Eastern Snow Conference 2025, Syracuse, NY

Evaluation of the Noah-MP Land Surface Model for Snowmelt-Driven Flood Generation: Guidelines for Selecting Parameterization Schemes

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Background: Missouri River Spring Flood

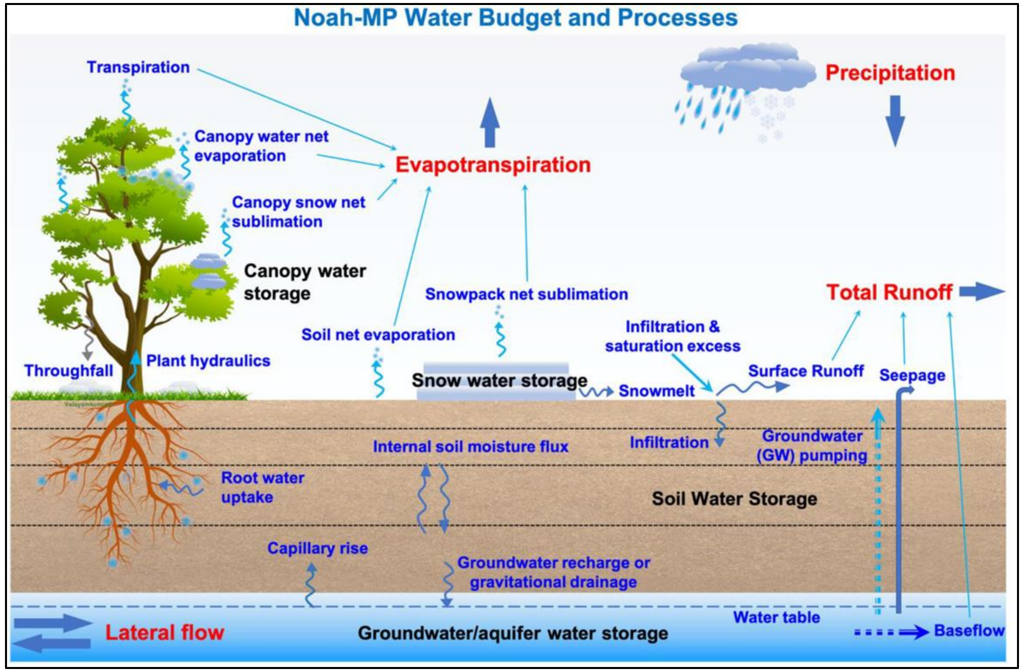
- Spring snowmelt-driven floods have significant societal and economic impacts, highlighting the need for accurate flood prediction.
- The **2019 Spring Missouri River Flood** was one of the most devastating flood events in the region's history, affecting parts of 9 U.S. states (NOAA, 2019; NYT, 2019; Pal et al., 2020; Velásquez et al., 2023).
- **Over $12 billion** in total damages and **more than 50 levees** were breached or overtopped (NSPE, 2019).

2019 Missouri River Flood

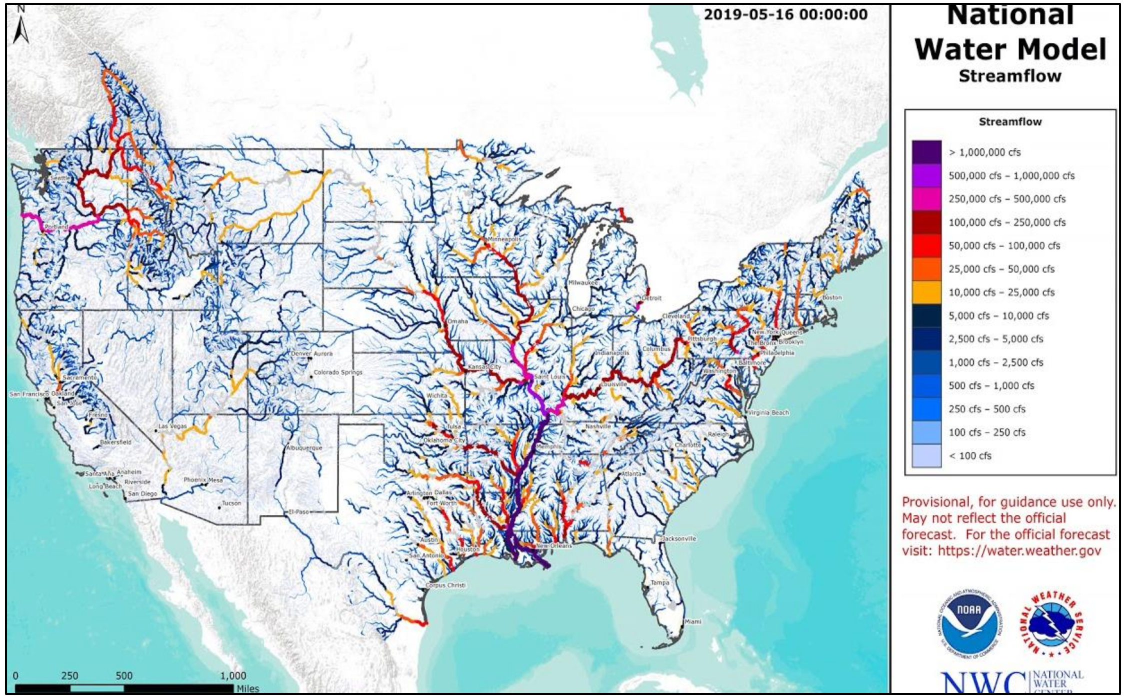
https://www.latimes.com/world-nation/story/2019-09-16/missouri-river-flooding

Motivation: Noah-MP Parameterization

- **Land Surface Models** are widely used for flood prediction, as they provide a comprehensive information of hydrological processes (Overgaard et al., 2006; Niu et al., 2011; Li et al., 2022; He et al., 2023).
- Previous studies and operational systems, including NOAA's National Water Model, often rely on only **single default parameterization**, overlooking the benefit of various Noah-MP schemes for regional application.



Hydrological Processes of Noah-MP (He et al., 2023)



National Water Model Streamflow Output (https://water.weather.gov)

Research Questions

Q1. What is the **impact of Noah-MP parameterization schemes** on overall runoff in Missouri River Basin?

