Year 1 Progress Report **Grant Numbers:** **G8R1RP5P-01 (CPO)**
???????????? (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 2 Progress Report

PI: Pingping Xie

Collaborators: Robert Joyce, John E. Janowiak

Period Covered: 07/03/08 – 07/02/09

Institution: Climate Prediction Center
5200 Auth Road, #605
Camp Springs, MD 20746
Tel. (301)763-8000, #7572
E-Mail: Pingping.Xie@noaa.gov

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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 2 Accomplishments:

Substantial progress has been made on both tasks as detailed below:

a) **Improving CMORPH algorithm through the use of a Kalman filtering technique**

In the original CMORPH of Joyce et al. (2004), precipitation analysis is defined by propagating estimates of instantaneous rain rates from passive microwave (PMW) observations aboard low orbiting satellite along the cloud / precipitation system advection vectors computed from the consecutive IR images in 30-minutes intervals from geostationary satellites. Estimates of PMW-based instantaneous rain rates are propagated backward and forward. The final precipitation estimates at the target time is defined as the weighted mean of the backward and forward propagated PMW estimates from the closest satellite observations. The weights inversely proportional to the separation of time between the target analysis time and the PMW satellite observation time.

While CMORPH estimates consistently present the best performance in estimating the spatial distribution and temporal variations of precipitation over most of the global regions and for all seasons, as demonstrated in various validations tests and inter-comparison projects, further improvements can be achieved through adopting the Kalman Filter technique.

Although the CMORPH technique is actually a simplified implementation of the Kalman Filter, the full version Kalman Filter (KF) combines the information from individual sources in a more effective and efficient way:

a) KF takes in precipitation estimates from both PMW and IR observations, while the original CMORPH only use IR data to compute the advection vectors. Despite their relatively poor accuracy, IR-based precipitation estimates provide useful information when no PMW estimates are available around the target analysis time;

b) KF is capable of combining information from propagated PMW estimates from multiple scans, while the original CMORPH only uses data from the closest observations;

c) KF optimizes the precipitation analysis through combining estimates from the propagated PMW estimates and IR estimates with weights defined from error (correlation) structures for the individual inputs, while the CMORPH uses weights inversely proportional to the separation time regardless of the error statistics for estimates from different instruments / platforms.

Key to the development of the KF-based CMORPH are the design of the decision strategy to or not to include the IR-based precipitation estimates and the definition of error structure for the propagated PMW estimates as a function of instrument type, propagation time, location, and season.

In the first year of this project (FY08), we focused our efforts on a) collecting and pre-processing (calibration et al) PMW estimates from all available satellites, and b) developing a conceptual model of the KF-CMORPH to establish the basic framework of the technique using data over CONUS.

During FY09, substantial progress has been made toward the development of a KF-based CMORPH for global applications. Specially,

a) We developed a prototype model of the KF-CMORPH using data over CONUS;

b) We implemented a test model to define the KF-CMORPH over the global domain; and

c) We performed preliminary tests as an integral part of this development to examine to what extent the KF-CMORPH precipitation estimates are improved upon the original CMORPH and what further improvements may be achieved through refined implementation.

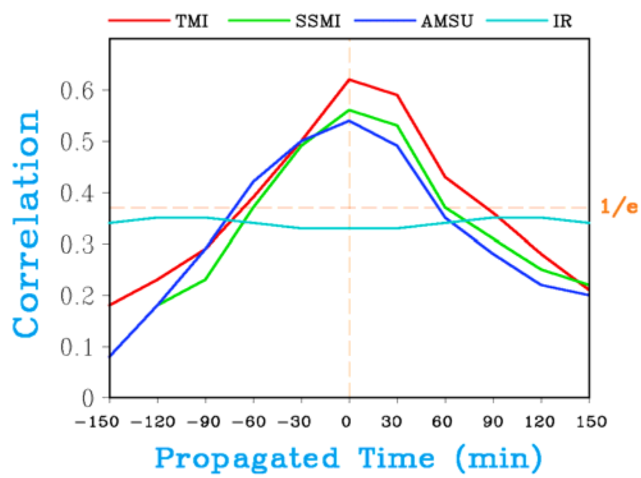

Fig.1: *Correlation for the IR-based and PMW propagated precipitation estimates as a function of instrument type and propagation time. Correlation is computed between the satellite estimates and the radar-estimated precipitation over CONUS. Positive and negative propagation times indicate forward and backward propagation, respectively.*

Figure 1 shows the correlation between the satellite precipitation estimates and the radar estimation (taken as the ‘ground truth’ in this study) as a function of instrument type and propagation time. Correlation for the PMW estimates degrades shapely as they are propagated from their observation time. The magnitude and the degradation rate of the correlation, however, differ for different instruments. The IR-based precipitation estimates outperform the PMW estimates when the propagation time is longer than 90 minutes or so.

