



## **Constraining Long-term Streamflow Projections of Colorado River Basin for Improved Water Resources Management**

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**Folsom, California**

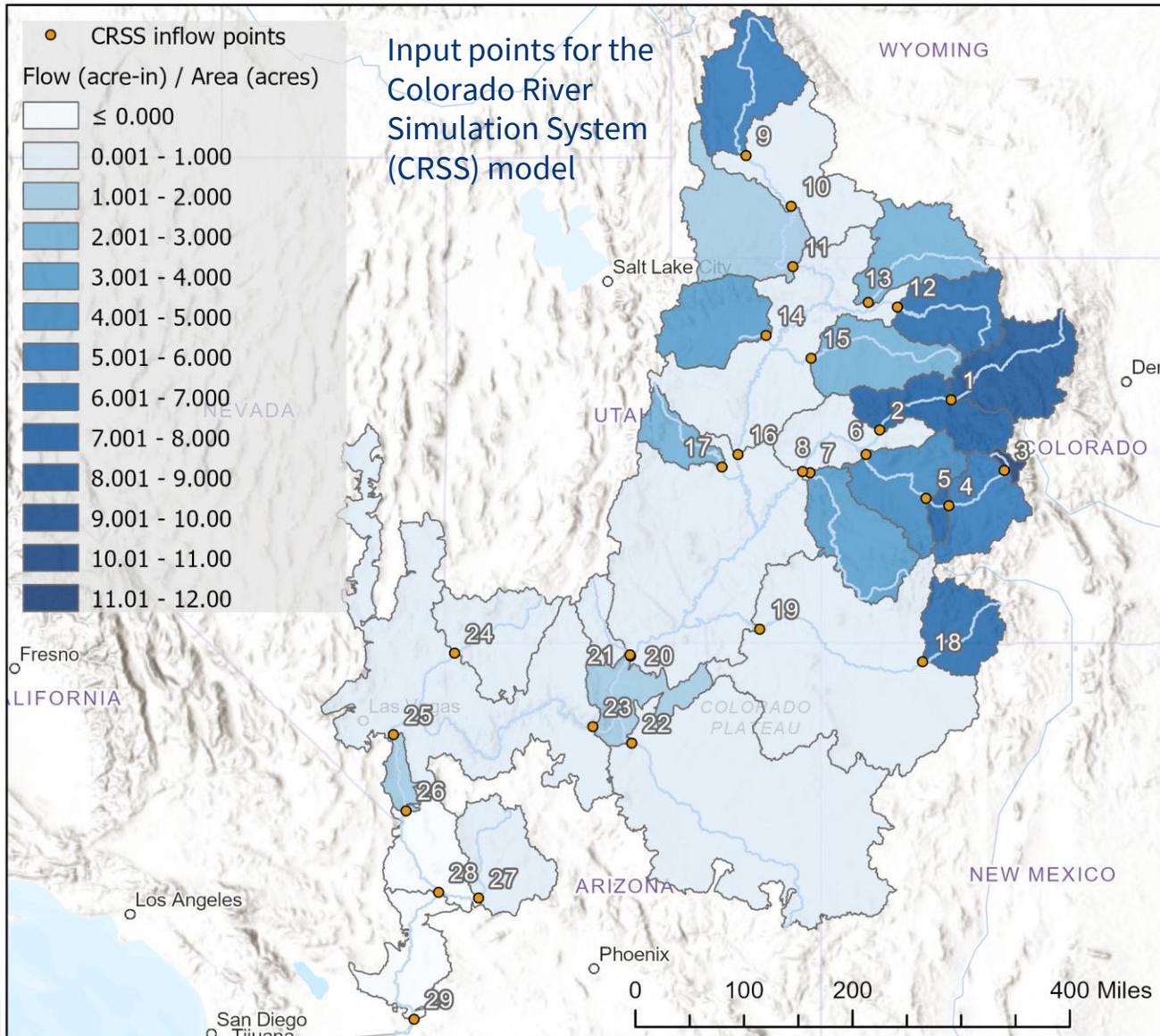
**May 13, 2025**

Sources of photos: (left) Brittany Peterson, Associated Press (top right) Joshua Lott, the Washington Post via Getty Images (bottom right) John Locher, Associated Press

# Outline

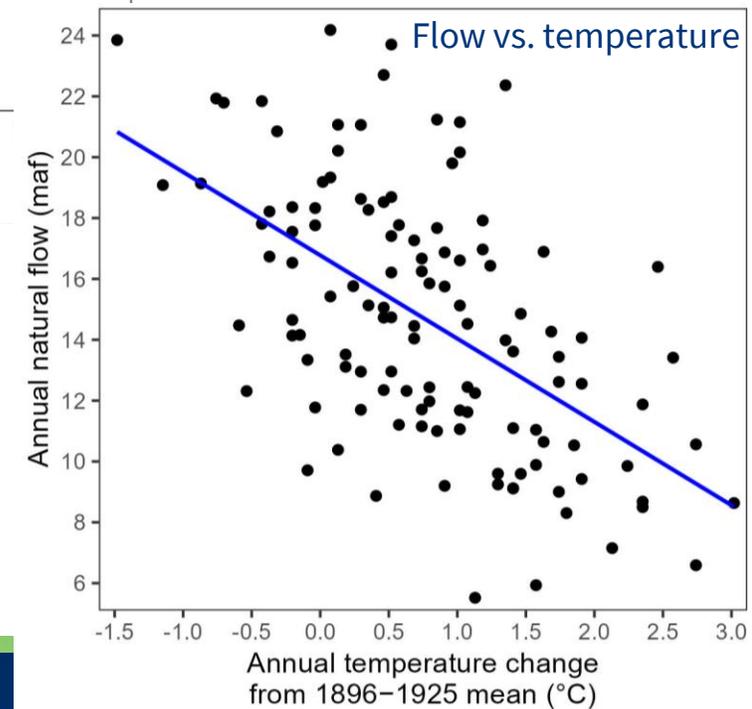
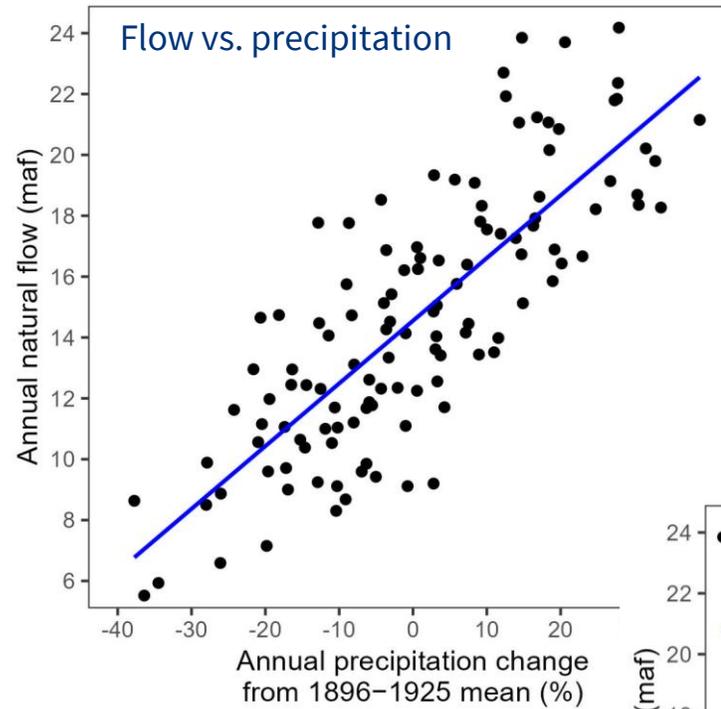
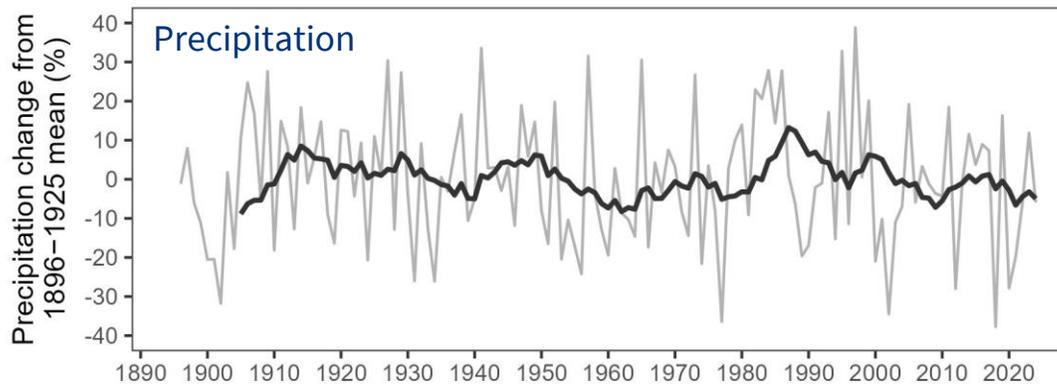
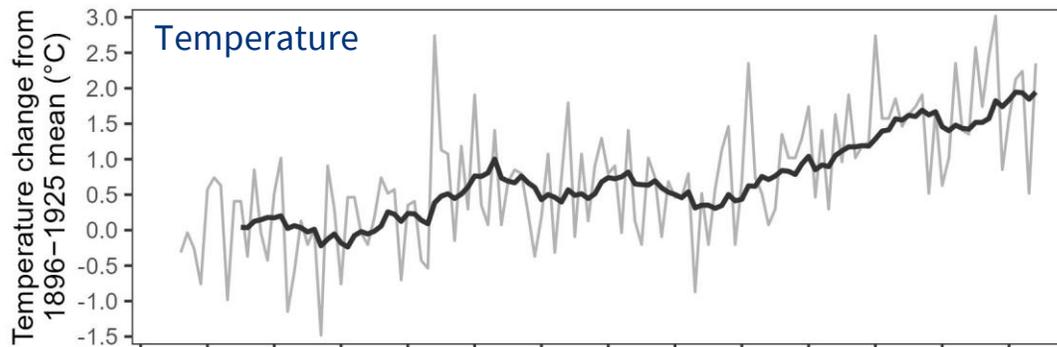
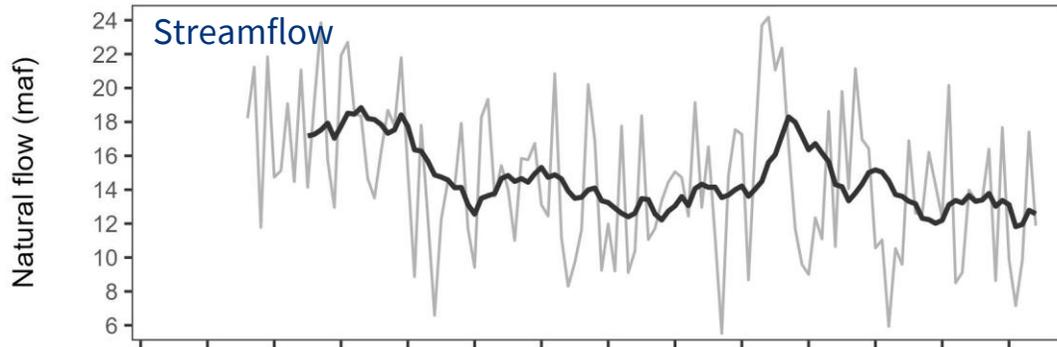
- Historical climate and hydrology in the Colorado River Basin
- Existing modeling and projections of future changes: challenges and uncertainties
- A proposed statistical modeling approach (state-space model; SSM)
- Results from the proposed statistical model (SSM) and conclusions

