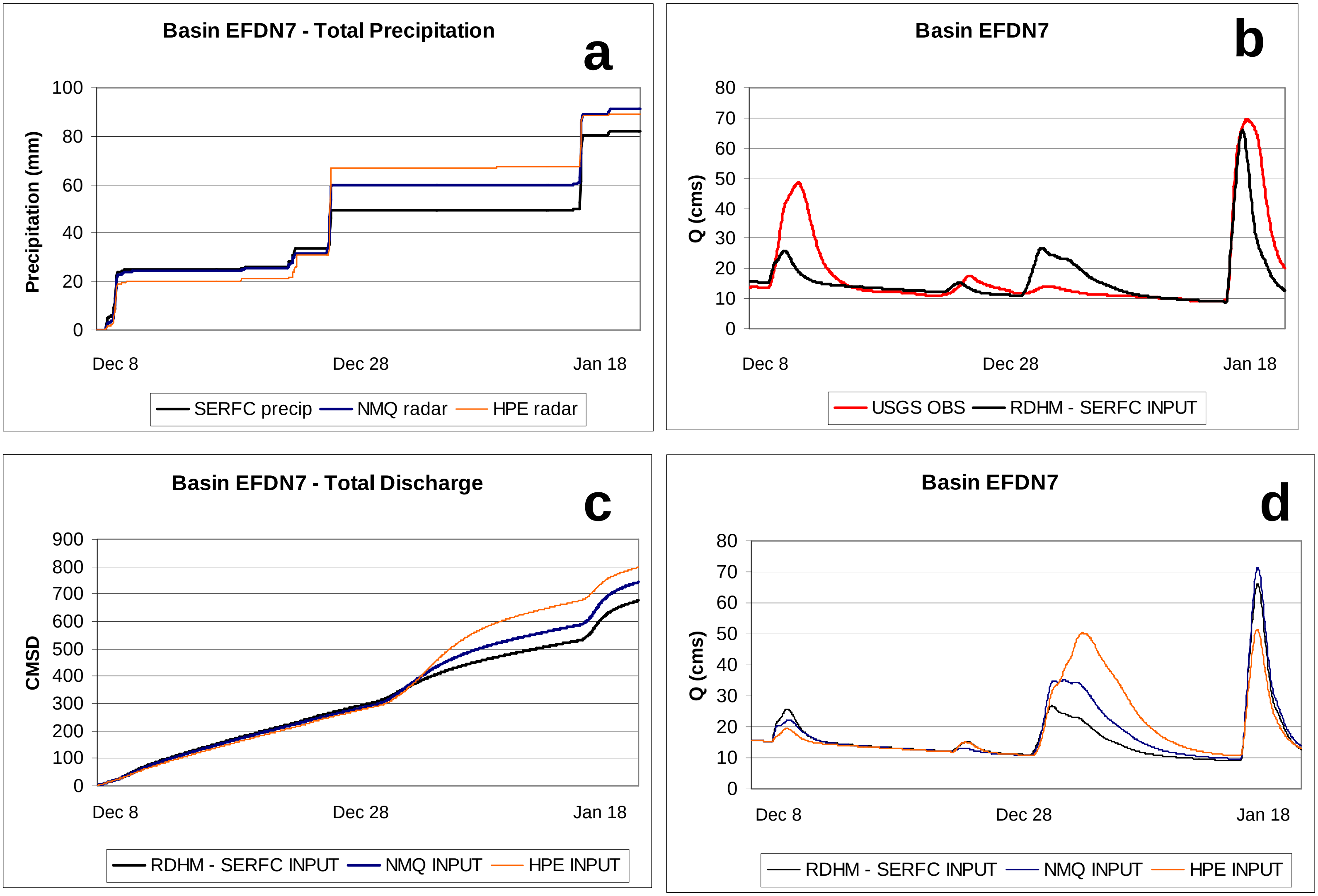

Figure 5. Precipitation and discharge at the outlet of basin EFDN7 (1362 km^2) from several sources, 8 December – 18 January 2004-2005. (a) Mean areal precipitation (mm) from SERFC analyses; (b) observed USGS discharge and RDHM model discharge based on operational SERFC input; (c) accumulated discharge (cms days) from RDHM based on SERFC, NMQ radar-only, and HPE radar-only precipitation; (d) discharge time series from RDHM based on the three precipitation inputs shown in (a).

