IM3 INTEGRATED MULTISECTOR MULTISCALE MODELING

THEME 2: ADVANCING REGIONAL MODELING TO BETTER CAPTURE RISKS AND IMPACTS

EXPLORING MULTISECTORAL DROUGHT VULNERABILITY IN COLORADO'S WEST SLOPE BASINS

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THEME 2 RISKS & IMPACTS – QUESTIONS

- *Q1: What is needed to improve the decision relevance of regional projections and better capture system shocks?*
- *Q2: What are the bottlenecks for advancing regional modeling to better capture risks and impacts?*

THEME 2 RISKS & IMPACTS – WHAT IS NEEDED

- *What is needed to improve the decision relevance of regional projections and better capture system shocks?*
  - *We need to more holistically engage with the drivers and determinants of regional risks*
  - *Better quantify highly uncertain extremes that could be experienced from both internal variability & anthropogenically forced climate changes*
  - *Decision relevance requires representation of institutionally complex human systems (e.g., water rights & infrastructure in the US West)*

THEME 2 RISKS & IMPACTS – A BROADER VIEW OF RISK

Systemic failures, extreme events and ‘hyper-risks’ emerge as a result of the ***highly complex and highly interconnected*** human-Earth systems

Dynamic relationships between agents, systems and sectors transmit risk for one to another

Drivers can ***amplify or buffer*** existing threats

Adapted from Simpson et al. (2021). https://www.cell.com/one-earth/abstract/S2590-3322(21)00179-2

THEME 2 RISKS & IMPACTS – A BROADER VIEW OF RISK

Need to Capture ***Compounding*** or ***Cascading*** Risks

Interacting risks can ***emerge*** across scales, systems, and sectors

Human responses can be strong determinants of risk

Combinations of multiple risks pose challenges for model-based insights

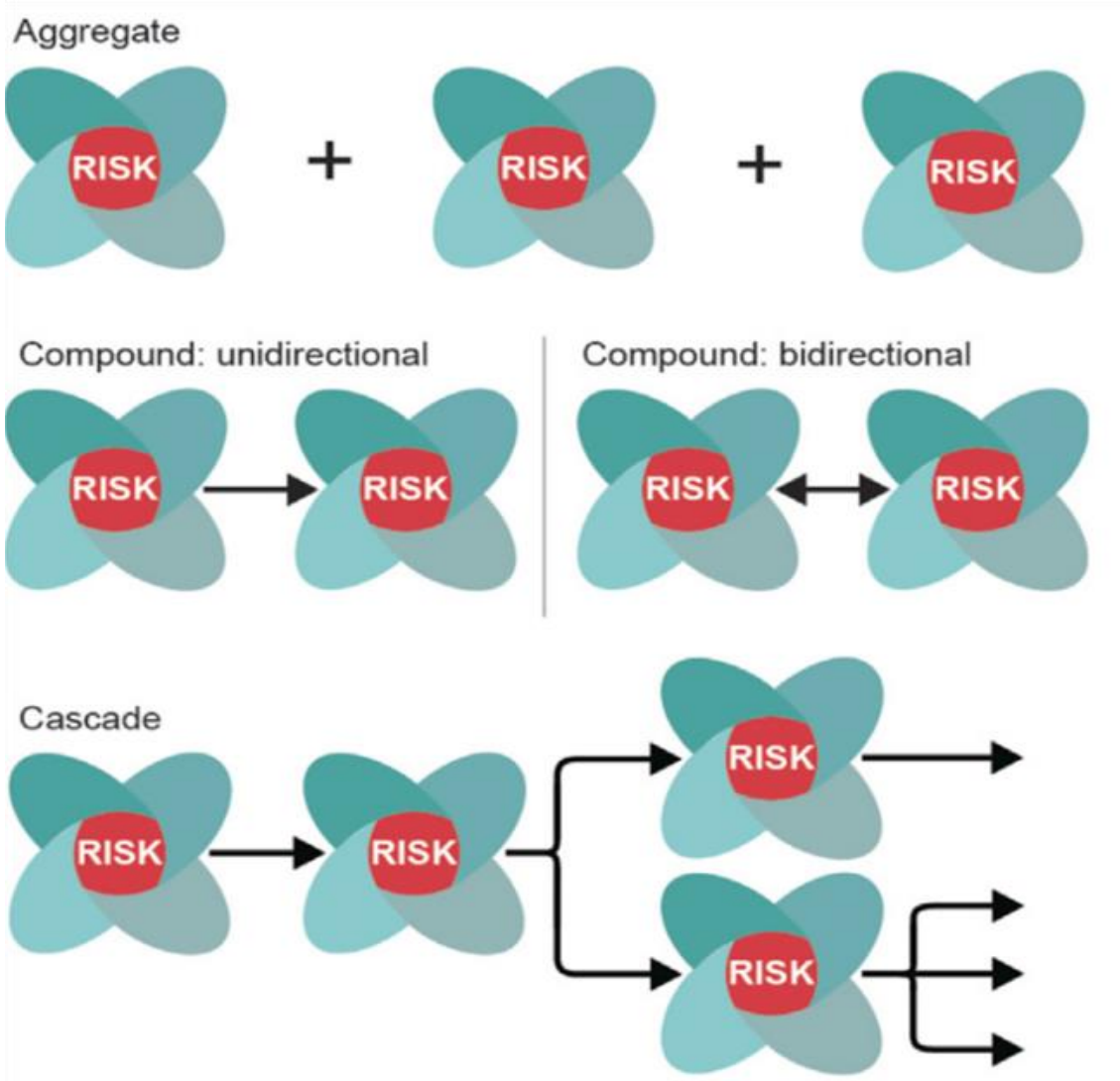

Figure adapted from Simpson et al. (2021). "A framework for complex climate change risk assessment". In: One Earth 4.4, 1648 pages 489–501. ISSN: 2590-3322.

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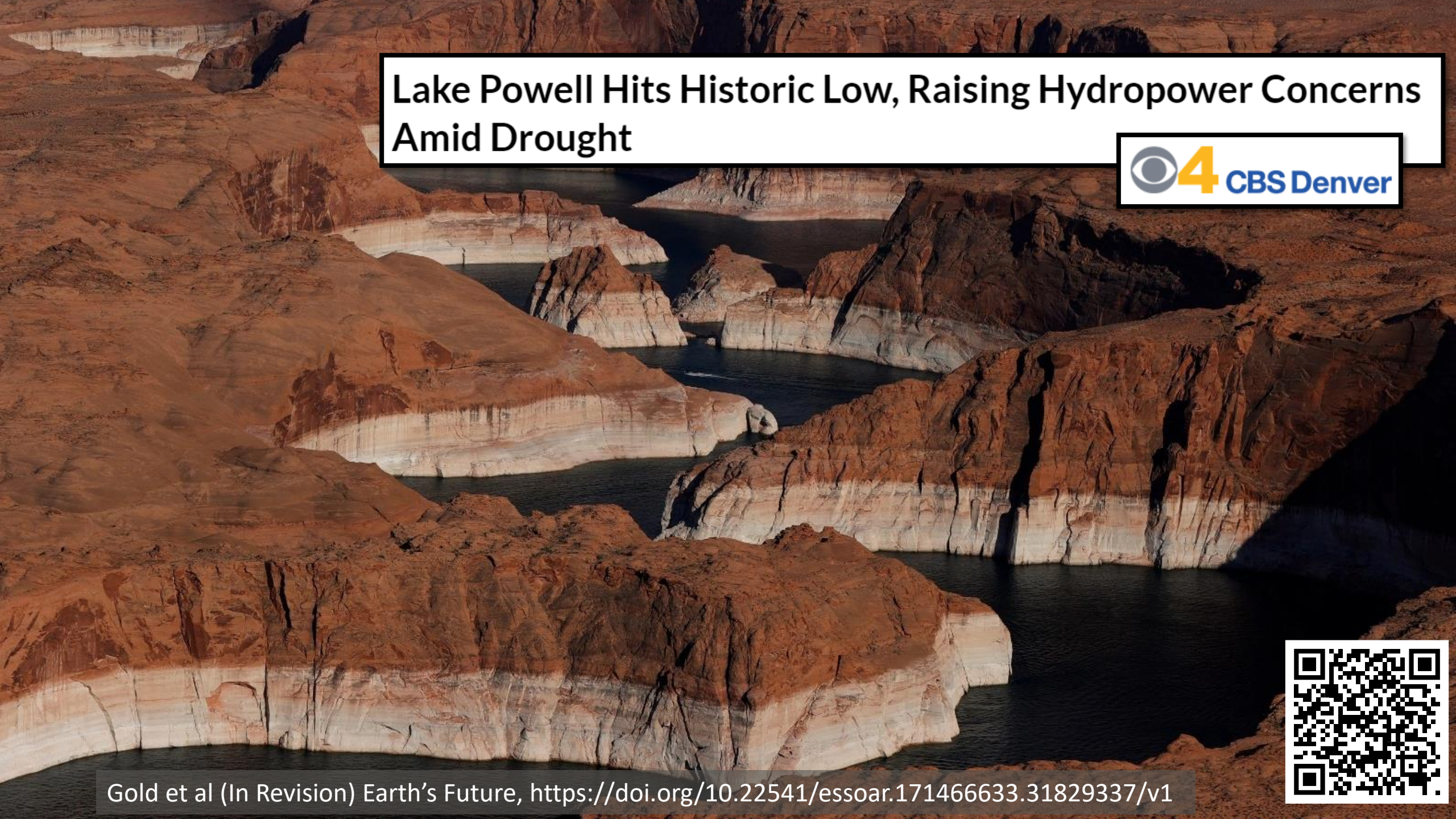
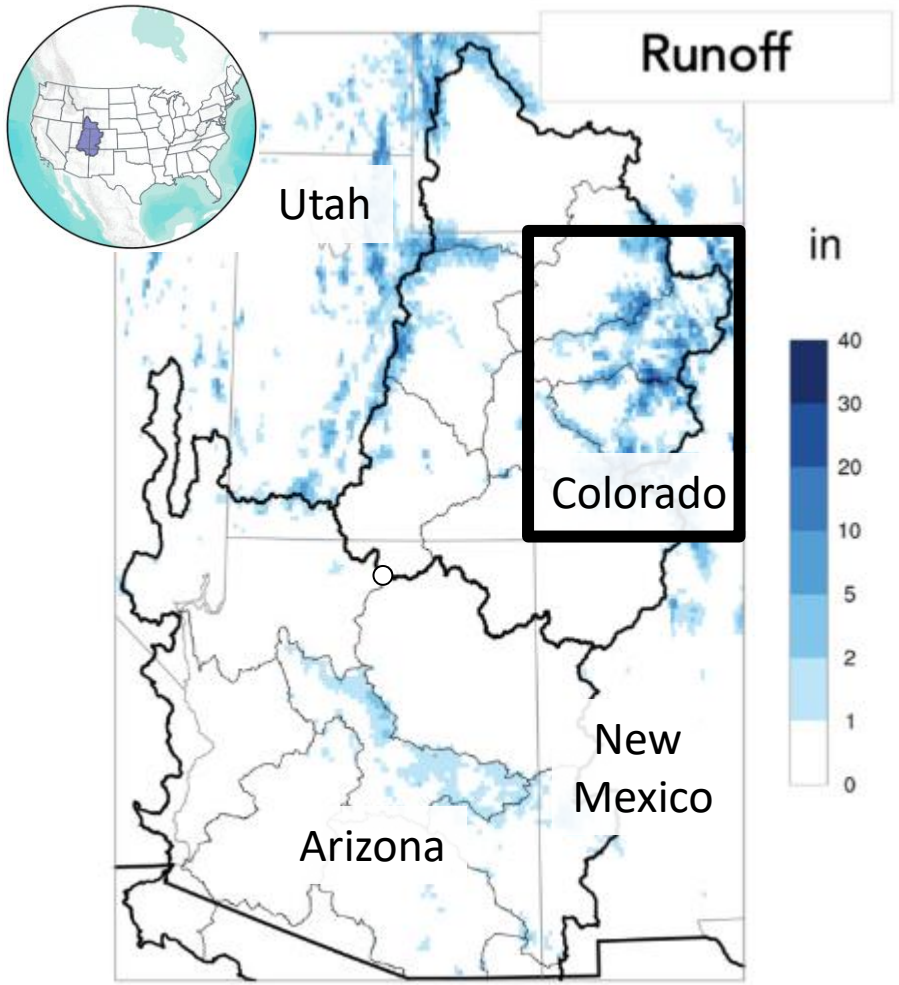
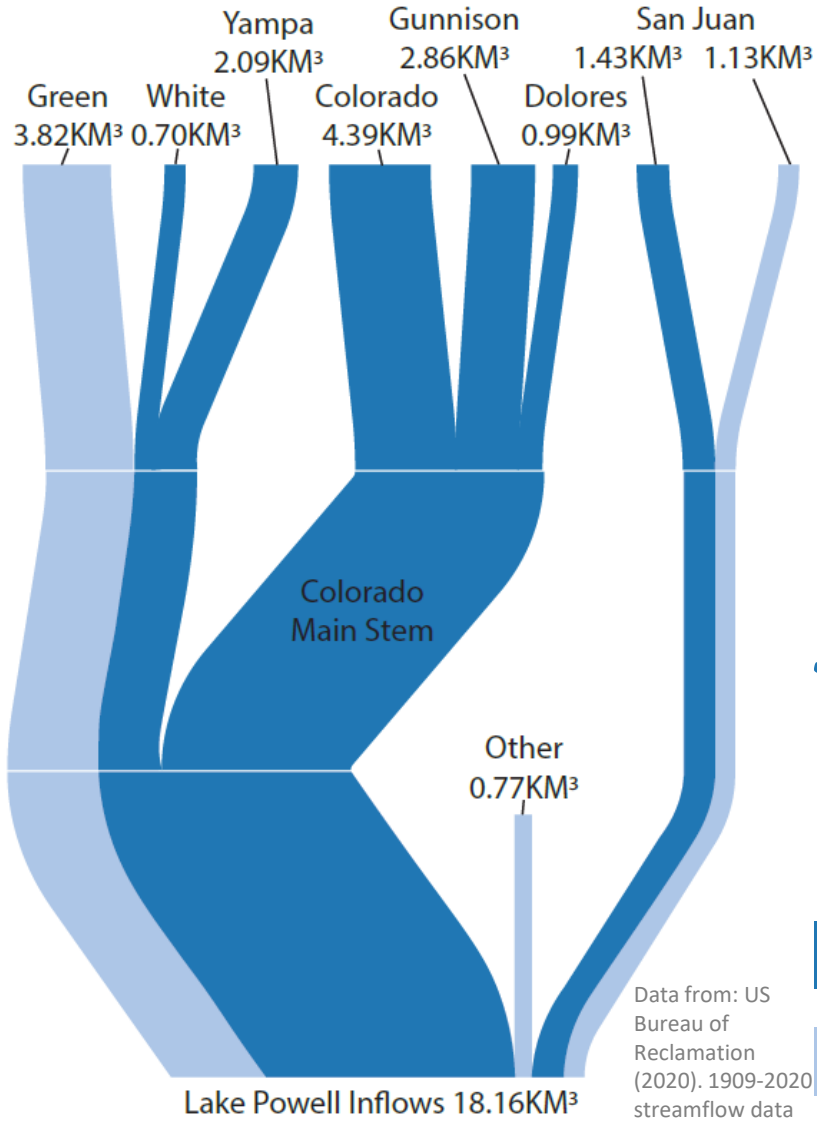