# Map of the Colorado River Basin and subbasins



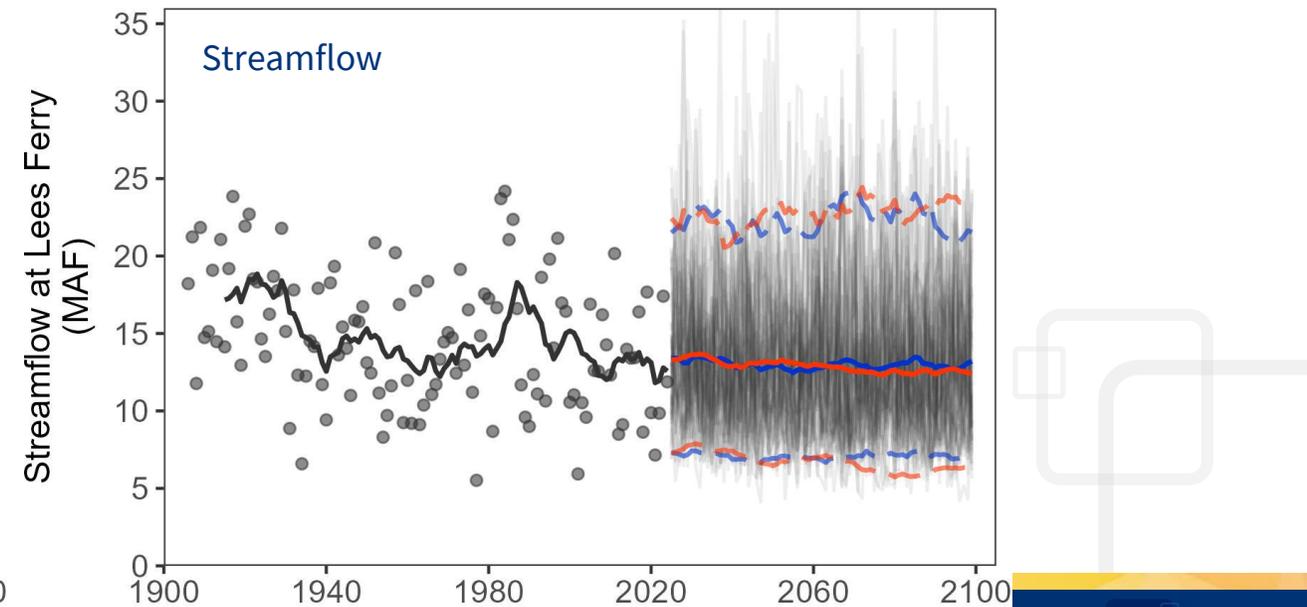
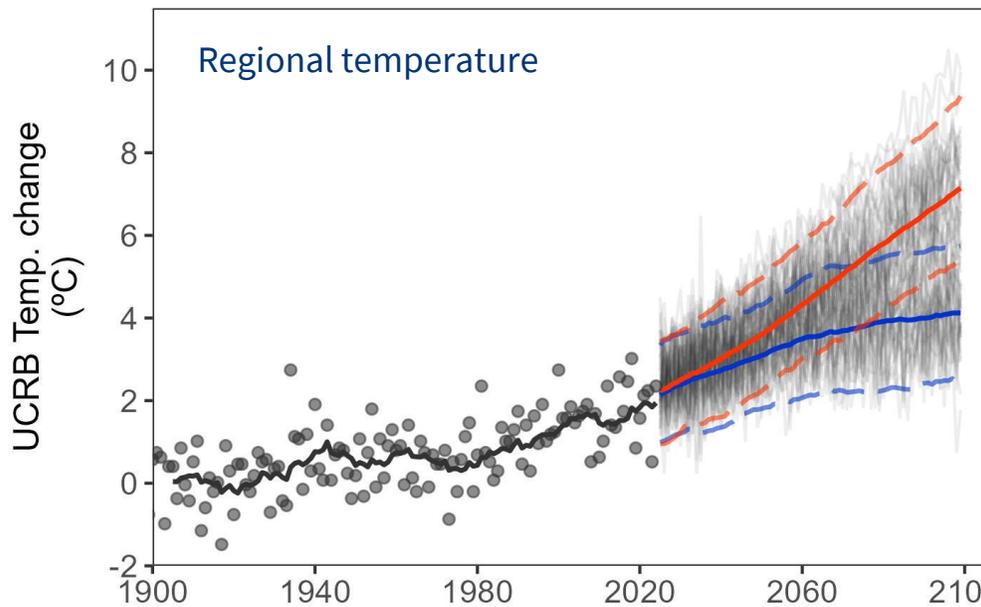
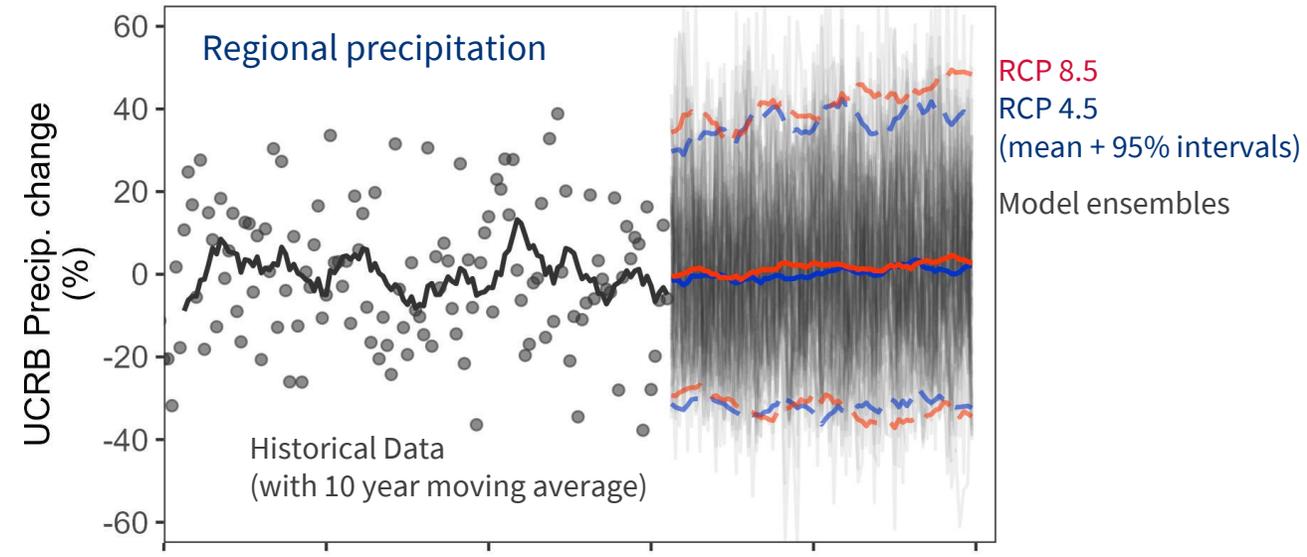
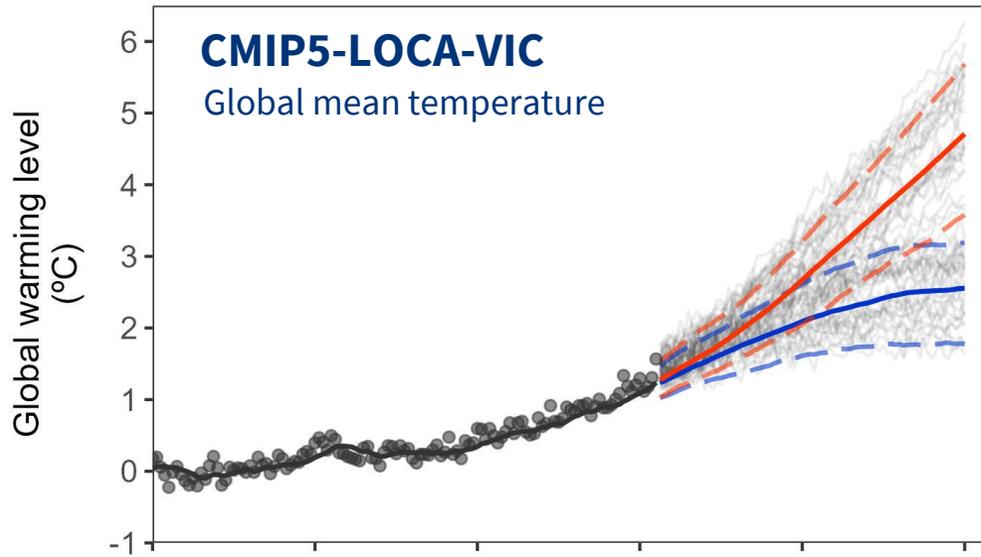
Number	Station ID	Station name
1	09072500	Colorado River At Glenwood Springs, CO
2	09095500	Colorado River Near Cameo, CO
3	09109000	Taylor River Below Taylor Park Reservoir, CO
4	09124700	Gunnison River Below Blue Mesa Dam, CO
5	09127800	Gunnison River Below Gunnison Tunnel, CO
6	09152500	Gunnison River Near Grand Junction, CO
7	09180000	Dolores River Near Cisco, UT
8	09180500	Colorado River Near Cisco, UT
9	09211200	Green River Below Fontenelle Reservoir, WY
10	09217000	Green River Near Green River, WY
11	09234500	Green River Near Greendale, UT
12	09251000	Yampa River Near Maybell, CO
13	09260000	Little Snake River Near Lily, CO
14	09302000	Duchesne River Near Randlett, UT
15	09306500	White River Near Watson, UT
16	09315000	Green River At Green River, UT
17	09328500	San Rafael River Near Green River, UT
18	09355500	San Juan River Near Archuleta, NM
19	09379500	San Juan River Near Bluff, UT
20	09380000	Colorado River At Lees Ferry, AZ
21	09382000	Paria River At Lees Ferry, AZ
22	09402000	Little Colorado River Near Cameron, AZ
23	09402500	Colorado River Near Grand Canyon, AZ
24	09415000	Virgin Rv At Littlefield, AZ
25	09421500	Colorado Rv Blw Hoover Dam, AZ-NV
26	09423000	Colorado River Below Davis Dam, AZ-NV
27	09426000	Bill Williams River Below Alamo Dam, AZ
28	09427520	Colorado River Below Parker Dam, AZ-CA
29	09429490	Colorado River Above Imperial Dam, AZ-CA

