Improved ensemble representation of soil moisture in SWAT for data assimilation applications

Amol Patil and RAAJ Ramsankaran

Hydro-Remote Sensing Applications (H-RSA) Group,

Department of Civil Engineering

Indian Institute of Technology, Bombay

Mumbai, India

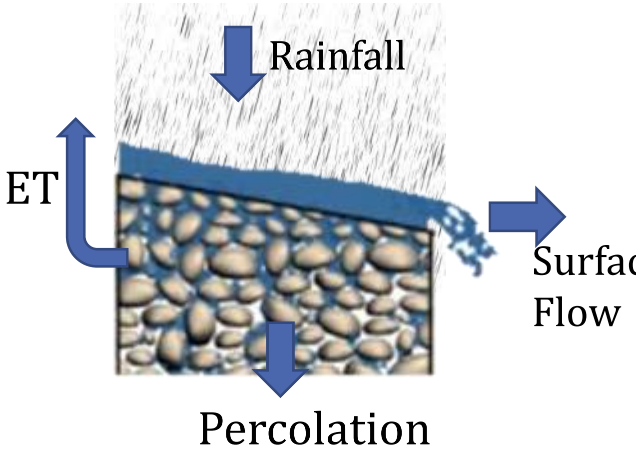
SWAT 2018

IIT Madras, Chennai, India

H-RSA
Hydro-Remote Sensing Applications Group
Department of Civil Engineering
Indian Institute of Technology Bombay

Why soil moisture?

Why Soil Moisture is so Important in Hydrological Modelling?



Controls partitioning of rainfall into runoff, infiltration, and evapotranspiration.

However, it posses lot of uncertainties ….

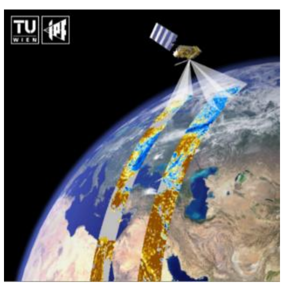
The accurate measurements of soil moisture is tedious task over large spatial extents

Hydro-Remote Sensing Applications Group
Department of Civil Engineering
Indian Institute of Technology Bombay

Satellite observations

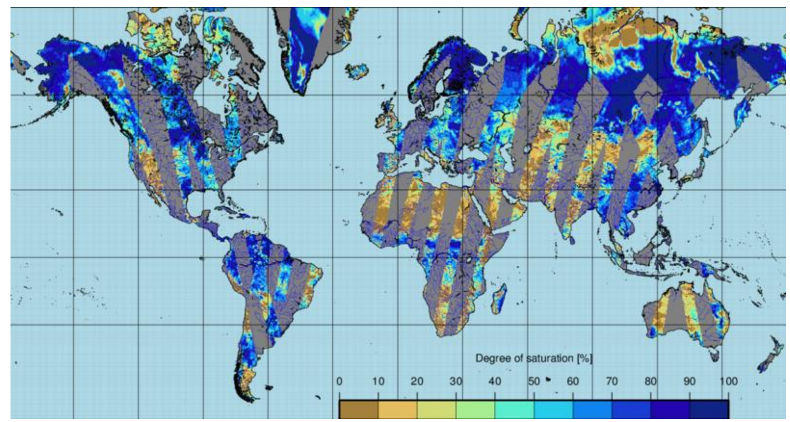
Other sources of soil moisture information over large spatial scales includes satellite observations

SMAP



ASCAT

SMOS



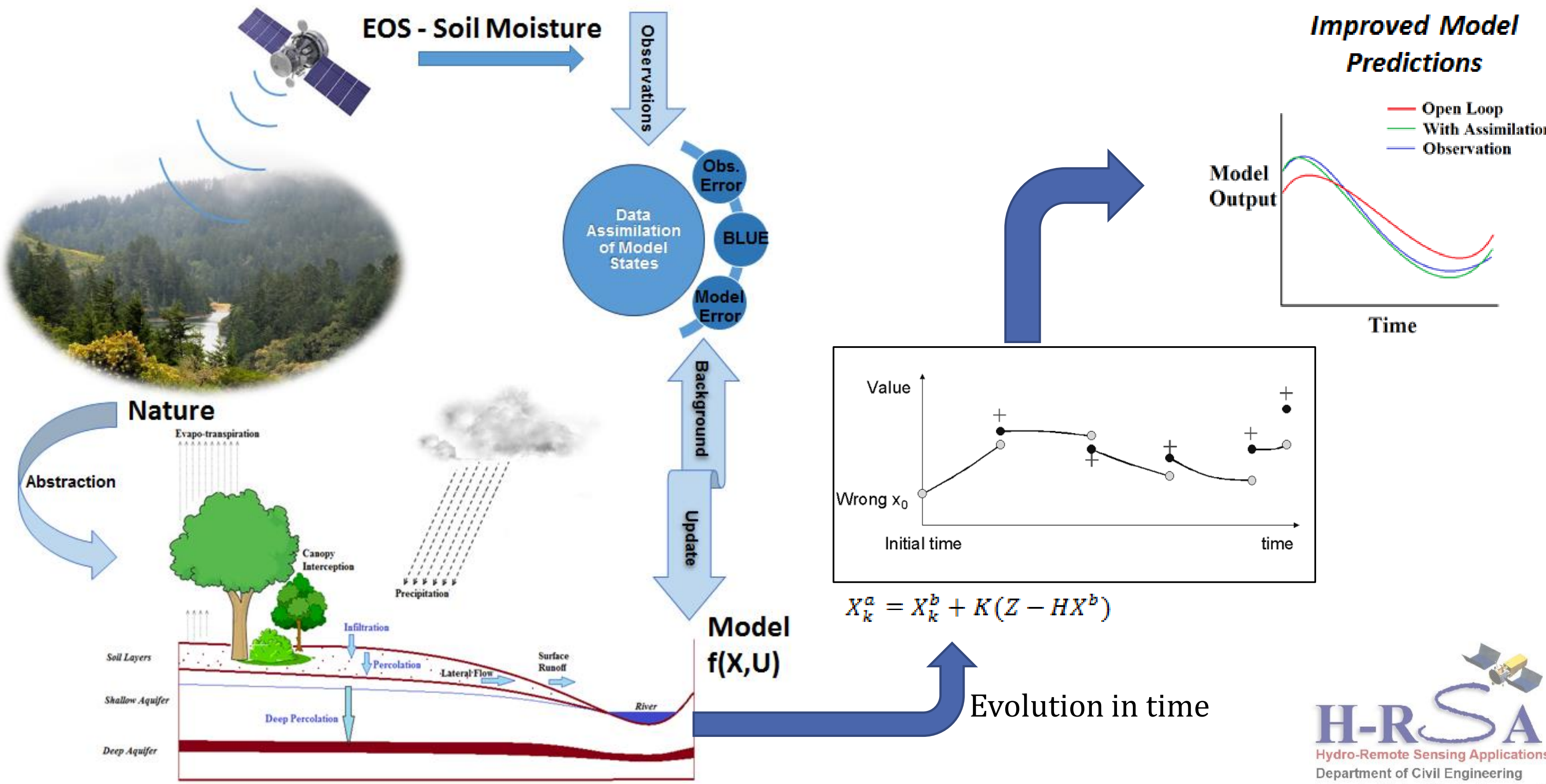
http://hsaf.meteoam.it/description-sm-ascat-ab-nrt.php