Gold et al (In Revision) Earth's Future, https://doi.org/10.22541/essoar.171466633.31829337/v1

COLORADO'S WEST SLOPE BASINS



Lukas, J. J., & Payton, E. A. (2020). Colorado River Basin climate and hydrology: State of the science.



Nearly ***70%*** of the inflow to Lake Powell originates in ***Colorado's West Slope Basins***

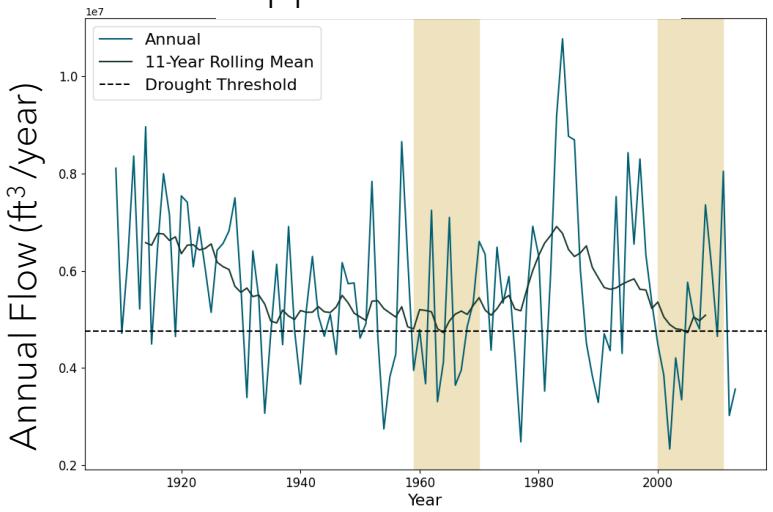
West Slope

Other

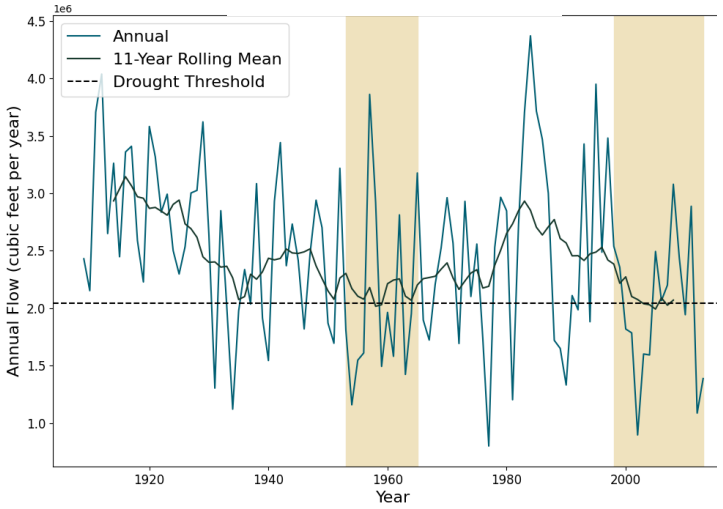
Data from: US Bureau of Reclamation (2020). 1909-2020 streamflow data for the Salt and Colorado River