# Historical climate and hydrologic changes and variability



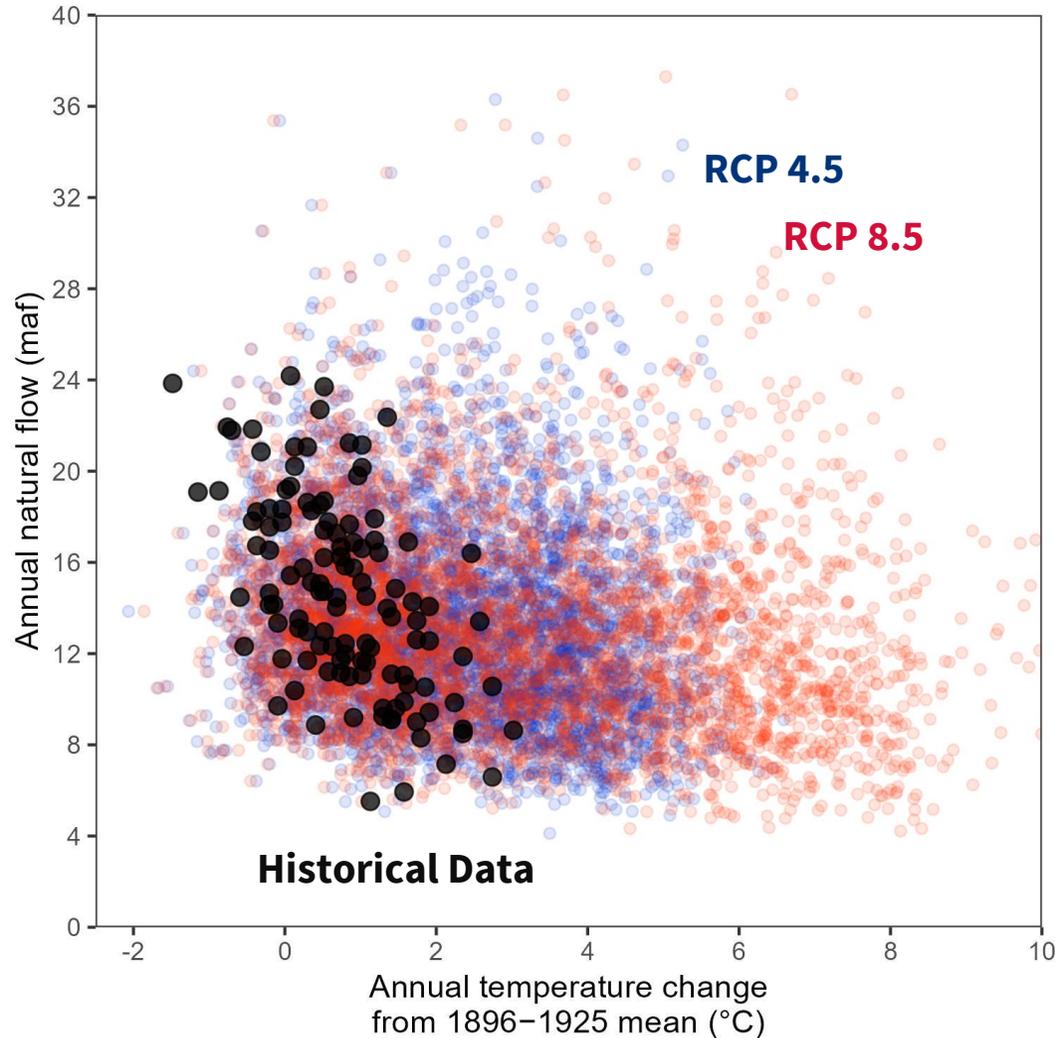
— Annual records — 10-year moving average

# Future climate and hydrologic model projections

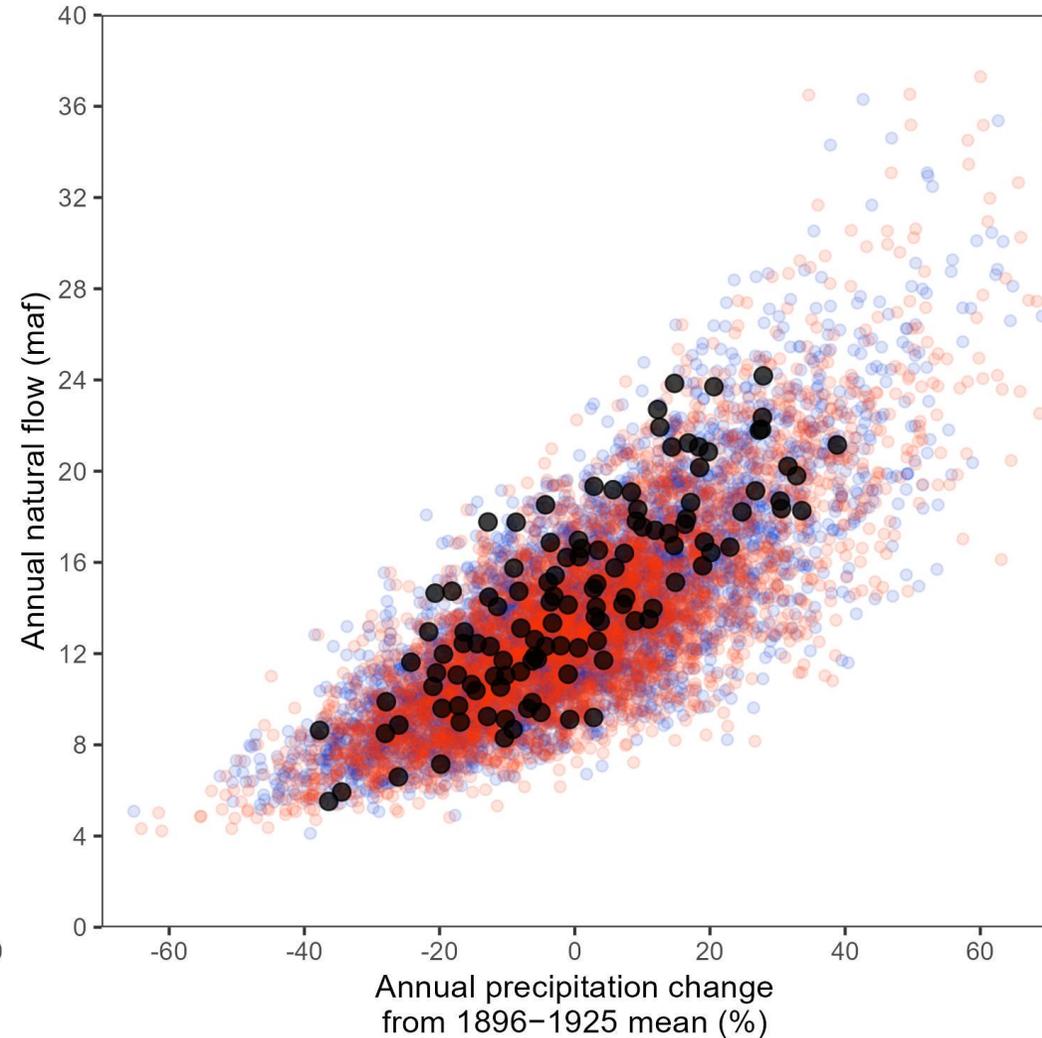


# GCM-coupled results show a smaller temperature effect than historical data, among other discrepancies

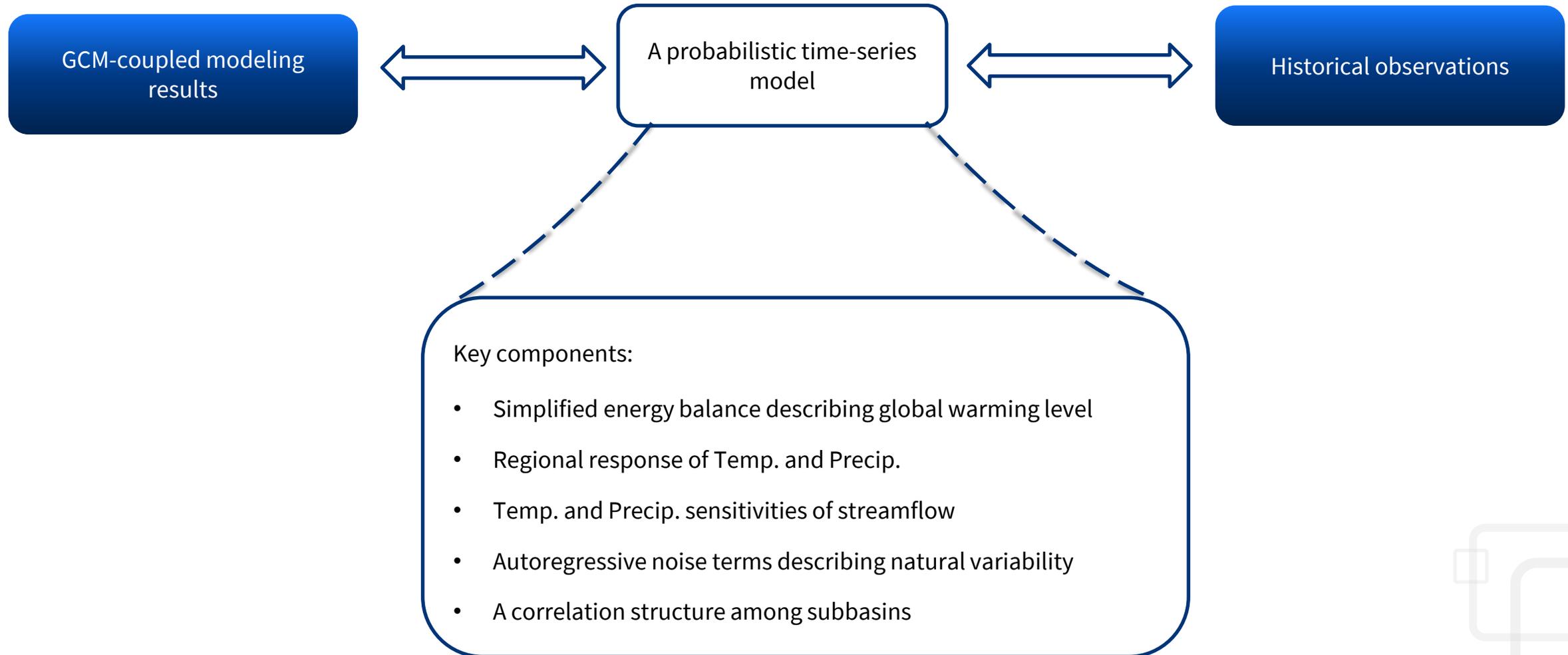
Flow vs. temperature



Flow vs. precipitation



# Developing a simplified, statistical model to describe and analyze *long-term* changes



# Developing a simplified, statistical model to describe and analyze *long-term* changes

## Using State-space representation and modeling (SSM)

State function:

$$\underbrace{x(t + \Delta t)}_{\text{Latent variables}} = \mathbf{A} x(t) + \mathbf{B} \underbrace{F(t)}_{\text{Forcings}} + \underbrace{\omega(t)}_{\text{Noise}}$$