Spatial Resolution ??
Accuracy ??
Depth ??
Data gaps ??

H-RSA
Hydro-Remote Sensing Applications Group
Department of Civil Engineering
Indian Institute of Technology Bombay

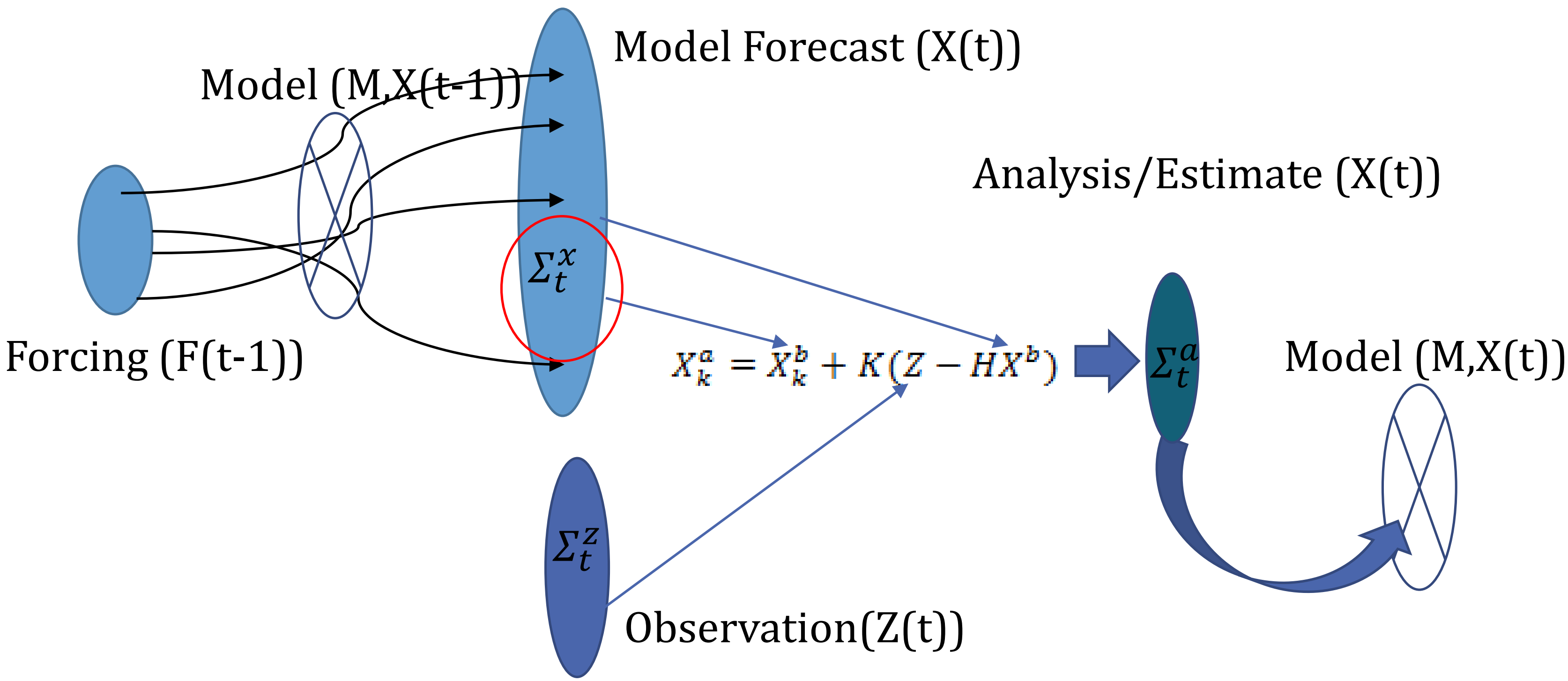
Data Assimilation

Combines information from imperfect models and uncertain data in optimal way (BLUE) to achieve uncertainty reduction



H-RSA
Hydro-Remote Sensing Applications Group
Department of Civil Engineering
Indian Institute of Technology Bombay

Data assimilation: overview



Where, K is $\boldsymbol{K} = \Sigma_t^{xz}[\Sigma_t^{zz} + \Sigma_t^{z}]^{-1}$ and for scalar case $\Sigma_t^a = \dfrac{\Sigma_t^x}{[\Sigma_t^x + \Sigma_t^z]}$

H-RSA
Hydro-Remote Sensing Applications Group
Department of Civil Engineering
Indian Institute of Technology Bombay

Current problems

Extrapolating the observed information from surface layer to soil profile during ensemble model simulations is the one of major hurdle being experienced by past studies

(e.g. Chen et al. 2011) and hence some of them have adopted slightly sub-optimal algorithms (e.g. use of nudging method by Lievens et al. 2015).

