Dynamic Data Assimilation for Improved Streamflow Forecast Using Sensitive Soil Moisture Observations

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Abstract

The accuracy of streamflow forecasts is important for efficient monitoring and mitigation of flood events. Unfortunately, the uncertainty in the model control variable which includes model parameters, initial and boundary conditions, propagates through the model, resulting in the degradation of streamflow forecast. Various studies in the past have shown the potential of soil moisture assimilation in hydrological models resulting in the improved forecast. Further, the efficiency of assimilation is based on the number and the distribution of observations used. This study proposes a new approach called Forward sensitivity method (FSM), which operates in two phases. By running the model and forecast sensitivity dynamics forward in time, the first phase places the observations at or near where the square of the forecast sensitivity with respect to the control takes maximum values. Then using only this subset of observations, the second phase estimates the unknown elements of the control by solving a resulting weighted least squares problem. The power of this approach is demonstrated by assimilating ASCAT soil moisture observations into a conceptual Two Parameter Model in a medium sized watershed lying in the Krishna River Basin, India. The model run extends for four monsoon years from June 2007 to June 2011 and two assimilation scenarios were tested. The first scenario uses all the observations, whereas, the second uses only sensitive observations during assimilation and the results were then compared against open loop simulation (model run without assimilation). Sensitivity results indicate that observations during monsoon time alone are sufficient for assimilation purpose, which accounts for only 37.42 percent of total observations. Also, the estimation and forecast results show improved streamflow performance when using only sensitive observations. From the results, it is concluded that FSM based assimilation can help in reducing the computation time greatly. Further, this study will be critically helpful in the places where data availability remains a major problem.

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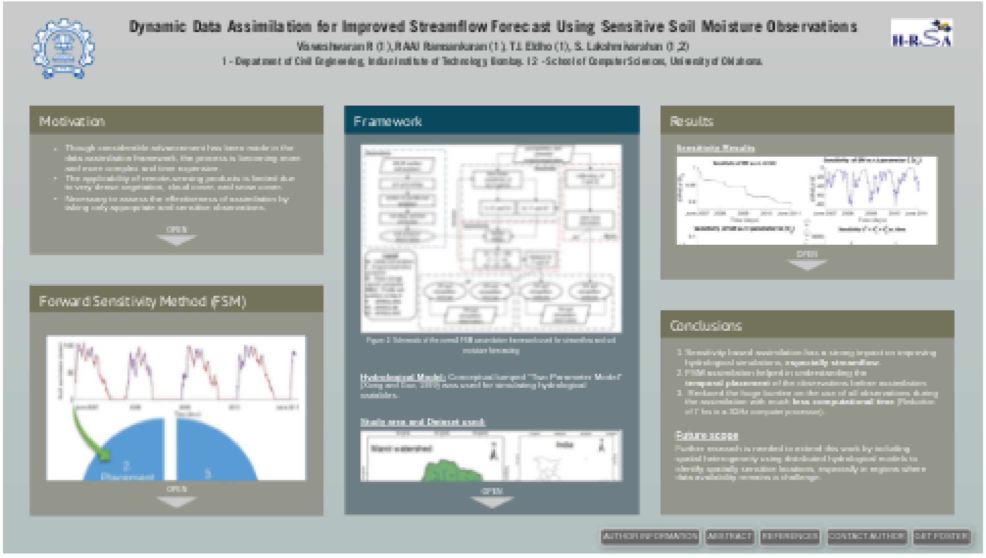

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PRESENTED AT:

MOTIVATION

- Though considerable advancement has been made in the data assimilation framework, the process is becoming more and more complex and time expensive.
- The applicability of remote-sensing products is limited due to very dense vegetation, cloud cover, and snow cover.
- Necessary to assess the effectiveness of assimilation by taking only appropriate and sensitive observations.

Forward Sensitivity Method (FSM) is based on the temporal evolution of model sensitivities with respect to the control variables consisting of initial conditions and model parameters (Lakshmivarahan, S., et al., 2017).

The application of FSM in the hydrological field is not yet tested till date.