Autoregressive noise is assumed and used to model natural variability:

$$\omega(t + \Delta t) = \underbrace{\phi}_{\text{A matrix with autoregressive coeff.}} \omega(t) + \underbrace{\delta(t)}_{\text{Gaussian noise}}$$

Measurement function:

$$y(t) = \mathbf{D} x(t) + \underbrace{v(t)}_{\text{Measurement noise}}$$

$$x(t) = \begin{bmatrix} x_t^{\text{GWL}} \\ x_t^{\text{RT}} \\ x_t^{\text{RP}} \\ x_t^{\text{S1}} \\ \vdots \end{bmatrix} \rightarrow \text{Latent variables}$$

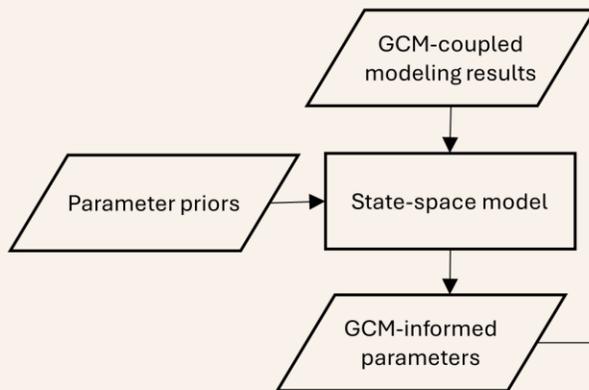
$x_t^{\text{GWL}}$ : latent global warming level  
 $x_t^{\text{RT}}$ : latent regional temperature change  
 $x_t^{\text{RP}}$ : latent regional precipitation change  
 $x_t^{\text{S1}}$ : latent subbasin streamflow change (subbasin 1)  
 ...

$$y(t) = \begin{bmatrix} \Delta T_t^{\text{G}} \\ \Delta T_t^{\text{R}} \\ \Delta P_t^{\text{R}} \\ \Delta R_t^{\text{S1}} \\ \vdots \end{bmatrix} \rightarrow \text{Measurements}$$

$\Delta T_t^{\text{G}}$ : measured global warming level  
 $\Delta T_t^{\text{R}}$ : measured regional temperature change  
 $\Delta P_t^{\text{R}}$ : measured regional precipitation change  
 $\Delta R_t^{\text{S1}}$ : measured subbasin streamflow change (subbasin 1)  
 ...

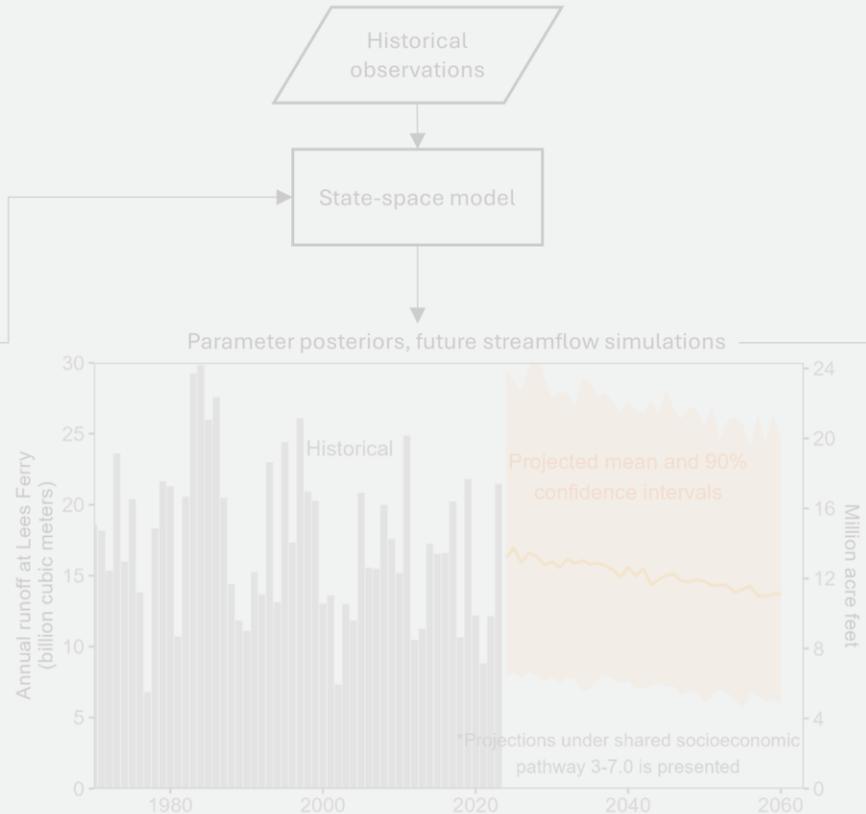
# Step 1: SSM is pre-trained (inferred) by GCM-coupled results

## Using GCM-coupled modeling results to inform parameters

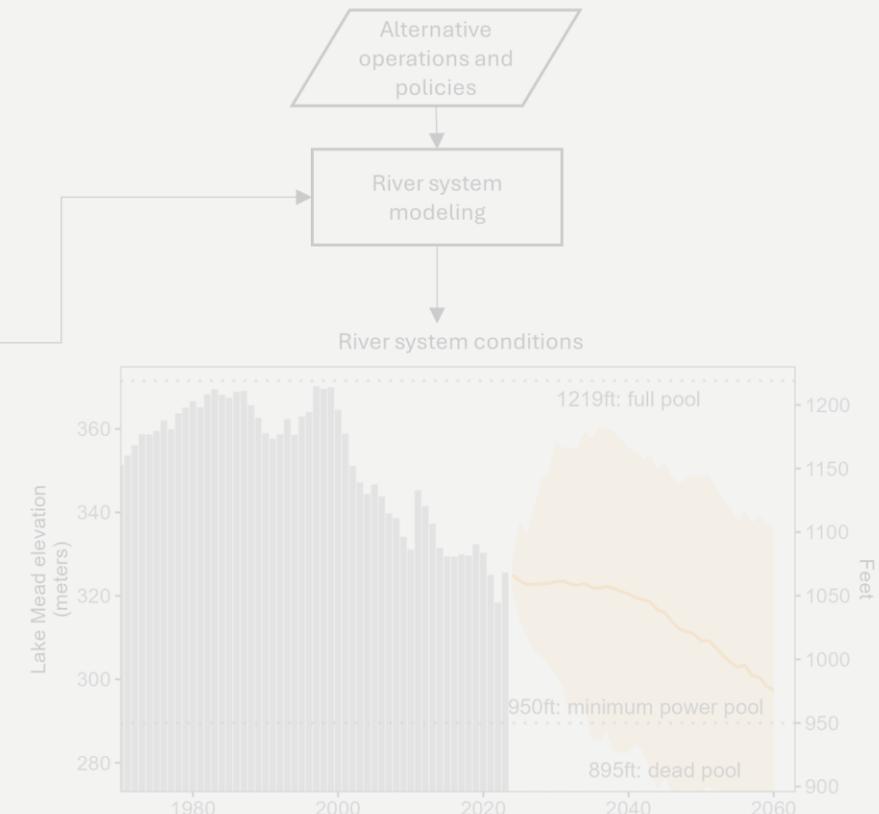


The State-space model is a time-series model developed in this work to statistically describe long-term global and regional climate change

## Using historical data to further constrain parameters and provide projections

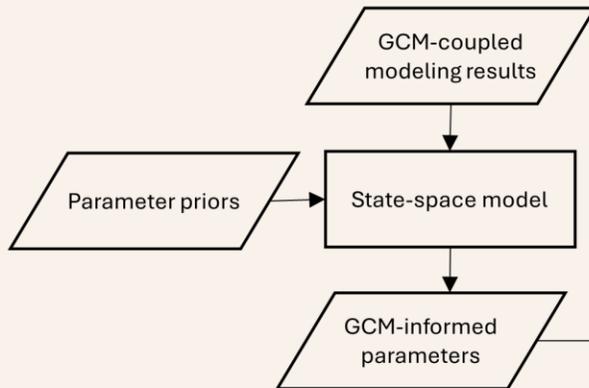


## Using a river system model to analyze future conditions



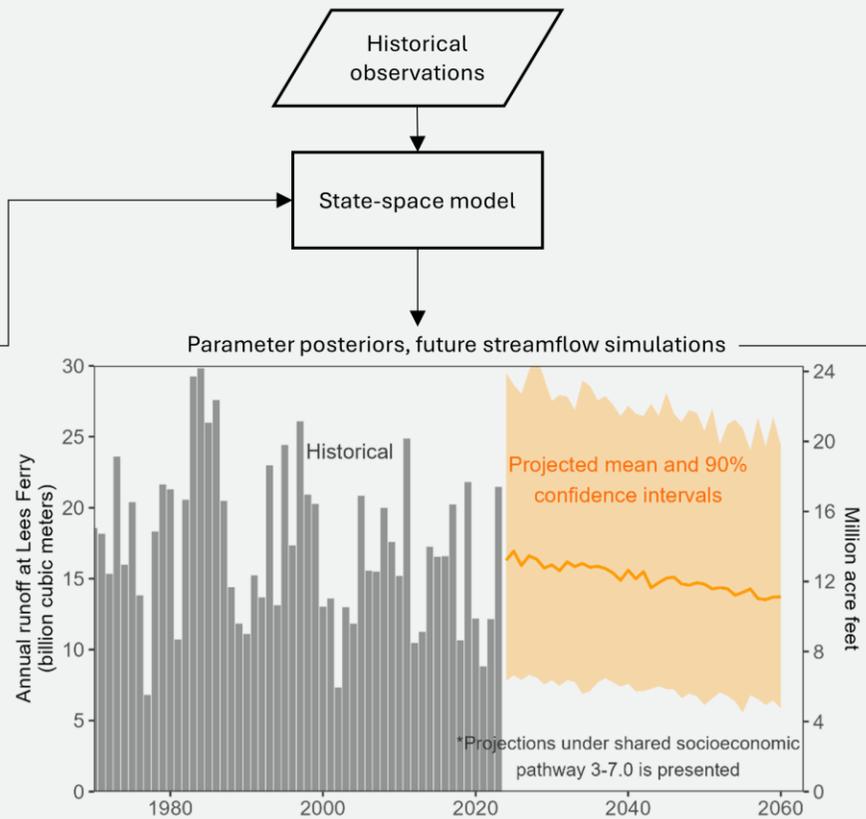
# Step 2: SSM is further calibrated based on historical data