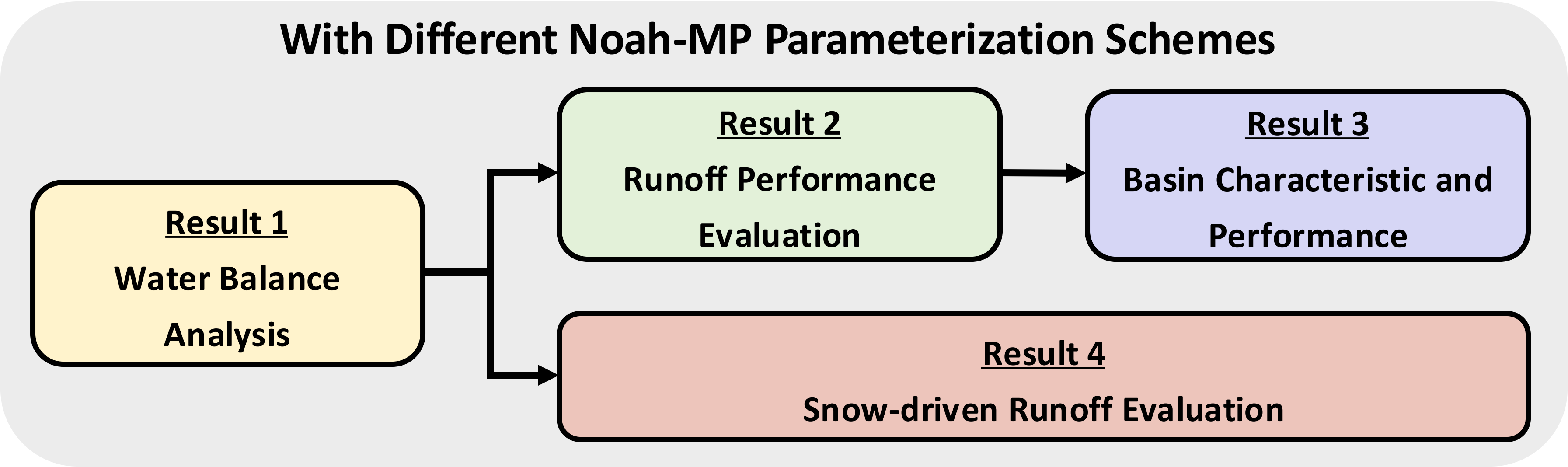
→ **Result 1 & Result 2**

Q2. How are **basin characteristics, such as climate classification, land-cover type, and snow classification**, related to Noah-MP runoff performance?

→ **Result 3**

Q3. How well does Noah-MP simulate **snow-water equivalent, snow-driven runoff**, and their ratio?

→ **Result 4**



Study Area: Missouri River Basin

Noah-MP Simulation Results

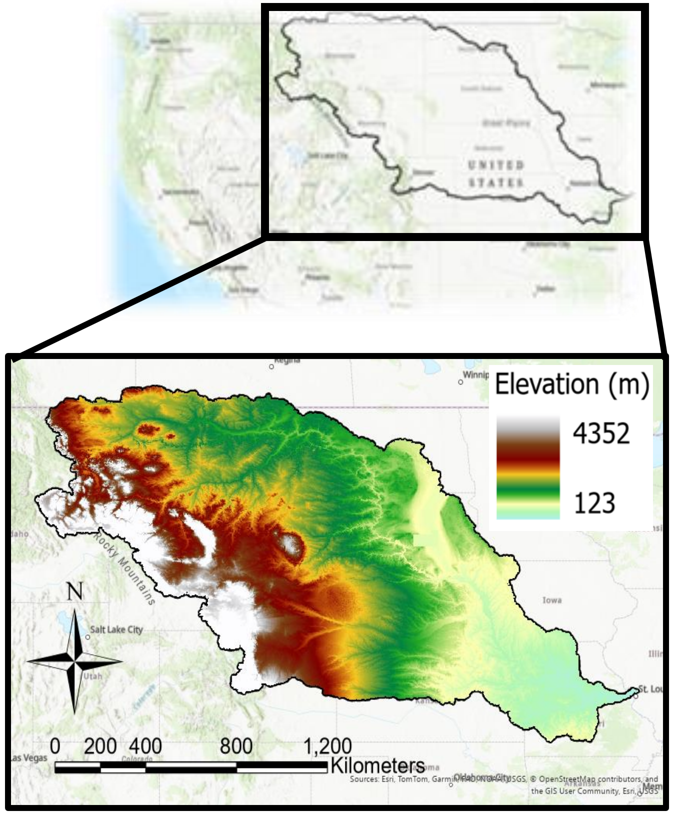
- Forcing Data: North American Land Data Assimilation System (NLDAS-2)
- Temporal Resolution: Daily
- Spatial Resolution: 0.125° × 0.125°
- Period: 2014-01-01 to 2023-12-31

USGS Streamflow Observation

- 50 Hydro-Climatic Data Network
- Temporal Resolution: Daily
- Period: 2014-01-01 to 2023-12-31

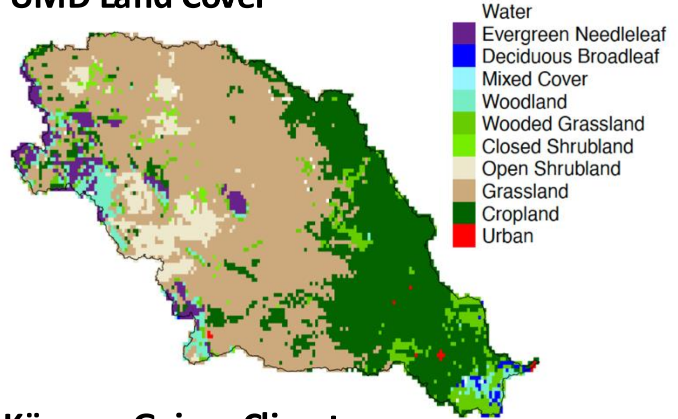
Snow Water Equivalent data

- University of Arizona SWE
- Temporal Resolution: Daily
- Spatial Resolution: 4 km × 4 km
- Period: 2014-01-01 to 2023-12-31

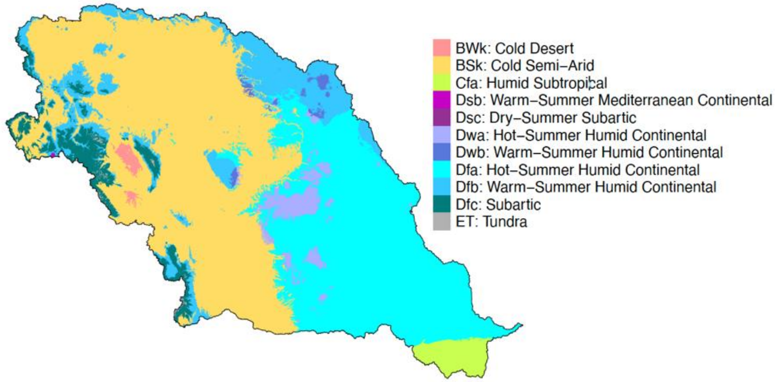


Missouri River Basin with Digital Elevation Model

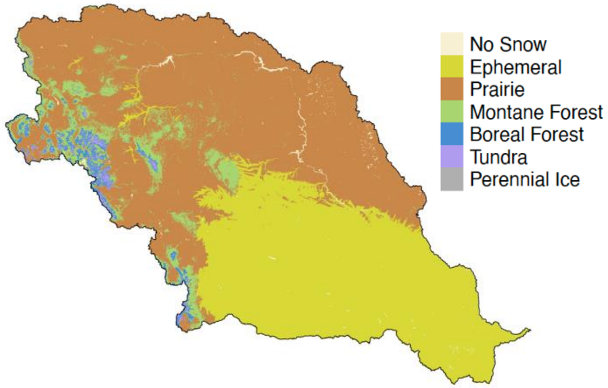
UMD Land Cover



Köppen-Geiger Climate



Sturm Snow Classification



Noah-MP Experiments: Different Parameterizations

Five Noah-MP Experiments

1) All **Default** setting
2) Alternative **Runoff and Groundwater** process (all others are default)
3) Alternative **Surface Exchange Coefficient for Heat** process (all others are default)
4) Alternative **Frozen Soil Permeability** process (all others are default)
5) Alternative **Snow/Soil Temperature Time Scheme** process (all others are default)

