# Demonstrating the Value of Adding Suction Losses for Channel Infiltration in WRF-Hydro Hydrological Model and Its Application in Semiarid Region

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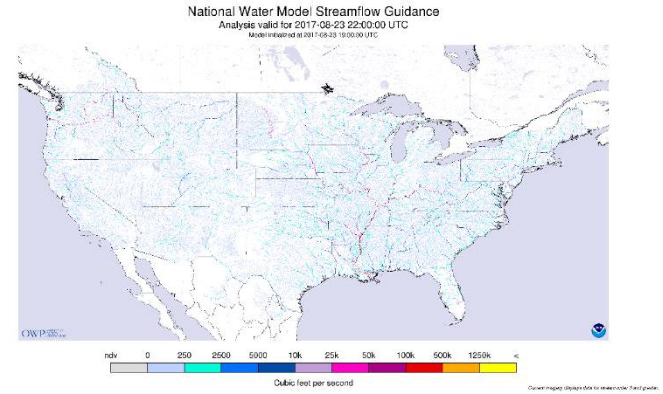
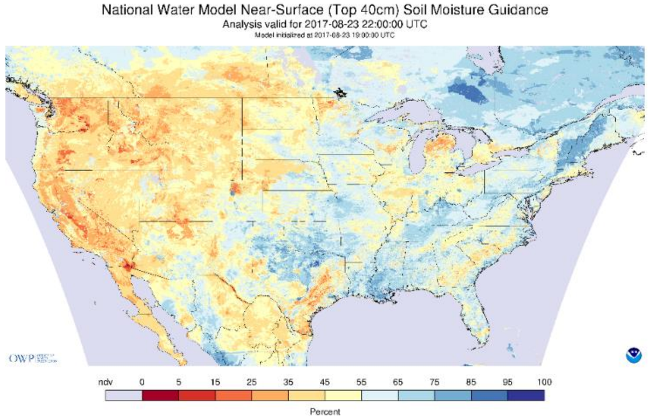
# Introduction

- The WRF-Hydro hydrological model (Gochis et al. 2018) configured as NOAA National Water Model (NWM) is *challenged to reproduce* hydrologic responses (infiltration losses) in southwestern CONUS.

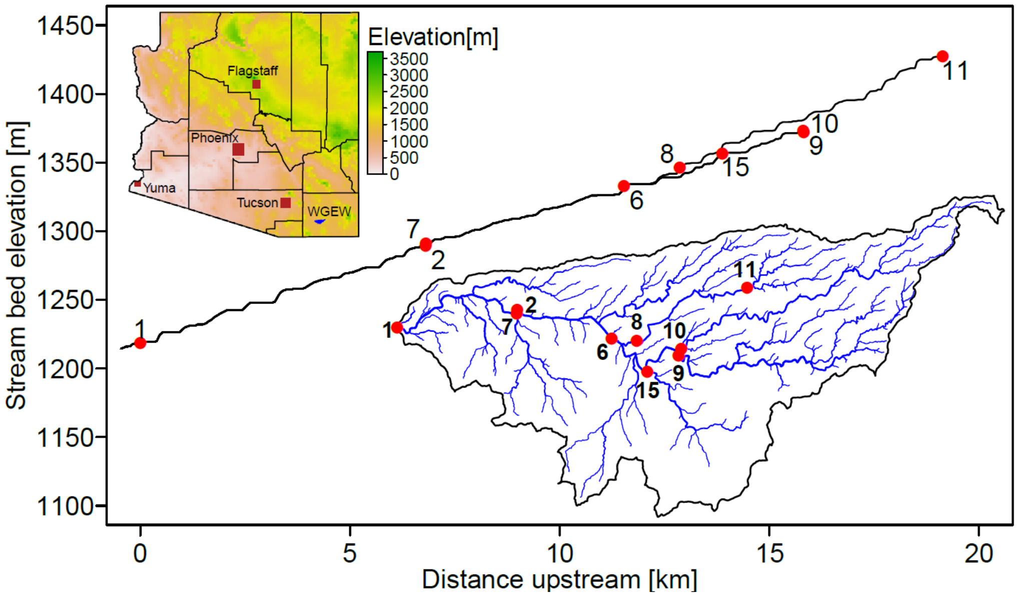
- NWM Background
  - Need for an NWM: Human Cost of Flood Events
    - $7.96 Billion Per Year
    - 82 Fatalities Per Year
  - Hydrologic model simulation for the entire Contiguous US
    - Analysis: Hourly streamflow based on observed precipitation
    - Forecasts: Numerical Weather Prediction models used as forcing.

