A study of 4D-VAR assimilation of the IMERG precipitation product

Jiaying Zhang[1] (jiaying.zhang@gatech.edu), **Liao-Fan Lin**[2], and **Rafael L. Bras**[1]

[1]Georgia Institute of Technology, Atlanta, Georgia, USA, [2]University of Utah, Salt Lake City, Utah, USA

PRECIPITATION MEASUREMENT MISSIONS
PMM 2017 Science Team Meeting
October 16-20, 2017
Wyndham San Diego bayside

Introduction

- Numerical weather prediction (NWP) Models have low accuracy in predicting convective precipitation at tropics in summers, while Integrated Multi-satellite Retrievals for GPM (IMERG) provides high-resolution and high-quality data.
- The motivation of this study is to understand the impact of the IMERG product on near-future NWP forecasts via data assimilation;
- The objective of this study is to find an appropriate way to assimilate IMERG precipitation into the Weather Research and Forecasting (WRF) 4D-Var system.

Data and Method

- **The 4D-VAR method**

The 4D-VAR method is embedded in the WRFDA model. The method is to obtain an analysis initial condition ($\mathbf{x}$) that minimizes the following cost function:

$$J(\mathbf{x}) = \frac{1}{2}(\mathbf{x}-\mathbf{x}^b)^{\mathrm{T}}\mathbf{B}^{-1}(\mathbf{x}-\mathbf{x}^b) + \frac{1}{2}\sum_{i=1}^{N}\left(H_i(M_i(\mathbf{x}))-\mathbf{y}_i\right)^{\mathrm{T}}\mathbf{R}_i^{-1}\left(H_i(M_i(\mathbf{x}))-\mathbf{y}_i\right)$$

where $\mathbf{x}^b$ is the background initial condition, $\mathbf{B}$ is the error covariance matrix of $\mathbf{x}^b$; $\mathbf{y}_i$ is the observation at time i, $\mathbf{R}$ is the error covariance of $\mathbf{y}$. M_i is the model operator that predicts state variables at time i, and H_i is the observation operator that transforms the state variables into the form of the observation. When applying logarithmic transformation on precipitation ($L(x) = \ln(x+1)$):

$$J(\mathbf{x}) = \frac{1}{2}(\mathbf{x}-\mathbf{x}^b)^{\mathrm{T}}\mathbf{B}^{-1}(\mathbf{x}-\mathbf{x}^b) + \frac{1}{2}\sum_{i=1}^{N}\left(L\left(H_i(M_i(\mathbf{x}))\right)-L(\mathbf{y}_i)\right)^{\mathrm{T}}\mathbf{R'}_i^{-1}\left(L\left(H_i(M_i(\mathbf{x}))\right)-L(\mathbf{y}_i)\right)$$

$\mathbf{R}'_i$ is the error covariance matrix of transformed observations $L(\mathbf{y}_i)$: $\mathbf{R}'_i \approx \left((\mathbf{y}_i+1)^{-1}\right)^{\mathrm{T}}\mathbf{R}_i(\mathbf{y}_i+1)^{-1}$

- **Background ($\mathbf{x}^b$) and its errors ($\mathbf{B}$):**

The background initial conditions are from NCEP FNL with a spatial resolution of 0.25º×0.25º and a temporal resolution of six hours. The errors of the background are estimated using the National Meteorological Center (NMC) method.

- **Observation ($\mathbf{y}_i$) and its errors ($\mathbf{R}$):**

The observations ($\mathbf{y}_i$) are precipitation data from level 3 IMERG final run product. The errors of the observation ($\sigma_{\mathbf{y}_i}$) vary in various experiments.

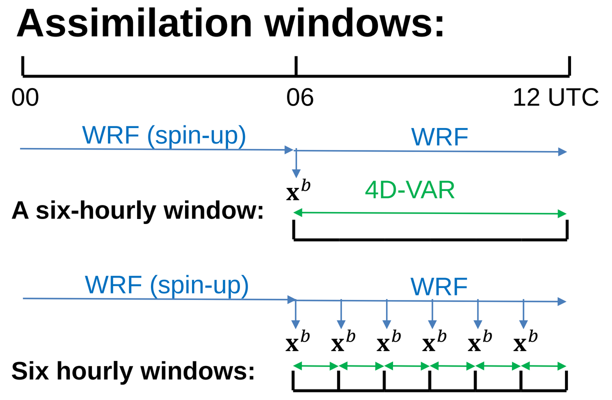
Model configuration and experiment design

A strong precipitation event during 06-12 UTC 5 August 2016 over the central United States was selected. The WRF and observation domains have a 10-km resolution.