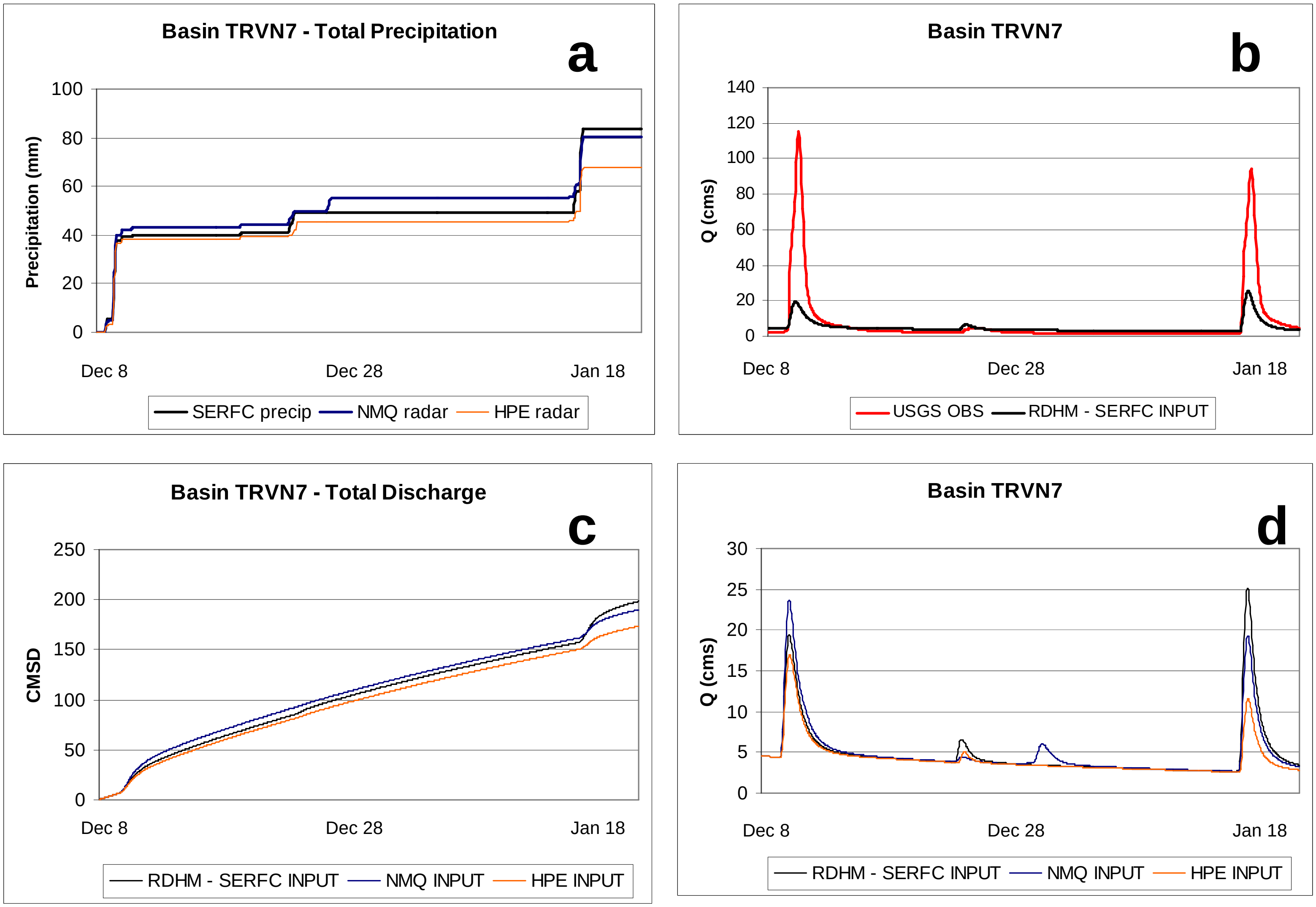

Figure 6. Same as Fig. 5, except precipitation and discharge for basin TRVN7 (432 km^2).