- NWM Data Samples



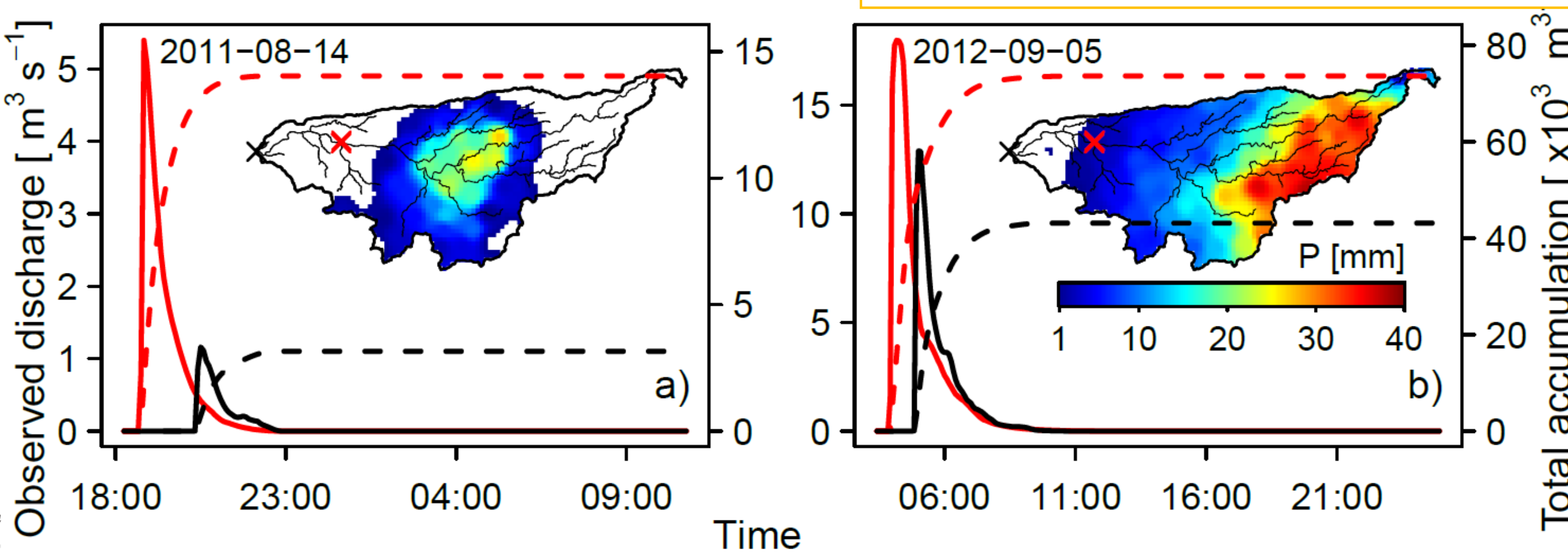



# Impact of infiltration at catchment scale




**USDA-ARS Walnut Gulch Experiment Watershed**

- Observational runoff data in Walnut Gulch Experimental Watershed (WGEW) shows the transmission losses in channel.
- Channel infiltration is identified to be a major physical process that controls the water balance in semiarid regions.



# KINEROS2: Mathematical Formulation

KINEROS2: A KINEMATIC RUNOFF and EROSION MODEL (USDA-ARS)

Surface is assumed as ponded at initial condition ($t = 0$)

$$f_c = K_s\left[1 + \frac{\alpha}{\exp\left[\frac{I'\alpha}{\Delta\theta G}\right] - 1}\right]$$

**Gravity Effect** **Suction Effect**

$f_c$: Channel Infiltrability
$K_s$: Saturated Hydraulic Conductivity
G: Capillary Drive
$I'(t)$: Cumulative Infiltration Depth
$\theta_s$: Saturated Soil Water Content
$\theta_i$: Initial Soil Water Content
$\alpha$: Soil Type Parameter (range from 0 to 1)

$$G = \frac{1}{K_s}\int_{-\infty}^{0} K(\varphi)\,d\varphi$$

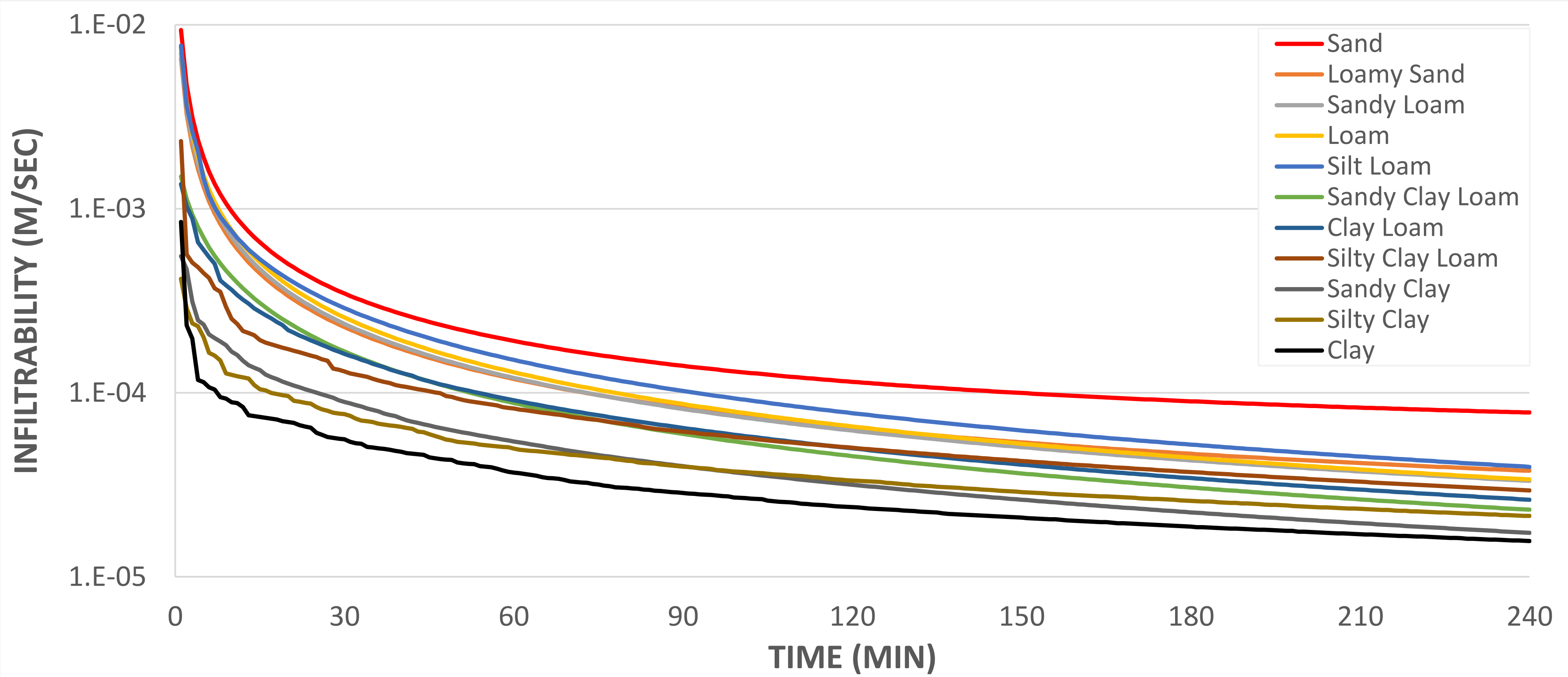
Note:

$$I = \frac{G\Delta\theta}{\alpha}\, ln\left[\frac{f_c - K_s + \alpha K_s}{f_c - K_s}\right] + K_i t \rightarrow I'(t) = \frac{G\Delta\theta}{\alpha}\, ln\left[\frac{f_c - K_s + \alpha K_s}{f_c - K_s}\right]$$