<table>
<tr><th>Name</th><th>Process</th><th>Default</th><th>Alternative</th></tr>
<tr><td rowspan="2">RUN</td><td rowspan="2">Runoff and Groundwater</td><td>TOPMODEL with groundwater storage</td><td>TOPMODEL with an equilibrium water table</td></tr>
<tr><td colspan="2">Default: Assumes an unconfined aquifer, with groundwater storage calculated as recharge minus discharge.
Experiment: Infers water table depth from soil moisture, assuming an equilibrium profile of water head.</td></tr>
<tr><td rowspan="2">SFC</td><td rowspan="2">Surface Exchange Coefficient for Heat</td><td>Monin–Obukhov (more ET)</td><td>Noah V3 (less ET)</td></tr>
<tr><td colspan="2">Default: Dynamically adjusts the thermal roughness length and applies stability corrections, lowering aerodynamic resistance.
Experiment: Fixes the scaling constant for thermal roughness length, effectively raising aerodynamic resistance.</td></tr>
<tr><td rowspan="2">INF</td><td rowspan="2">Frozen Soil Permeability</td><td>NY06 (Linear effects; more permeable)</td><td>Koren99 (Nonlinear effects; less permeable)</td></tr>
<tr><td colspan="2">Default: Assumes a linear effect of soil ice on infiltration, leading to more permeable frozen soil.
Experiment: Assumes a nonlinear effect of soil ice on permeability, leading to less permeable frozen soil.</td></tr>
<tr><td rowspan="2">STC</td><td rowspan="2">Snow/Soil Temperature Time Scheme</td><td>Semi-implicit (more dynamic)</td><td>Full implicit (more stable)</td></tr>
<tr><td colspan="2">Default: After calculating ground temperature, it re-evaluates heat fluxes.
Experiment: Directly calculates ground temperature using an implicit equation.</td></tr>
</table>

1. Water Balance Analysis

- **Overall, Noah-MP parameterization choices affect water balance, especially ET, ΔGW, and Total Q.**
- **RUN scheme** produced the highest groundwater recharge (ΔGW = 2.8 mm), indicating change in groundwater dynamics and runoff generation.
- **SFC scheme** results in the lowest evapotranspiration, and this led to the highest total runoff (81 mm).
- **INF scheme** led to the highest surface runoff (28 mm) due to limited infiltration under frozen soil.

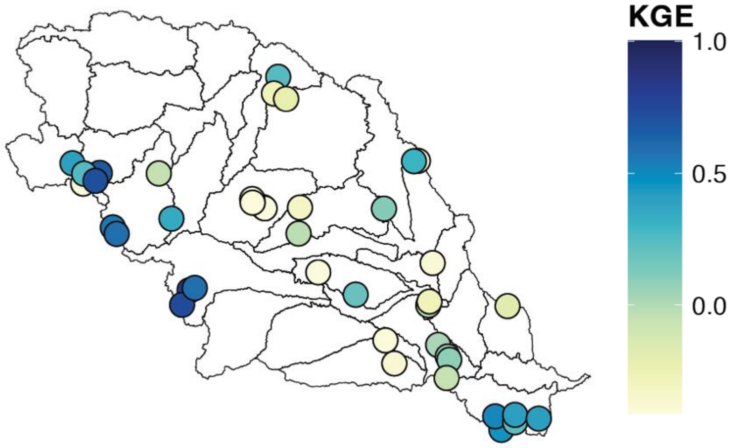
(mm/year)

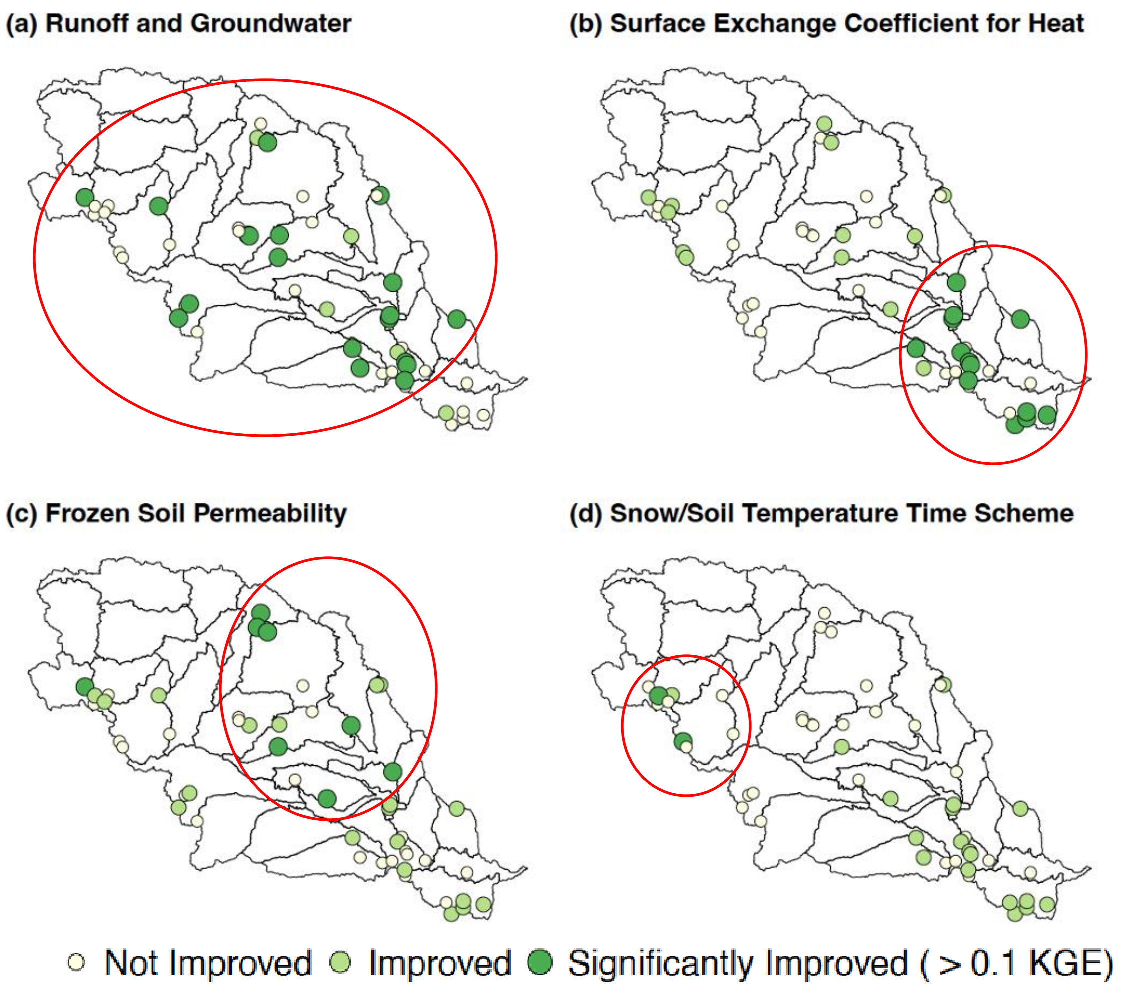
Name	Process	Precipitation	ET	△GW	△SM	Surface Q	Subsurface Q	Total Q
Default		535	480	-0.3	-6.1	21	44	65
RUN	Runoff and Groundwater	535	474	**2.8**	-5.6	**27**	41	68
SFC	Surface Exchange Coefficient for Heat	535	**464**	0.1	-6.3	**25**	**56**	**81**
INF	Frozen Soil Permeability	535	477	-0.1	-6.0	**28**	39	68
STC	Snow/Soil Temperature Time Scheme	535	474	-0.3	-5.8	**22**	**48**	70