FORWARD SENSITIVITY METHOD (FSM)

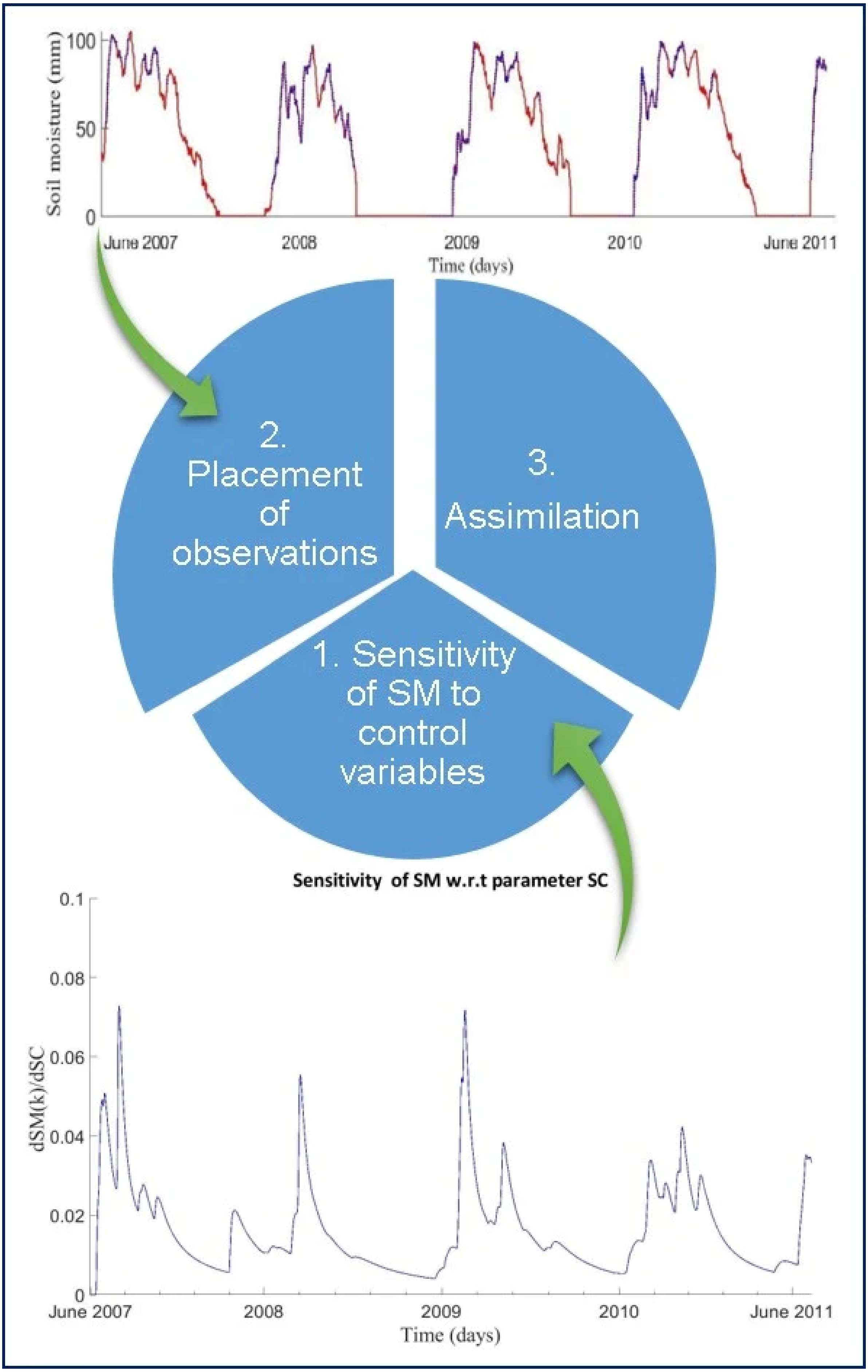

Figure 1: Schematic representation of FSM methodology

Note: control variables (cv) = Initial condition and model parameters

1) Sensitivity functions:

$$U(k) = \frac{\partial SM(k)}{\partial SM_0} V_1(k) = \frac{\partial SM(k)}{\partial \alpha_1} V_2(k) = \frac{\partial SM(k)}{\partial \alpha_2}$$

2) Identification/Placement of sensitive observations:

$$thresh = \frac{\sum_{k=1}^{N} \left(U(k)^2 + V_1(k)^2 + V_2(k)^2\right)}{N}$$

$$sens_{obs} \geq thresh$$

3) Assimilation by perturbing 'cv' iteratively close to SM observations:

Using the standard weighted least square method

$$\delta cv_{ls} = (H^T R^{-1} H) H^T R^{-1} E$$

where,

R - Error covariance of observation Z(k)

$E = \sum_{k=1}^{N} Z(k) - h(Y(k))$ (within the time window)

H - Sensitivity function [U(k) V(k)]

Repeated iteratively until cv reaches the optimal value.

