Year 3 Progress Report **Grant Numbers:** **G8R1RP5P-01 (CPO)**
G8R2WRP (HMT)

Title:	Improvement and Validation of a Multi-Satellite, Multi-Sensor Precipitation Estimation Algorithm: A Prototype 'Day 1' GPM Product
Funding Agency:	NOAA
Type of Report:	Year 3 Progress Report
PI:	Pingping Xie
Collaborators:	Robert Joyce, John E. Janowiak
Period Covered:	07/03/09 – 07/02/10
Institution:	Climate Prediction Center 5200 Auth Road, #605 Camp Springs, MD 20746 Tel. (301)763-8000, #7572 E-Mail: Pingping.Xie@noaa.gov
Grant Numbers:	G8R1RP5P-01 (CPO) G8R2WRP (HMT)

Overall Project Objective:

To improve and validate CMORPH multi-satellite, multi-sensor global precipitation estimates for possible applications as a prototype GPM 'Day 1' product

Overall Project Methodology:

The project is organized into the following two tasks to achieve the overall objective:

a) Improving CMORPH algorithm through the use of a Kalman filtering technique; and
b) Developing a new algorithm to combine the CMORPH satellite estimates with gauge observations;

Year 3 Accomplishments:

Substantial progress has been made on both tasks in the 3rd year of this project, including:

a) **Constructed a prototype processing system to construct satellite-based precipitation estimates using the Kalman Filter based CMORPH (KF-CMORPH)**

In the 2nd year of this project, we successfully developed the conceptual model of Kalman Filter based CMORPH and demonstrated improved depiction of global precipitation compared to the existing CMORPH. In the 3rd year of this project, we constructed a processing system to implement the Kalman Filter based CMORPH for the routine production of high-resolution global precipitation. Major tasks involving the construction include:

a) Modifying the input data preprocessing sub-system

In particular, we examined the newly available passive microwave estimates (PMW) from the SSMIS aboard DMSP 16, and DMSP-17, adjusted our inter-calibration procedures accordingly to ensure that the calibrated SSMIS PMW estimates works well with our CMORPH procedures.

b) Fine tuning and quantitative assessments of the Kalman Filter CMORPH

We performed fine tuning for the Kalman Filter based CMORPH. Seasonally and regionally sensor dependent global Kalman Filter models were developed from temporally and spatially matched collocations of withheld TRMM TMI to forward and backward in time propagated PMW rainfall. In particular, we experimented with the best strategy to take in the IR-based estimates in filling the gaps between the PMW observations. We found that the IR estimates should be incorporated when no PMW estimates are available within a window of 90 minutes and that when the IR data at the target analysis is not available, IR-based estimates from the next geostationary scan (30-min later) should be propagated to the target time and utilized.

The KF-CMORPH system has been applied to produce global high-resolution precipitation estimates for a 10-month period from July 2009 to April 2010 and compared against in situ observations as well as the current version operational CMORPH for the evaluation of quality and improvements. As shown in fig.1&2, through the inclusion of IR-based estimates, the KF-CMORPH is capable of capturing precipitation variations associated with the rapid development of typical summer time convection over systematic PMW orbit gaps by comparing against high temporal/spatial resolution NSSL Q2 radar rainfall.

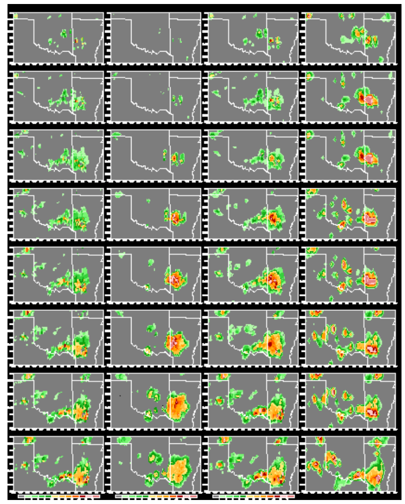

Fig.1: Time evolution of 30-min precipitation (mm/hr) from (top) 19:30UTC to (bottom) 23:30UTC, 19 July 2009, as depicted by (left column) the current version CMORPH, (2nd column from left) IR-based estimates, (3rd column from left) KF-CMORPH, and (right column) radar observations. PMW observations are available only at the first and last slots of time series in this case.