2. Runoff Performance Evaluation

- 50 watersheds are selected which are not impacted by human activities and hydraulic structures.
- For selected watersheds, **Kling-Gupta Efficiency (KGE)** is calculated using USGS observed streamflow.
- **KGE improvement** is computed as the KGE from the alternative scheme minus that from the default setting.

Default setting





Kling–Gupta efficiency (KGE)

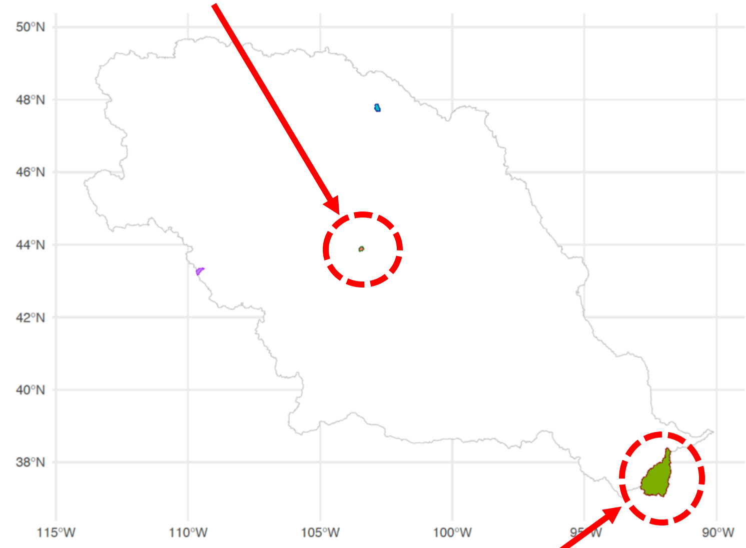
$$\mathrm{KGE} = 1 - \sqrt{(r-1)^2 + (\alpha-1)^2 + (\beta-1)^2}$$

where:

- r is the Pearson correlation coefficient,
- α is a term representing the variability of prediction errors,
- β is a bias term.

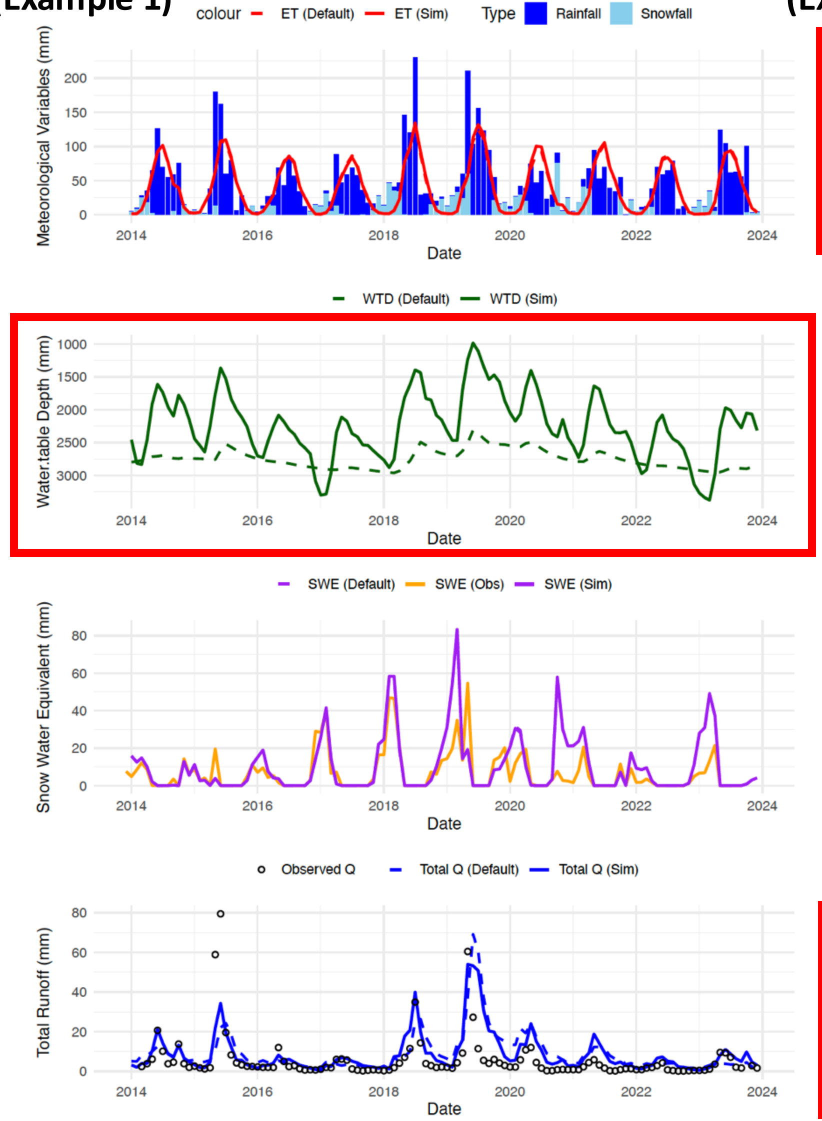
Class	Watersheds	States	Land Cover Classification	Climate Classification	Snow Classification
Example 1	Battle Creek	South Dakota	Evergreen Needleleaf Forest	Warm-Summer Humid Continental	Montane Forest
Example 2	Gasconade River	Missouri	Woodland/Scrubland	Humid Subtropical	Ephemeral