$\alpha = 0 \rightarrow$ Green-Ampt; $\alpha = 1 \rightarrow$ Smith-Parlange

KINEROS2 recommends $\alpha$=0.80

# Time-Variant Channel Infiltrability




**Time-Variant Infiltrability shows:**

- ✓ The suction affects most at the *first 30 min*.
- ✓ *Overall* effect extends to around *120 min (2hr).*
- ✓ After around 180 min (3hr), Infiltrability approaches to saturated hydraulic conductivity

# Model Re-initialization

- KINEROS2 is an event oriented, physically based model, so it needs to be re-initialized.
- Three Parameter Infiltration Equation:

$$f_c = K_s \left[1 + \frac{\alpha}{\exp\left[\frac{I'\alpha}{\Delta\theta G}\right] - 1}\right] \qquad I'(t) = \frac{G\Delta\theta}{\alpha}\, ln\left[\frac{f_c - K_s + \alpha K_s}{f_c - K_s}\right]$$

Current Research:

✓ $I'(t)$ exponetially returns to "zero" within "2" days (2880 min)

$$I'(t) = ae^{b(t-t_0)};\; a = I_{total}; b = ln\,\frac{\left[\frac{I_{5min}}{I_{total}}\right]}{2880\ (min)}$$

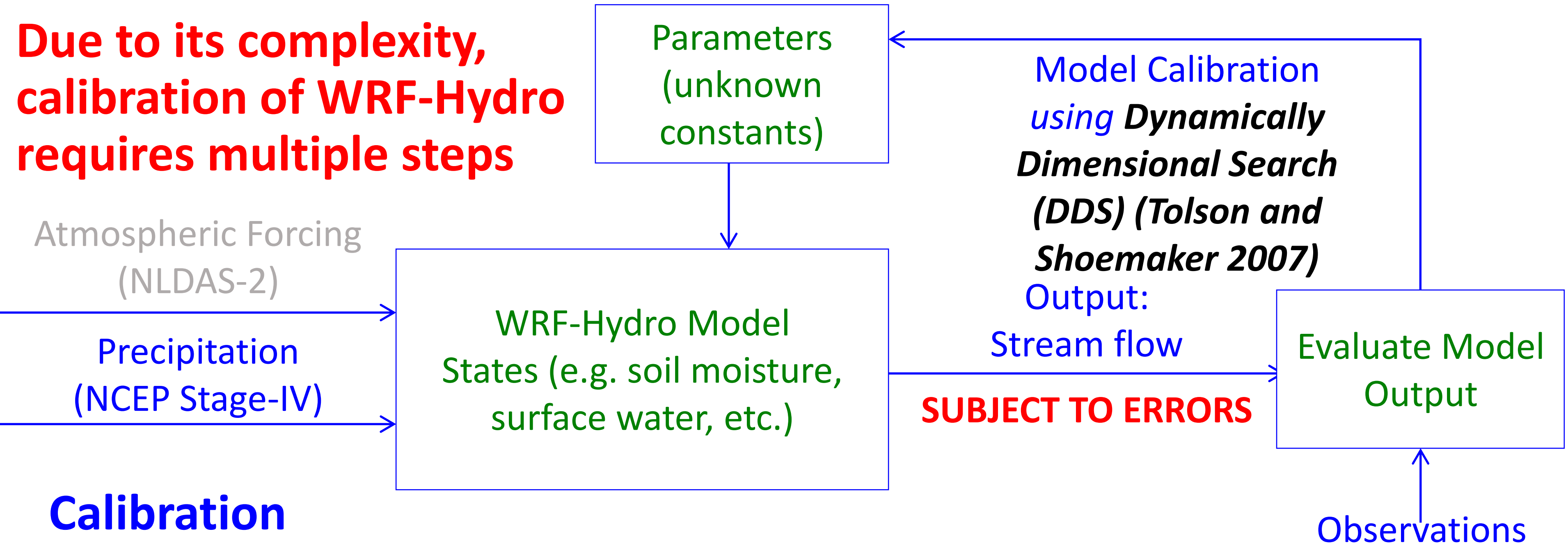
$I_{total}$: Total cumulative infiltration depth during one single flow event

$I_{5min}$: The first five minute cumulative infiltration depth

There are multiple other ways to solve this problem.