HISTORICAL DECADAL DROUGHTS

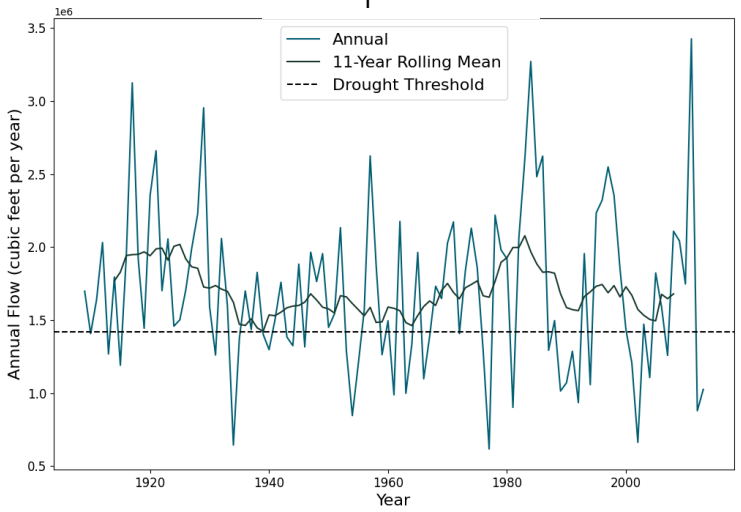
Upper Colorado River



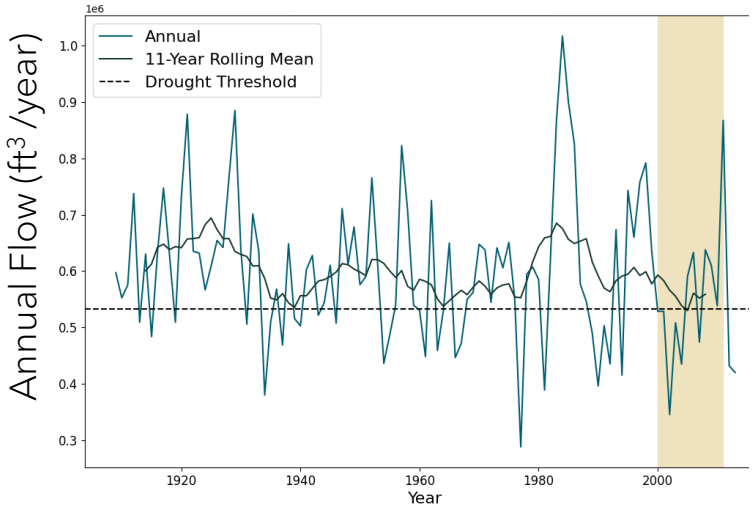
Gunnison River



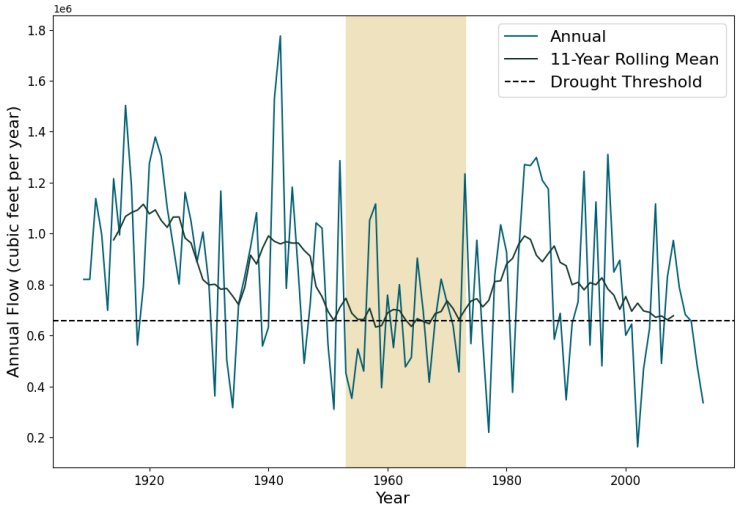
Yampa River



White River



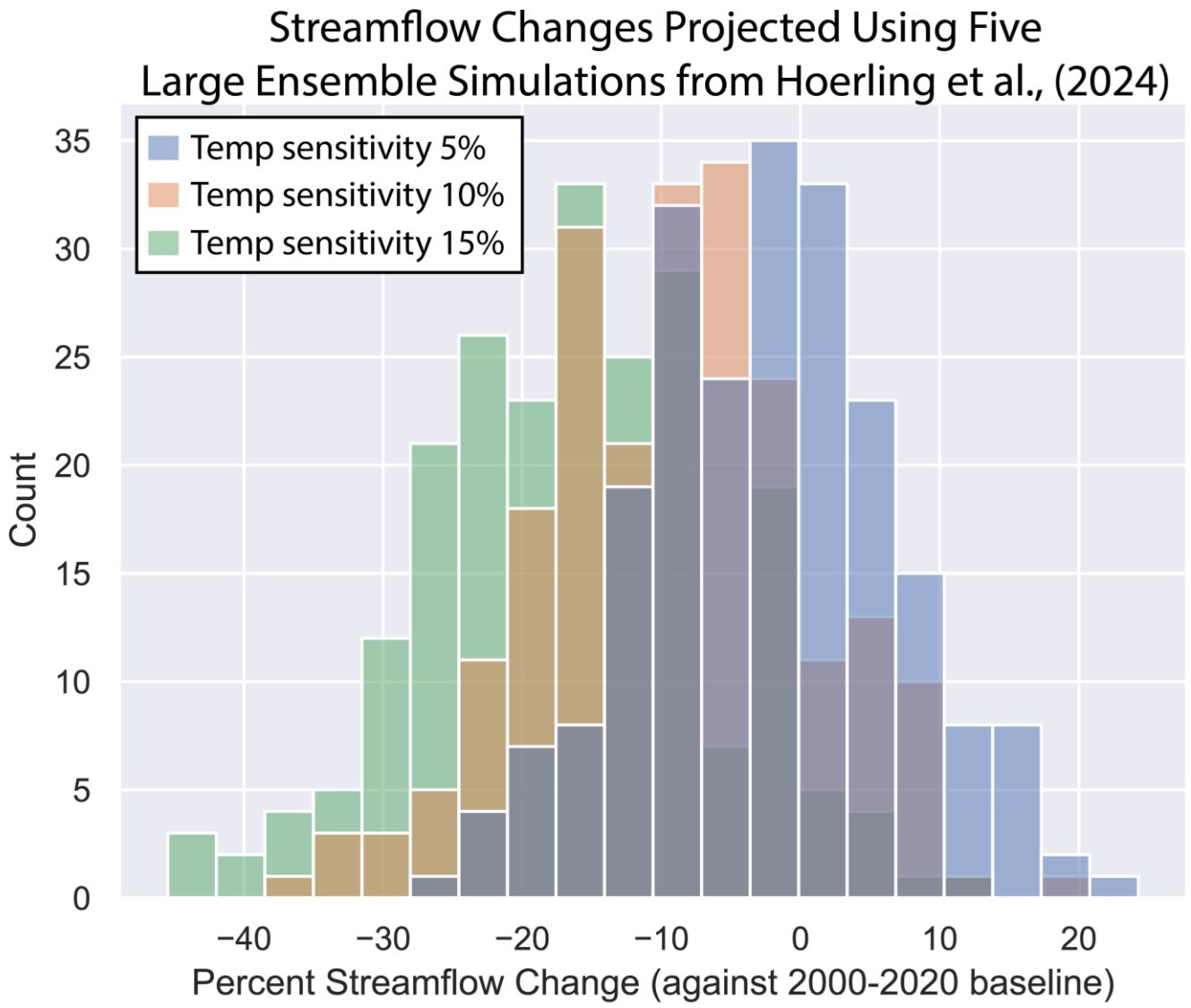
Southwest



HISTORICAL DECADAL DROUGHTS

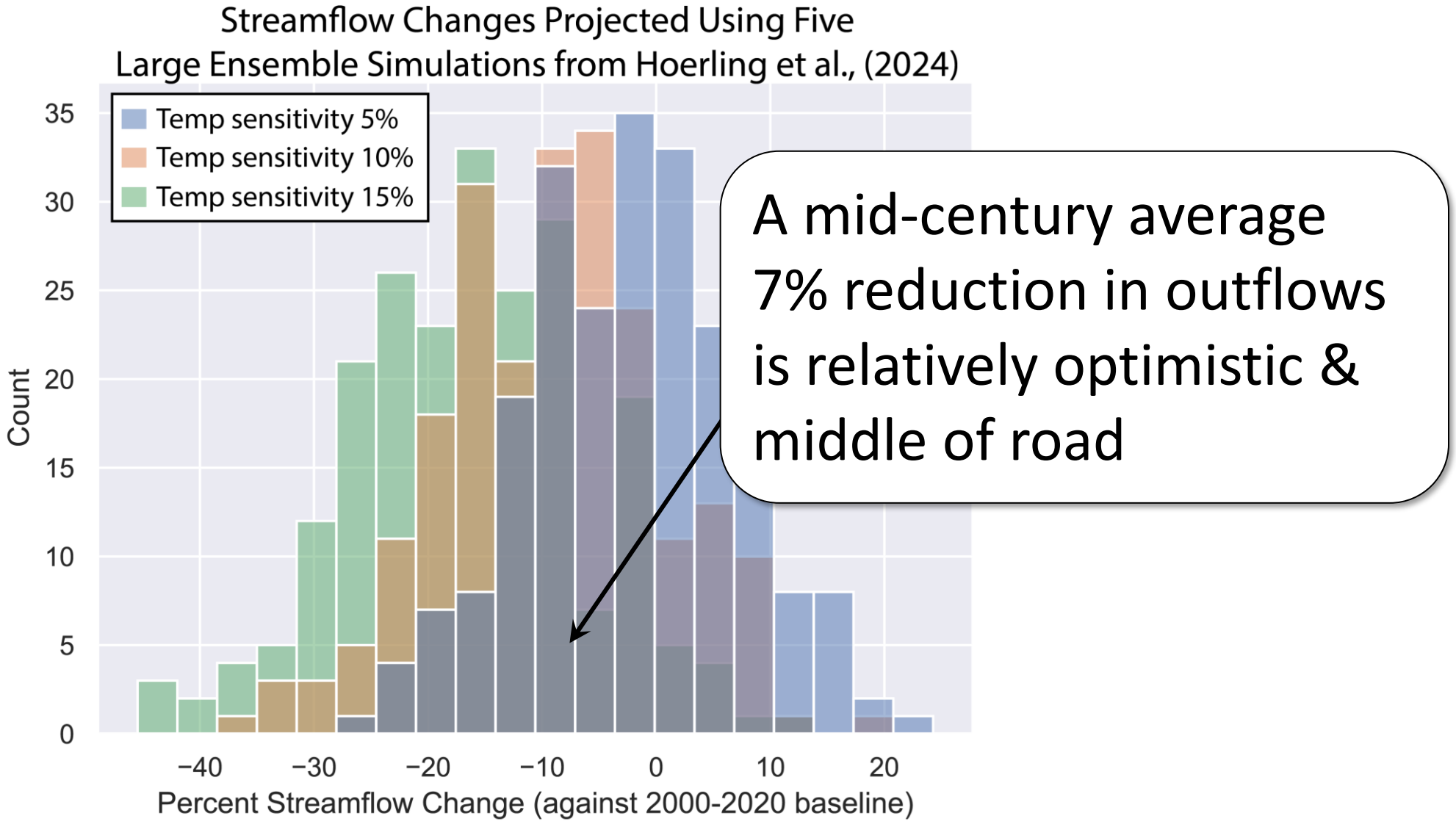
How could drought risks evolve for this region by 2050?

A MIDDLE-OF-THE-ROAD CLIMATE SCENARIO



Hoerling et al (2024) Journal of Climate, https://doi.org/10.1175/JCLI-D-23-0617.1

A MIDDLE-OF-THE-ROAD CLIMATE SCENARIO



A mid-century average 7% reduction in outflows is relatively optimistic & middle of road

Hoerling et al (2024) Journal of Climate, https://doi.org/10.1175/JCLI-D-23-0617.1

THEME 2 RISKS & IMPACTS – BETTER CAPTURE EXTREMES

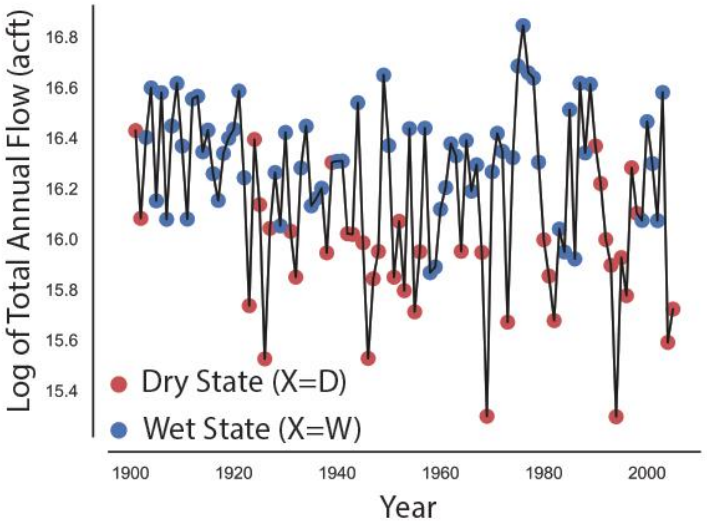
- The modern observation record of the last century is limited in its ability to capture persistent drought extremes and the internal variability of the system
  - *What if we had a 1000 replicate centuries of record? How different would we perceive persistent drought risks?*
  - *What if these 1000 replicate centuries experienced 7% reductions of streamflow due to climate change?*

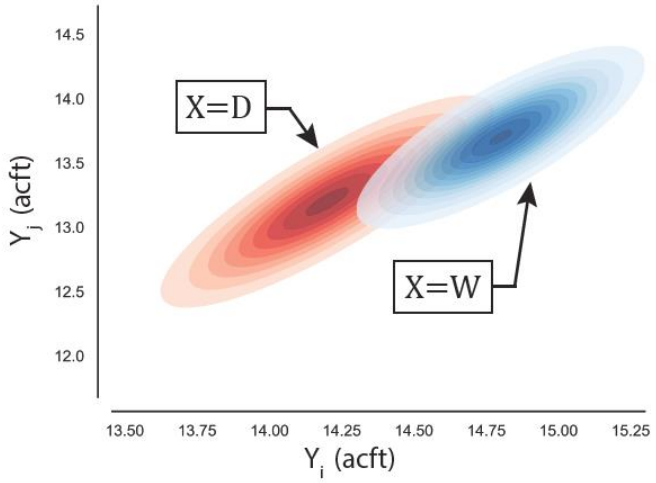
A HIDDEN MARKOV MODEL-BASE STOCHASTIC STREAMFLOW GENERATOR TO CAPTURE INTERNAL VARIABILITY

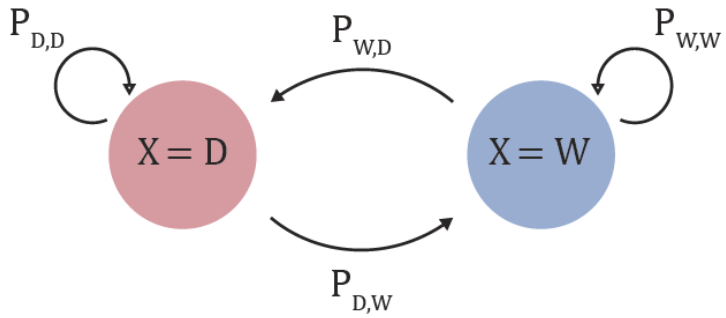
I. Classify historical record into two states (wet and dry)

II. Fit a multivariate Gaussian dist. to the log flows in each state

III. Determine the transition probabilities between states

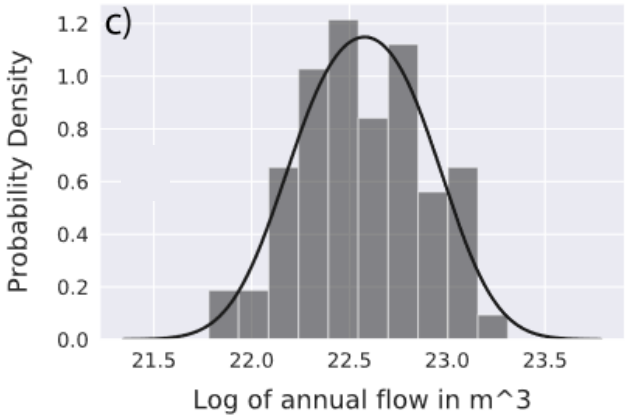


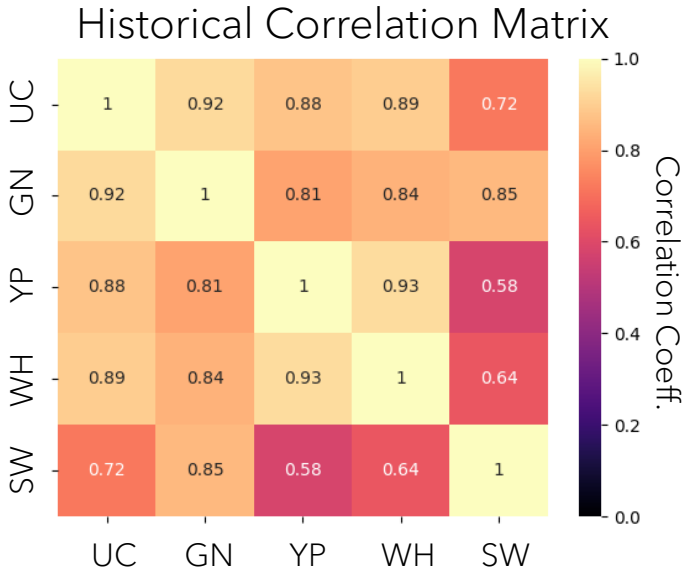




CAPTURING INTERNAL VARIABILITY

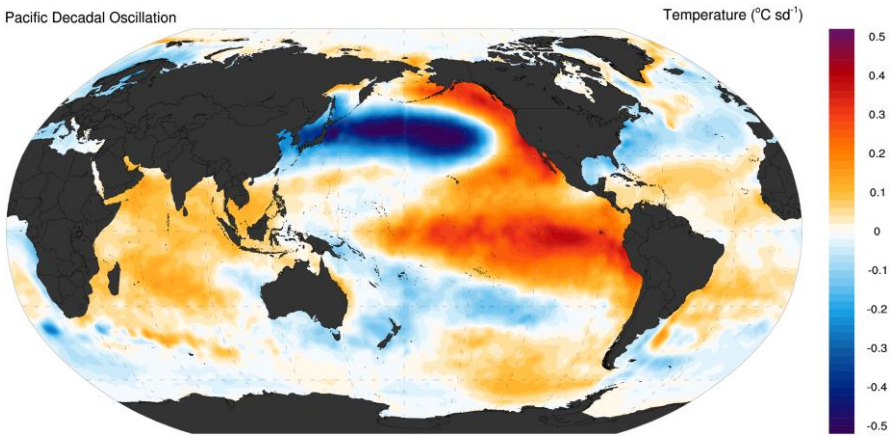
Preserve ***statistical properties*** of the historical record