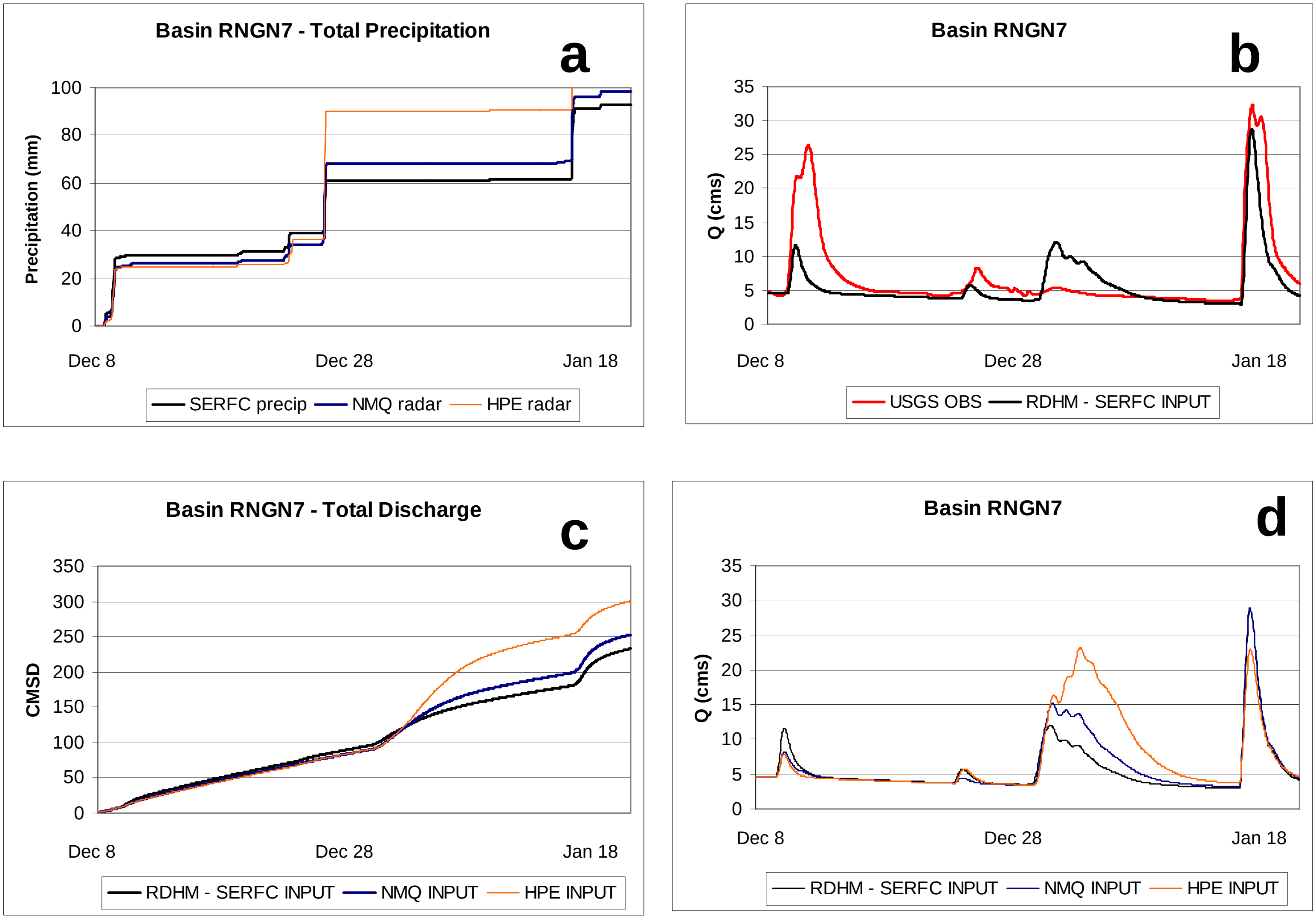

Figure 7. Same as Fig. 5, except precipitation and discharge for basin RNGN7 (458 km^2).