# Event-Based Calibration in WGEW

**Due to its complexity, calibration of WRF-Hydro requires multiple steps**




## Calibration

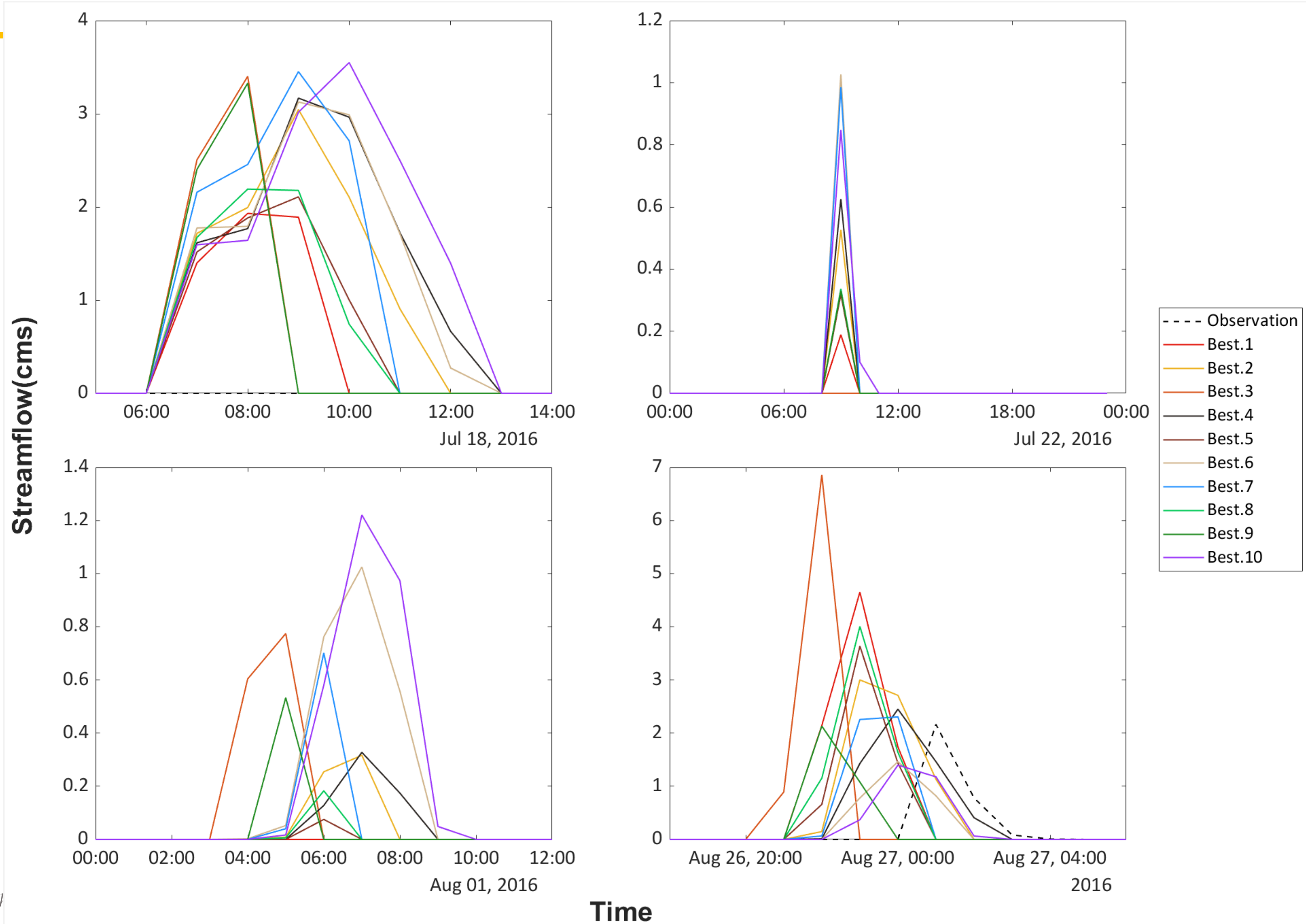
- Choose Walnut Gulch Experiment Watershed as illustrative example
- Spin up Period ranges from Jun 1st 2014 to May 31st 2016
- Calibration Period ranges from Jun 1st 2016 to Aug 31st 2016
- **Calibration based on basin outlet using Kling Gupta Efficiency (KGE) objective function and total of 250 DDS steps**
- **Repeat the same procedure for 10 times**

| Name | Description | Units |
|---|---|---|
| | **Soil Parameters** | |
| **BEXP** | Pore size distribution index | dimensionless |
| **SMCMAX** | Saturation soil moisture content (i.e., porosity) | volumetric fraction |
| **DKSAT** | Saturated hydraulic conductivity | m/s |
| | **Runoff Parameters** | |
| **REFKDT** | Surface runoff parameter | unitless |
| **SLOPE** | Linear scaling of "openness" of bottom drainage boundary | 0-1 |
| **RETDEPRTFAC** | Multiplier on retention depth limit | unit less |
| **LKSATFAC** | Multiplier on lateral hydraulic conductivity | unitless |
| | **Groundwater Parameters** | |
| **Zmax** | Maximum groundwater bucket depth | mm |
| **Expon** | Exponent controlling rate of bucket drainage as a function of depth | dimensionless |
| | **Vegetation Parameters** | |
| **CWPVT** | Canopy wind parameter for canopy wind profile formulation | 1/m |
| **VCMX25** | Maximum carboxylation at 25C | $umol/m^2/s$ |
| **MP** | Slope of Ball-Berry conductance relationship | unitless |
| | **Snow Parameters** | |
| **MFSNO** | Melt factor for snow depletion curve | dimensionless |
| | **Channel Parameters** | |
| **ths** | Saturated soil water content | volumetric fraction |
| **thin** | Initial soil water content | volumetric fraction |
| **al** | Pore size distribution index | unitless |
| **g** | Mean capillary drive | m |