Using these error statistics, a prototype model KF-CMORPH is developed to construct high-resolution precipitation estimates over CONUS. Results are compared against the radar precipitation observations to examine their quantitative accuracy. As shown in figure 2, precipitation estimates generated by the KF-CMORPH present consistently improved accuracy compared to those from the original CMORPH.

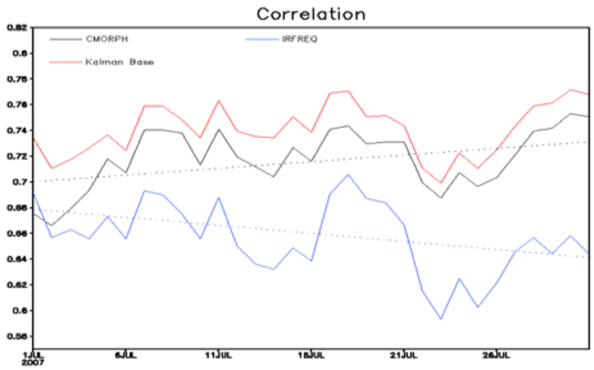

Fig. 2: Time series of correlation between radar-estimated precipitation and satellite precipitation estimates derived from a) IR observations (blue); b) the original CMORPH (black); and c) the prototype Kalman Filter (KF) CMORPH over CONUS.

This prototype type KF-CMORPH developed using the CONUS is implemented for constructing the precipitation estimates over the entire global domain from 60^{o}S to 60^{o}N. Statistical parameters are modified to take into account seasonal variations and regional dependence of the error structures for individual satellite estimates and cloud / precipitation systems. An example of the global precipitation distribution for 20:00GMT, 29 April, 2009, is illustrated in figure 3.

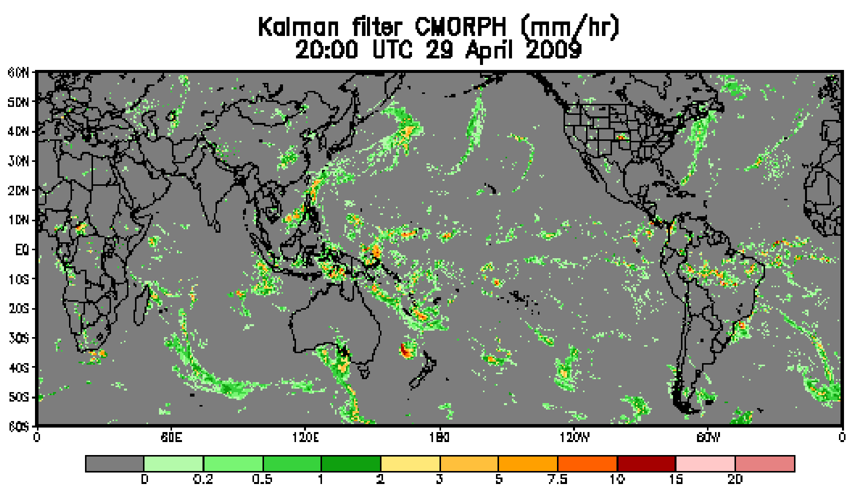

Figure 3: Global distribution of 30-min mean precipitation starting at 20:00GMT, 29 April, 2009, derived from the test version global KF-CMORPH.

b) Removing CMORPH Bias through PDF Matching with Gauge Data

As shown in many validation studies, all satellite-based precipitation estimates contain regionally dependent and seasonably changing biases. One way to remove the bias is to combine information from gauge observations. In the first year of this project, a prototype algorithm was developed to remove the CMORPH bias through matching the probability density function (PDF) of the daily CMORPH with that of the daily gauge analysis using data over China. In this year (FY09), we implemented this prototype algorithm to remove the CMORPH biases over the entire global land.

This bias correction is performed for each 0.25^{o}lat/lon grid box over the global land and updated daily. First, co-located daily CMORPH and gauge analysis data are collected over grid boxes with at least one gauge over a spatial domain centering at the target grid box and a 30-day time period ending at the target date. PDF for the CMORPH is then created and matched against that of the gauge analysis to correct the biases. In this test version, all statistical parameters are fixed as the same as those defined using the Chinese data. Further tuning is underway to set the parameters as a function of season and region to optimize the performance.

The bias corrected CMORPH estimates are compared against gauge analyses over the entire global land. As shown in figure 4, seasonally changing biases in the original CMORPH are removed substantially after the correction, and the correlation for the bias-corrected CMORPH is improved by ~0.05 upon that for the original CMORPH.