ELSEVIER
Contents lists available at ScienceDirect
Advances in Water Resources
journal homepage: www.elsevier.com/locate/advwatres

Improving hydrologic predictions of a catchment model via assimilation of surface soil moisture

Fan Chen[a], Wade T. Crow[b,*], Patrick J. Starks[c], Daniel N. Moriasi[c]

[a] Science Systems and Applications, Inc./USDA ARS Hydrology and Remote Sensing Laboratory, Beltsville, MD 20705, United States
[b] USDA ARS Hydrology and Remote Sensing Laboratory, Beltsville, MD 20705, United States
[c] USDA ARS Grazinglands Research Laboratory, El Reno, OK 73036, United States

ARTICLE INFO

Article history:
Received 1 October 2010
Received in revised form 25 January 2011
Accepted 26 January 2011
Available online 4 February 2011

Keywords:
Soil moisture
Hydrologic modeling
Data assimilation
Remote sensing

ABSTRACT

This paper examines the potential for improving Soil and Water Assessment Tool (SWAT) hydrologic predictions of root-zone soil moisture, evapotranspiration, and stream flow within the 341 km^2 Cobb Creek Watershed in southwestern Oklahoma through the assimilation of surface soil moisture observations using an Ensemble Kalman filter (EnKF). In a series of synthetic twin experiments assimilating surface soil moisture is shown to effectively update SWAT upper-layer soil moisture predictions and provide moderate improvement to lower layer soil moisture and evapotranspiration estimates. However, insufficient SWAT-predicted vertical coupling results in limited updating of deep soil moisture, regardless of the SWAT parameterization chosen for root-water extraction. Likewise, a real data assimilation experiment using ground-based soil moisture observations has only limited success in updating upper-layer soil moisture and is generally unsuccessful in enhancing SWAT stream flow predictions. Comparisons against ground-based observations suggest that SWAT significantly under-predicts the magnitude of vertical soil

ELSEVIER
Contents lists available at ScienceDirect
Remote Sensing of Environment
journal homepage: www.elsevier.com/locate/rse

SMOS soil moisture assimilation for improved hydrologic simulation in the Murray Darling Basin, Australia

CrossMark

H. Lievens[a,*], S.K. Tomer[b], A. Al Bitar[b], G.J.M. De Lannoy[c], M. Drusch[d], G. Dumedah[e], H.-J. Hendricks Franssen[f], Y.H. Kerr[b], B. Martens[a], M. Pan[g], J.K. Roundy[h], H. Vereecken[f], J.P. Walker[e], E.F. Wood[g], N.E.C. Verhoest[a], V.R.N. Pauwels[e]

[a] Laboratory of Hydrology and Water Management, Ghent University, Ghent, Belgium
[b] Centre d'Etudes Spatiales de la Biosphère, Toulouse, France
[c] Global Modeling and Assimilation Office, NASA Goddard Space Flight Center, Greenbelt, MD, USA
[d] European Space Agency, Noordwijk, The Netherlands
[e] Department of Civil Engineering, Monash University, Victoria, Australia
[f] Forschungszentrum Jülich, Jülich, Germany
[g] Land Surface Hydrology Group, Princeton University, Princeton, NJ, USA
[h] Hydrological Sciences Branch, NASA Goddard Space Flight Center, Greenbelt, MD, USA

Therefore improved methodologies for ensemble forecasting of soil moisture at multiple soil layers is required..

H-RSA
Hydro-Remote Sensing Applications Group
Department of Civil Engineering
Indian Institute of Technology Bombay

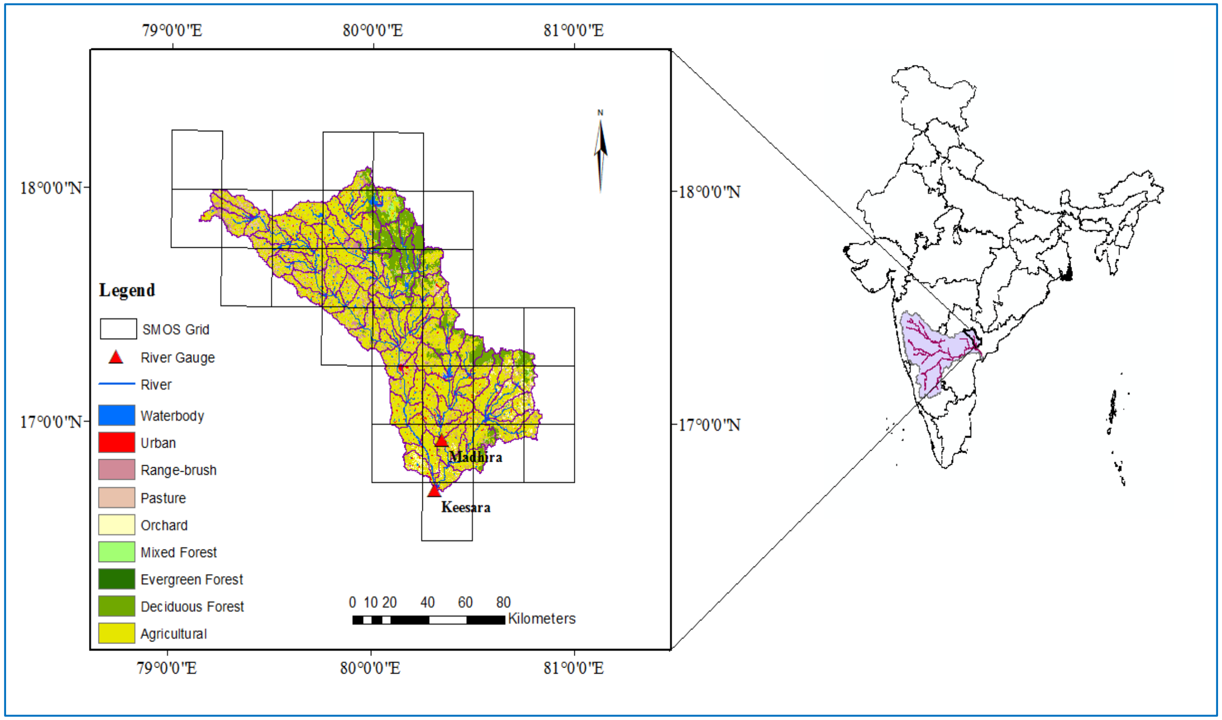
Objective of this study

To provide better surface to sub-surface soil moisture error correlation without altering model physics during ensemble simulations.