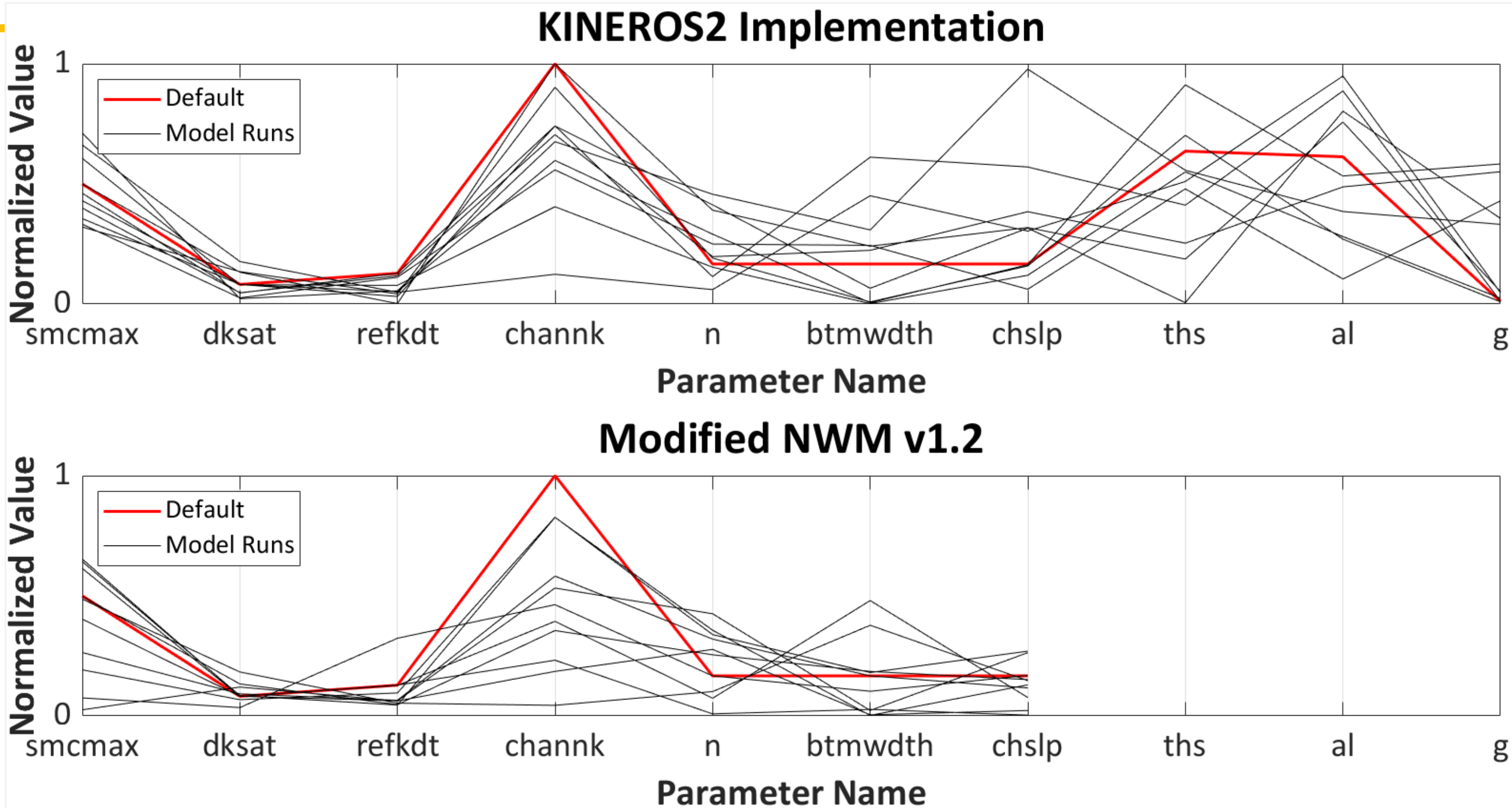
# Selected Parameters (10 PAR)

| Name | Description | Units |
|---|---|---|
| **Soil Parameters** | | |
| SMCMAX | Saturated soil moisture content (i.e., porosity) | volumetric fraction |
| DKSAT | Saturated hydraulic conductivity | m/s |
| **Runoff Parameters** | | |
| REFKDT | Surface runoff parameter (partitioning of total runoff into surface and subsurface runoff) | Unitless |
| **Channel Parameters** | | |
| ChannK | Channel bed conductivity (for channel infiltration function) | m/s |
| btmwdth | Bottom width of Channel | m |
| ChSlp | Channel side slope | Unitless |
| n | Manning's N | $s/m^{1/3}$ |
| ths | Saturated soil water content | volumetric fraction |
| al | Pore size distribution index | unitless |
| g | Mean capillary drive | m |

# Calibration on the Real Data



# Uncertainty in Best Parameter

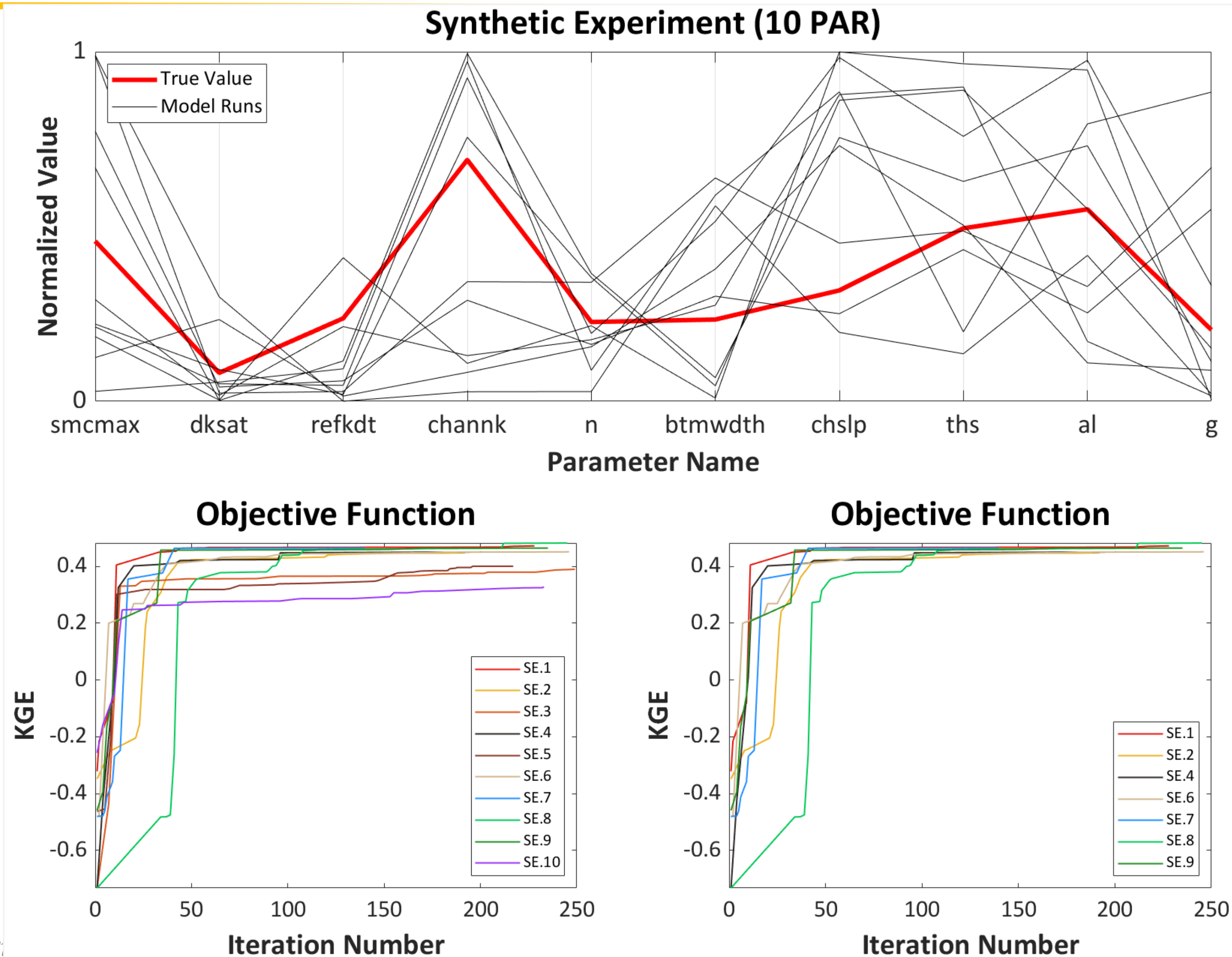



- ✓ Both NWM versions suggest that only two LSM parameters *"dksat"* and *"refkdt"* are sensitive.
- ✓ Capillary Drive *"g"* seems to be the most sensitive parameter among other three new added channel parameters