FRAMEWORK

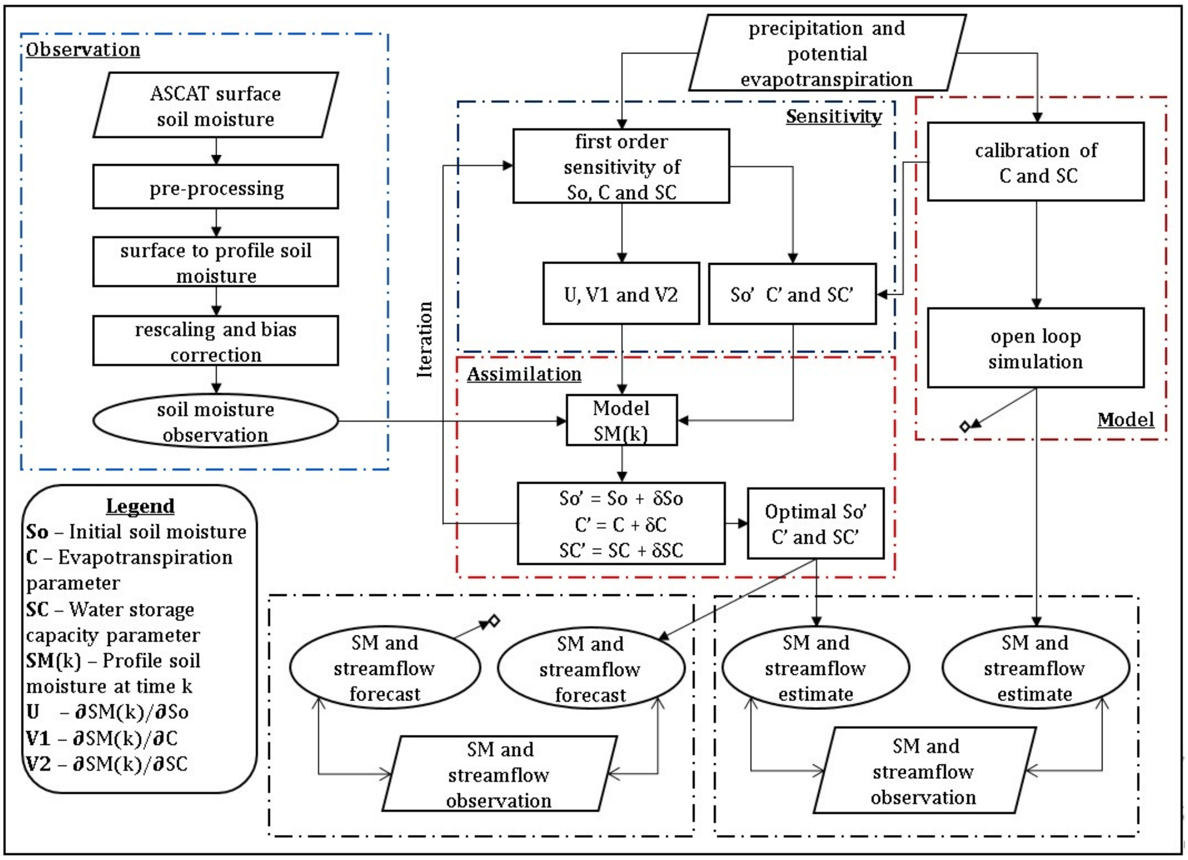

Figure 2: Schematic of the overall FSM assimilation framework used for streamflow and soil moisture forecasting

Hydrological Model: Conceptual lumped "Two Parameter Model" (Xiong and Guo, 1999) was used for simulating hydrological variables.