H-RSA
Hydro-Remote Sensing Applications Group
Department of Civil Engineering
Indian Institute of Technology Bombay

Study Area, Data and Model

The present study has been carried out in Munneru river basin which is one of the left tributaries of Krishna River, India.



Area – 10156 Km^2
Lat –16^0 41’ N to 18^0 7’ N
Long – 79^0 7’ E to 80^0 50’ E

Figure: Geographical location of the study area along with the land use information, river network and stream gauge locations.

H-RSA
Hydro-Remote Sensing Applications Group
Department of Civil Engineering
Indian Institute of Technology Bombay

Study Area, Data and Model

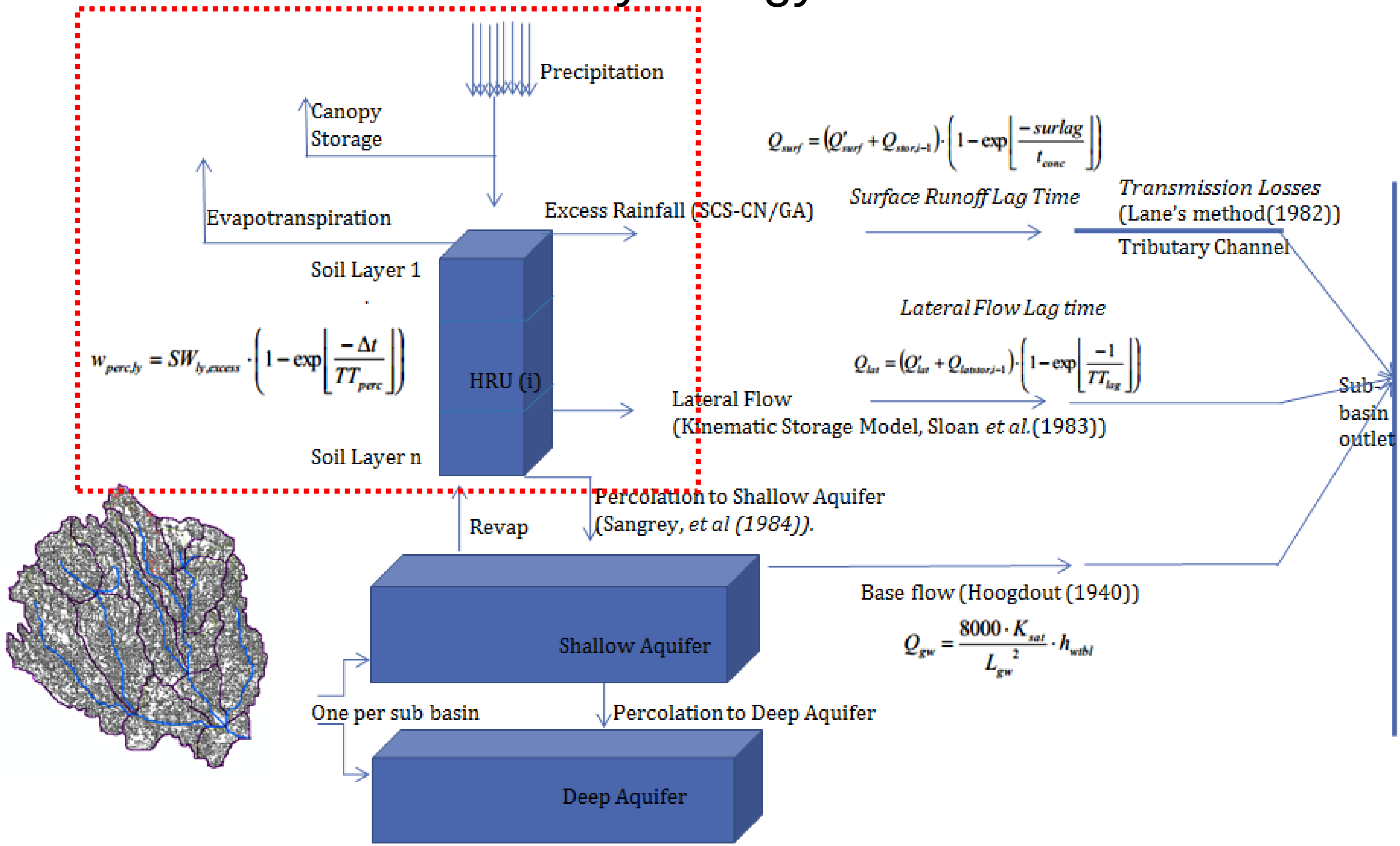
Table: List of datasets used in the present study