## Using GCM-coupled modeling results to inform parameters

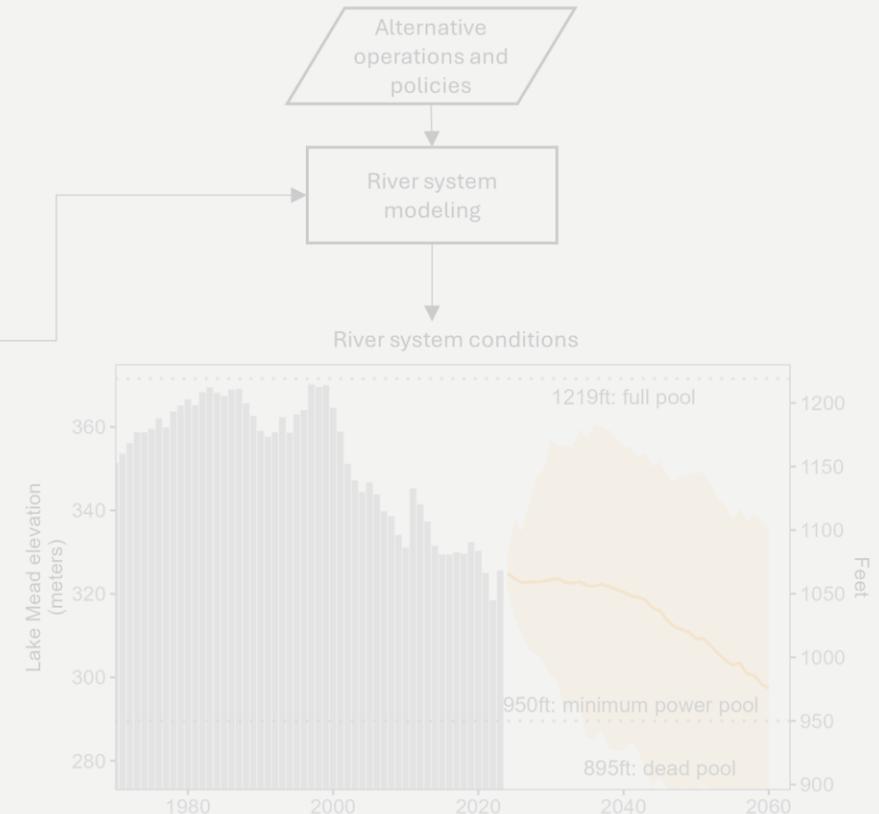


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## Using historical data to further constrain parameters and provide projections

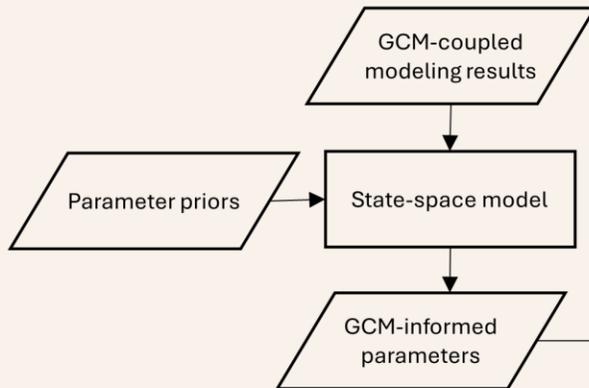


## Using a river system model to analyze future conditions



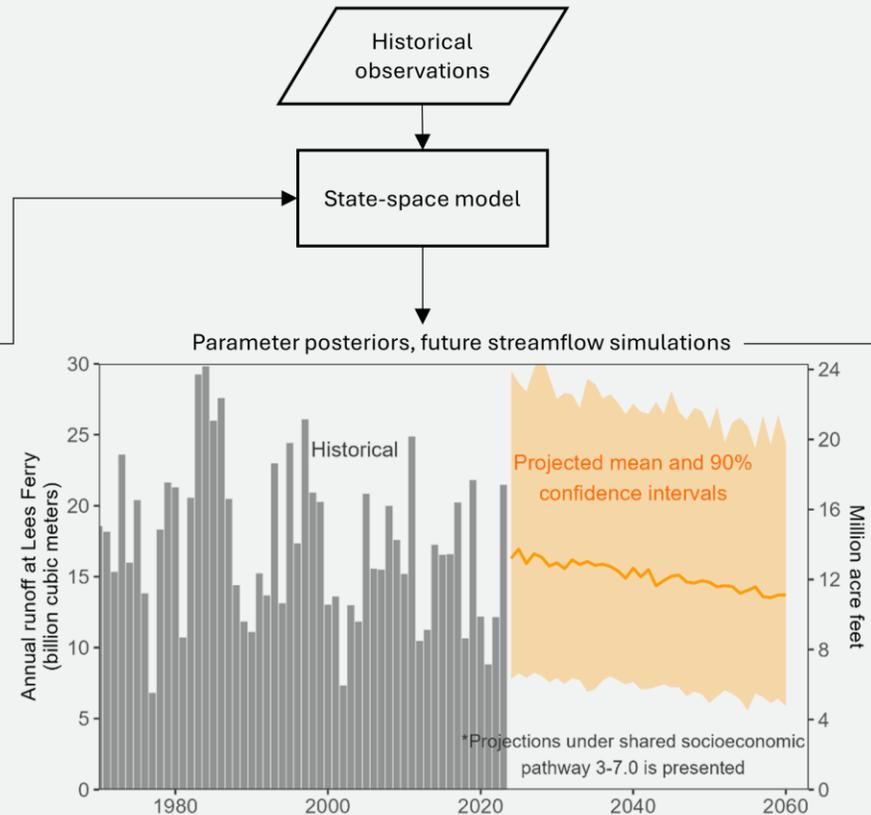
# Step 3: SSM results are used in river system modeling

