MICHIGAN STATE UNIVERSITY

University of Colorado Boulder

# Improving land model simulation of natural streamflow through sensitivity analysis and parameter optimization

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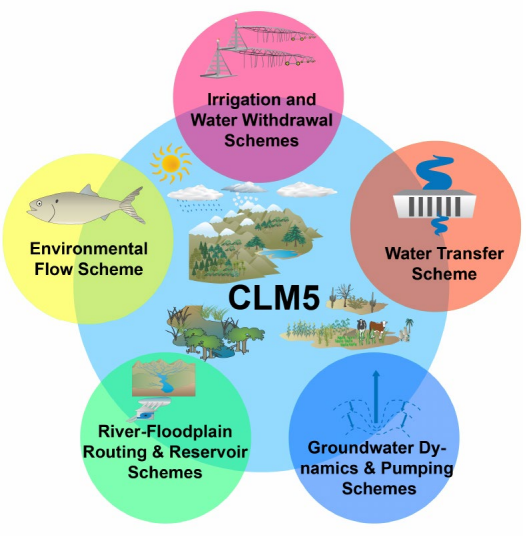
LAND MODEL/BIOGEOCHEMISTRY 2025 WINTER WORKING GROUP MEETING
Tuesday 25th, February 2025

# Explore **3 levers** related to water sustainability in the Southwest U.S.

- Natural river flows
- Water demand
- Reservoir management

CLM5 is at the core of our modeling framework



# Insufficient model ability to represent observed hydrologic processes

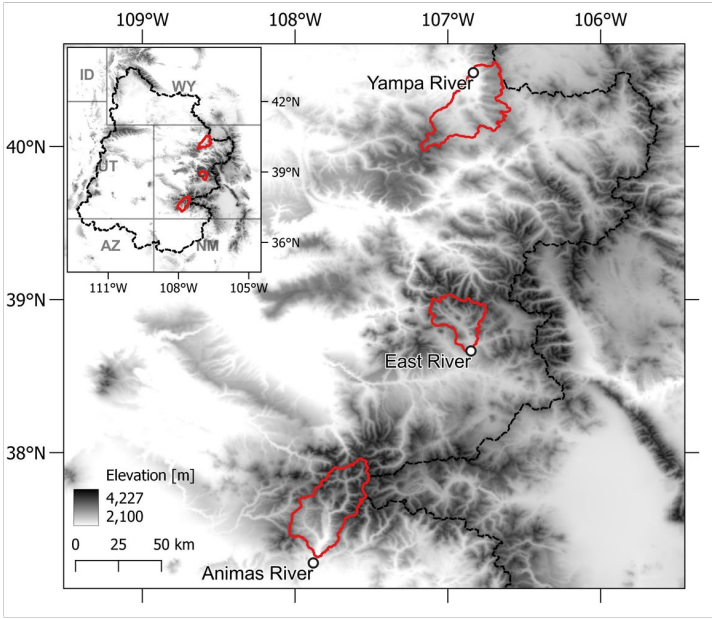
- Which land model parameters are most important for the simulation of hydrologic processes and their sensitivity to climate?
- Does the model, with optimized parameter values, reproduce observed natural streamflow?

# Which land model parameters are most important for the simulation of hydrologic processes?

- Meteorological variables (1915-2018)
  (Livneh et al. 2015)
- CLM5.2-SP, single-point
- Variance-based (Sobol) sensitivity analysis
- 19 parameters
- Sample 10,752 parameters sets (simulations)

Elkouk et al. (2024, WRR)

Minimally regulated headwaters



# Process-oriented selection of parameters

Thanks to previous works (PPE, Yifan, Guoqiang, Linnia)

| Process | Parameter |
| --- | --- |

Varied within ±20% of their default value

Elkouk et al. (2024, WRR)