Data type	Dataset	Source	Scale/ Resolution	Period	Remarks	Reference
Forcing Variable	Rainfall	IMD Gridded	$0.25^0 \times 0.25^0$	2003 – 2013	Interpolated gauge data	Pai et al., (2014)
	Temperature	IMD Gridded	$1^0 \times 1^0$	2003 – 2013	Interpolated gauge data	Srivastava et al., (2009)
	Humidity	NCEP – CFSR	$0.25^0 \times 0.25^0$	2003 – 2013	Reanalysis	Saha et al., (2010)
	Wind Speed	NCEP – CFSR	$0.25^0 \times 0.25^0$	2003 – 2013	Reanalysis	Saha et al., (2010)
	Solar Radiation	NCEP – CFSR	$0.25^0 \times 0.25^0$	2003 – 2013	Reanalysis	Saha et al., (2010)
State Variables	Soil moisture	SMOS L3	$0.25^0 \times 0.25^0$	2010 – 2013	Passive microwave retrievals	Kerr et al., (2001)
Outflow	Discharge	CWC Gauge	-	2006 - 2013	Observed gauge data	CWC,(2012)
Thematic Data	Land Use	NRSC	1:250,000	2007	Derived from AWiFS optical data	NRSC, (2008)
	Soil	FAO HWSD V1.2	1:5,000,000	2009	Prepared from soil survey datasets	FAO/IIASA/ISRIC/ISS CAS/JRC, (2012)
	Topography	SRTM GDEM	90 m	2002	Interferometric SAR product	Jarvis, (2008)

H-RSA
Hydro-Remote Sensing Applications Group
Department of Civil Engineering
Indian Institute of Technology Bombay

Study Area, Data and Model

SWAT Hydrology Model



Methods

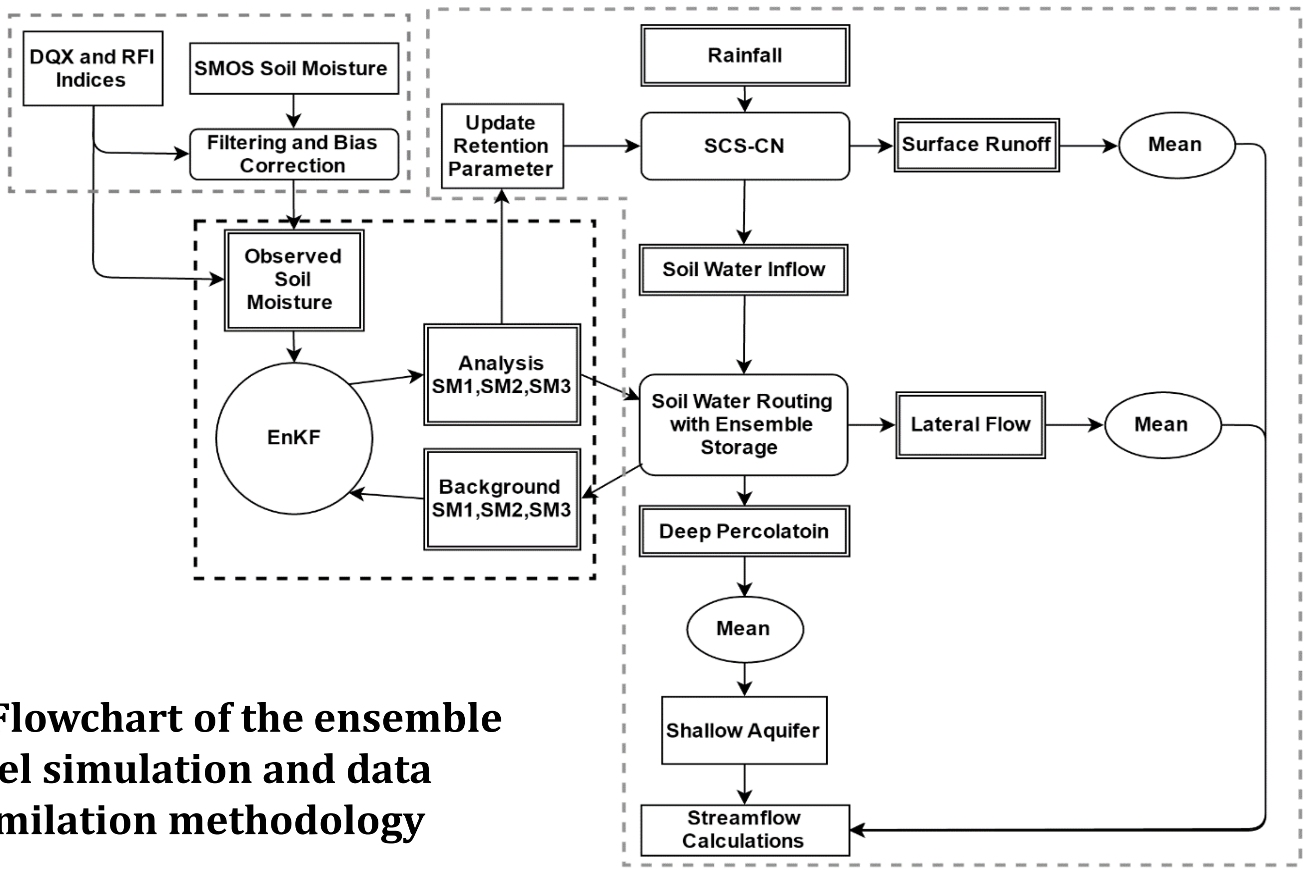


Figure: Flowchart of the ensemble model simulation and data assimilation methodology

H-RSA
Hydro-Remote Sensing Applications Group
Department of Civil Engineering
Indian Institute of Technology Bombay

Methods

Model Calibration: 2006-2009 **Model Validation:** 2010-2012

Forecast Error

Sampling method used: Latin Hypercube
Number of Ensemble: 100
Rainfall error std. dev.: 0.15*Rainfall magnitude

Direct perturbation to soil layers:
layer 1 (0-50mm) - 0.1 mm/mm
layer 2 (0-50mm) - 0.07 mm/mm
layer 3 (0-50mm) - 0.01 mm/mm
(Vertical error correlation of one)

Perturbation to soil storages: 0.1 mm/mm
(Error correlation of one with ensemble inflow to soil layer)

Observation Error
Observation error is defined using data quality flags varying from 0.01 to 0.25 mm/mm standard deviation

H-RSA
Hydro-Remote Sensing Applications Group
Department of Civil Engineering
Indian Institute of Technology Bombay

Methods

Scenario 1 (EnKF1)