## Using GCM-coupled modeling results to inform parameters

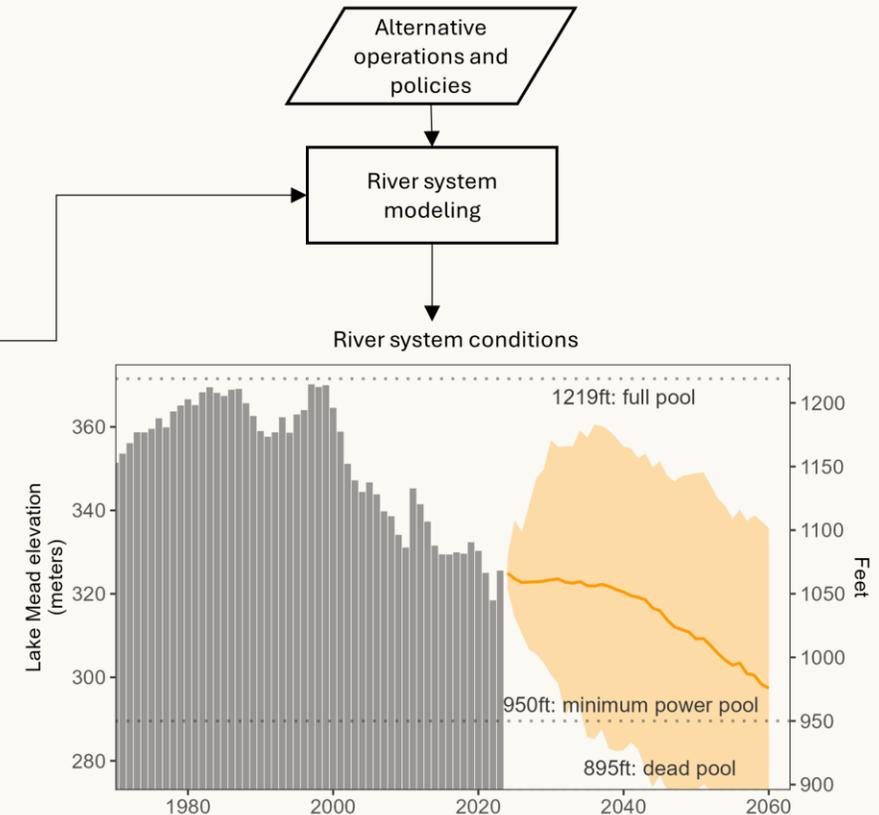


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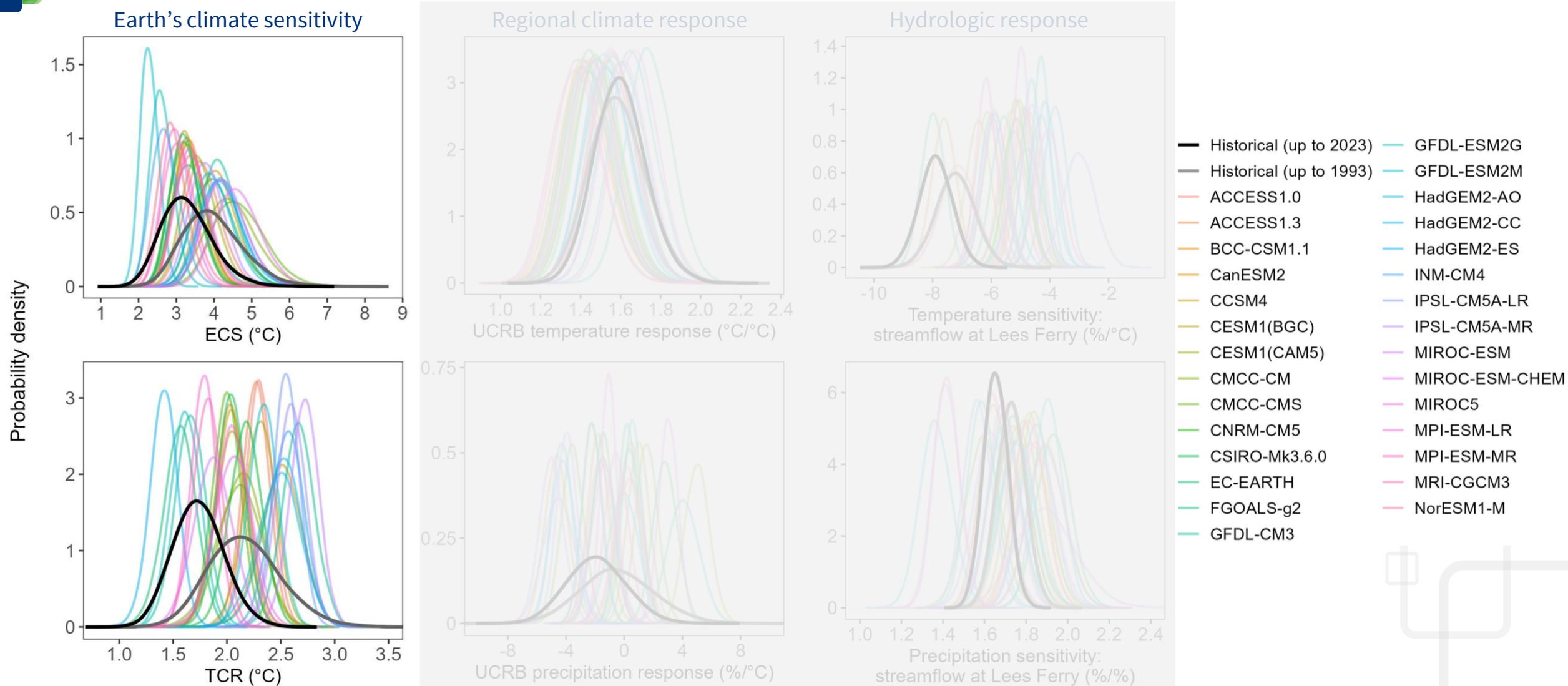
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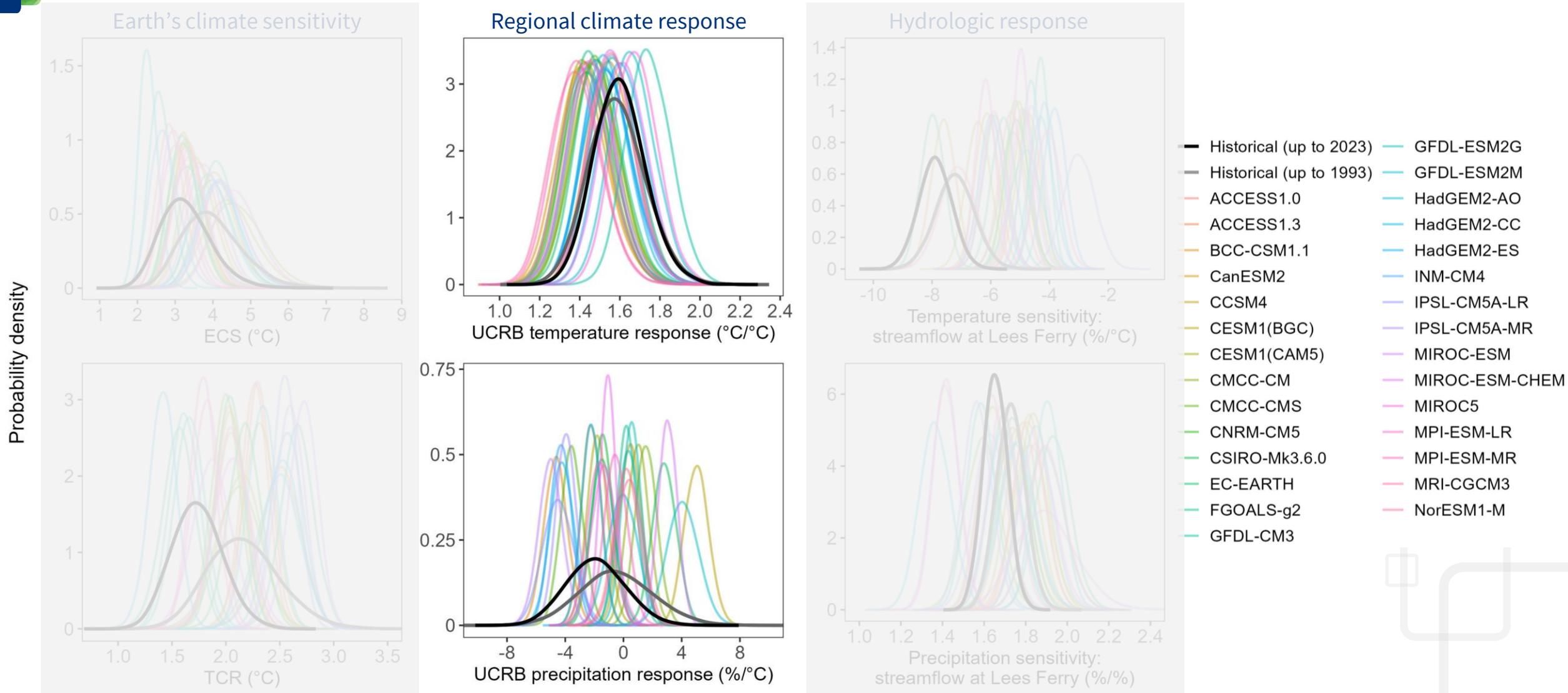
## Using a river system model to analyze future conditions



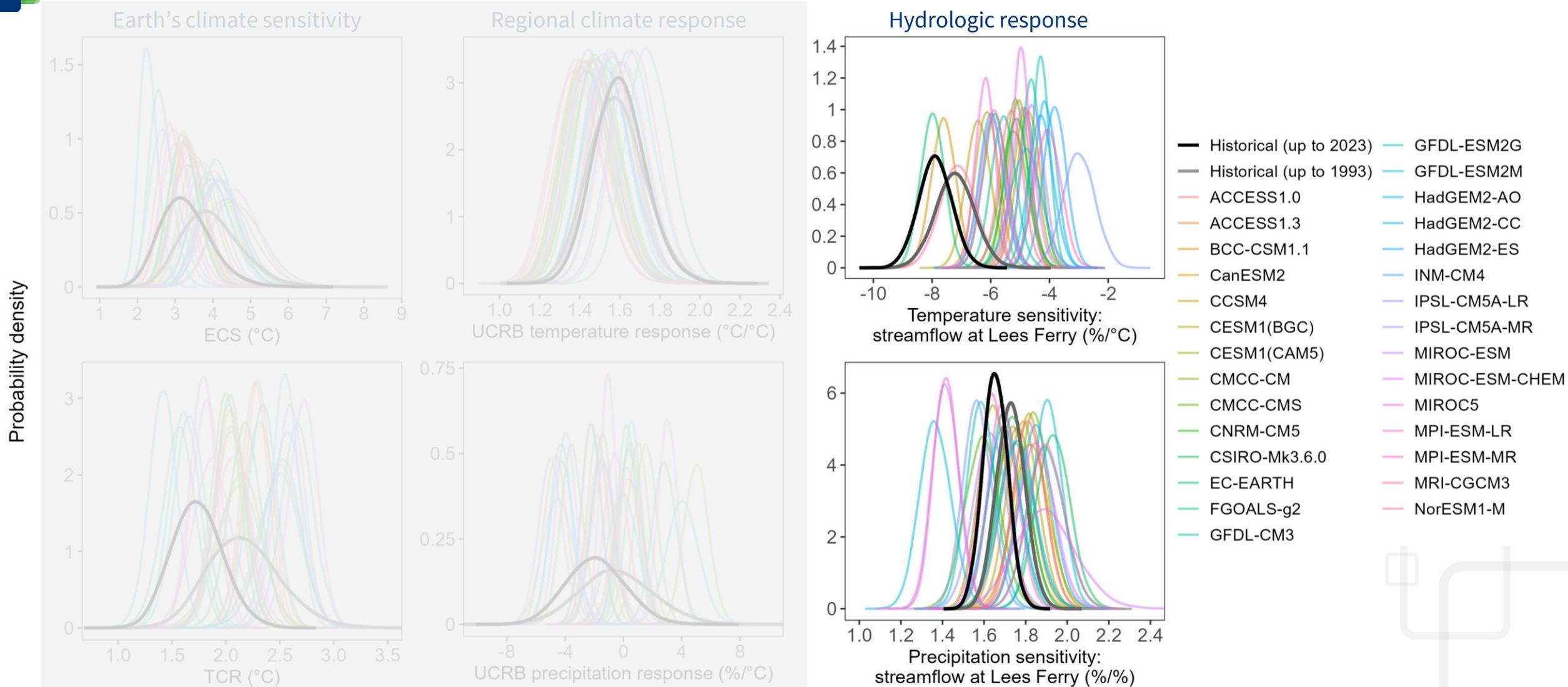
# Bayesian inference with SSM facilitates interpretation