- **Quality control:**

Observations are rejected if $\left|\mathbf{y}_i - H_i(M_i(\mathbf{x}))\right| > \mathrm{QCI}\times\sigma_{\mathbf{y}_i}$ for the original precipitation data, or $\left|L(\mathbf{y}_i) - L\left(H_i(M_i(\mathbf{x}))\right)\right| > \mathrm{QCI}\times\sigma_{L(\mathbf{y}_i)}$ for the log-transformed precipitation.

- **Assimilation windows:**



- **Experiments:**

	Assimilation Window	Transformation of precipitation	Errors in original space (mm/hr)	Errors in log space (mm/hr)	QCI (default:5)
EXP_1	6-hourly	No transformation	2 (mm/6hr)	--	5
EXP_2	Hourly	No transformation	1/3	--	5
EXP_3	Hourly	Log transformation	0.3*($\mathbf{y}_i$+1)	0.3	5
EXP_4	Hourly	Log transformation	0.15*($\mathbf{y}_i$+1)	0.15	10
EXP_5	Hourly	Log transformation	0.3*($\mathbf{y}_i$+1)	0.3	10

Results:

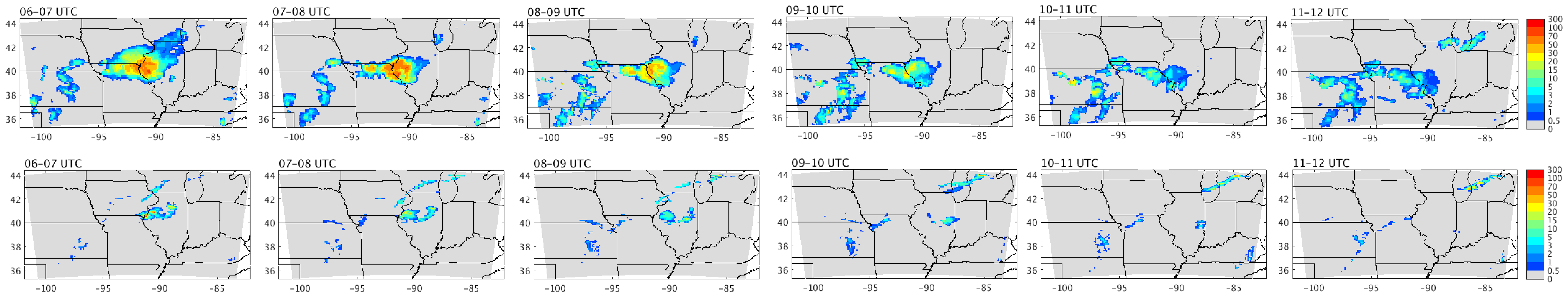


Figure 1: Hourly precipitation depth (mm) from IMERG (first row) and WRF model (also called "open loop"; second row) on 5 August 2016.