Perturbed (stochastically represented) only model forcing and state variables

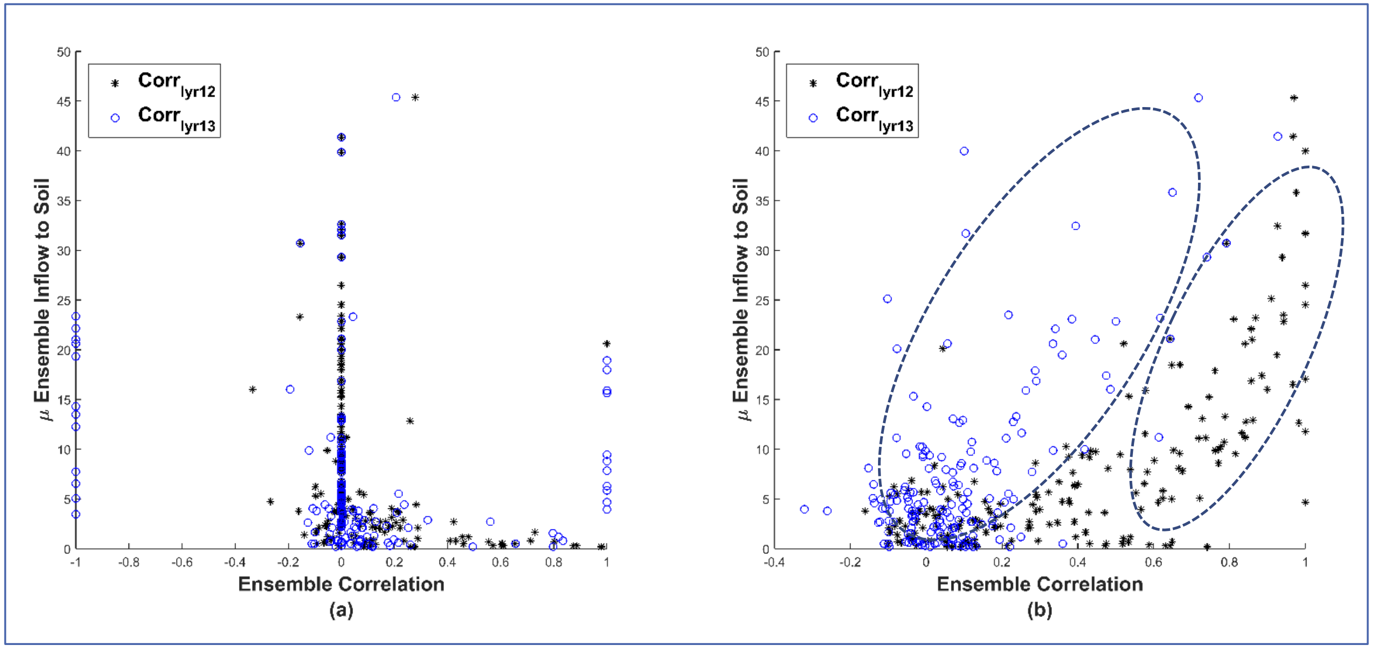
Scenario 2 (EnKF2)

Perturbed (stochastically represented) only model forcing and state variables as well as key model parameters representing soil water routing.

H-RSA
Hydro-Remote Sensing Applications Group
Department of Civil Engineering
Indian Institute of Technology Bombay

Results: error correlation

Error correlation between surface and sub-surface soil moisture



Scatter plot of error correlation of the first layer to each subsurface layer with respect to the mean ensemble inflow to soil profile for
(a) EnKF1 run with unperturbed soil water storage capacity, and
(b) EnKF2 run with perturbed soil water storage capacity

Key outcomes

- ✓ The error correlation of forecasted soil moisture increased along with profile soil water inflow
- ✓ Improvement in correlation shows that better coupling between top soil layer and second soil layer than top layer to third layer which is more realistic

Hydro-Remote Sensing Applications Group
Department of Civil Engineering
Indian Institute of Technology Bombay

Results: error correlation

	EnKF1	EnKF2
$Corr_{lyr}12$	0.10	0.29
$Corr_{lyr}13$	0.09	0.16

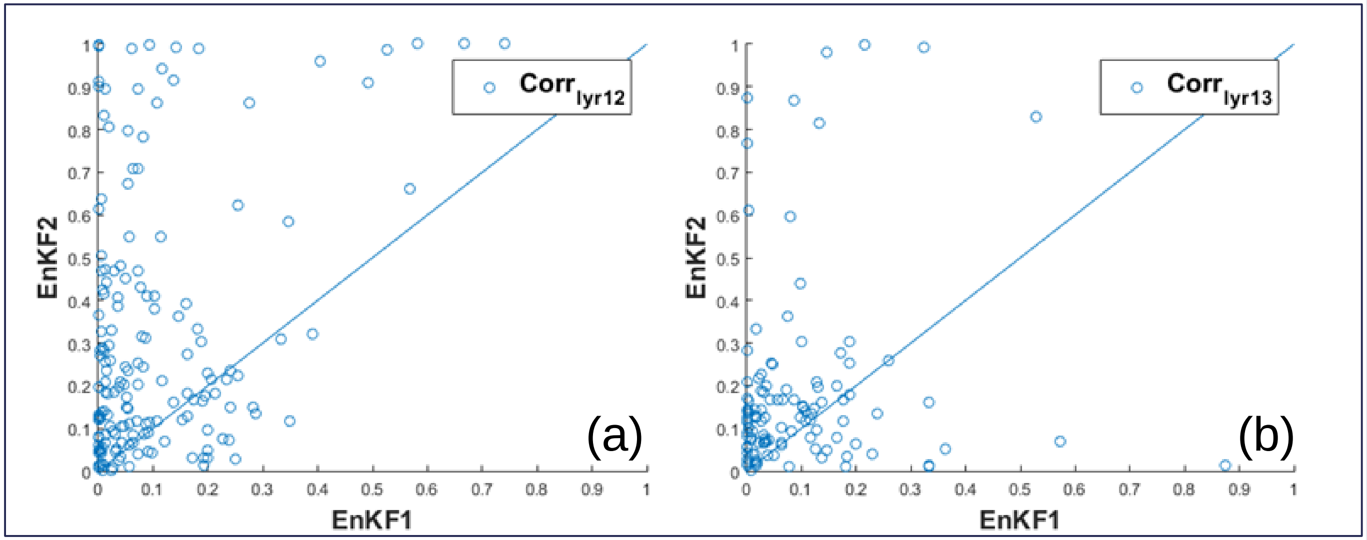


Table: Average error correlation of the first layer to each subsurface layer over entire basin (mean ensemble inflow >5mm)
(a) EnKF1 run with unperturbed soil water storage capacity, and
(b) EnKF2 run with perturbed soil water storage capacity