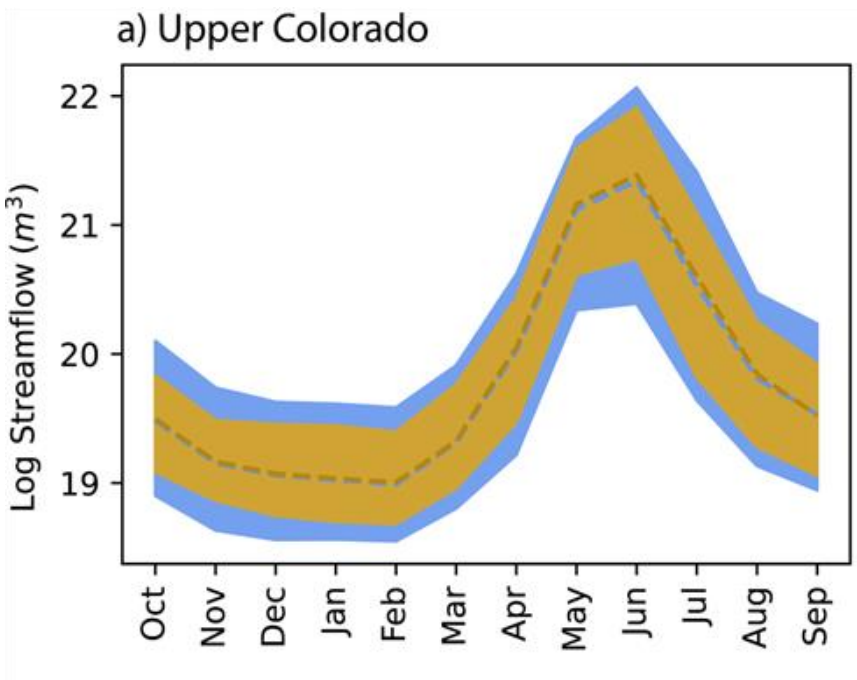


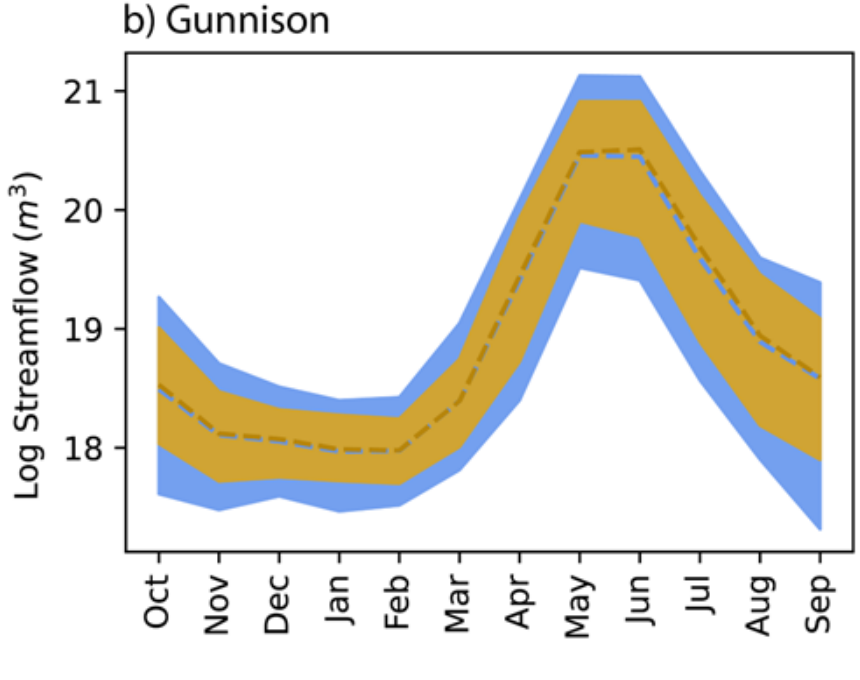
Replicate ***spatial correlation*** between basins

Capture ***persistence*** caused by large scale climate phenomena



STATIONARY ENVELOPES (NO CLIMATE CHANGE)





Historical Range (10th - 90th percentile)

Baseline Ens. Range (10th - 90th percentile)

Historical Mean

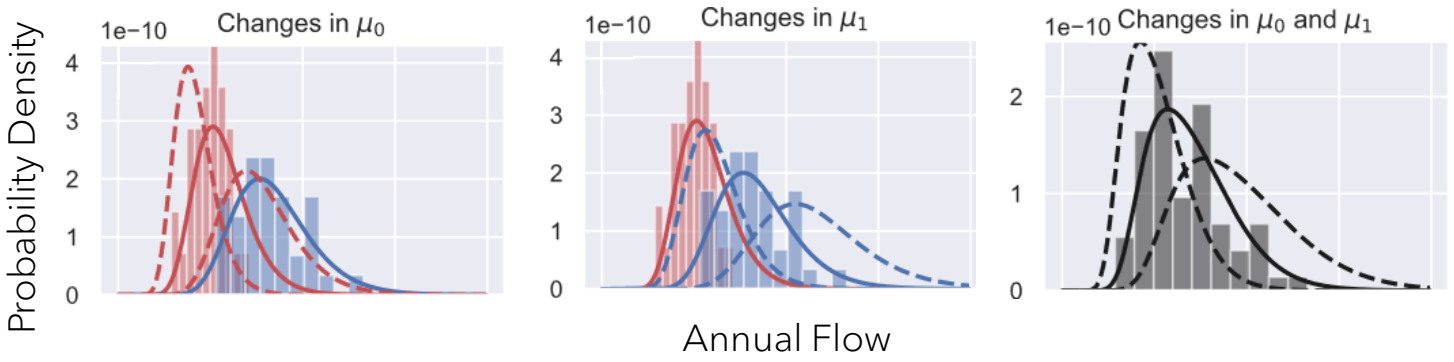
Synthetic Mean

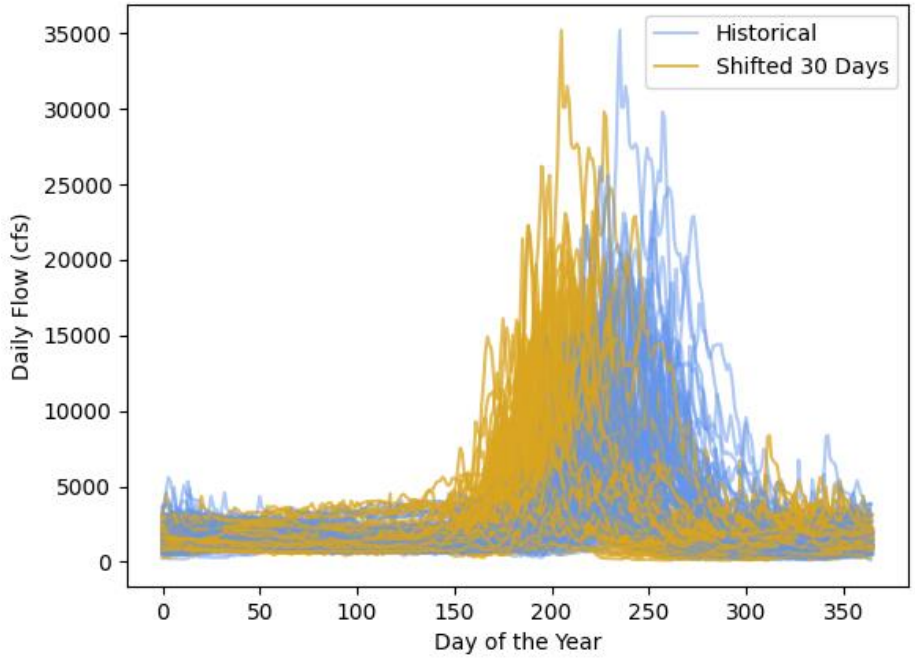
CAPTURING CLIMATE CHANGE

Perturb HMM parameters to reflect plausible changes in climate:

a. Scale ***means*** of dry and wet state distributions

b. Shift the ***timing of peak flows*** to capture changes to snowmelt





COMPUTATIONAL EXPERIMENT

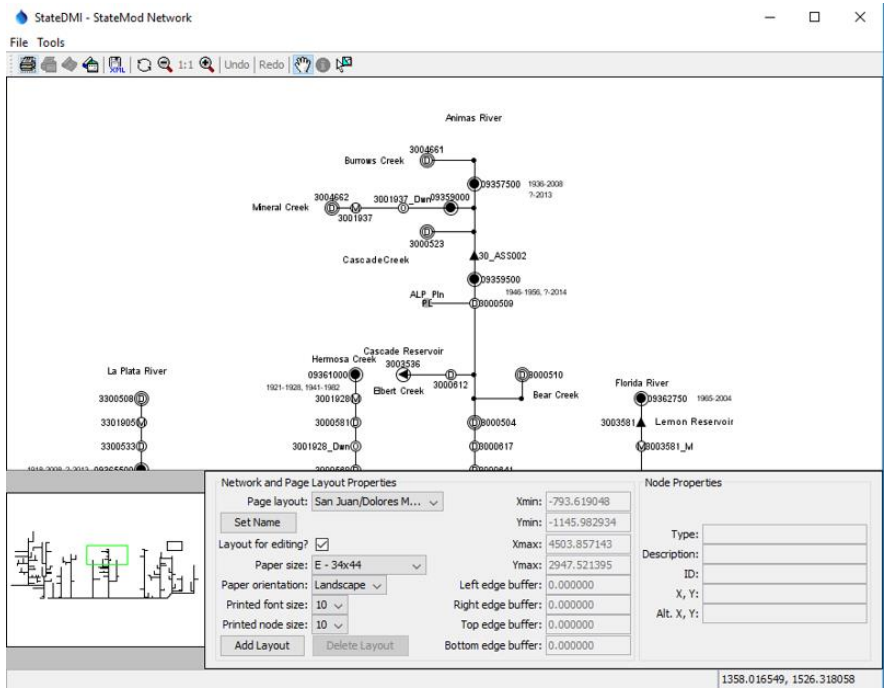
Run "***baseline***" and "***climate-adjusted***" ensembles through a planning model