Example 1.
Alternative RUN Scheme
Battle Creek, SD

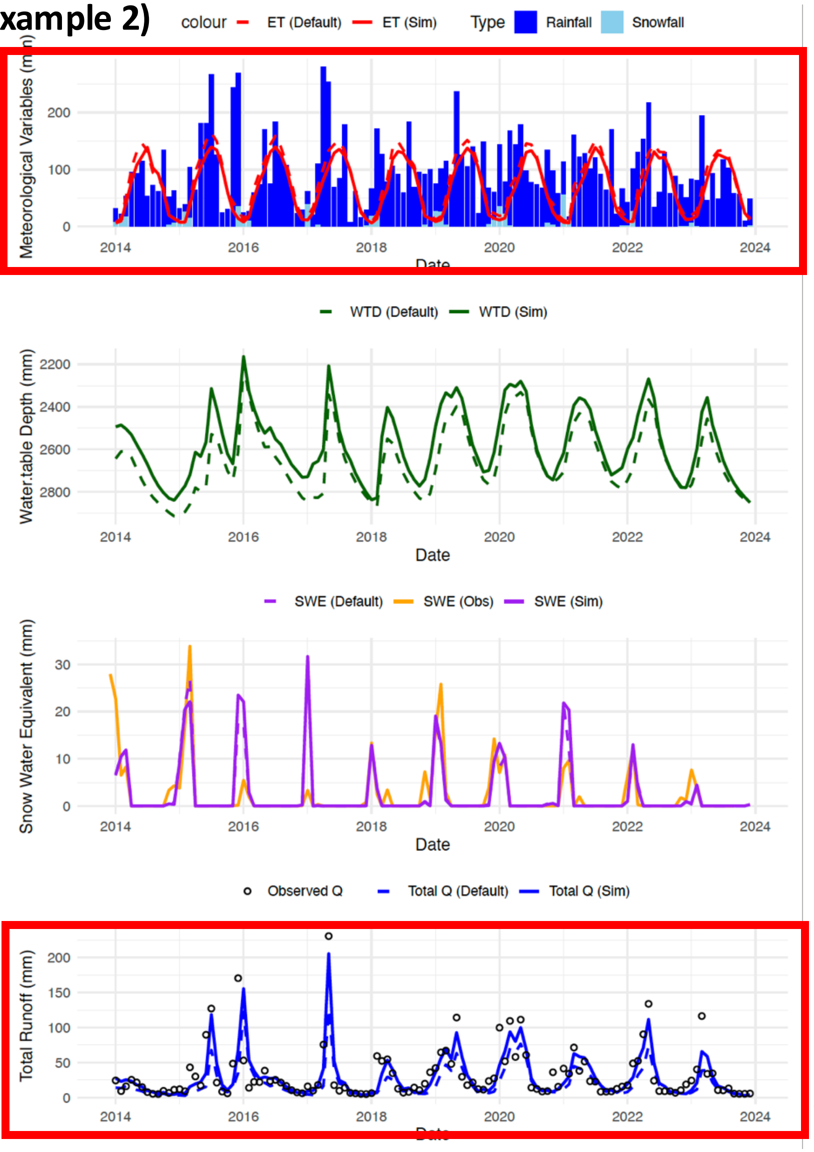


Example 2.
Alternative SFC Scheme
Gasconade River, MO

(Example 1)

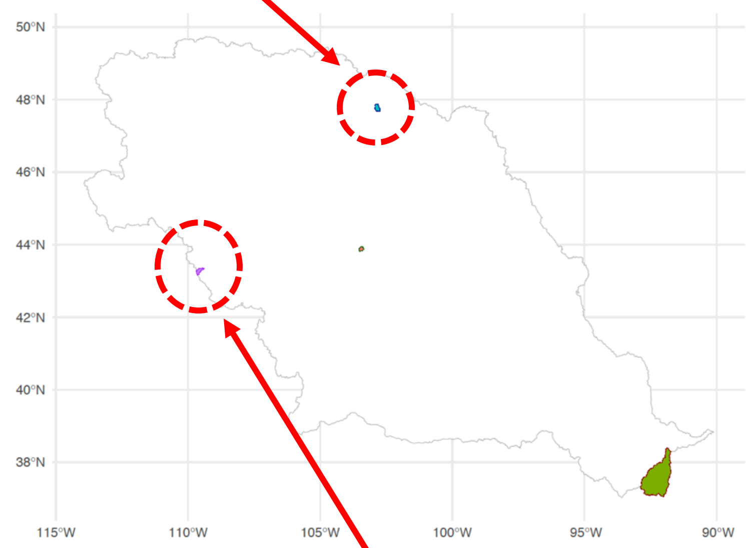


(Example 2)



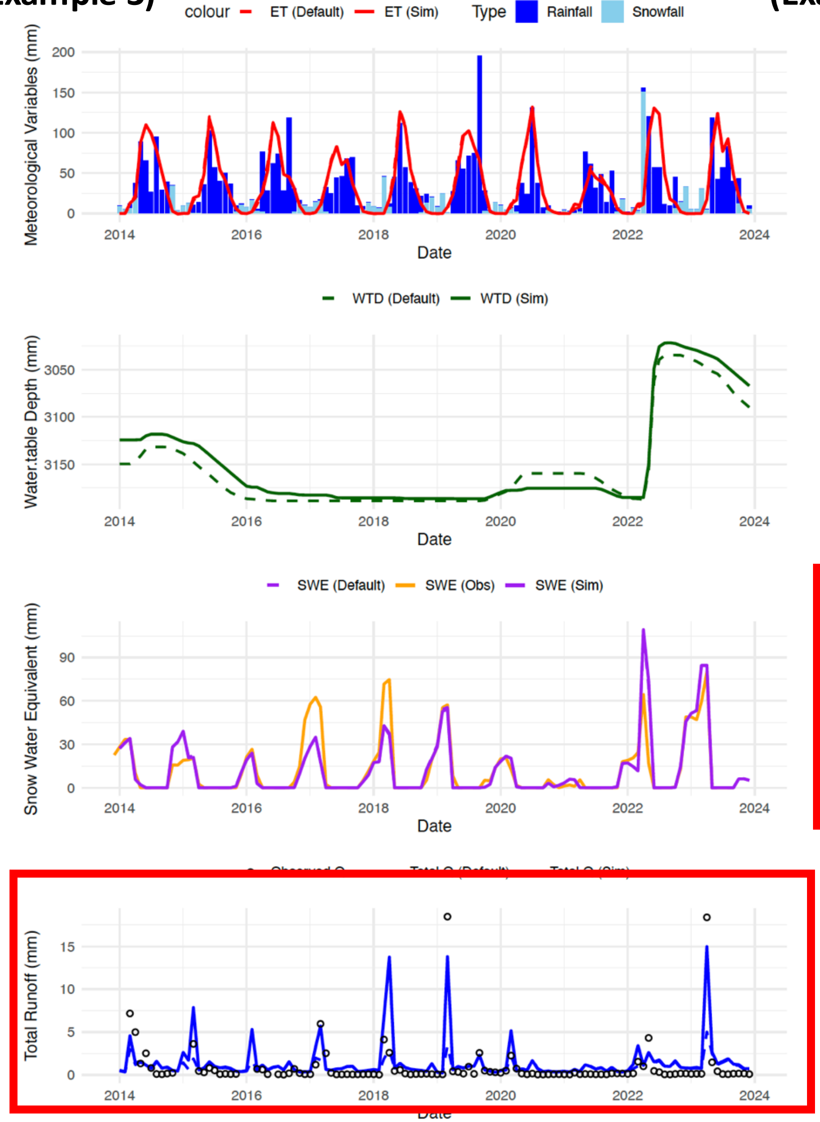
Class	Watersheds	States	Land Cover Classification	Climate Classification	Snow Classification
Example 3	Bear Den Creek	North Dakota	Grassland	Warm-Summer Humid Continental	Prairie
Example 4	Dinwoody Creek	Wyoming	Woodland/Scrubland	Subartic	Tundra