# Bayesian inference with SSM facilitates interpretation

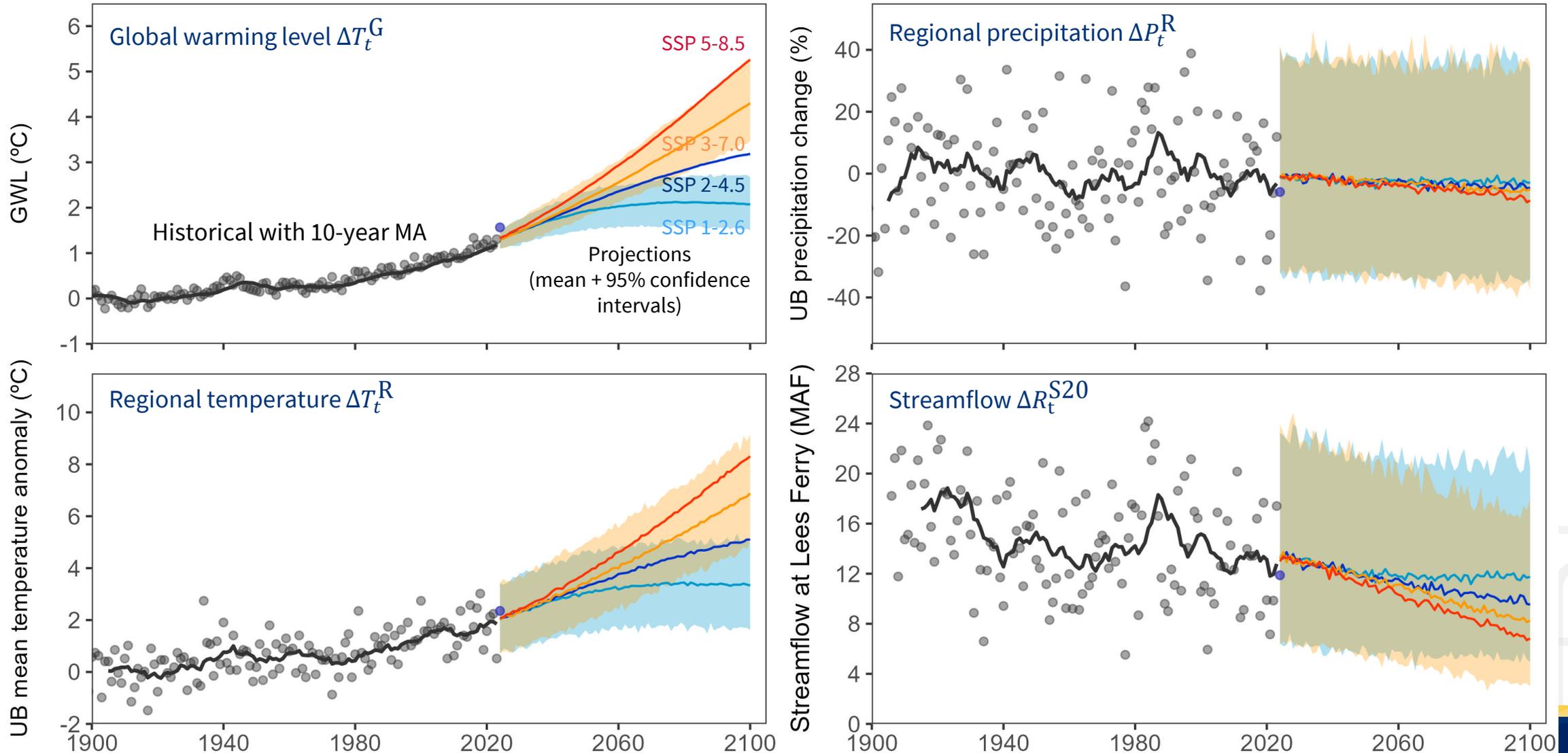


# Bayesian inference with SSM facilitates interpretation



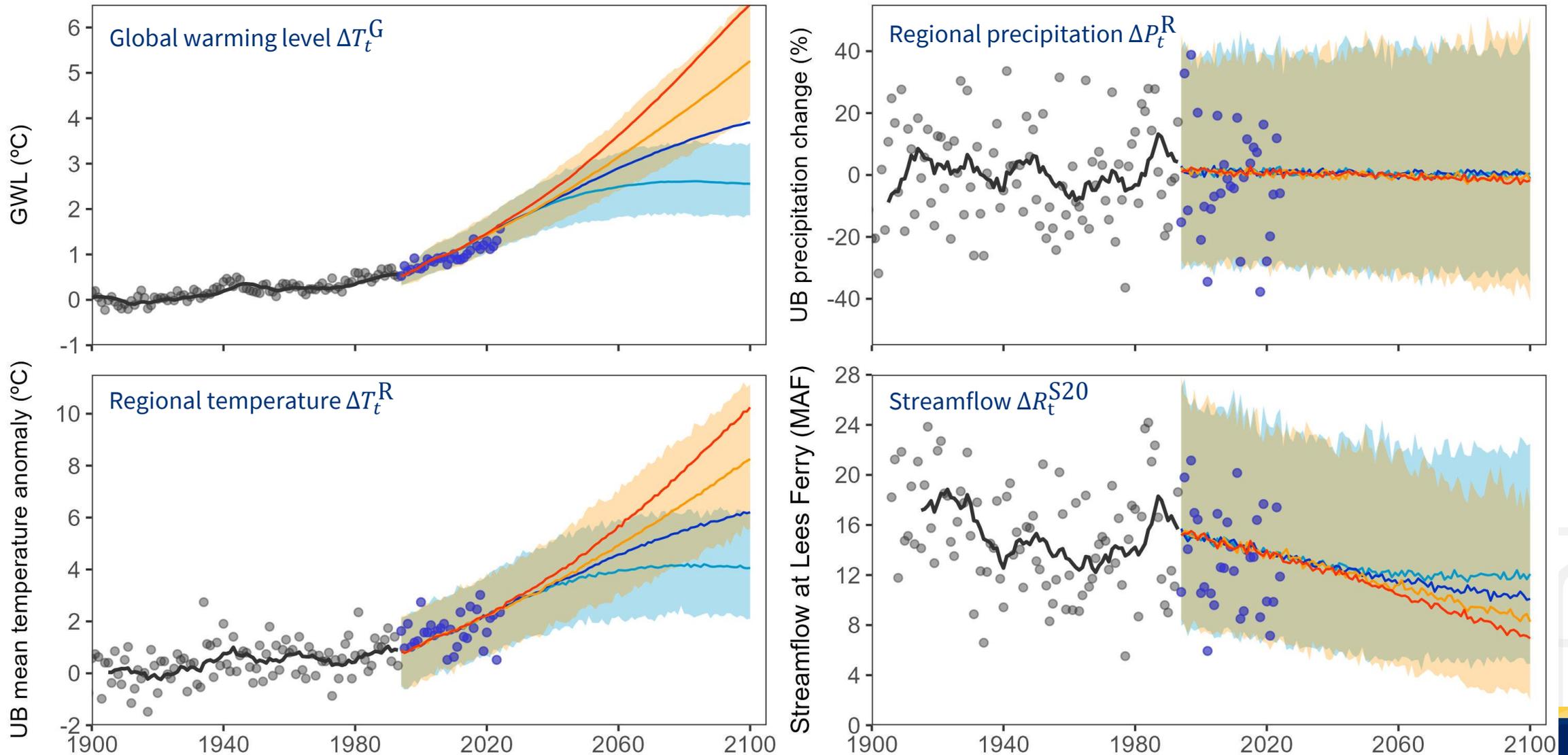
# Probabilistic projections can subsequently be made