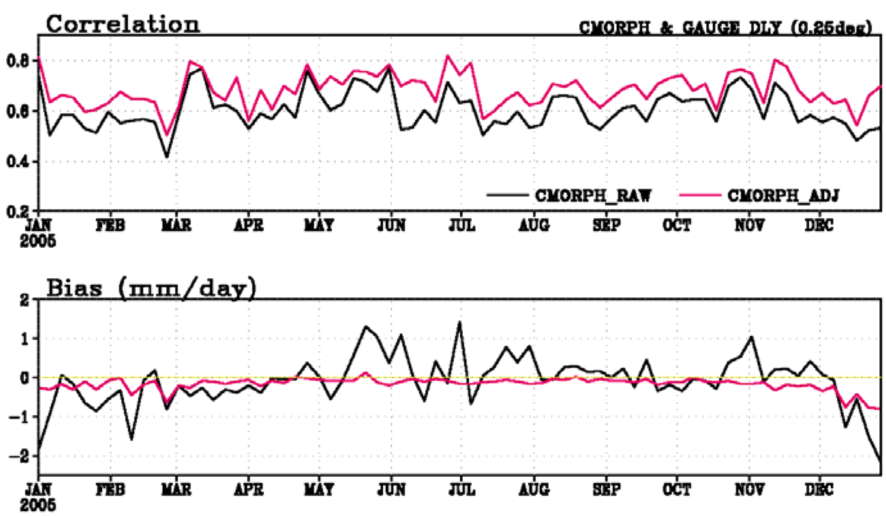

Figure 4: Time series of correlation between the daily gauge-based analysis of precipitation and the daily estimates from a) the CMORPH (black), and b) the bias-corrected CMORPH over the global land.

Expected Accomplishments for Year 3

During the third year, we will continue our development and validation work toward achieving the final goal of our project.

a) Improving CMORPH algorithm through the use of a Kalman filtering technique

Our plan for the next project year includes:

- Completing the development of the Kalman Filter based CMORPH and start test for operational applications
- Performing comprehensive evaluations of the precipitation estimates generated by the KF-CMORPH; and
- Starting reprocessing precipitation estimates using KF-CMORPH

b) Combining CMORPH satellite estimates with gauge observations

In the third year of this project, we will complete the development of the gauge – satellite merging algorithms for test operational applications over the global land. Our goals are:

- Completing the development of an operational version algorithm for global CMORPH bias correction; and
- Continuing the development of an analysis algorithm to combine the bias-corrected CMORPH with gauge analysis over several regions (CONUS, China, South America, Africa..)

Publications and Presentations:

Publications:

Joyce, R.J, P. Xie, and J.E. Janowiak, 2009: CMORPH: A ‘Morphing’ Approach for High Resolution Precipitation Product Generation. Book chapter in '*Satellite Application for Surface Hydrology*', in press.

Shen, Y., A. Xiong, Y. Wang, and P.Xie, 2009: Performance of High-Resolution Precipitation Products over China. *J. Geophy. Res.*, accepted.

Presentations

Joyce, R.J., P.Xie, and J.E. Janowiak, 2008: CMORPH and Gauge Adjusted CMORPH Product Updates. *Precipitation Measurement Missions Workshop*, August 4-7, 2008. Fort Collins CO.

Joyce, R.J., P. Xie, and J.E. Janowiak, 2008: Updates to Retrospective Reprocessing and Kalman Filter CMORPH. *4^{th} International Precipitation Working Group (IPWG) Workshop*, 13-17 October 2008, Beijing, China.

Joyce, R.J., P. Xie, and J.E. Janowiak, 2009: A Kalman Filter Approach to Blend Various Satellite Rainfall Estimates in CMORPH. *GSMaP International Symposium*, Feb 16-18, 2009, Tokyo Japan.

Joyce, R.J., P. Xie, and J.E. Janowiak, 2009: A Global Kalman Filtered CMORPH using TRMM to Blend Satellite Rainfall. Invited seminar on 16 April at NASA GSFC.

Xiong, A., , P. Xie, J. Liang, J.E. Janowiak, Y. Shen, and R. J. Joyce, 2008: Merging Gauge Observations and Satellite Estimates of Daily Precipitation over China. *4^{th} International Precipitation Working Group (IPWG) Workshop*, 13-17 October 2008, Beijing, China.

Budget

Our project is sponsored jointly by NOAA Hydeometeorology Testbed (HMT) and the NOAA Climate Program Office (CPO) Climate Change Detection and Data (CCDD) programs. The spending plan for Year 2 and budget request for Year 3 are listed below:

a) Year 2 Spending Plan

Sponsoring Program	CPO	HMT	TOTAL
Contractors Support	$41K (23% of Joyce)	$76K (42% of Joyce)	$117K
Domestic Travels		$2K	$2K
International Travel		$4.5K	$4.5K
IT Equipments:		$0.5K	$0.5K
TOTAL COST:	$41K	$83K	$124K

b) Year 3 Budget Request

Sponsoring Program	CPO	HMT	TOTAL
Contractors Support*	$45K (23% of Joyce)	$81K (42% of Joyce)	$126K
Travels	$2K	$4K	$6K
IT Equipments:		$1K	$1K
TOTAL COST:	$47K	$86K	$133K

* Request for contractors support has been increased in consideration of the rising living cost. Funding for IT equipment ($1K) is for the purchase of additional tapes to archives the satellite data. Funding for travels is requested for facilitate the PIs to attend PMM science meetings and other scientific meetings to report our research / development results.