Each ensemble has ***1,000 105 year records***

Total of ***210,000 years of streamflow***

STATEMOD: COLORADO'S WATER PLANNING MODEL

COLORADO'S
Decision Support Systems
CWCB / DWR



Prior Appropriation
Compacts
Environmental Flow Requirements

Streamflow
Evaporation

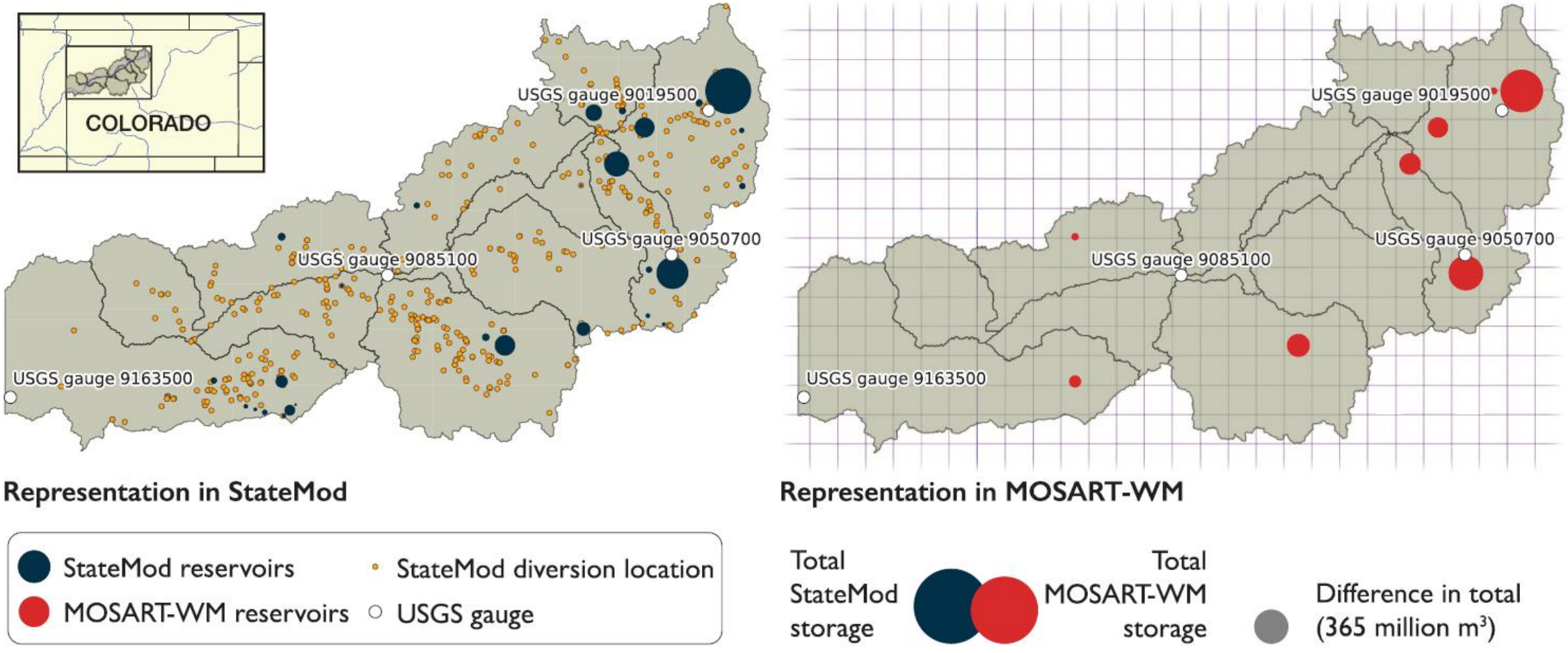
StateMod

Reservoirs
Tunnels
Transfers

Municipal Demands
Irrigation Demands

STATEMOD VS MOSART-WM SCALE REPRESENTATION ILLUSTRATION

Illustration for the Upper Colorado Basin where the grid represents 1/8-degree spatial resolution



Hadjimichael et al 2023 JWRPM, https://ascelibrary.org/doi/abs/10.1061/JWRMD5.WRENG-5522

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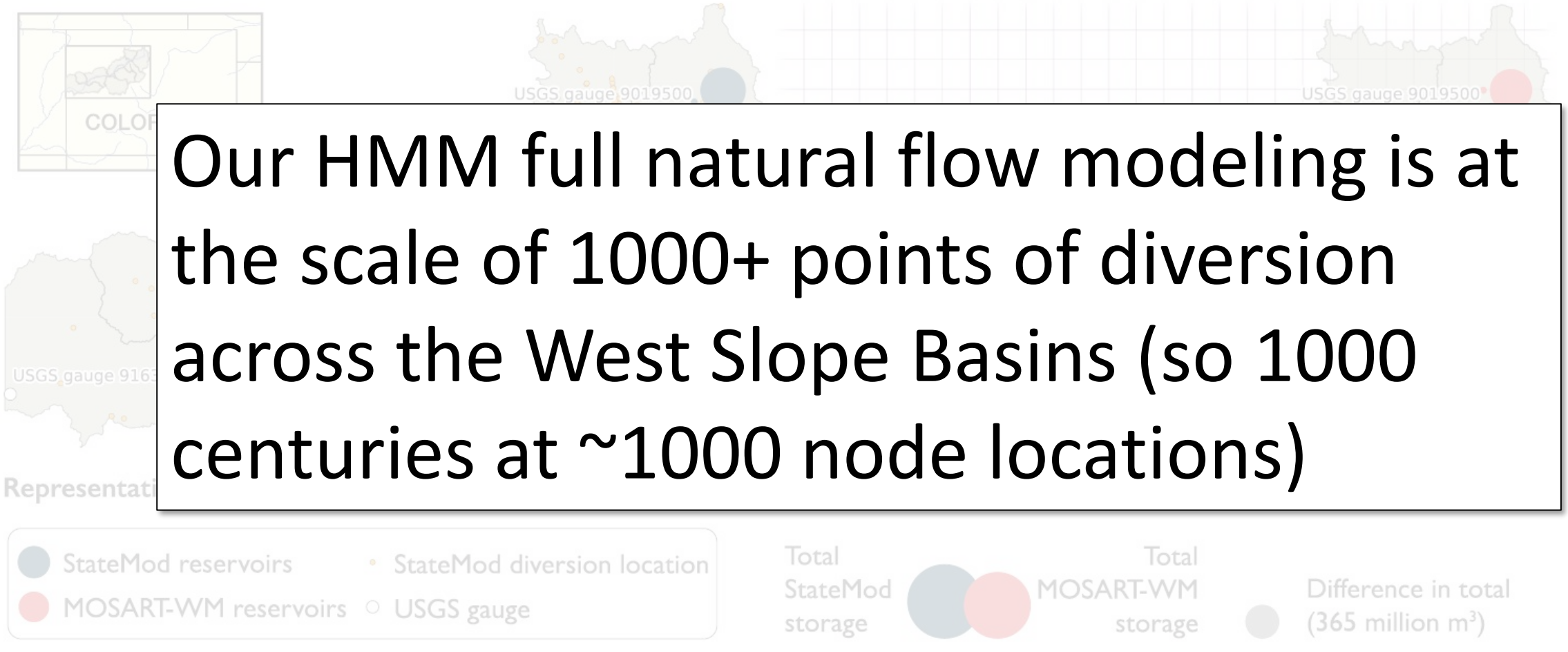
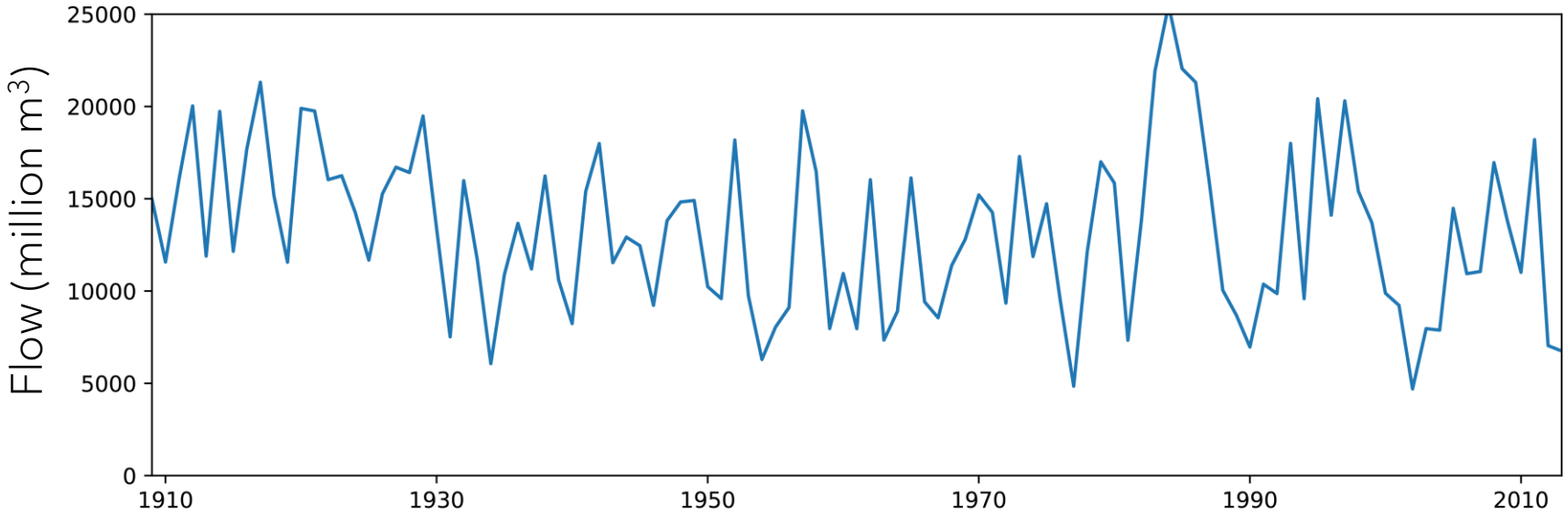


Our HMM full natural flow modeling is at the scale of 1000+ points of diversion across the West Slope Basins (so 1000 centuries at ~1000 node locations)

Hadjimichael et al 2023 JWRPM, https://ascelibrary.org/doi/abs/10.1061/JWRMD5.WRENG-5522

DELIVERIES TO LAKE POWELL



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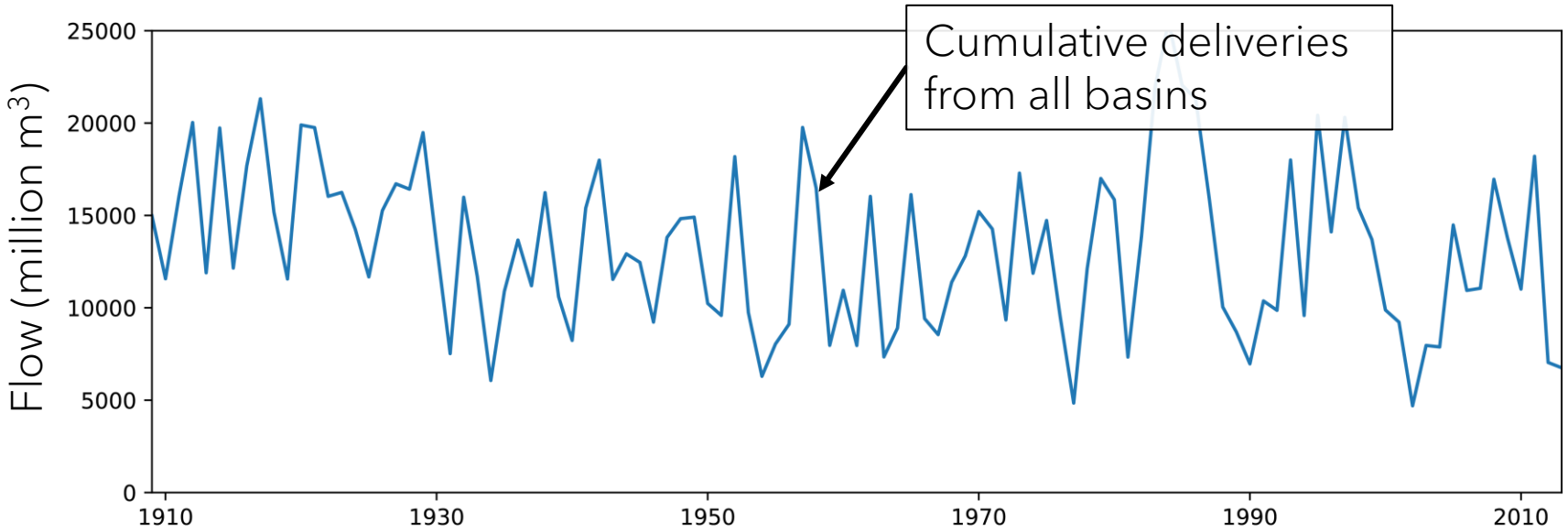