# Synthetic Experiment (SE)

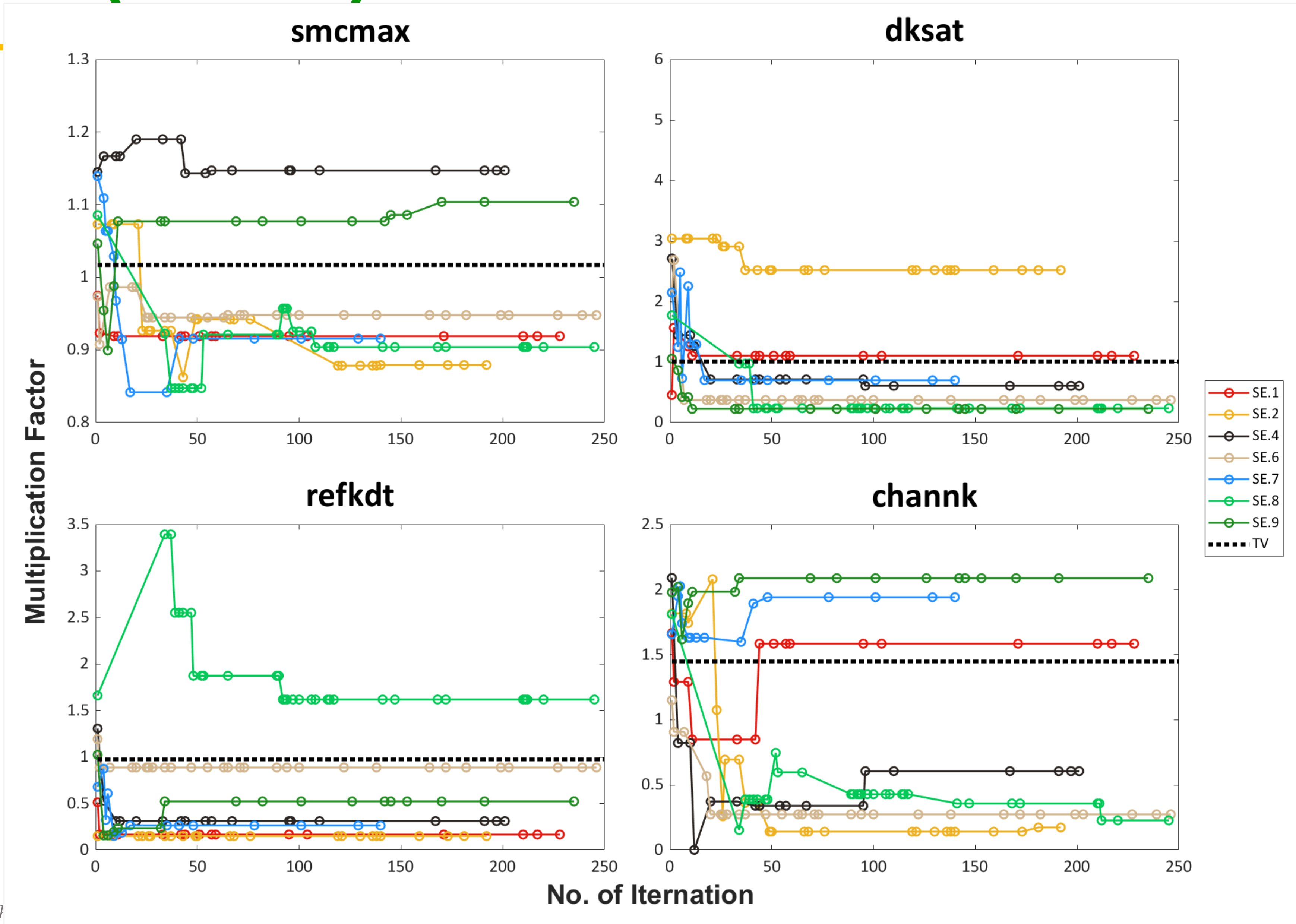
- Remove the model/data error
  - Use the *"median"* of 10 best parameter value as *"true value"*
- Simulation:
  - Fix nine parameters at their *"true value"* and perturbed one parameter at a time
  - Examine the effects that each parameter plays on the hydrograph
- Calibration:
  - Use the same "*first searching direction*" of previous 10 DDS runs
  - Calibrate 10 parameters (10 runs) using 250 DDS iterations
  - Calibrate 9 parameters (10 runs) using 250 DDS iterations (Remove *"Channk"*)
  - Calibrate 6 parameters (10 runs) using 250 DDS iterations (Remove *"Channk" and* three parameters in Noah-MP LSM)