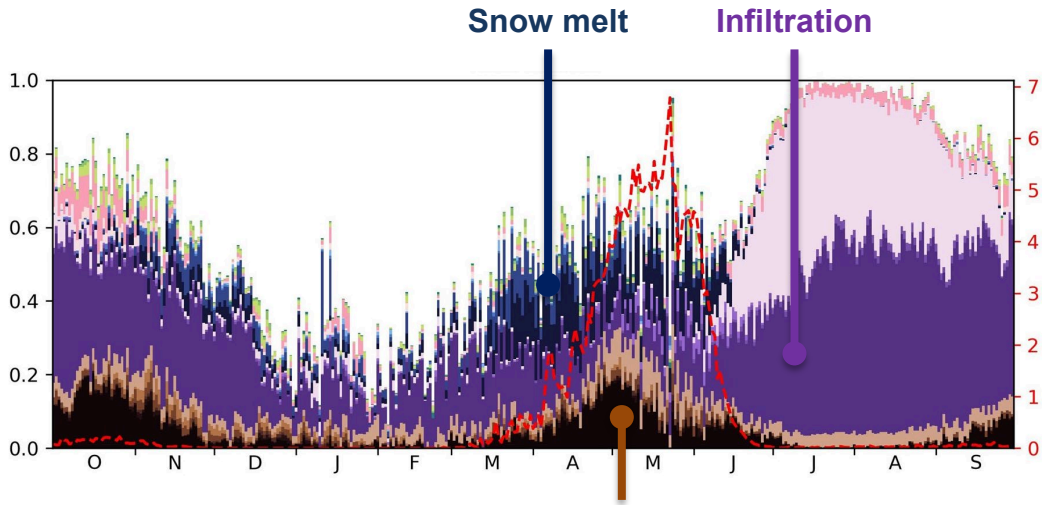
# Animas River basin

(1935-2018)

**Sensitivity***

$$\overline{S_i}$$

$$S_i = \frac{V_i}{V}$$




**Total runoff**

Variance

(mm/day)$^2$

Elkouk et al. (2024, WRR)

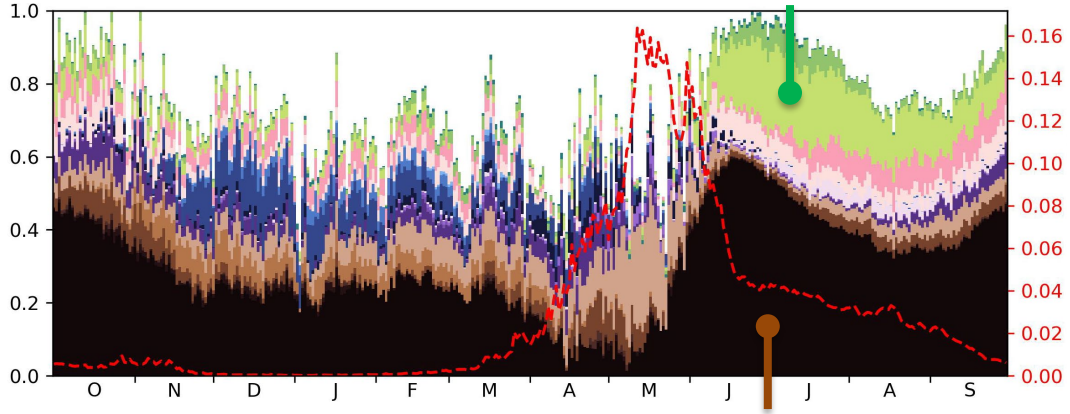
*10,752 CLM simulations were performed on the **Derecho supercomputer**

# Animas River basin

(1935-2018)

**Plant water use efficiency**
(medlynslope)

**Sensitivity**
$\overline{S_i}$



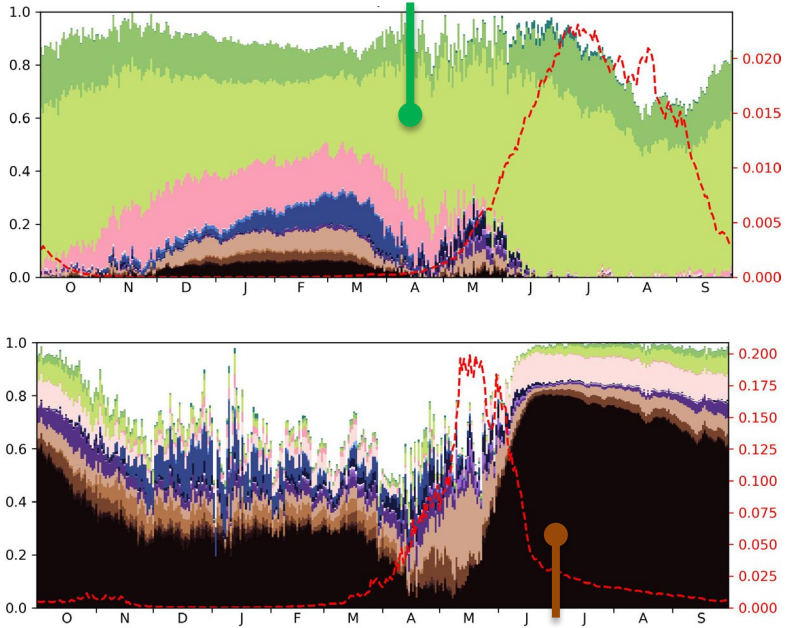

**Evapotranspiration**
Variance
$(mm/day)^2$

**Storage and transmission of water in soils**

Elkouk et al. (2024, WRR)