Study area and Dataset used:

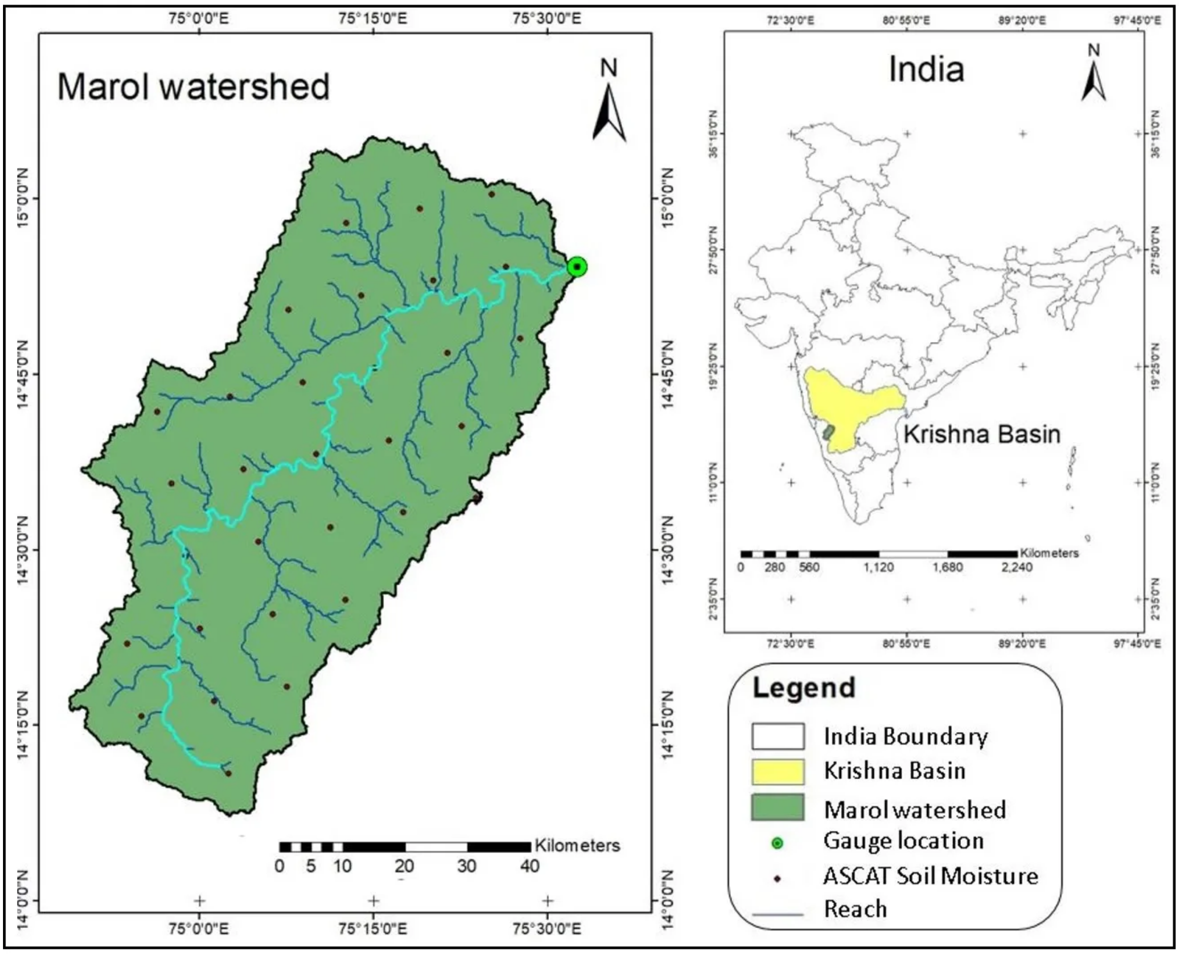

Figure 3: Study area map showing the location of ASCAT soil moisture observation points, streamgauging station, and streamnetworks of the Marol watershed.

Surface soil moisture observation - ASCAT- L2 at 0.1^{o}

Temperature - NCEP-CFSR at 0.25^{o}

Rainfall - Karnataka State Govt.