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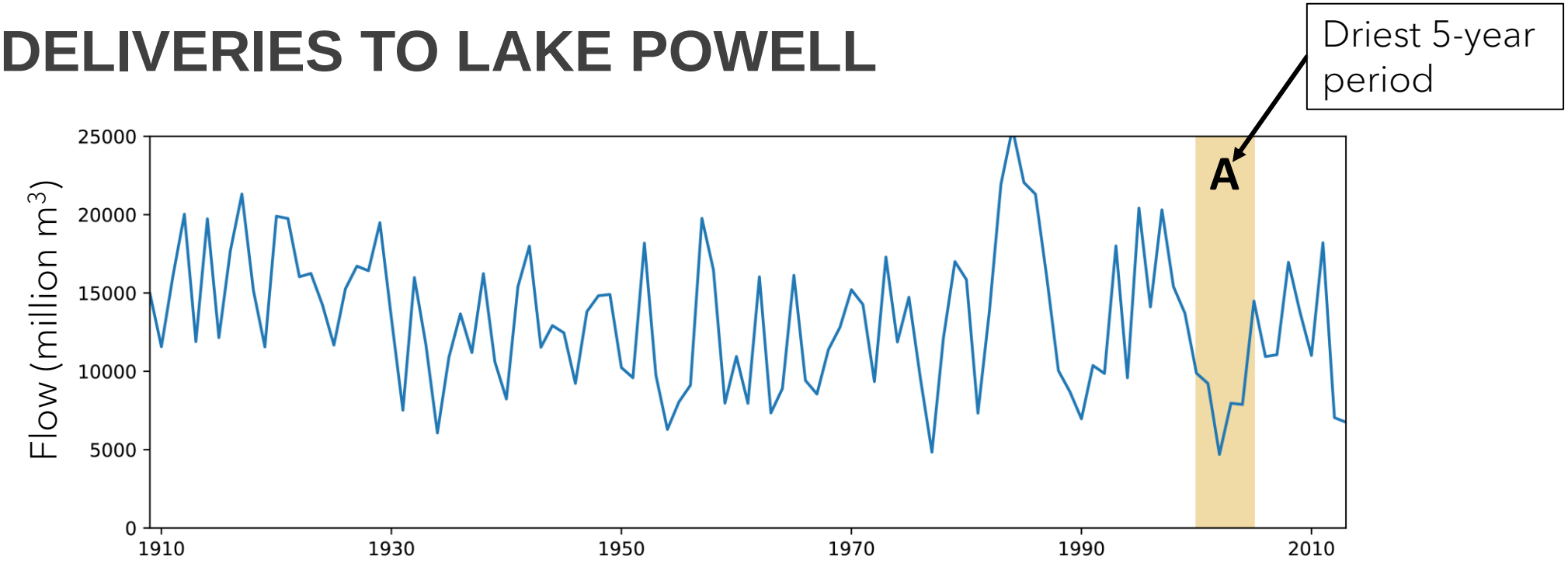

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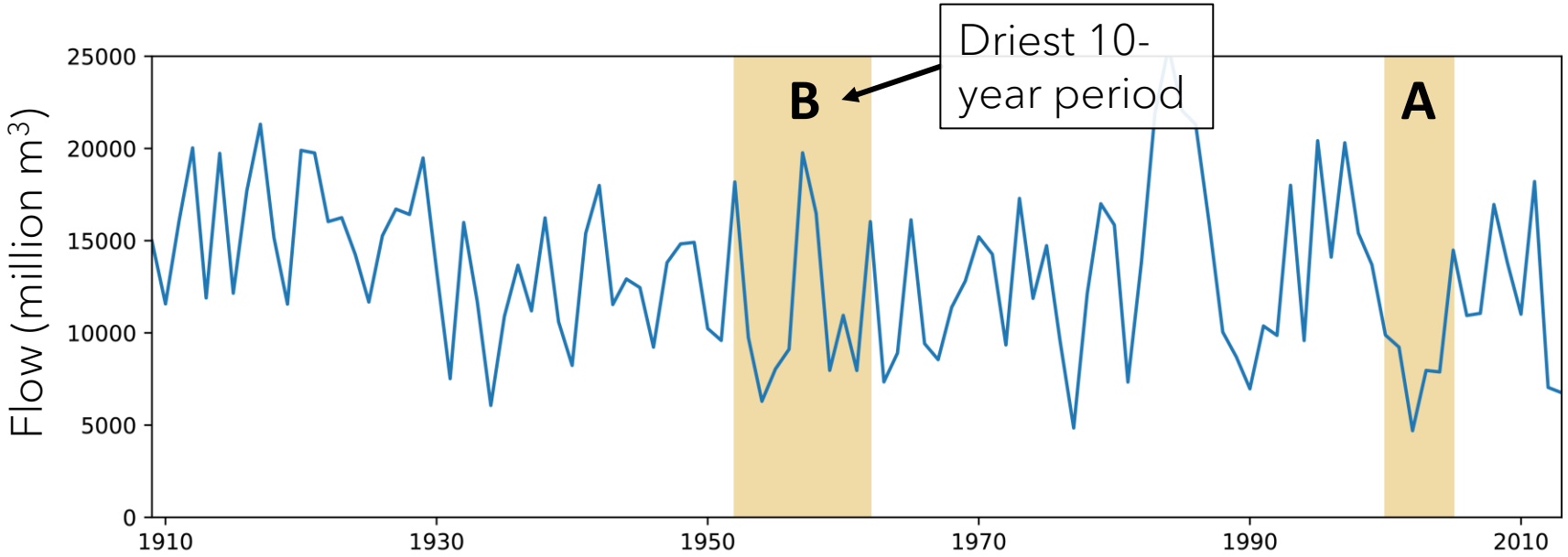

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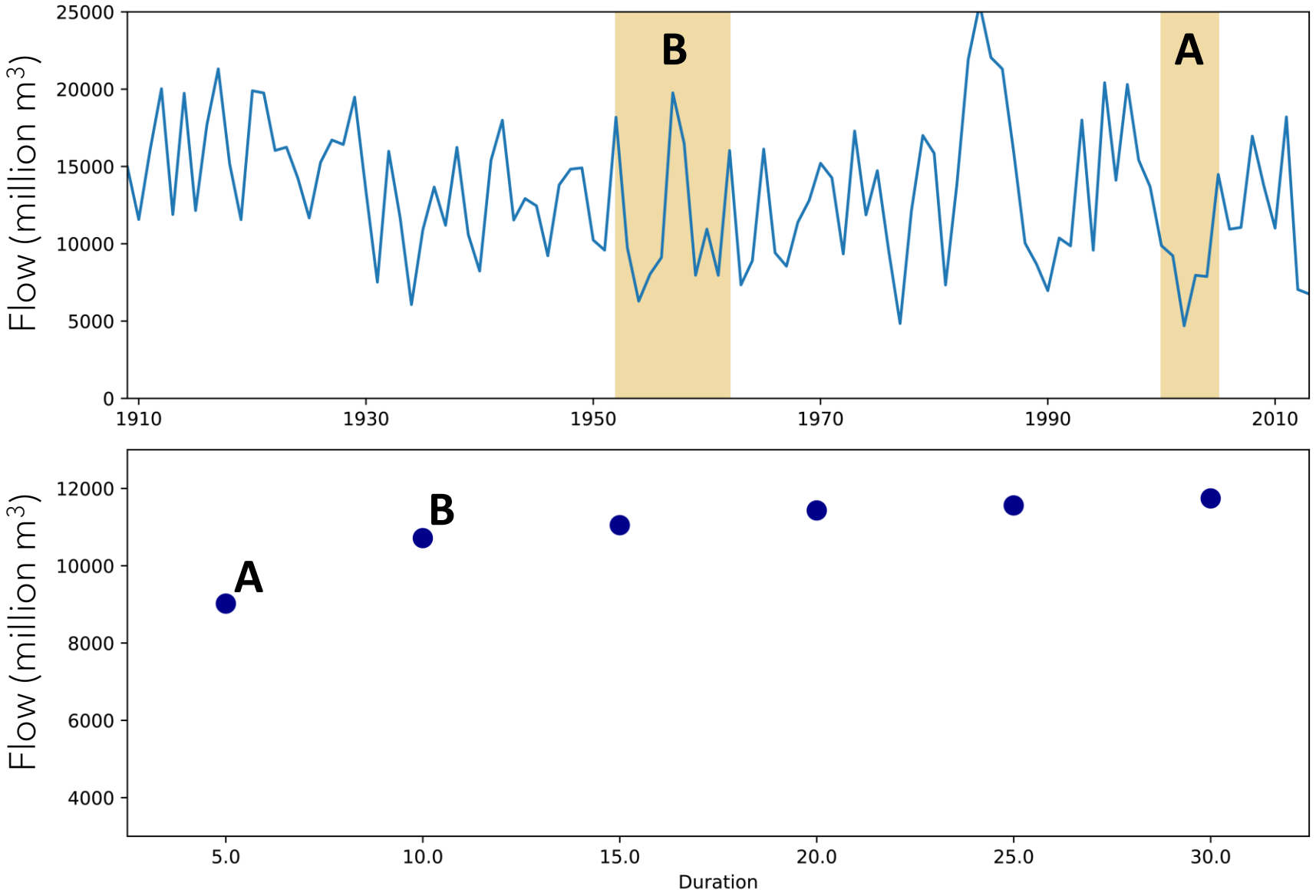

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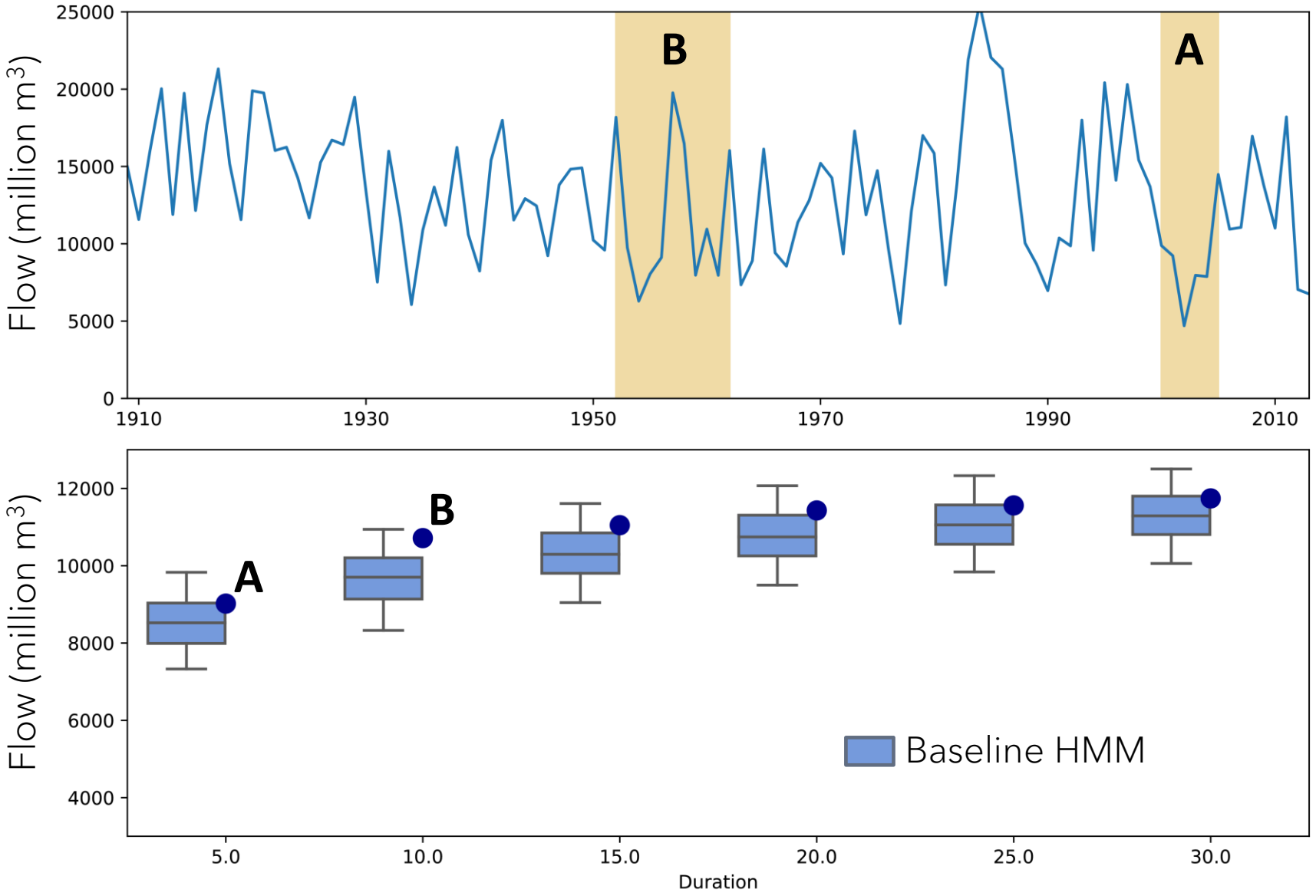