# SE (10 PAR)



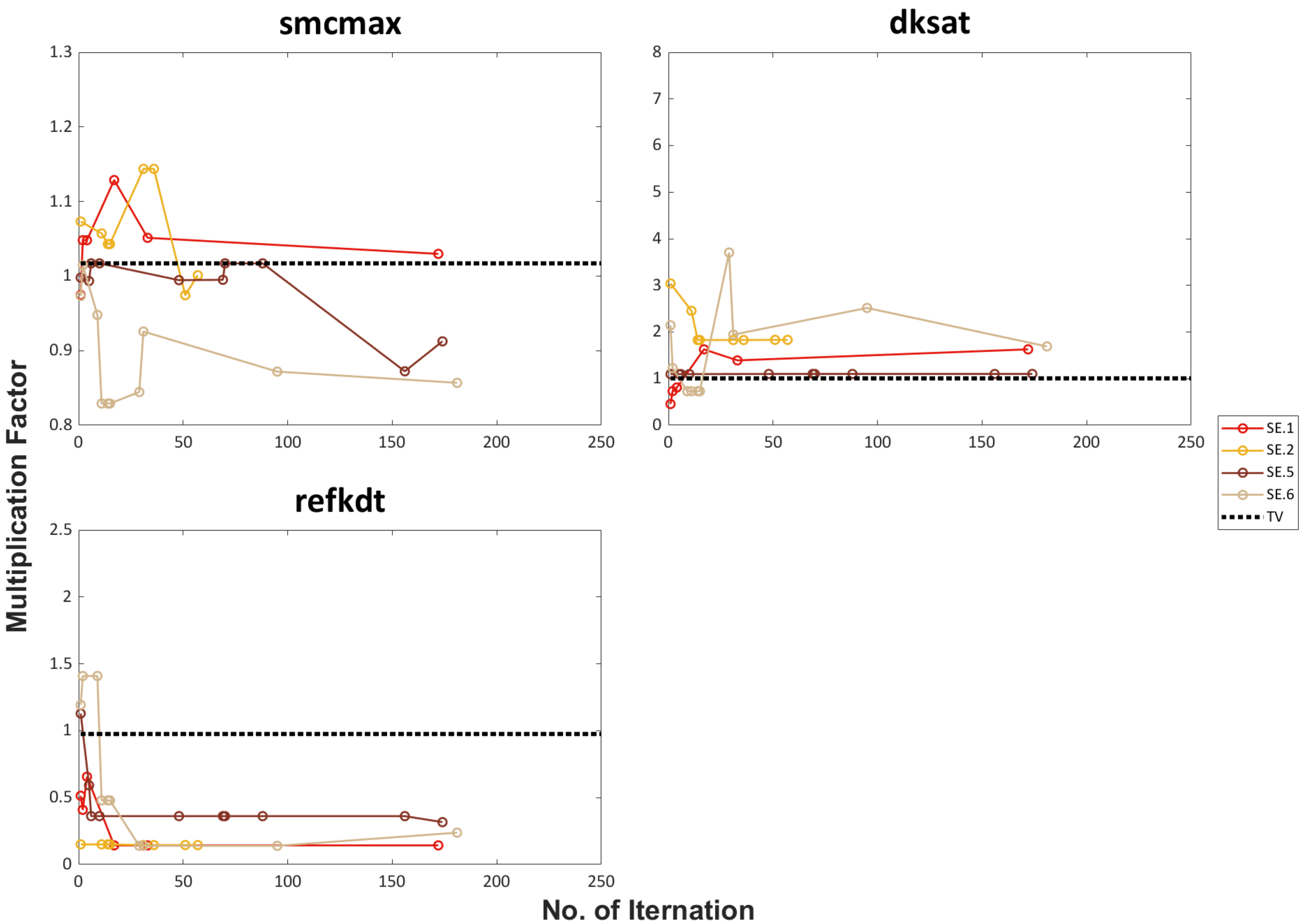
Synthetic Experiment (10 PAR)
Normalized Value
1
0
True Value
Model Runs
smcmax
dksat
refkdt
channk
n
btmwdth
chslp
ths
al
g
Parameter Name
Objective Function
KGE
0.4
0.2
0
-0.2
-0.4
-0.6
0
50
100
150
200
250
Iteration Number
SE.1
SE.2
SE.3
SE.4
SE.5
SE.6
SE.7
SE.8
SE.9
SE.10
Objective Function
KGE
SE.1
SE.2
SE.4
SE.6
SE.7
SE.8
SE.9
Iteration Number