RESULTS

Sensitivity Results

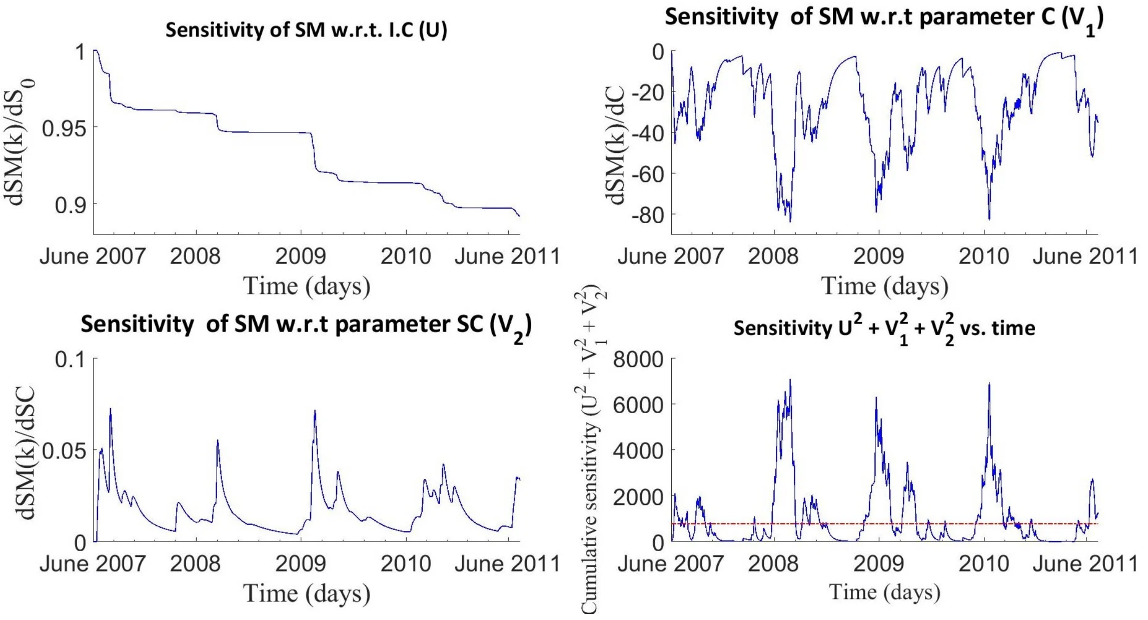

Figure 4: Sensitivity evolution of the soil moisture with respect to a) Initial condition 'S_o', b) parameter 'C', c) Parameter 'SC', and d) cumulative sensitivity.

1. Sensitivity was predominantly dominant during the monsoon period of the year.

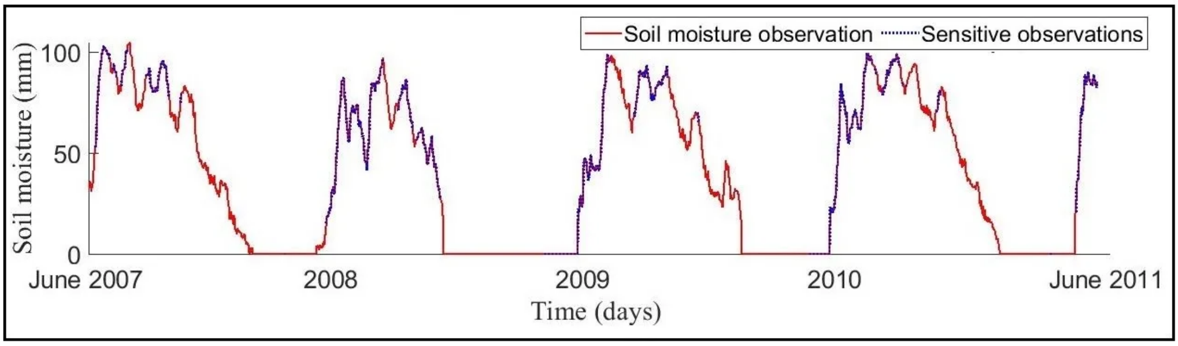

Figure 5: Identification of the sensitive soil moisture observations selected for assimilation purpose.

1. 558 observations were classified/identified as sensitive out of 1491 observations that account for just **37.42 percent.**

Estimation Results

Table 1: Performance measures of the estimated soil moisture and streamflow for open-loop and two assimilation scenarios representing KGE, RMSE, and PBIAS values.

