Title: Utilizing TRMM Precipitation Products in Operational Hydrology through Multi-Satellite and Multi-Sensor Quantitative Precipitation Estimation (QPE)

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Type of Report: Year 3 Progress Report

PI: Robert J. Kuligowski

Collaborators: Yu Zhang, David Kitzmiller, Dong-Jun Seo

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Institution: NOAA/NESDIS Center for Satellite Applications and Research
E/RA2 RM 712 WWBG
Camp Springs, MD 20746-4304
Voice: 301-763-8251x192
Email: Bob.Kuligowski@noaa.gov

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Overall Project Objective
Assess and demonstrate the value of TRMM/GPM precipitation products for quantitative hydrologic forecasting in NOAA/NWS by infusing these data into an integrated framework of multi-satellite and muti-sensor precipitation estimation and hydrologic validation.

Overall Project Methodology
To meet the overall project objective, this project was divided into three stages:

Stage 1: Integrate TRMM data into a multi-satellite framework to provide satellite-derived rainfall estimates at the high temporal resolution required for hydrologic forecasting.

Stage 2: Integrate the multi-satellite rainfall estimates into a multi-sensor framework to optimally merge data from satellites, radars, and rain gauges.

Stage 3: Evaluate the impact of the resulting multi-satellite, multi-sensor rainfall estimates and their components by evaluating their impact on hydrologic model simulations.

Original Annual Milestones
The original annual milestones for all three stages are:

Stage 1: Integrate TRMM data into a multi-satellite framework

1. Year 1: (NESDIS/STAR) Accumulate real-time and archive TRMM data and Self-Calibrating Multivariate Precipitation Retrieval (SCaMPR) input data (geostationary and microwave satellite data) dating back to 2002.

2. Year 1: (NESDIS/STAR) Evaluate the impact of both TMI and TRMM PR data on SCaMPR performance via data withholding experiments. Evaluate the relative impact of these data at full resolution versus spatially aggregating them to the 15-km footprint of the Special Sensor Microwave / Imager (SSM/I) and Advanced Microwave Sounding Unit-B (AMSU-B) / Microwave Humidity Sounder (MHS) input data.

Stage 2: Integrate the multi-satellite rainfall estimates into a multi-sensor framework

1. Year 1: (NWS/OHD) Collect hourly and daily co-operative rain gauge data dating back to 2002 for Multisensor Precipitation Estimator (MPE) evaluation. Also collect hourly operational rain gauge data and Digital Precipitation Array (DPA, a radar-only precipitation product) from WSR-88D for the study period for multi-sensor precipitation estimation.
2. Year 2: (NWS/OHD) Incorporate the SCaMPR products into the satellite-radar-rain gauge multi-sensor framework and perform data denial experiments over the West Gulf River Forecast Center (WGRFC) region.
3. Year 2: (NWS/OHD) Generate the MPE product suite and carry out validation using rain gauge data.

Stage 3: Evaluate the impact

1. Year 3: (NWS/OHD) Design hydrologic model experiments with various QPE forcings.
2. Year 3: (NWS/OHD) Assess parametric uncertainties in the hydrologic models.
3. Year 3: (NWS/OHD) Adopt/Adapt/Develop a post-processing framework to reduce hydrologic model uncertainty.
4. Year 3: (NWS/OHD) Carry out hydrologic validation experiments and generate results.

Actual Accomplishments for Year 3

Stage 2: Integrate the multi-satellite rainfall estimates into a multi-sensor framework

This stage is about 12 months behind schedule due to delays in stage 1 and 2. NESDIS delivered the rest of the SCaMPR products in August 2009. Since then, OHD has produced produce radar-only, gauge-only, and satellite-only gridded QPEs (for SCaMPR with and without TRMM ingest) via MPE. A total of seven gauge-only analyses were generated via the data denial experiments (retaining 90%, ½, and ¼ of the original sample size). OHD also conducted hourly validation of the QPEs on a point basis (using Lower Colorado River Authority rain gauge data as reference) and on an areal-mean basis for 23 WGRFC watersheds (using WGRFC Multisensor QPE as reference). Only the gauge-only analysis using 90% of the gauge set was evaluated while the rest is pending validation. OHD also has collected and reformatted streamflow observations from USGS for the hydrologic experiments.

The basic findings from Stage 2 are as follows:

SCaMPR SPEs show tangible skill in detecting low to moderate intensity rain (<15 mm/h) on a point basis and the skill is comparable to gauge-only analysis at 0.9 of full size (i.e., nearly all the gauge data used). Both SPE and gauge-only analysis show very limited skill in resolving heavier rain (>15 mm/h). Ingesting TRMM helps mitigate the overall positive bias in SCaMPR SPEs and improve the FAR values, but also leads to deterioration in POD values and a negative conditional bias (i.e., for pairs where both point gauge and gridded rain rate values equal or

exceed 1 mm/h). The basin-based validation largely confirms the findings from point validation. It points to a positive overall bias in SCaMPR SPE products that is most pronounced during the warm season and that is mitigated to a certain extent by ingesting TRMM data (Figure 1).