- **Hourly window vs. 6-hourly window**

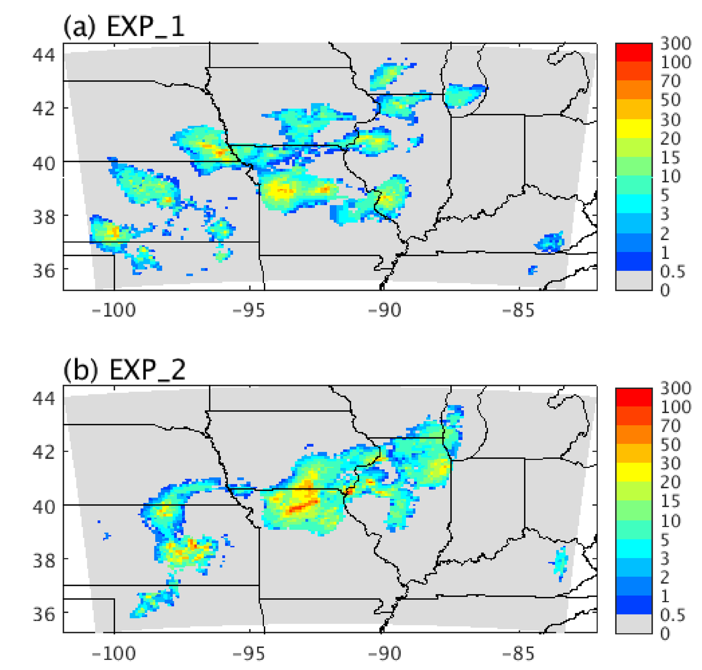


Figure 2: Hourly precipitation depth from experiments 1 (figure a) and 2 (figure b) valid at 06-07 UTC 5 August 2016.

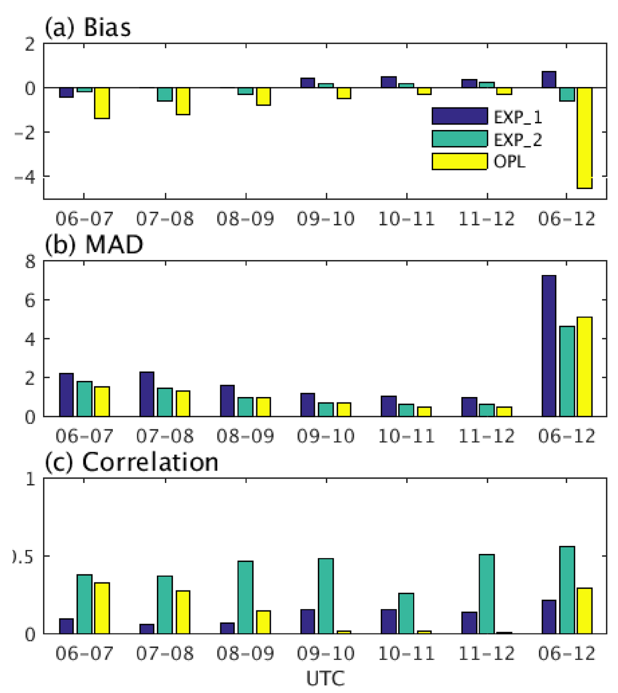


Figure 3: Quality metrics of precipitation from experiments (experiments 1 and 2 and open loop) against those from IMERG at each time period.

- **Impact of observation errors**

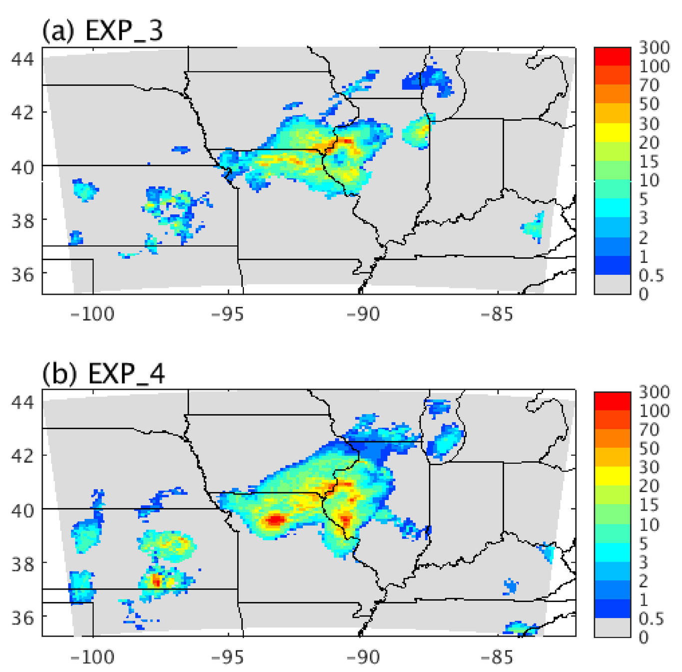


Figure 6: The same as Figure 2, except from experiments 3 and 4.