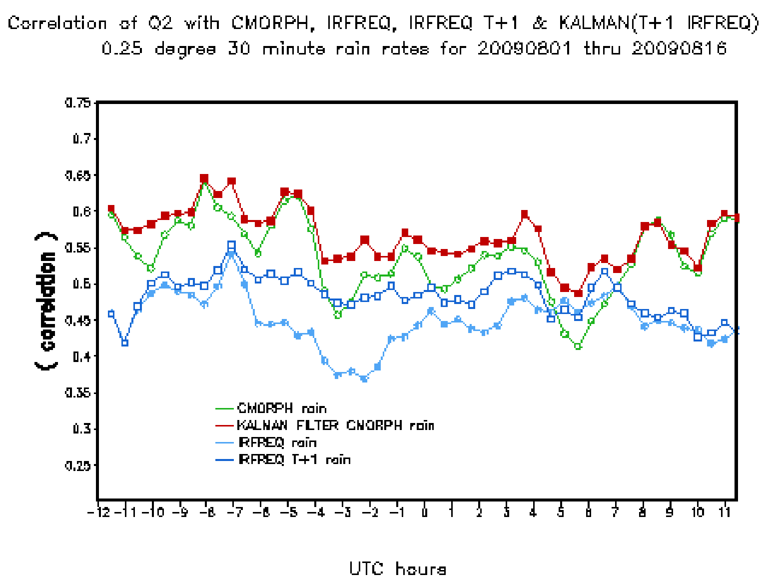

Fig.2: Time series of correlation of (red) KF-CMORPH, (green) operational CMORPH, and (dark blue) IR-estimates at the target time and (light blue) 30-min after the target time, compared against Q2 radar observations for each of the 48 half hour periods within a day. Comparisons are performed for 30-min precipitation averaged on a 0.25^{o}lat/lon grid over CONUS.

Further examinations of the operational and KF-CMORPH revealed that the improvements in the KF-CMORPH are achieved when the operational CMORPH exhibits relatively low skills (fig.2), indicating that the IR-based estimates provide useful information in filling in temporal gaps between PMW observations in our KF-CMORPH system.

b) Developed a prototype system to remove CMORPH Bias over the global land through PDF matching with gauge data

In the 3rd year of this project, we developed a prototype processing system to remove the biases in the CMORPH satellite precipitation estimates through comparison with concurrent gauge observations. This system is developed based on the preliminary work we performed in the 2nd year of the project to correct the bias over China. In performing bias correction for CMORPH precipitation estimates over a target grid box of 0.25^{o}lat/lon, co-located data pairs of CMORPH and gauge observations are collected over a spatial / time domain centering at the target grid box. Probability density function (PDF) of daily CMORPH is then constructed and matching against that of the daily gauge data to remove the CMORPH biases.

In our prototype system, the CMORPH bias is corrected in two steps. First, the bias correction is performed using PDF tables constructed from historical data from 2001-2009. PDF tables are created for each 0.25^{o}lat/lon grid box over land for each calendar day using data over a 31-day period centering at the target calendar day and over a spatial domain surrounding the target grid box. The spatial domain is expanded until sufficient number of data pairs (>500) are collected to ensure stable PDF tables. Through the use of historical data, the PDF tables can be created using data over a relatively small spatial domain, reducing the scale of remaining biases.