*10,752 CLM simulations per basin were performed on the **Derecho supercomputer**

**Plant water use efficiency**
(medlynslope)




**Storage and transmission of water in soils**

**Transpiration**
Variance
$(mm/day)^2$

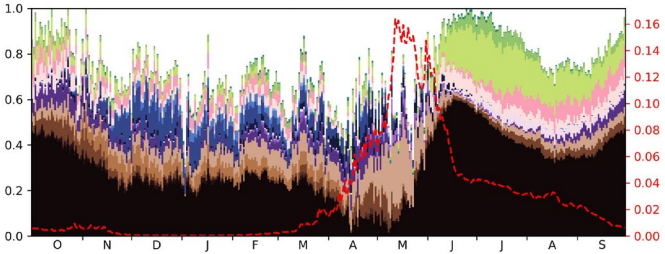
\+

**Evaporation**
Variance
$(mm/day)^2$

=

Animas River basin (1935-2018)

**Evapotranspiration**

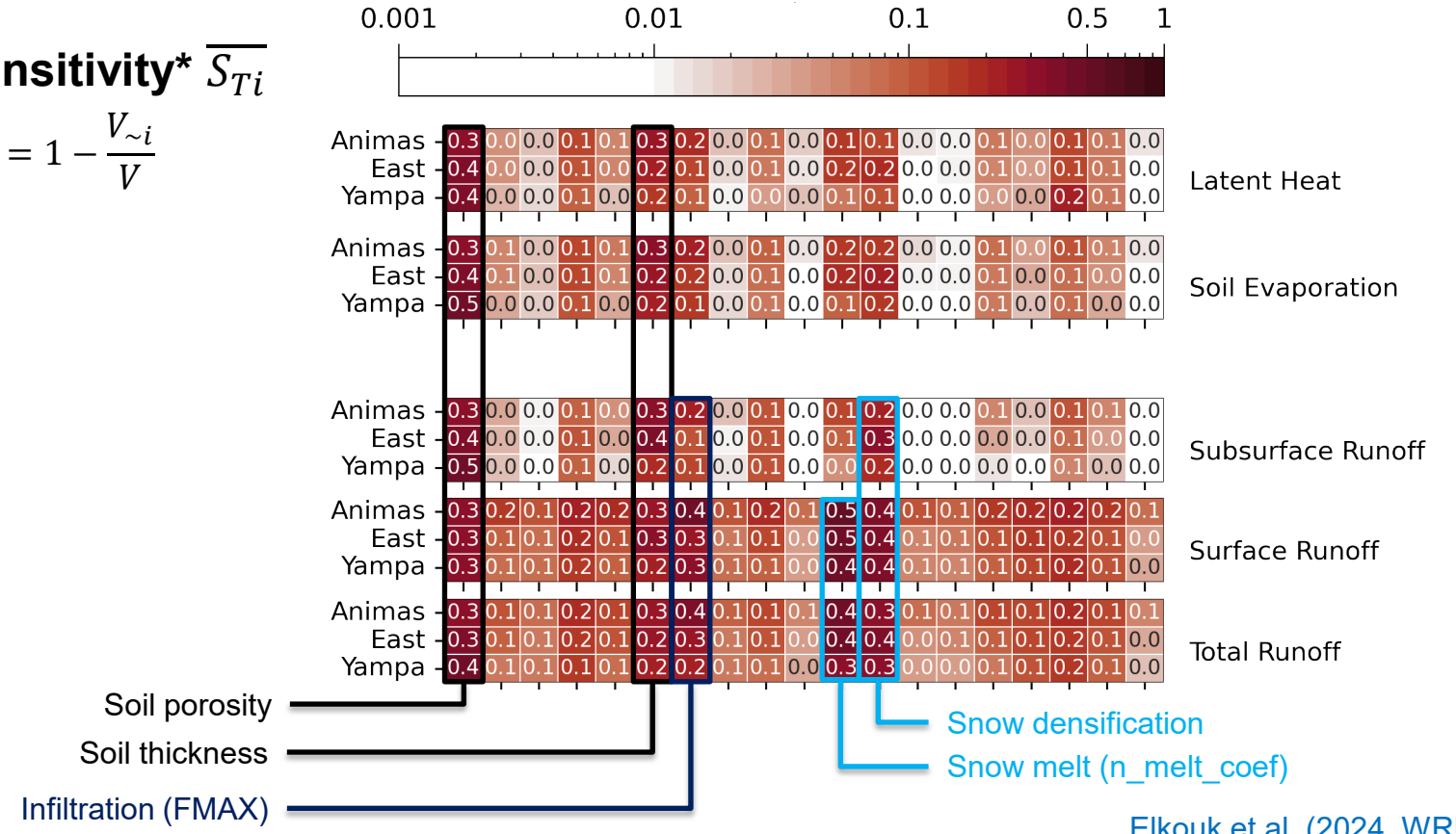



Elkouk et al. (2024, WRR)