Example 3.
Alternative INF Scheme
Bear Den Creek, ND

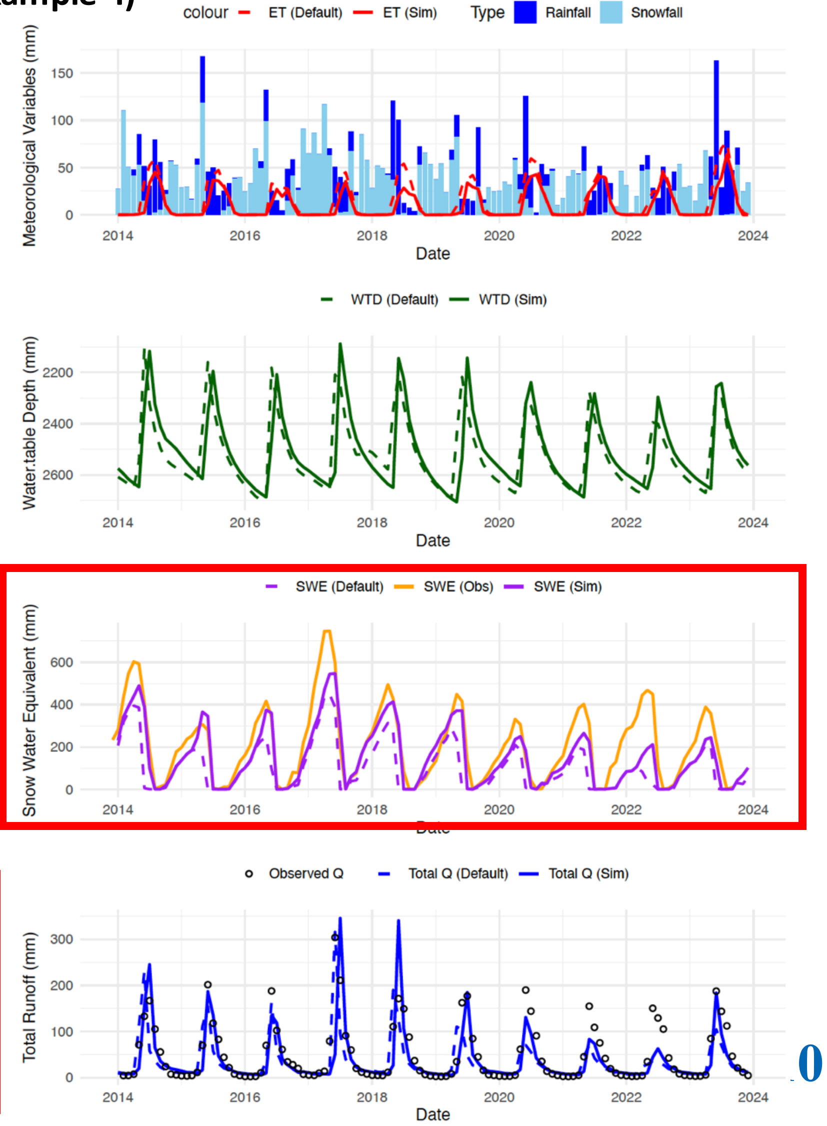


Example 4.
Alternative STC Scheme
Dinwoody Creek, WY

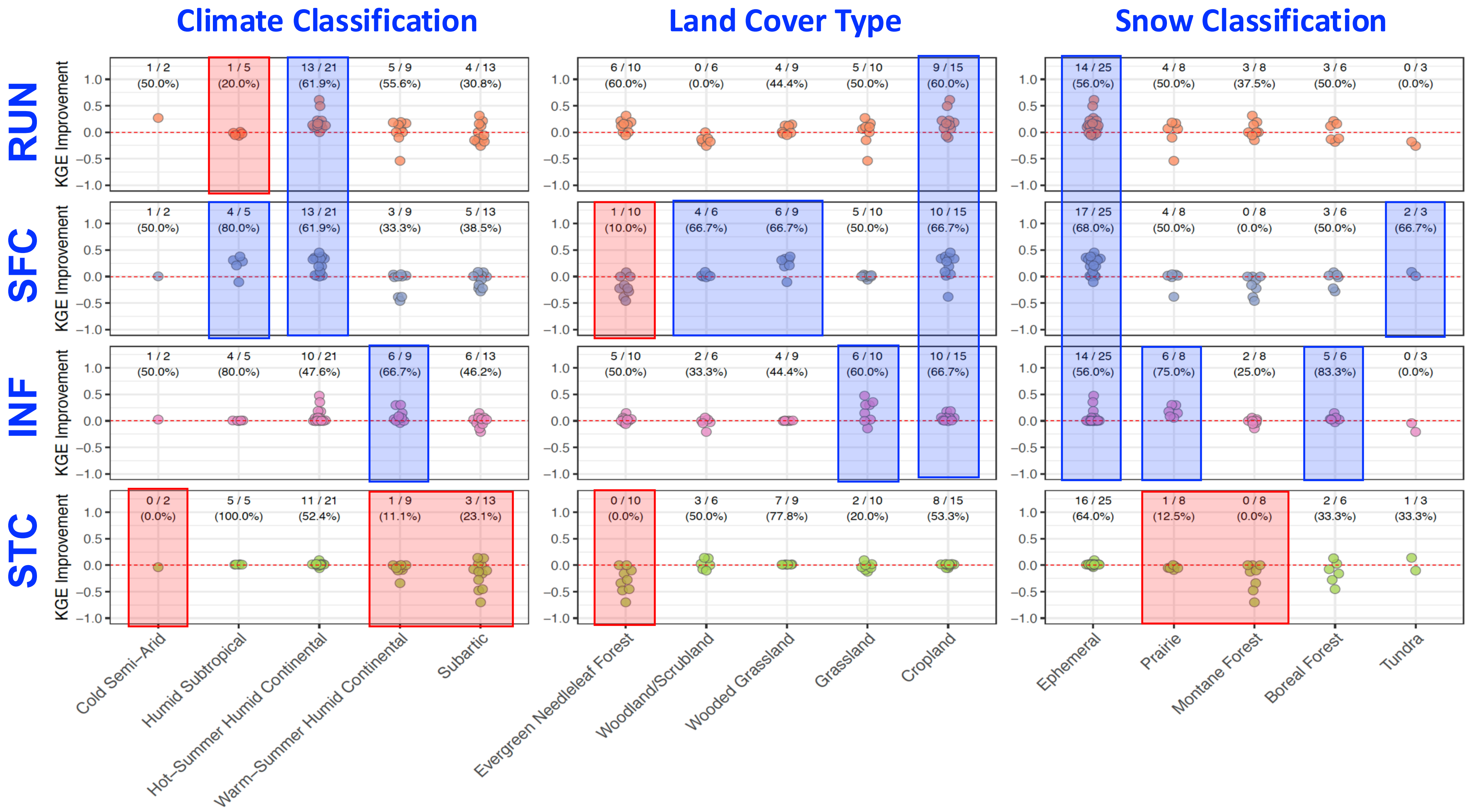
(Example 3)



(Example 4)



3. Basin Characteristics and Performance



- For each watershed, **dominant characteristic** of climate, land cover and snow classification is determined.
- In this plot, y-axis is the improvement of KGE and x-axis is the basin characteristics.