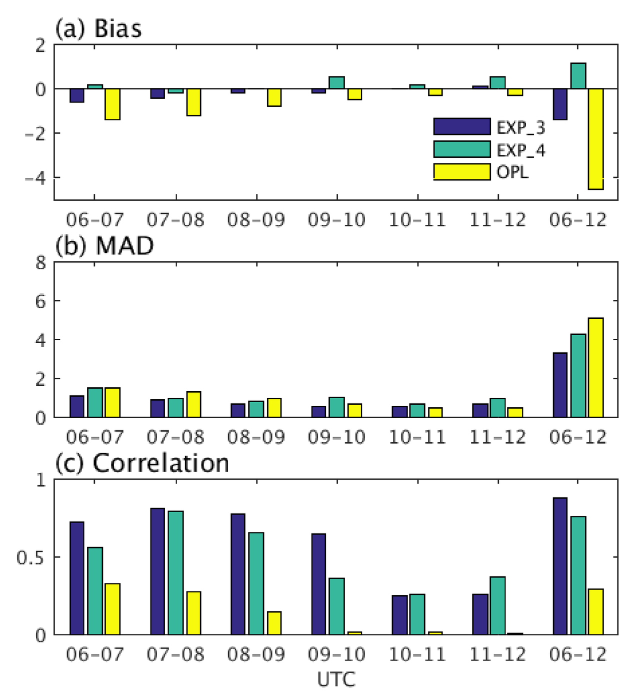


Figure 7: The same as Figure 3, except from experiments 3 and 4.

- **Impact of logarithmic transformation**

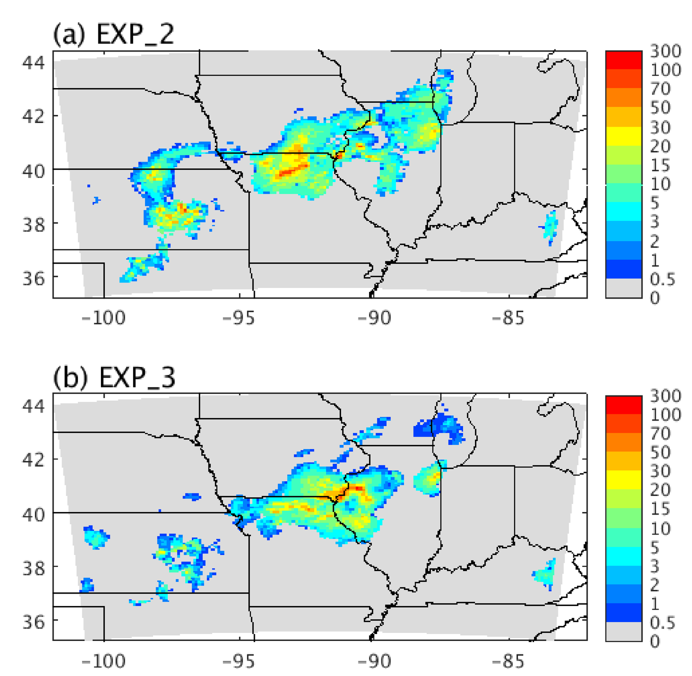


Figure 4: The same as Figure 2, except from experiments 2 and 3.

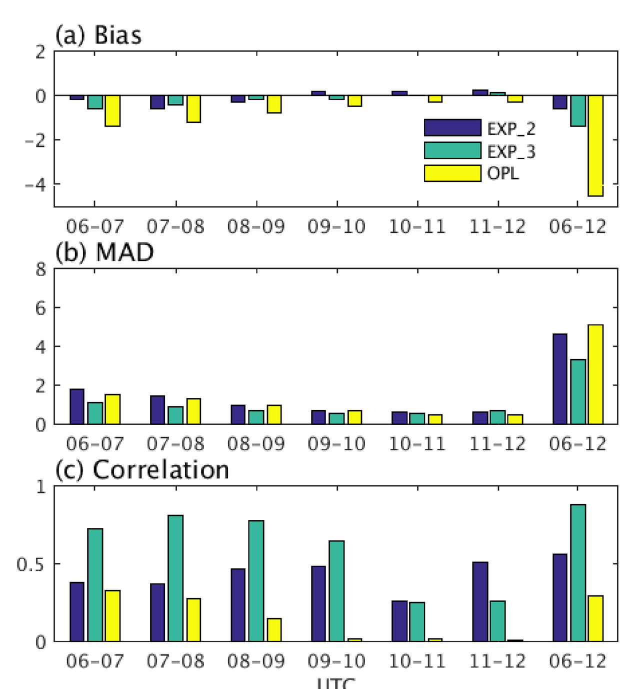


Figure 5: The same as Figure 3, except from experiments 2 and 3.