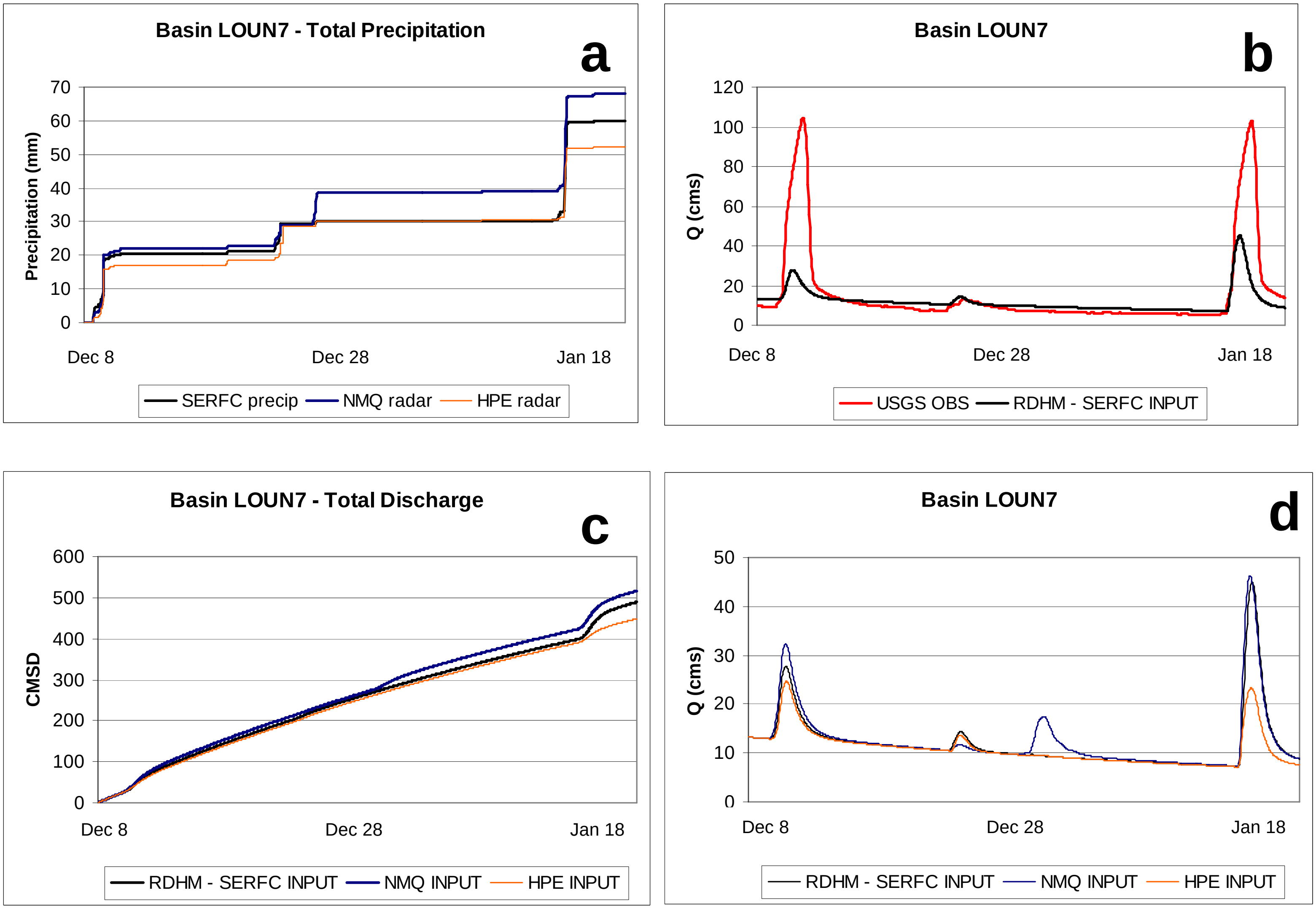

Figure 8. Same as Fig. 5, except precipitation and discharge for basin LOUN7 (1105 km^2).