3. Basin Characteristics and Performance

- Recommended parameterization scheme is the case which improved KGE more than 60% of 50 HCDN.

Dataset	Categories	Recommended Parameterization Scheme
Köppen-Geiger Climate	Humid Subtropical	- Surface Exchange Coefficient for Heat - Frozen Soil Permeability
	Hot-Summer Humid Continental	- Runoff and Groundwater - Surface Exchange Coefficient for Heat - Frozen Soil Permeability
	Warm-Summer Humid Continental	- Frozen Soil Permeability
UMD Land Cover Map	Evergreen Needleleaf Forest	- Runoff and Groundwater
	Woodland/Scrubland	- Surface Exchange Coefficient for Heat
	Wooded Grassland	- Surface Exchange Coefficient for Heat
	Grassland	- Frozen Soil Permeability
	Cropland	- Runoff and Groundwater - Surface Exchange Coefficient for Heat
Sturm Snow Classification	Ephemeral	- Runoff and Groundwater - Surface Exchange Coefficient for Heat - Frozen Soil Permeability
	Prairie	- Frozen Soil Permeability
	Boreal Forest	- Frozen Soil Permeability
	Tundra	- Surface Exchange Coefficient for Heat

4. Snow-driven Runoff Evaluation

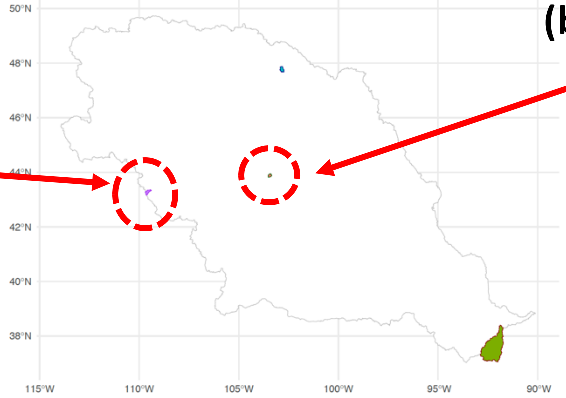
- **SWE:** Maximum SWE of each water year
- **Q:** Total runoff volume from April to July
- **Q/SWE:** Evaluate snow driven runoff and SWE together
- Scatter plot is based on **Noah-MP Q & Noah-MP SWE (y-axis)** and **USGS Q & UA SWE (x-axis)**.

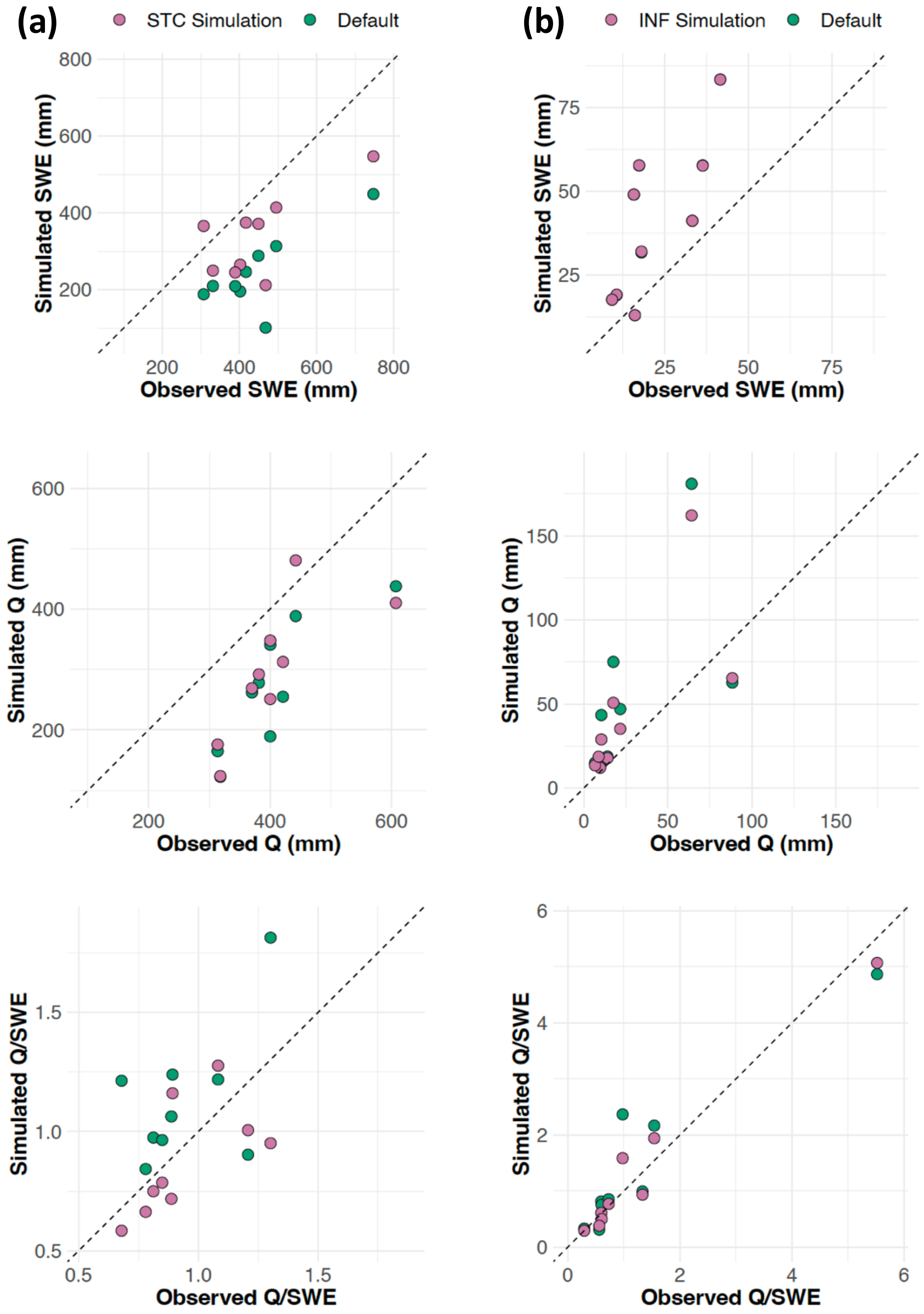
a) **Dinwoody Creek, WY (Subartic, Woodland/Scrubland, Tundra)**
   Snow/Soil Temperature Time Scheme

b) **Battle Creek, SD (Warm-Summer Humid Continental, Evergreen Needleleaf Forest, Montane Forest)**
   Frozen Soil Permeability

(a) Dinwoody Creek, WY

(b) Battle Creek, SD





Take-home Messages

1. Parameterization schemes have a **significant impact on runoff simulations**. When information of climate, land cover, and snow classifications is available, parameterization schemes can be recommended **for better runoff generation**.