- **Impact of quality control index**

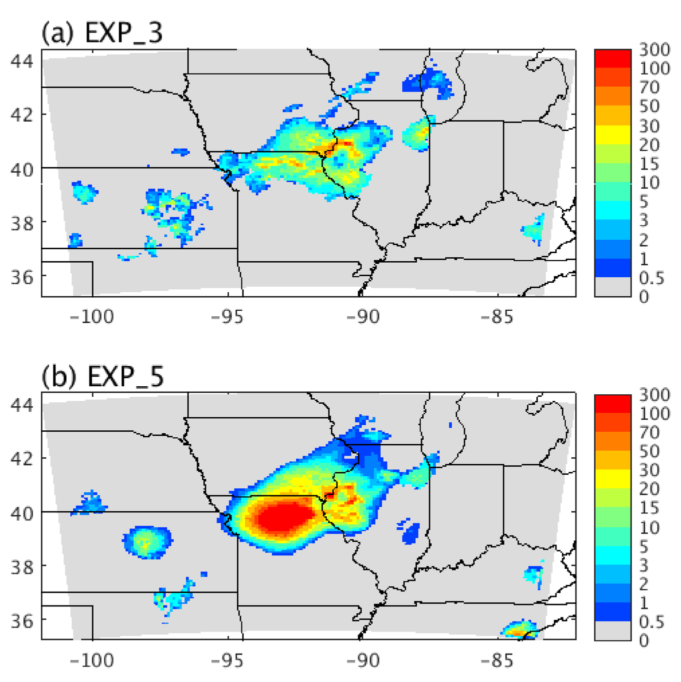


Figure 8: The same as Figure 2, except from experiments 3 and 5.

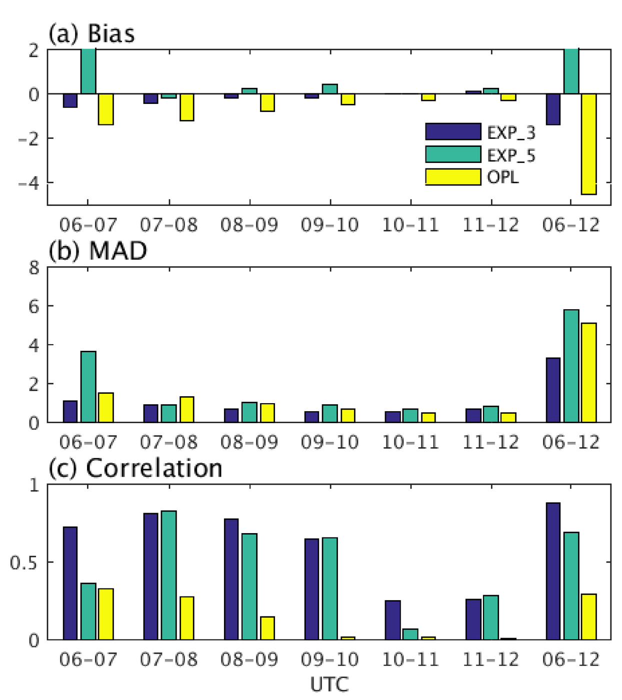


Figure 9: The same as Figure 3, except from experiments 3 and 5.

Summary:

(1) The assimilation of IMERG precipitation notably improved WRF precipitation analysis, especially when using hourly observations in an hourly assimilation window and using logarithmic transformation on precipitation and constant errors in the log space;

(2) Smaller errors of observations did not further improve the analysis;

(3) Higher threshold for rejecting observations, QCI, did not further improve the analysis;

Based on information we did not show here, we believe conclusions (2) and (3) are due to the validity of linearized model.

Acknowledgements

This study is supported by NASA PMM science program through NNX16AE36G. Models and data are obtained from NCAR.