*10,752 CLM simulations per basin for 95 years were performed on the **Derecho supercomputer**

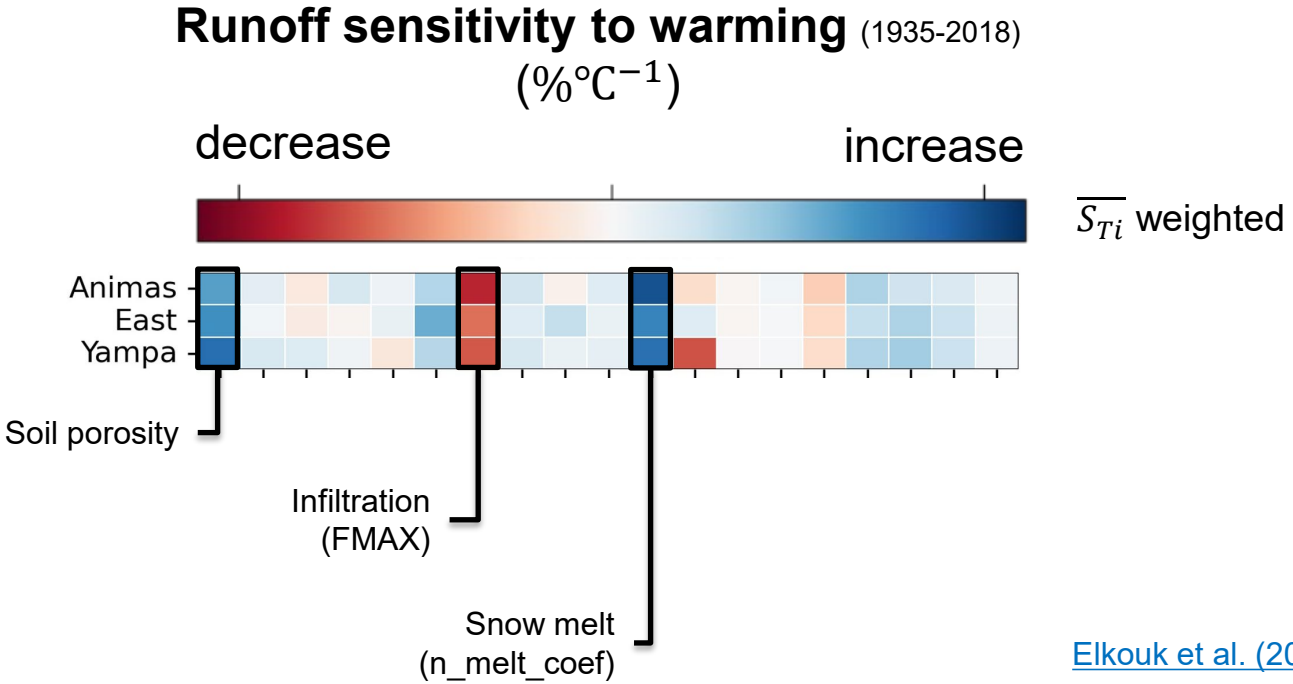
## Sensitivity* $\overline{S_{Ti}}$

$$S_{Ti} = 1 - \frac{V_{\sim i}}{V}$$




Elkouk et al. (2024, WRR)