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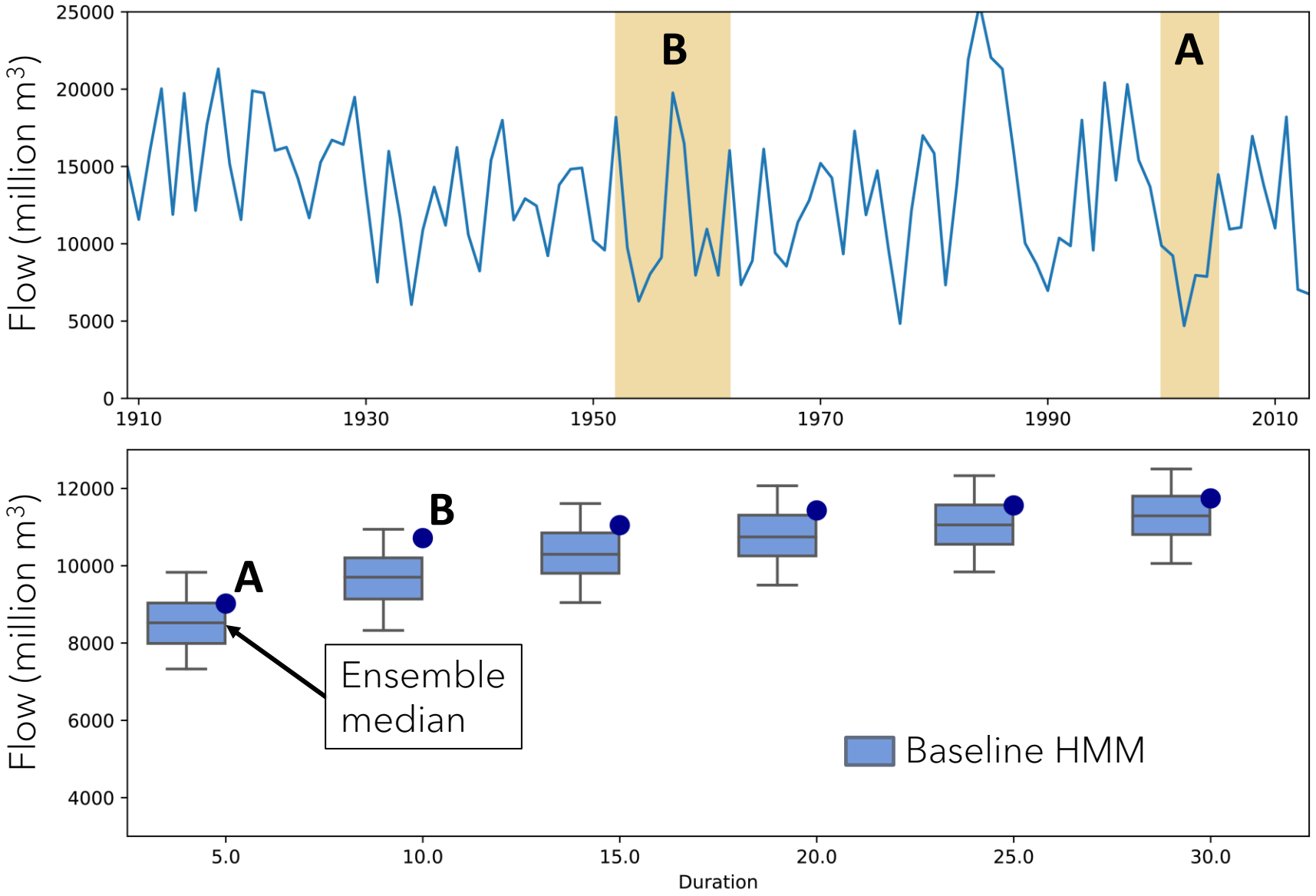

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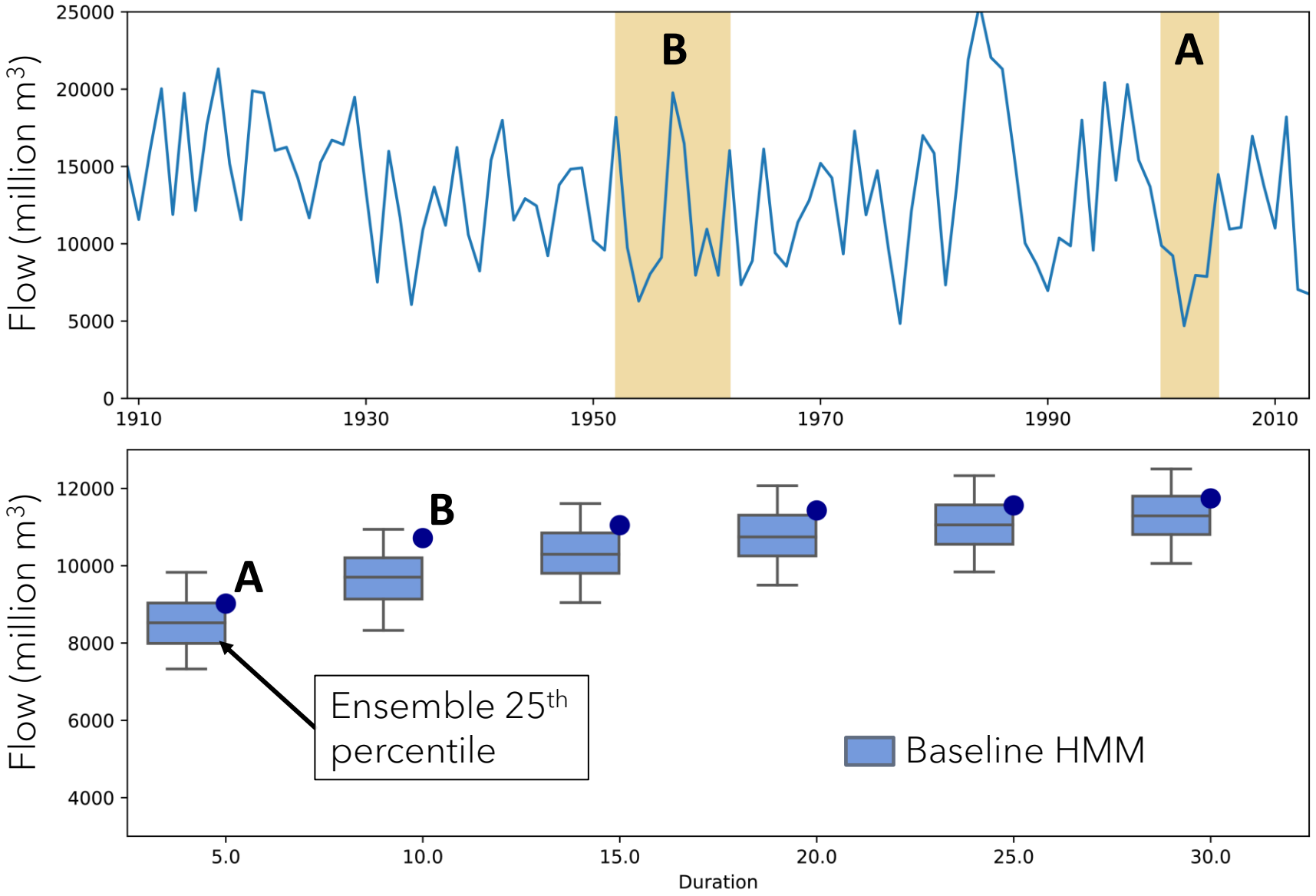