# SE (10 PAR)

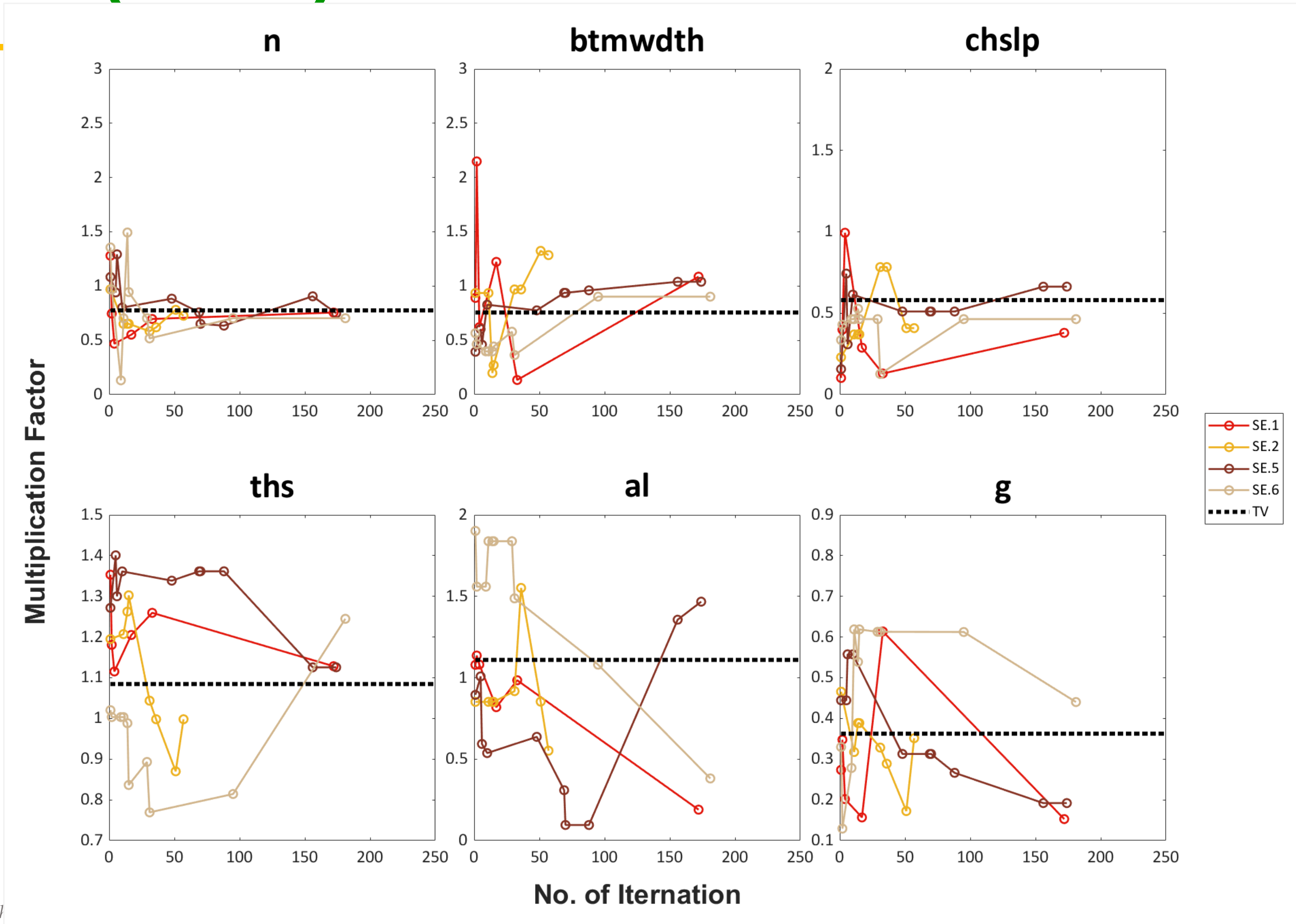



100th

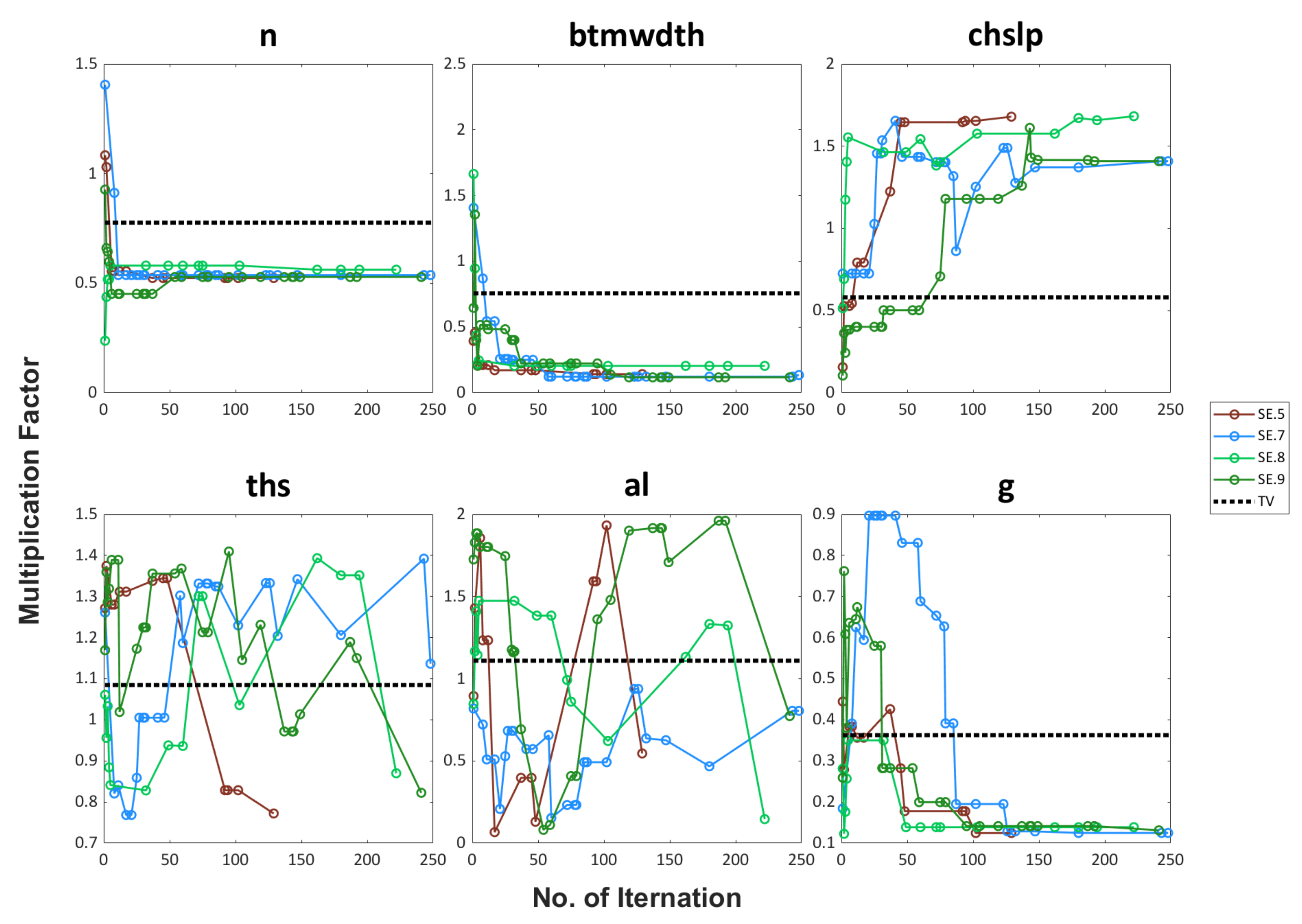
# SE (9 PAR)-Fixed ChannK



# SE (9 PAR)-Fixed ChannK



# SE (6 PAR)-Fixed ChannK & LSM PAR



# Conclusions & Future Research

- Our implementation of the updated infiltration scheme works for semi-arid region
- It is not ideal to calibrate all 10 parameter at one time
- In the synthetic experiment the calibrated parameters did not converge to the “true value” for any demonstrated cases
- The reason may be:
  - The data contains insufficient information
  - The interdependence between different parameters leads to compensation while searching for the optimum
  - The selected objective function (KGE) is *not sensitive* to the channel“ infiltrability” at the beginning of the flow event

# Thank You (Question?)