Stage 3: Evaluate the impact

OHD conducted a set of hydrologic experiments via AB-opt using each QPE as forcing. AB-opt, or adjoint-based optimizer that automatically estimates bias in precipitation forcing, unit hydrograph, and hydrologic model parameters given observed precipitation and streamflow time series for a given watershed. In these experiments, the time periods 2000-5 and 2006-7 were designated as calibration and validation periods, respectively. For 17 out of the 23 basins, AB-opt yielded a bias factor for each forcing and a combination of Sacramental Soil Moisture Accounting (SAC-SMA) parameter values over each basin. Preliminary analysis of the hydrologic simulation results was carried out to determine the relative accuracy of runoff simulations using each QPE as forcing. Additional analysis is being carried out to investigate the problems of non-convergence with the remaining 6 basins (likely due to flow regulation by dams or similar means).

The basic findings from Stage 3 are as follows:

The precipitation bias values produced via AB-opt are largely consistent with the validation results. Among the QPE products, gauge-only QPE outperforms SCaMPR QPEs in bias and correlation after the bias correction for a majority of basins (Figure 2). Ingesting TRMM leads to deterioration in the simulation results.

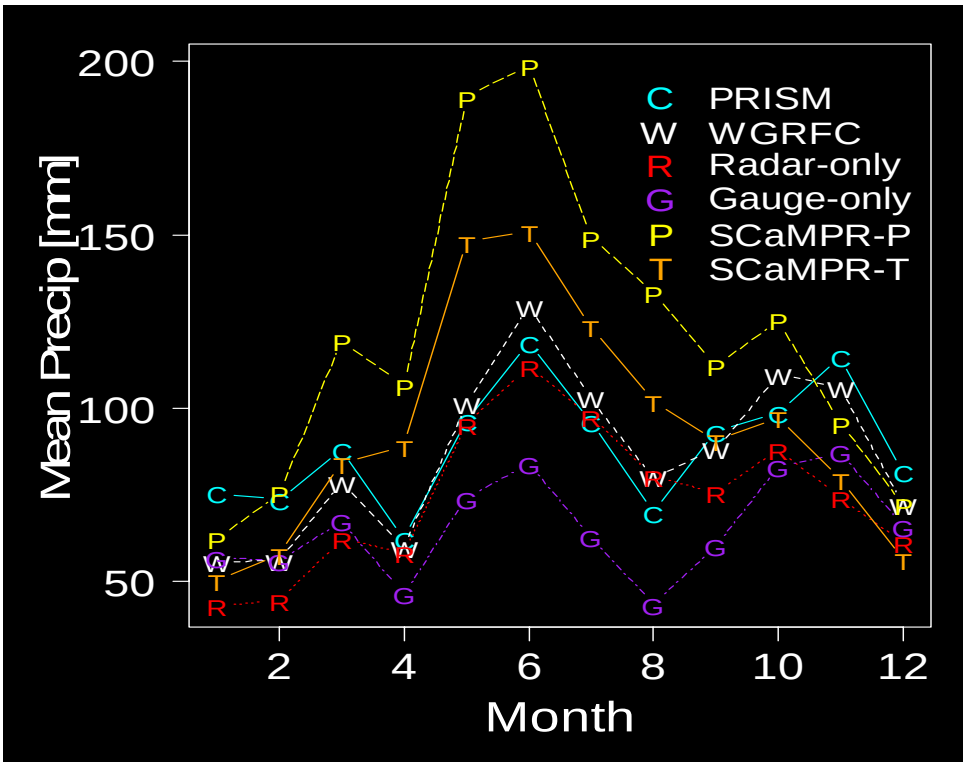

Figure 1: Monthly mean precipitation averaged over 22 test basins in WGRFC. Shown are the values from 1) PRISM climatology, 2) WGRFC multi-sensor QPE, 3) radar-only QPE, 4) gauge-only QPE, 5) SCaMPR-P and 6) SCaMPR-T. Positive bias in SCaMPR QPEs is pronounced and ingesting TRMM data helped suppress this bias.