S.no	Soil moisture			Streamflow		
Evaluation indices	KGE	RMSE	PBIAS	KGE	RMSE	PBIAS
(Unit)	(-)	(mm)	(%)	(-)	(cumecs)	(%)
Open-loop	0.335	29.413	-40.187	0.668	119.729	24.595
All observations	0.717	21.77	-0.952	0.77	82.226	6.182
Sensitivity observations	0.389	28.461	-37.232	0.824	98.3	3.56

1. Soil moisture showed only marginal improvement while assimilating only sensitive observations.
2. Streamflow estimates showed significant improvement during both the assimilation scenarios with a KGE value of more than 0.75

Forecast Results

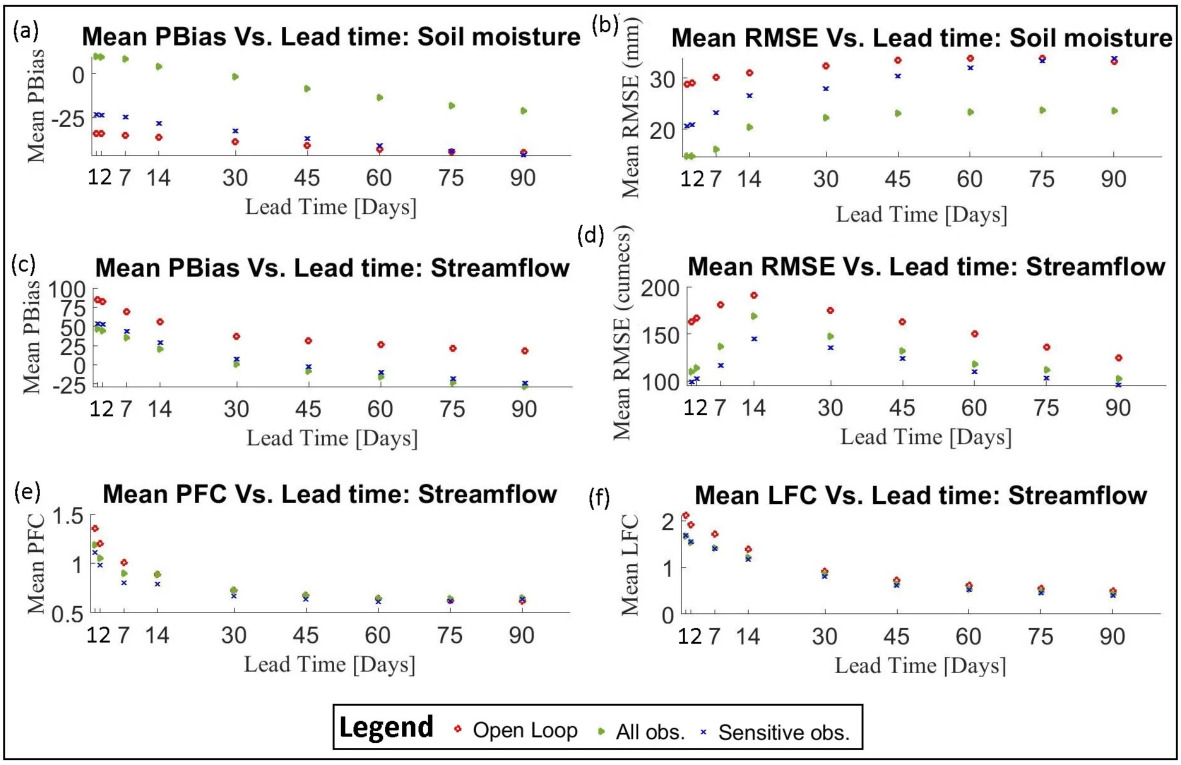

Figure 6: Mean values of PBIAS, RMSE, PFC, and LFC evaluated for 95 simulations of a-b) soil moisture, and c-f) streamflow forecasts represented for nine different lead times.

1. Streamflow forecast showed better performance for both the scenarios than the open-loop run up to **45 lead days**.

CONCLUSIONS

1. Sensitivity based assimilation has a strong impact on improving hydrological simulations, **especially streamflow**.
2. FSM assimilation helped in understanding the **temporal placement** of the observations before assimilation.
3. Reduced the huge burden on the use of all observations during the assimilation with much **less computational time** (Reduction of 7 hrs in a 3GHz computer processor).

Future scope

Further research is needed to extend this work by including spatial heterogeneity using distributed hydrological models to identify spatially sensitive locations, especially in regions where data availability remains a challenge.

AUTHOR INFORMATION

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ABSTRACT

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