Alternative Parameterization Scheme	Improvement
Runoff and Groundwater	Better groundwater dynamics
Surface Exchange Coefficient for Heat	Better total runoff in lower basin
Frozen Soil Permeability	Better surface runoff generation

2. Although the Snow/Soil Temperature Time Scheme did not notably enhance runoff performance, it improved SWE estimates, leading to a **better representation of snow-driven runoff.**

3. For future study, the combined impact of **multiple alternative parameterization schemes** need to be investigated.

Thank you for listening

Question and Answer

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Discussion

1) **Number of Parameterization Schemes**

   While Noah-MP offers a wide range of physics options, we limited the experiment to four schemes to keep the study focused.

2) **Interactive Impact of Parameterization Schemes**

   Combinations of schemes can generate compounding effects. Evaluating these coupled impacts was beyond the scope, so each scheme was evaluated separately.

3) **Runoff–streamflow Comparison**

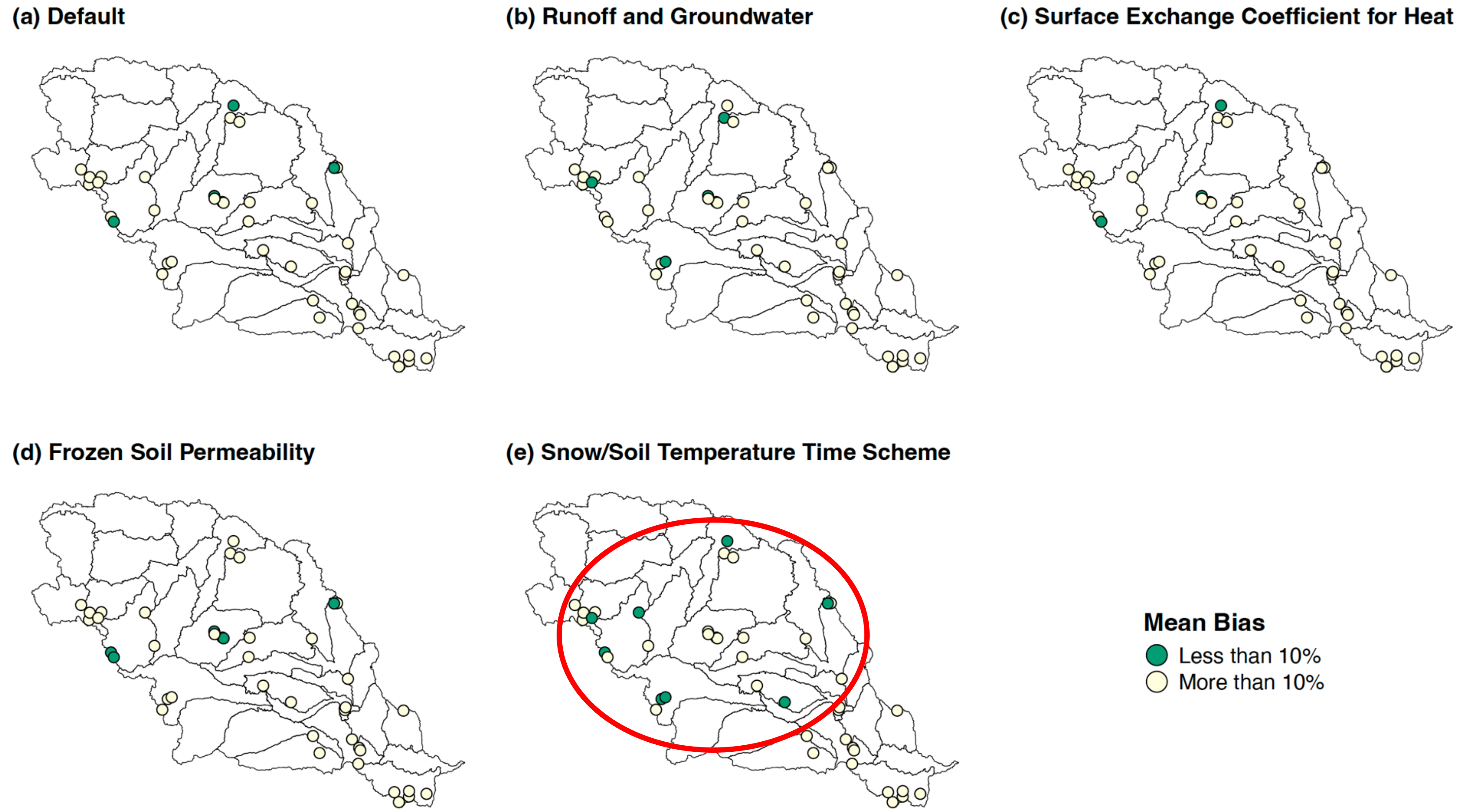
   Routing uncertainties can obscure the relationship between simulated runoff and observed streamflow. To reduce this effect, we restricted the analysis to relatively small, minimally regulated catchments

4) **Validation of Recommended Parameterization Schemes**

   The parameterization recommendations derived from this study require validation across watersheds with diverse climate, land cover and snow classification.

4. Snow-driven Runoff Evaluation

- **SWE:** Maximum SWE of each water year; **Q:** Total runoff volume from April to July
- **Mean Bias** is calculated comparing **Noah-MP Q / SWE** and **USGS Q / UA SWE**.
- The STC scheme provided limited improvement in total runoff for entire season but **noticeably improved snow-driven runoff and SWE** representation.



Impact of Parameterization Scheme on Water Balance

Name	Process	Precipitation	ET	△GW	△SM	Surface Q	Subsurface Q	Total Q	Water Balance
Default		535.4	479.7	-0.3	-6.1	20.9	44.0	64.8	-3.2
RUN	Runoff and Groundwater	535.5	473.7	**2.8**	-5.6	**27.2**	41.1	68.3	1.8
SFC	Surface Exchange Coefficient for Heat	535.2	**463.6**	0.1	-6.3	**25.2**	**56.0**	**81.2**	-3.2
INF	Frozen Soil Permeability	534.9	476.7	-0.1	-6.0	**28.2**	39.4	67.6	-3.4
STC	Snow/Soil Temperature Time Scheme	535.4	474.1	-0.3	-5.8	**22.0**	**48.3**	70.3	-3.5

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   Snow/Soil Temperature Time Scheme

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   Frozen Soil Permeability

(a) Dinwoody Creek, WY

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