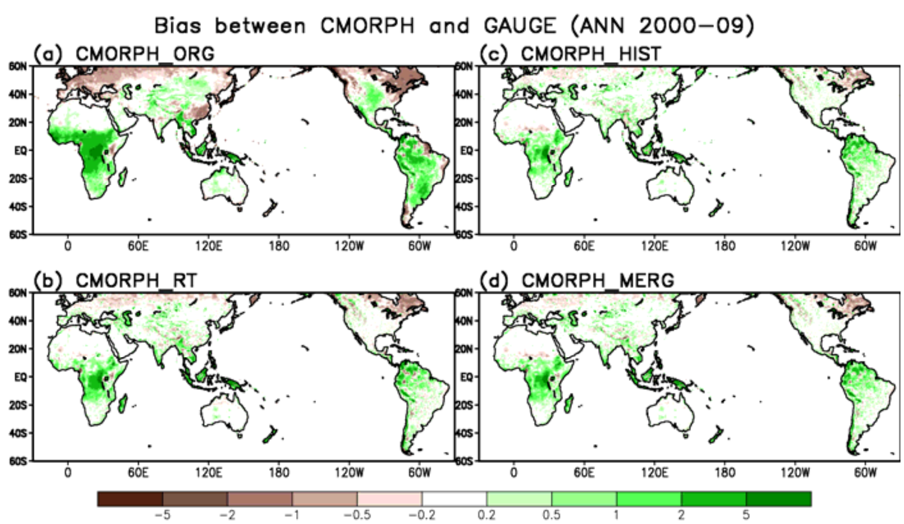

Figure 3: 2000-2009 mean annual bias(mm/day) in (top-left) original CMORPH, (top-right) CMORPH after correction using historical data; (bottom-left) CMORPH after bias correction using real-time data alone; and (bottom-right) CMORPH after using both historical and real-time data.

A second step is implemented to repeat the PDF matching procedure using data pairs collected from the satellite and gauge data over a 30-day period ending at the target data. This step is designed to reduce the year-to-year variations of the biases remaining in the CMORPH after the correction in the first step.

It is clear from the comparison results in fig.3 that the prototype system is capable of reducing the CMORPH biases effectively over most of the global land areas. In particular, the two-step approach adopted in this system ensures stable performance over regions with sparse gauge network (e.g. Africa, fig.4). The bias corrected CMORPH exhibits higher correlation compared to the original CMORPH and presents close-to-zero bias throughout the seasonal cycle.

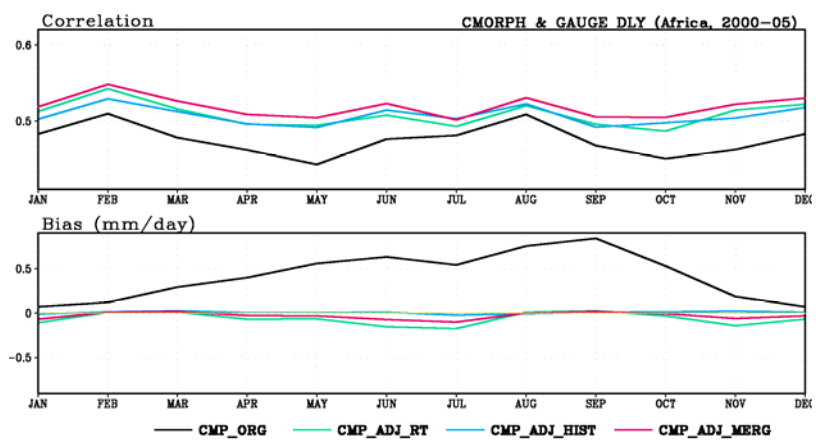

Figure 4: Time series of (top) correlation and (bottom) bias between CMORPH and gauge observations over Africa. Results for the original CMORPH, CMORPH after correction using historical data, CMORPH after bias correction using real-time data alone, and (bottom-right) CMORPH after using both historical and real-time data are plotted in black, blue, green and pink, respectively.

Expected Accomplishments for Continued Project Year 1

During the first year of this renewed project, we will start working on the development of a Kalman Filter based CMORPH for global precipitation estimates and a new technique to integrate satellite estimates with additional regional information for a regional precipitation estimates with refined spatial resolution and quantitative accuracy.

a) Improving CMORPH algorithm through the use of a Kalman filtering technique for a pole-to-pole global satellite precipitation estimates

Our plan for the next project year includes:

- Completing the development of the Kalman Filter based CMORPH for the production of precipitation estimates over the globe from 60^{o}S to 60^{o}N;

- Exploring best strategy to compute cloud advection vectors over high latitudes;

- Refine IR-based precipitation estimates for mid- and hi-latitudes;

- Investigate possible ways to include information from model generated fields;

b) Combining global CMORPH with gauge observations and other regional information

Specific work includes:

- Completing and implementing the global bias correction for real-time operation;
- Developing a prototype model to combine CMORPH with hourly gauge analysis over CONUS;
- Starting examinations of radar observations and their application in the merging processes;

Publications and Presentations:

Publications:

Joyce, R.J, P. Xie, J.E. Janowiak, and S.-H. Yoo, 2010: Kalman Filter based CMORPH. (to be submitted to J. Hydrometeor.)

Presentations

Joyce, R., and P.Xie, 2009: A Gauge Adjusted Kalman Filter CMORPH Rainfall Prototype using TRMM and Future GPM. the NASA Precipitation Measurement Mission (PMM) annual meeting, 26-30 October in Salt Lake City Utah.