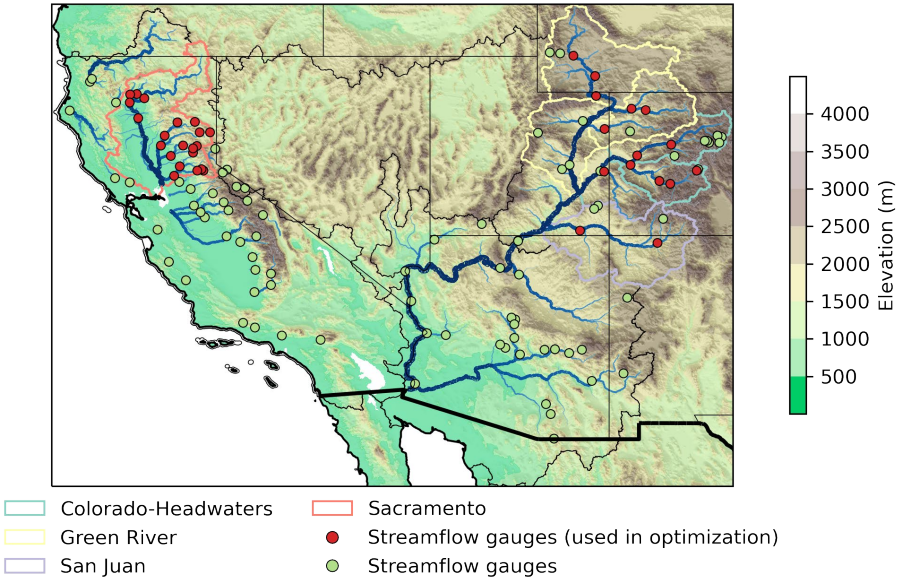
# How do parameter values affect runoff sensitivity to climate?




Elkouk et al. (2024, WRR)

# Parameter estimation

- Emulation-based optimization
  (Cheng et al. 2023)
- Natural/unregulated streamflow
  (Bureau of reclamation, CA department of resources)
- Satellite snow-covered area
  (MODIS, AVHRR)
- CONUS404 (NCAR-USGS)
- CLM5.2-SP at 4 km resolution
- Optimization: 2003-2008 (water-years)

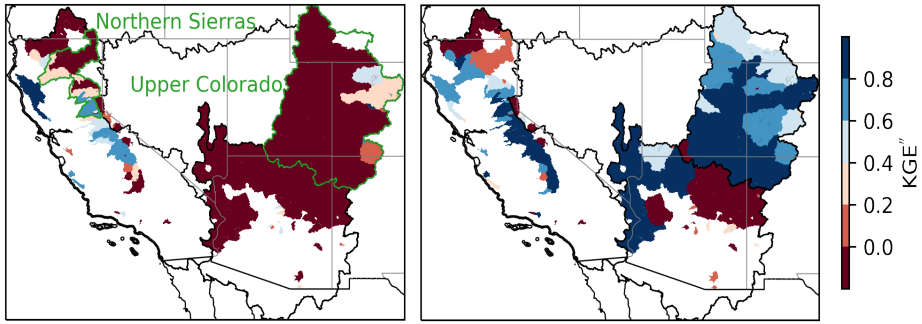



Elkouk et al. (under-revision)

# Substantial improvement in natural flows simulation

**Reference**
median KGE″ = **0.09**

**Optimized**
median KGE″ = **0.64**

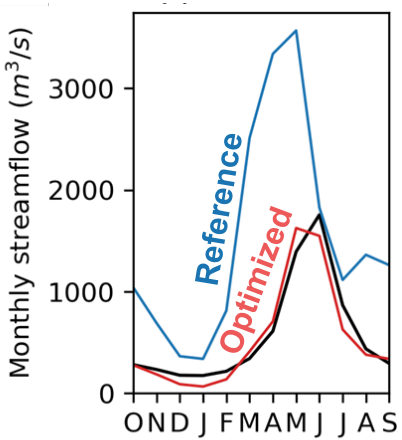


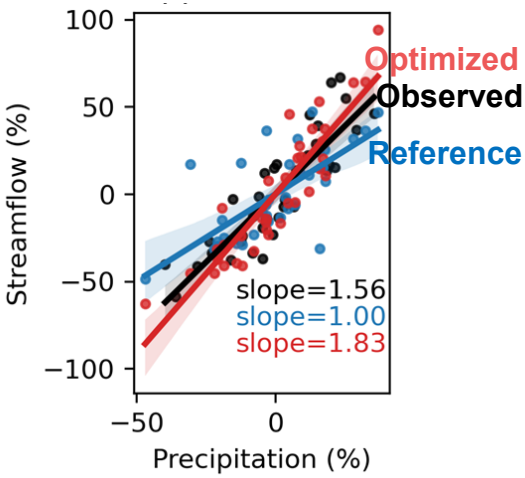

**1981-2020** (water-years)

**121** natural flow gauging locations

modified Kling-Gupta Efficiency (Kling et al., 2012)

Upper Colorado basin
(at Lees Ferry, AZ)




Elkouk et al. (under-revision)

# In conclusion

- **Storage and transmission of water in soils**
- **Infiltration and surface runoff**
- **Snow melt** (missing sub-grid variability in snow depth)

be the focus of **process-oriented estimation of spatial fields of CLM parameters** and **characterizing and reducing uncertainty in future projections of water availability**

# Thank you

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