## Projections start from 2023

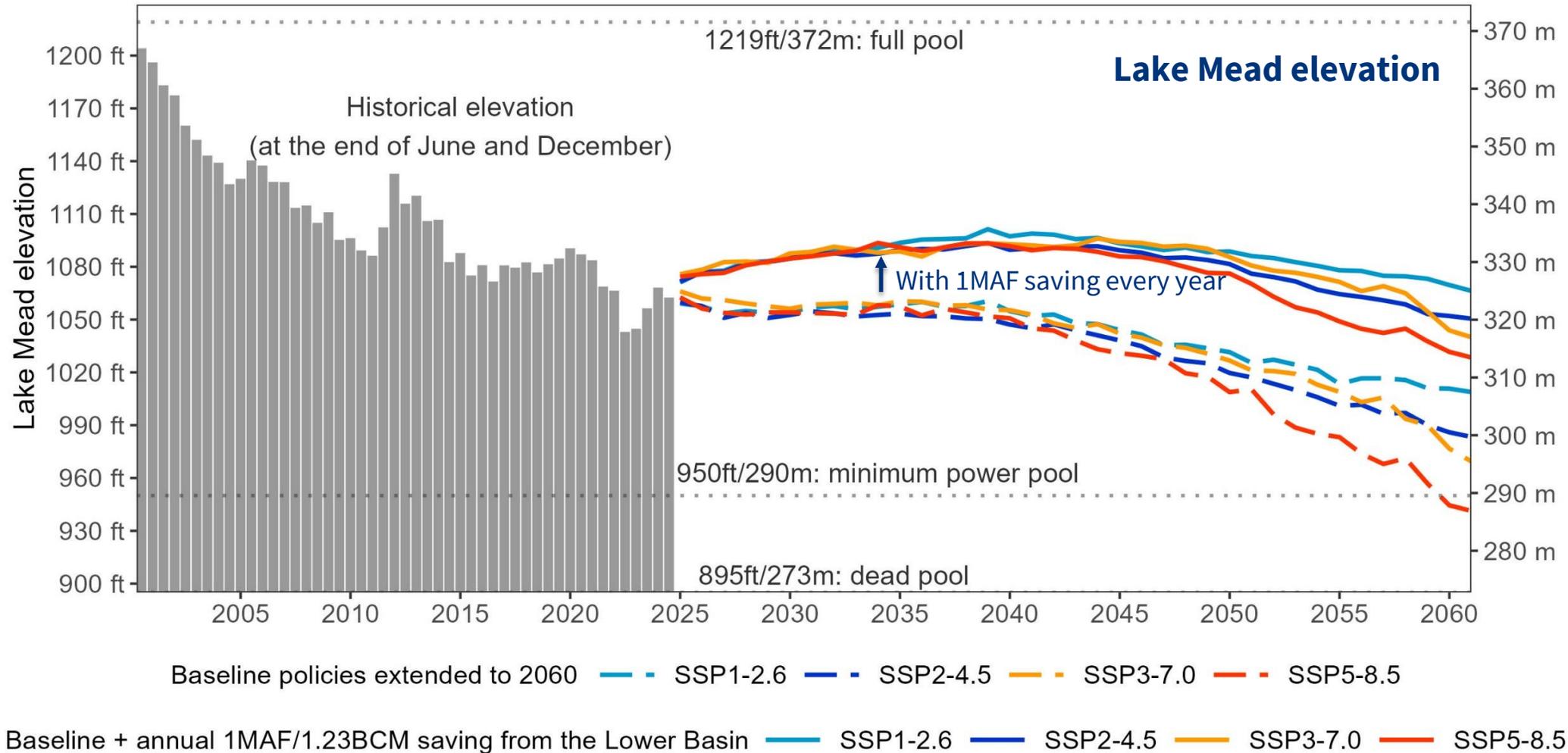


# Validation suggests a reasonable alignment with historical data

Projections start from 1993



# Projected system conditions suggest further stress

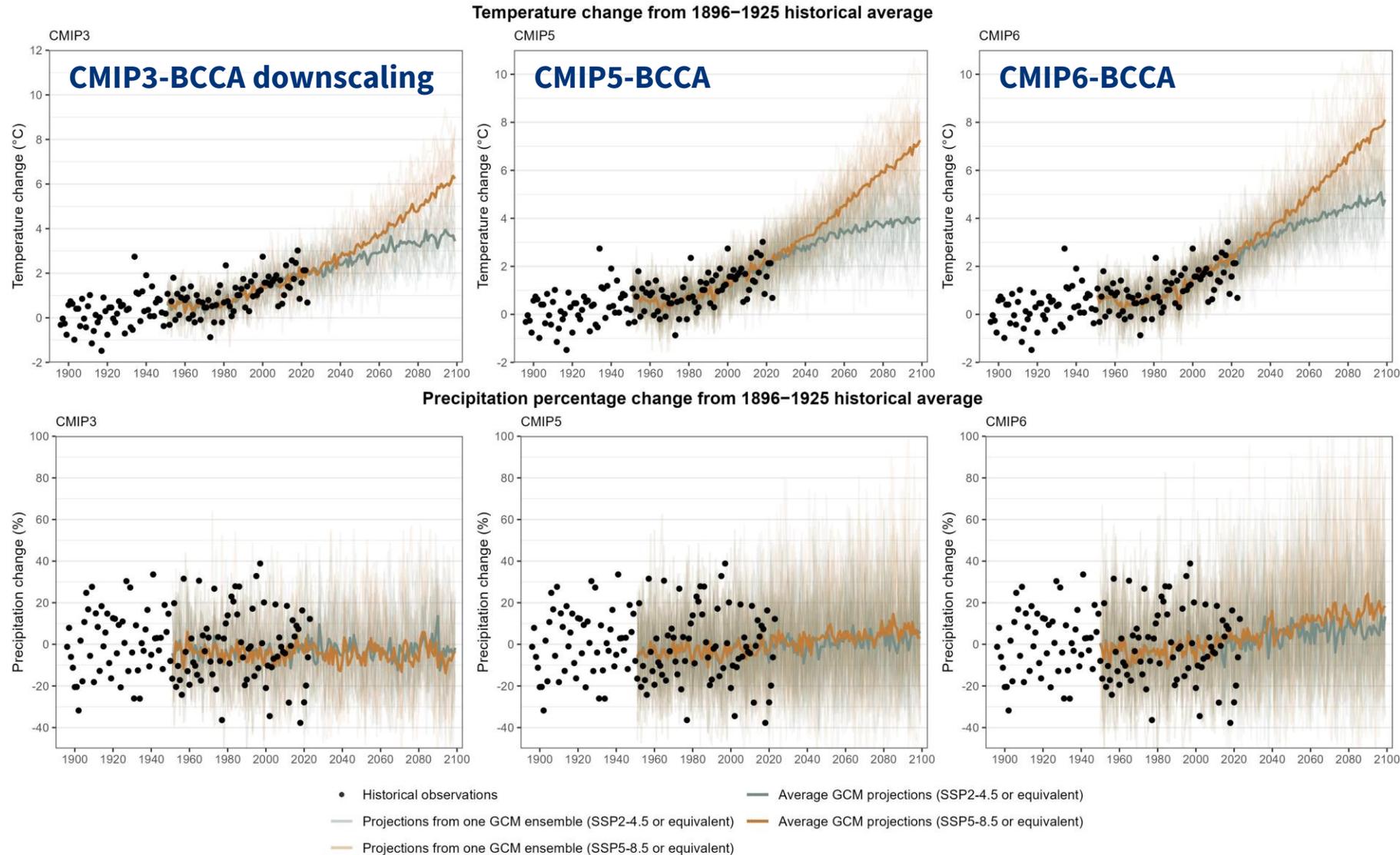


# Summary and Conclusions

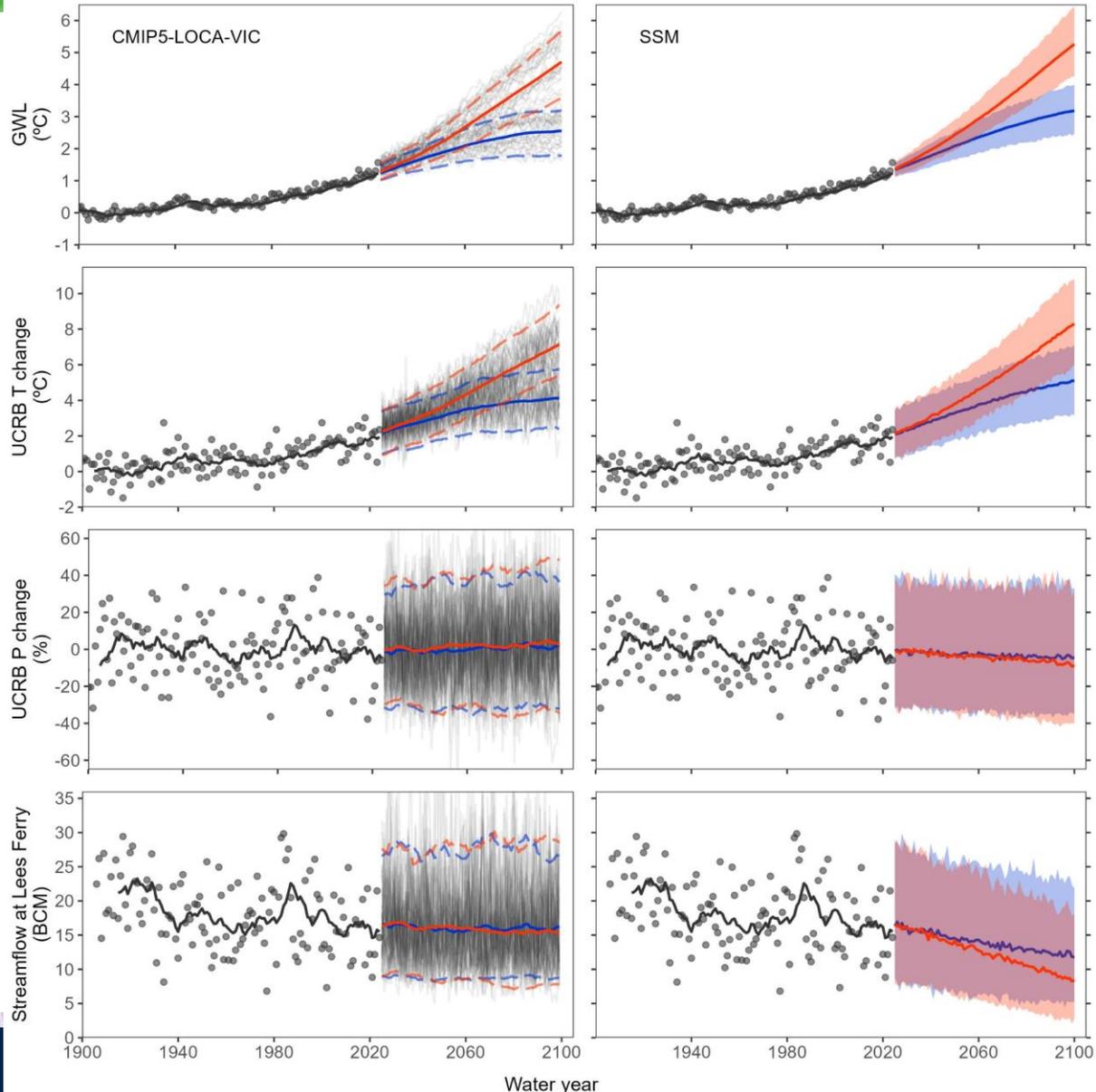
- The recent decline of streamflow in Colorado River Basin suggests a notable warming temperature effect
- Existing GCM-coupling results (GCM-statistical downscaling-hydrologic modeling) show less temperature effect than historical data
- A probabilistic time-series model (SSM) was developed and used in this work to bridge the gap
- The decrease of streamflow in Colorado River Basin in recent years aligns with SSM projections
- SSM projections suggest a further decrease in the future, highlighting regional water supply challenges

# Supplemental Slides

# Projected future climate in Upper Basin (CMIP3, CMIP5, and CMIP6)



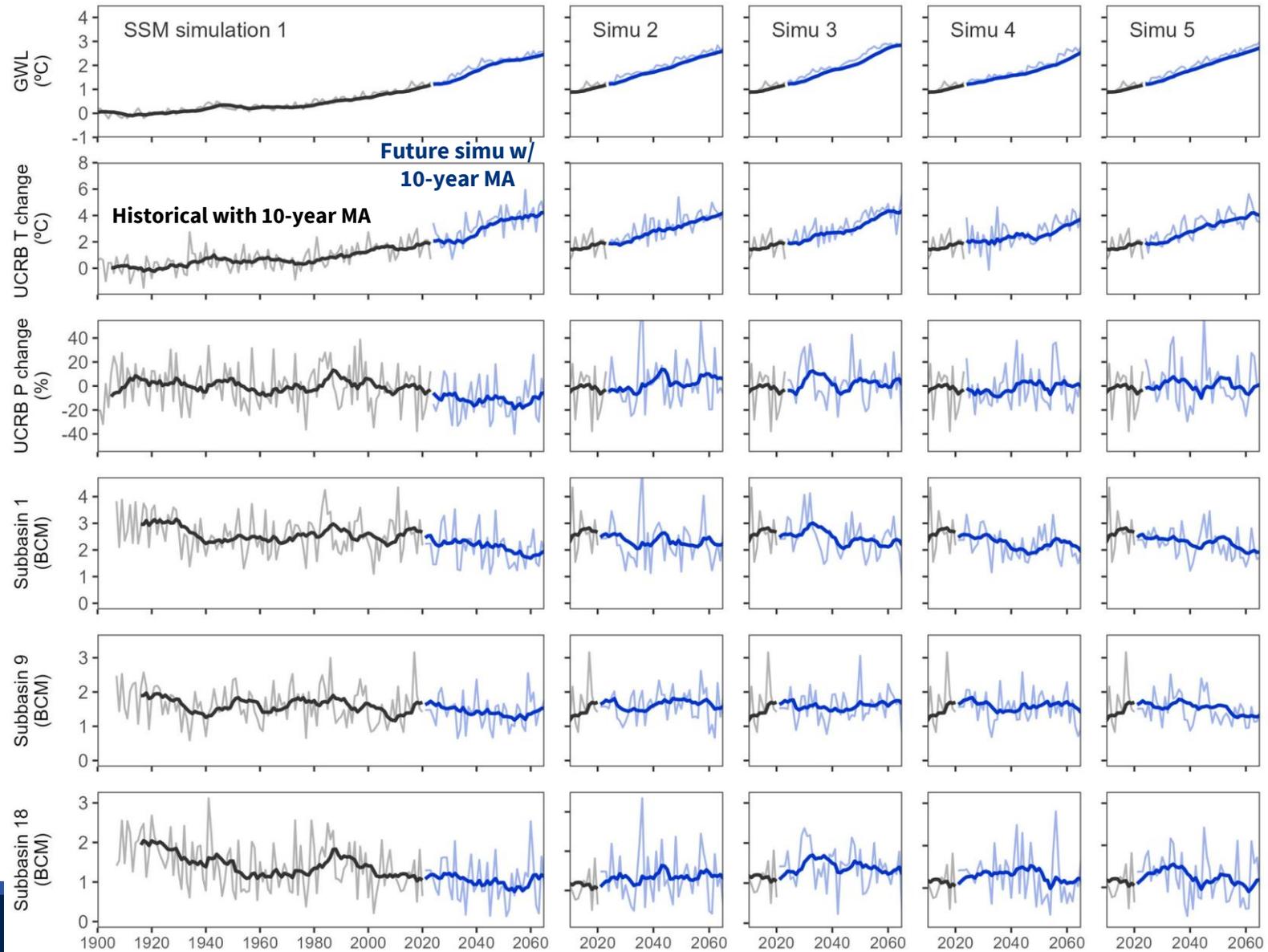
# Projected future climate in Upper Basin (CMIP3, CMIP5, and CMIP6)



- Historical observations
- Historical 10-year moving averages (MA)
- Individual GCM results
- Median projection with 10-year MA (RCP4.5)
- Empirical 95% bounds with 10-year MA (RCP4.5)
- Median projection with 10-year MA (RCP8.5)
- Empirical 95% bounds with 10-year MA (RCP8.5)
- SSM projection mean (SSP2-4.5)
- SSM projection mean (SSP5-8.5)
- SSM 95% confidence intervals (SSP2-4.5)
- SSM 95% confidence intervals (SSP5-8.5)



# New simulations are generated to run CRSS



# Projected water deliveries show similar long-term management challenges

## Annual total deliveries to the entire basin