Key outcomes

- ✓ The error correlation structure is improved most of the times during entire simulation period
- ✓ The overall improvement in error correlation is again better for second layer than top layers than bottom ones

H-RSA
Hydro-Remote Sensing Applications Group
Department of Civil Engineering
Indian Institute of Technology Bombay

Results Soil Moisture assimilation

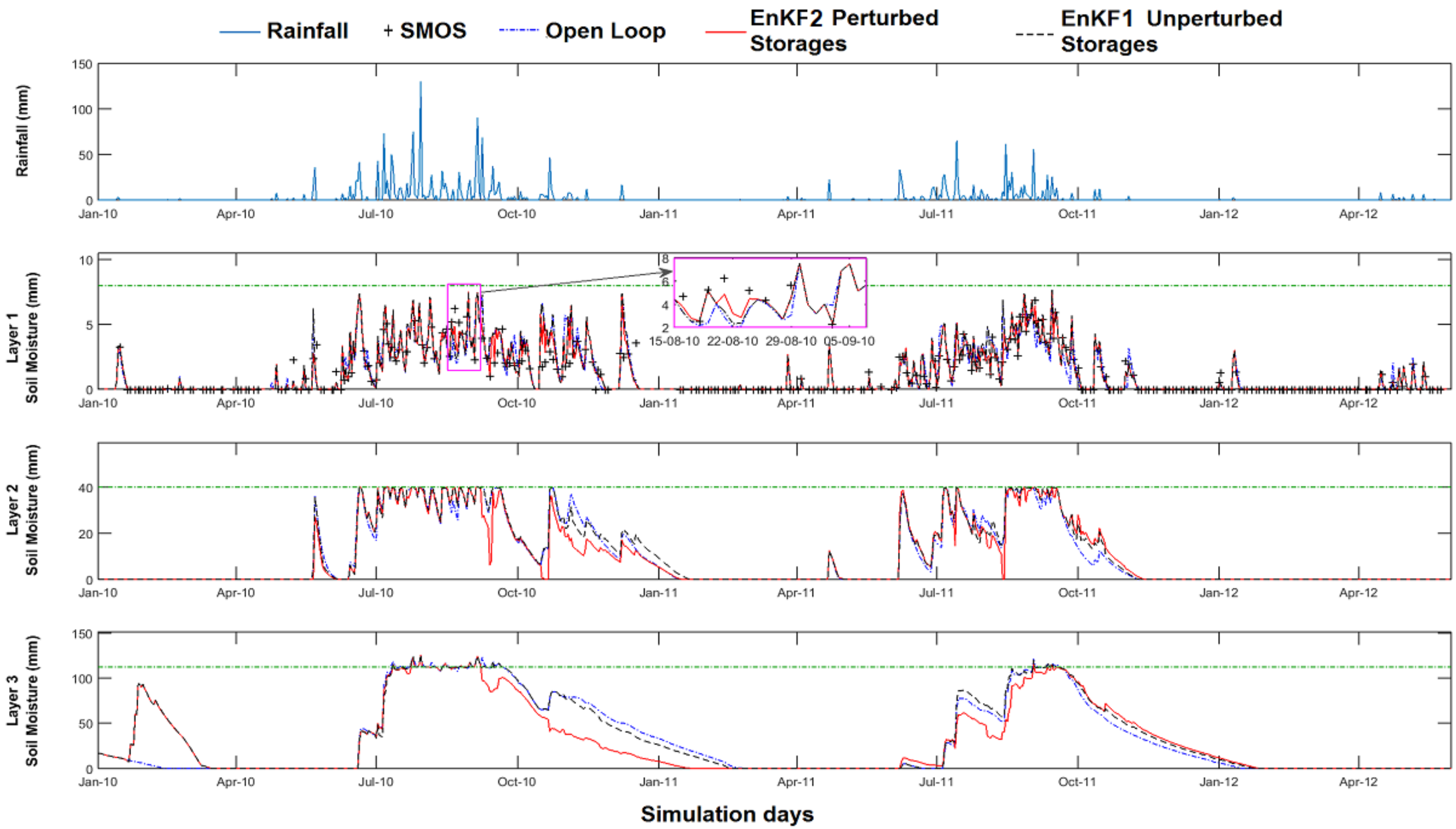


Figure: Comparison of observed and simulated soil moisture for all model runs

(Patil and Ramsankaran, 2017)

H-RSA
Hydro-Remote Sensing Applications Group
Department of Civil Engineering
Indian Institute of Technology Bombay