Joyce, R., P. Xie, S.-H. Yoo, 2009: Gauge Adjusted Global Kalman Filtered Rainfall Prototype Using the TRMM TMI and Future GPM GMI, the NASA Precipitation Measurement Mission (PMM) annual meeting, 26-30 October in Salt Lake City Utah.

Xie, P., S.-H. Yoo, W. Shi, 2009: CPC Unified Precipitation Products: Global High-Resolution Gauge-Satellite Merged Analyses of Daily Precipitation. 6th International Scientific Conf. on the Global Energy and Water Cycle, August 23-28, 2009, Melbourne, Australia.

Xie, P. and **S.-H. Yoo**, 2009: Uncertainties in the global oceanic precipitation observed by the current generation merged satellite products. OceanObs'09 Conference, September 21-25, Venice, Italy.

Xie, P., S.-H. Yoo, R. Joyce, and Y. Yarosh, 2009: CPC Unified Gauge-Satellite Merged Precipitation Analysis for Improved Monitoring and Assessments of Global Climate. 34th Annual Climate Diagnostics and Prediction Workshop. October 26 – 30, 2009, Monterey, CA.

Xie, P., **S.-H. Yoo**, R. Joyce, and Y. Yarosh, 2010: A new CPC high-resolution Gauge-Satellite merged analysis for improved observation of global daily precipitation. 90th AMS Annual Meeting, January 17-21, Atlanta, Georgia.

Xie, P., and S.-H. Yoo, 2010: Bias correction for CMORPH land precipitation. ESSIC Seminar, April 26, 2010, College Park, Maryland.

Xie, P., R. Joyce, S.-H. Yoo, and Y. Yarosh, 2010: A Kalman Filter based CMORPH to integrate precipitation information from satellite and gauge observations over the globe. 2010 IEEE International Geosci. And Remote Sensing Symp., July 25-30, 2010, Honolulu, Hawaii.

Budget

Our project is sponsored jointly by NOAA Hydeometeorology Testbed (HMT) and the NOAA Climate Program Office (CPO) Climate Observation and Monitoring (COM) programs. The spending plan for Year 1 and budget request for Year 2 are listed below:

a) Year 1 Spending Plan

Sponsoring Program	CPO	HMT	TOTAL
Contractors Support	$78K	$73K	$151K
	(30% of Joyce)	(30% of Joyce)	
	(15% of Yarosh)	(10% of Yarosh)	
		(25% for a visitor, 5K)	
Domestic Travels	$3K		$3K
International Travel	$4K		$4K
IT Equipments:		$2K	$2K
TOTAL COST:	$85K	$75K	$160K

b) Year 2 Budget Request

Sponsoring Program	CPO	HMT	TOTAL
Contractors Support*	$81K	$73K	$154K
	(30% of Joyce)	(30% of Joyce)	
	(15% of Yarosh)	(10% of Yarosh)	
Travels	$5K	$3K	$8K
IT Equipments:	$1K	$2K	$3K
TOTAL COST:	$87K	$78K	$165K

* Request for contractors support has been increased in consideration of the rising living cost. Funding for IT equipment ($3K) is for the purchase of additional tapes

to archives the satellite data. Funding for travels is requested for facilitate the PIs and the contractors to attend PMM science meetings and other scientific meetings to report our research / development results.

Linkage to Other NOAA Programs

The techniques developed in this project will be utilized to improve the precipitation products being used in various NOAA research, operation and service activities in weather, water, climate, ocean and hydrology. The high-resolution precipitation analysis is being used by NOAA/CPC for climate monitoring, assessments, and model verifications. The techniques developed in this program will be used to improve the precipitation analyses being constructed at CPC as NOAA's contribution to the WMO/GEWEX Global Precipitation Climatology Project (GPCP). The CMORPH precipitation estimates may be also a good candidate as a key component for the NOAA Climate Data Record (CDR).

Linkage to NASA GPM Activities

CMORPH presents stable and best performance as the Level 3 gridded precipitation estimates for TRMM. We are working together with colleagues in NASA/GSFC to develop a US national unified Level 3 algorithm for the GPM based on the CMORPH technique.

The CMORPH precipitation estimates are being used by NASA/GSFC hydrology team as forcing to their LIS land surface model.