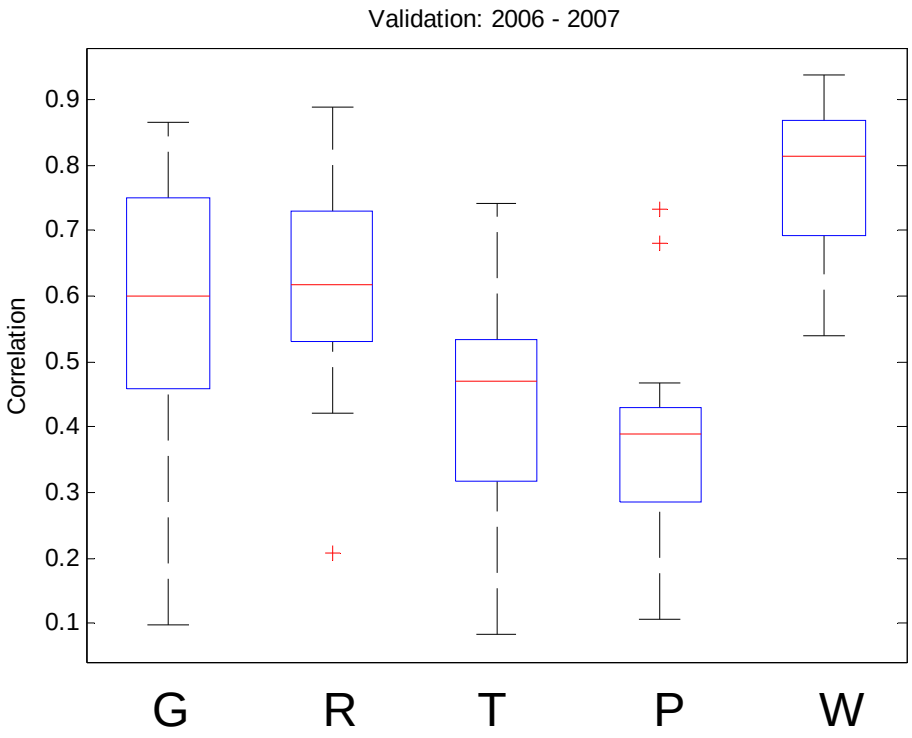

Figure 2: Correlation between simulated and observed streamflow over 17 test basins for the validation period 2006-7 as driven by the gauge-only analysis (G), the radar-only analysis (T), SCaMPR-T (T), SCaMPR-P (P), and WGRFC (W). The boxplot characterizes the distribution of correlation values computed over the 17 basins.

Expected Accomplishments for Year 4

We expect to close this project by completing the validation and hydrologic experiments and produce 3 journal-ready articles. Below is a list of topics:

1st Paper: Enhancement of SCaMPR to incorporate TRMM TMI and TPR data (to be submitted to J. Hydromet)
2nd Paper: Comparative accuracy of SCaMPR QPE and gauge-only QPE and the effects of local bias correction on SCaMPR accuracy (to be submitted to J. Hydromet)
3rd Paper: Uncertainties in satellite and ground-sensor based QPEs versus those in hydrologic model parameters in hydrologic simulations (to be submitted to J. Hydrology)

The items to be completed include a) generation and validation of bias adjusted SCaMPR SPE, b) validation of gauge-only analysis at coarser gauge density (namely ½ and ¼) and comparisons with SPE products at 3, 6, 12, 24, and 48-h time scales, c) AB-opt runs with an ensemble of calibration/validation time periods to determine the uncertainties in parameter combinations through calibration.

Conference Presentations

Yu Zhang presented a talk entitled "Evaluation of the impacts of ingesting TRMM data on the accuracy of quantitative precipitation estimates obtained via the SCaMPR framework" at the 24th conference for Hydrology at the annual AMS meeting in Atlanta, GA.

Budget

Year 1

Subcontracts/Subawards	**Budget**	**Actual**
STAR Contractor	$75 K	$75 K
OHD Contractor (see Attachment)	$ 9 K	$9 K
Travel		
2007 PMM Science Team Meeting, Atlanta	$ 2 K	$2 K
Facilities and Administrative	$8 K	$8 K
Total Estimated Costs	**$94 K**	**$94 K**

Year 2

Subcontracts/Subawards	**Budget**	**Actual**
OHD Contractor	$43 K	$43 K
UCAR scientists	$24 K	$24 K
2008 PMM Science Team Meeting, Fort Collins	$2 K	$2 K
Other		
Page charges: SCaMPR paper	$2 K	$0 K
Facilities and Administrative	$22 K	$20 K
Total Estimated Costs	**$93 K**	**$91 K**

Year 3

Subcontracts/Subawards	**Budget**	**Actual**
OHD Contractor	$9 K	$15 K
UCAR scientists	$80 K	$100 K
2009PMM Science Team Meeting, Salt Lake City	$2 K	$2 K
Other		
Page charges: multi-sensor paper	$2 K	$0 K
Page charges: hydrologic validation	$2 K	$0 K
Facilities and Administrative	$29 K	$7 K
Total Estimated Costs	**$124 K**	**$124 K**

Final work to be completed as a no-cost extension