Results: stream flow evaluation

NSE_OL = 0.573 NSE_EnKF1 = 0.667 NSE_EnKF2 = 0.703

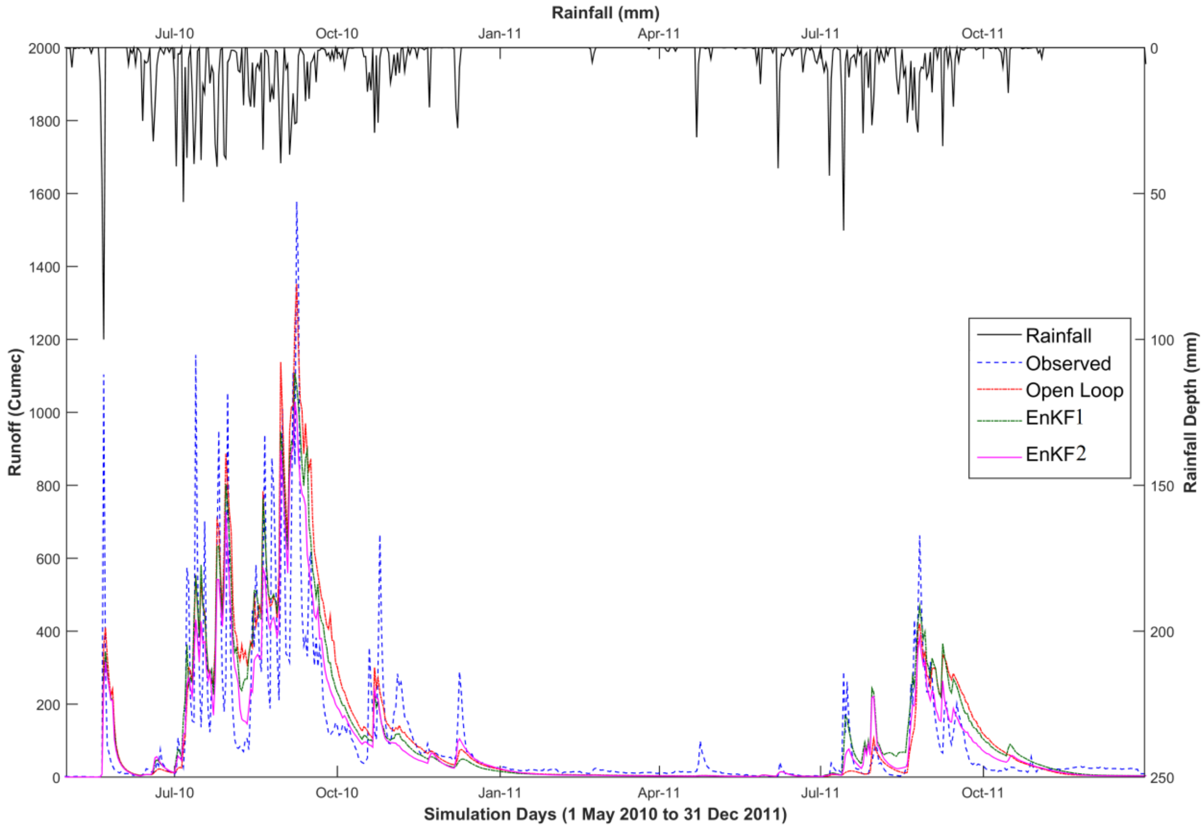


Figure: Comparison of observed and simulated streamflow for all model runs

(Patil and Ramsankaran, 2017)

Key outcomes

- ✓ Model simulations for rising limb and recession limb flood hydrograph have shown significant improvements
- ✓ Overall EnKF2 run gives best assimilation performance

H-RSA
Hydro-Remote Sensing Applications Group
Department of Civil Engineering
Indian Institute of Technology Bombay

Conclusions and Future Directions

- Randomizing the key parameters in soil water routing facilitates ensemble soil water storages which further improves the error correlation structure required for data assimilation applications

- The SMOS soil moisture can be used for improving the streamflow estimates by assimilating into large-scale distributed hydrological models operating at a daily time step

- Further studies are needed to understand the requirements of model structures that could handle stochastic or ensemble model simulations to help related applications.

H-RSA
Hydro-Remote Sensing Applications Group
Department of Civil Engineering
Indian Institute of Technology Bombay

Publication

Based on this concept, a recent article is available at https://www.sciencedirect.com/science/article/pii/S0022169417307357

Journal of Hydrology 555 (2017) 683–696

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

ELSEVIER

Research papers

Improving streamflow simulations and forecasting performance of SWAT model by assimilating remotely sensed soil moisture observations

CrossMark

Amol Patil, RAAJ Ramsankaran *

Hydro-Remote Sensing Applications (H-RSA) Group, Department of Civil Engineering, Indian Institute of Technology Bombay, Powai, Mumbai 400076, India

ARTICLE INFO

Article history:
Received 17 March 2017
Received in revised form 12 October 2017
Accepted 24 October 2017
Available online 28 October 2017
This manuscript was handled by C. Corradini, Editor-in-Chief, with the assistance of Magdeline Laba, Associate Editor

Keywords:
Data assimilation
SMOS
EnKF
SWAT
Large catchment
Streamflow predictions

ABSTRACT

This article presents a study carried out using EnKF based assimilation of coarser-scale SMOS soil moisture retrievals to improve the streamflow simulations and forecasting performance of SWAT model in a large catchment. This study has been carried out in Munneru river catchment, India, which is about 10,156 km^2. In this study, an EnKF based new approach is proposed for improving the inherent vertical coupling of soil layers of SWAT hydrological model during soil moisture data assimilation. Evaluation of the vertical error correlation obtained between surface and subsurface layers indicates that the vertical coupling can be improved significantly using ensemble of soil storages compared to the traditional static soil storages based EnKF approach. However, the improvements in the simulated streamflow are moderate, which is due to the limitations in SWAT model in reflecting the profile soil moisture updates in surface runoff computations. Further, it is observed that the durability of streamflow improvements is longer when the assimilation system effectively updates the subsurface flow component. Overall, the results of the present study indicate that the passive microwave-based coarser-scale soil moisture products like SMOS hold significant potential to improve the streamflow estimates when assimilating into large-scale distributed hydrological models operating at a daily time step.

H-RSA
Hydro-Remote Sensing Applications Group
Department of Civil Engineering
Indian Institute of Technology Bombay

H-RSA
Hydro-Remote Sensing Applications Group
Department of Civil Engineering
Indian Institute of Technology Bombay