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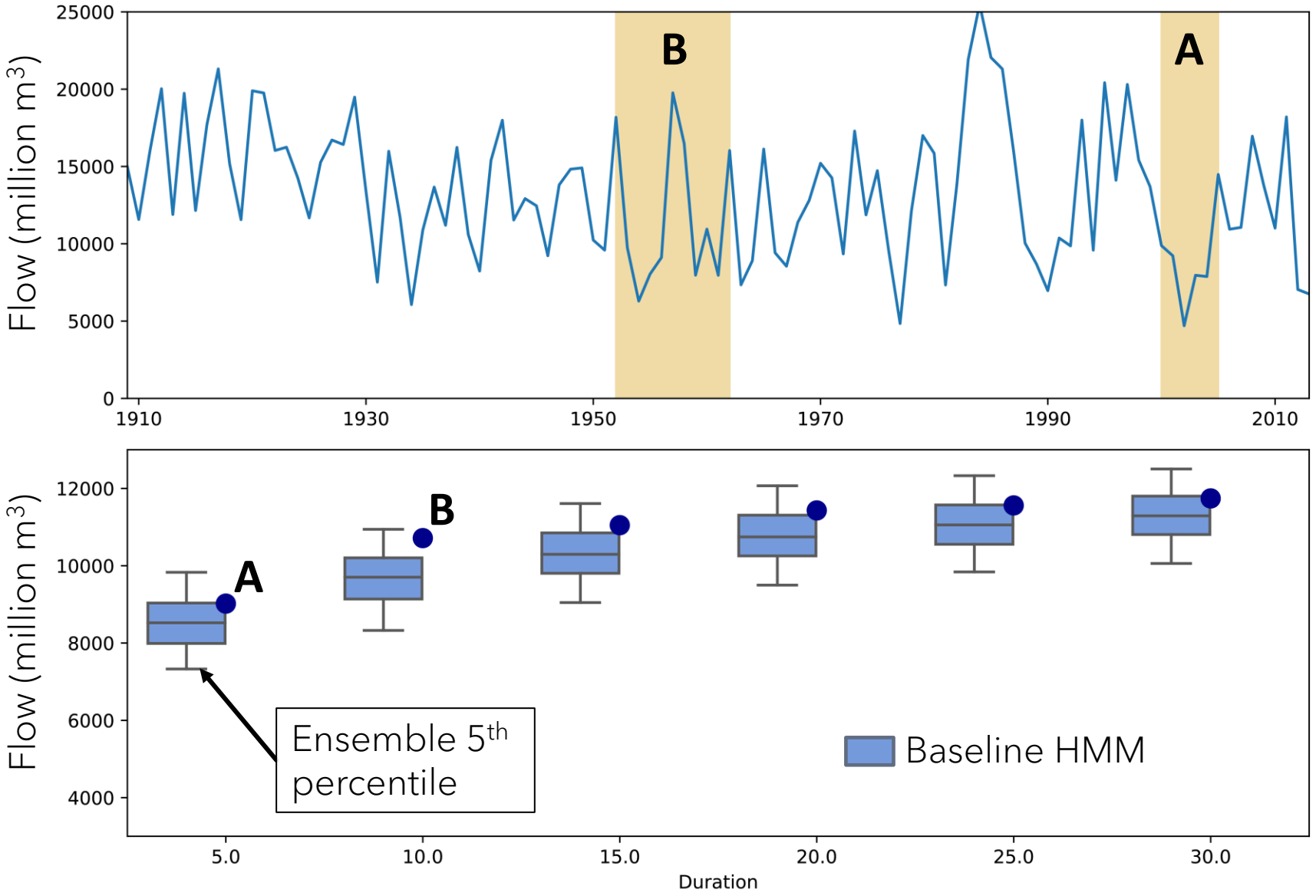
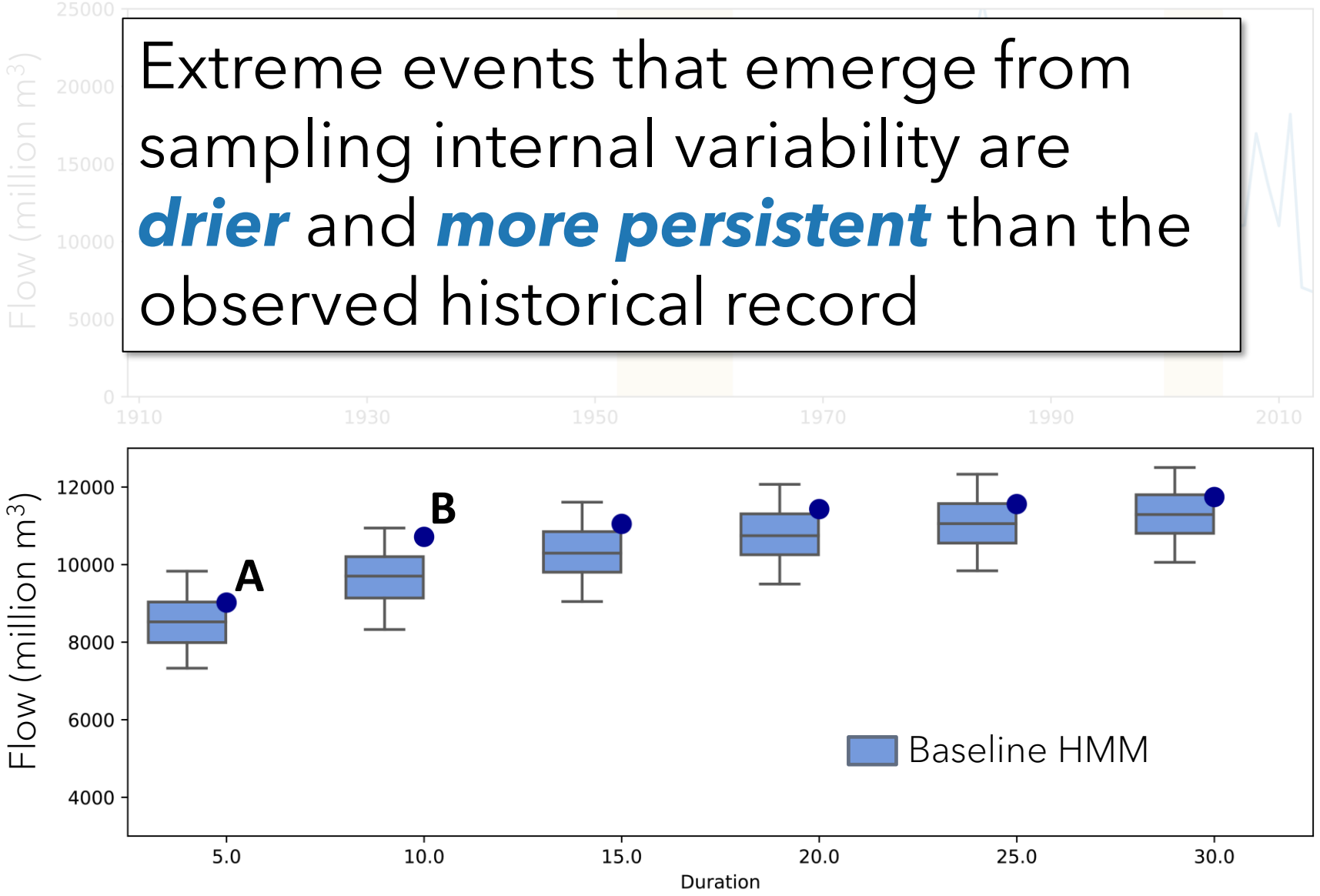


DELIVERIES TO LAKE POWELL

Extreme events that emerge from sampling internal variability are ***drier*** and ***more persistent*** than the observed historical record



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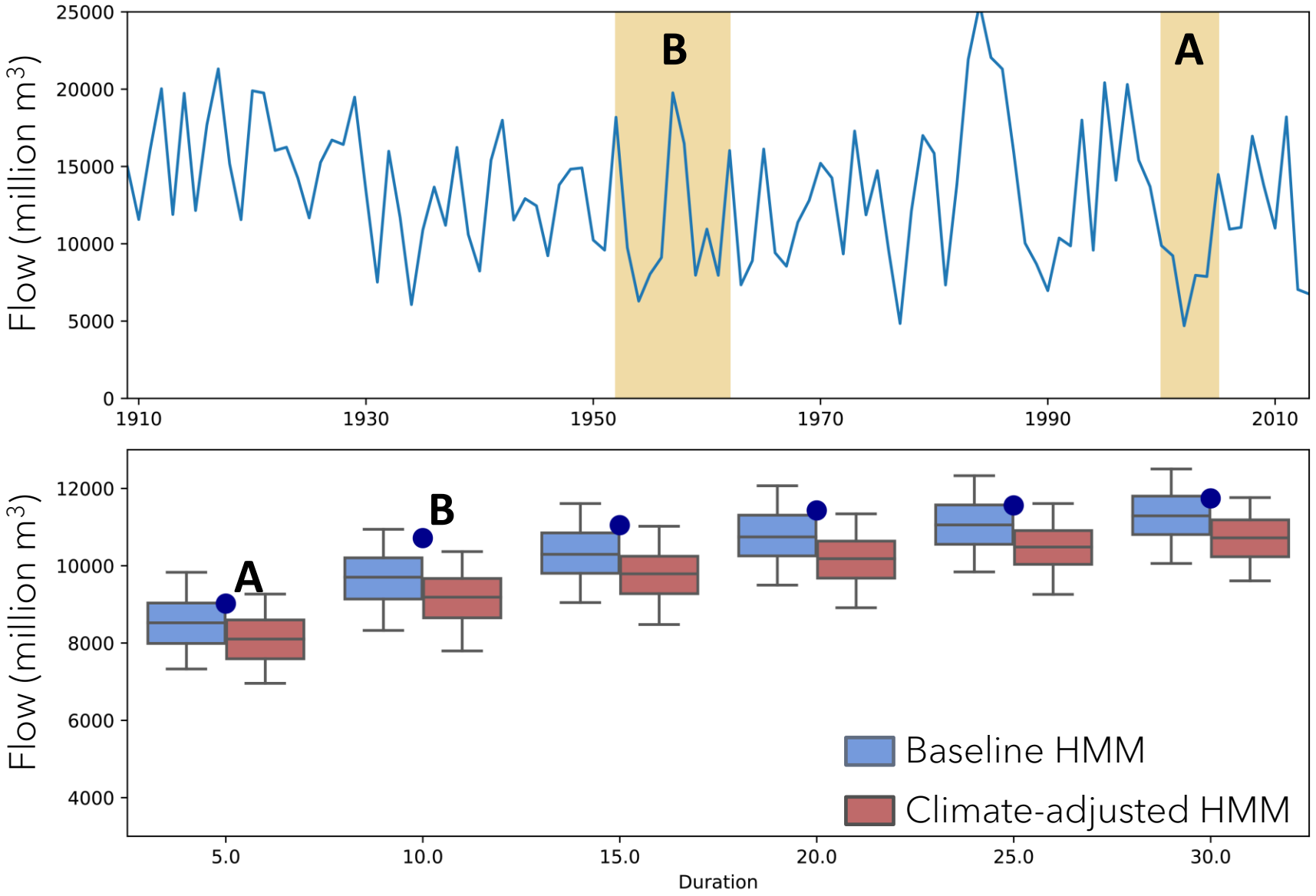
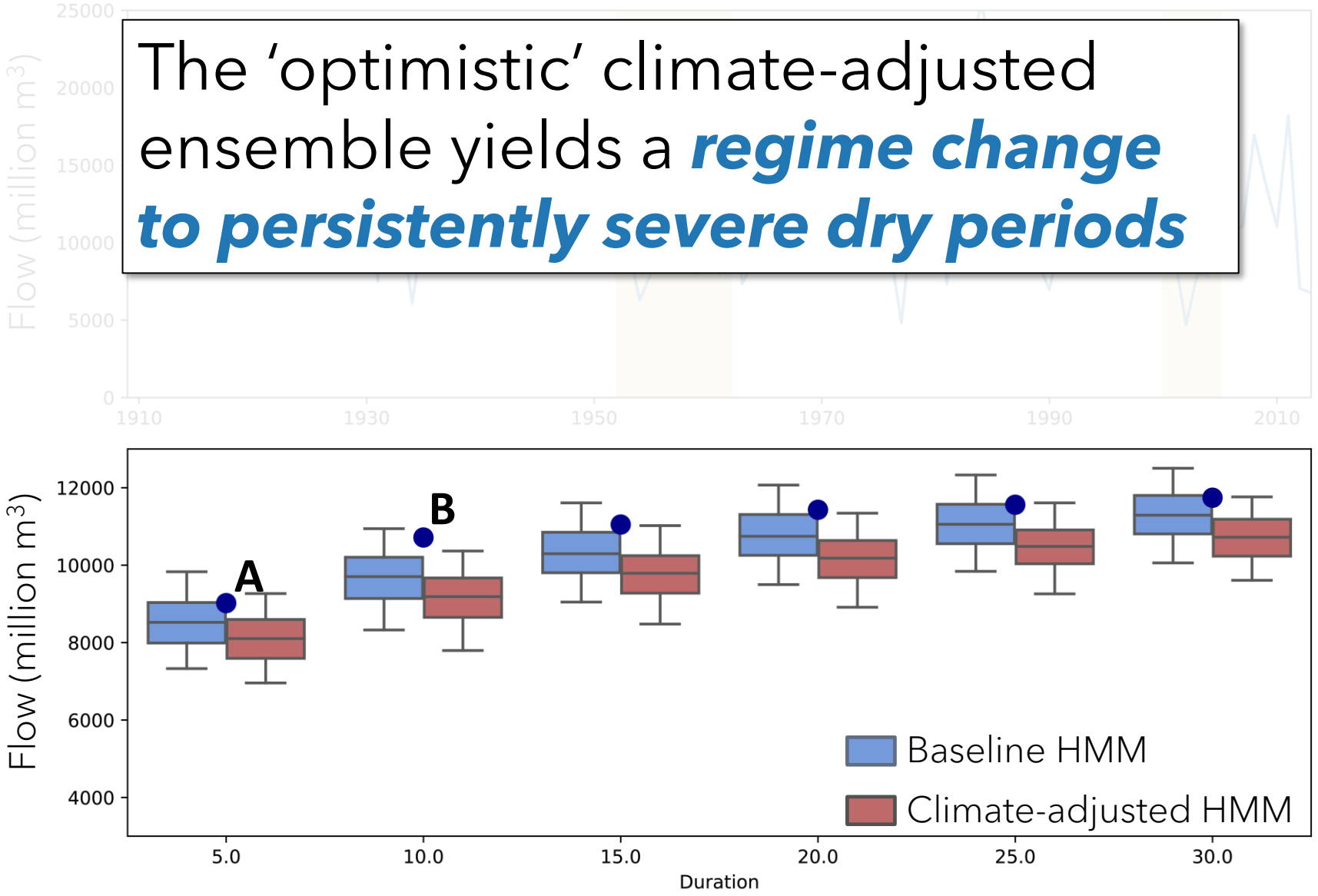
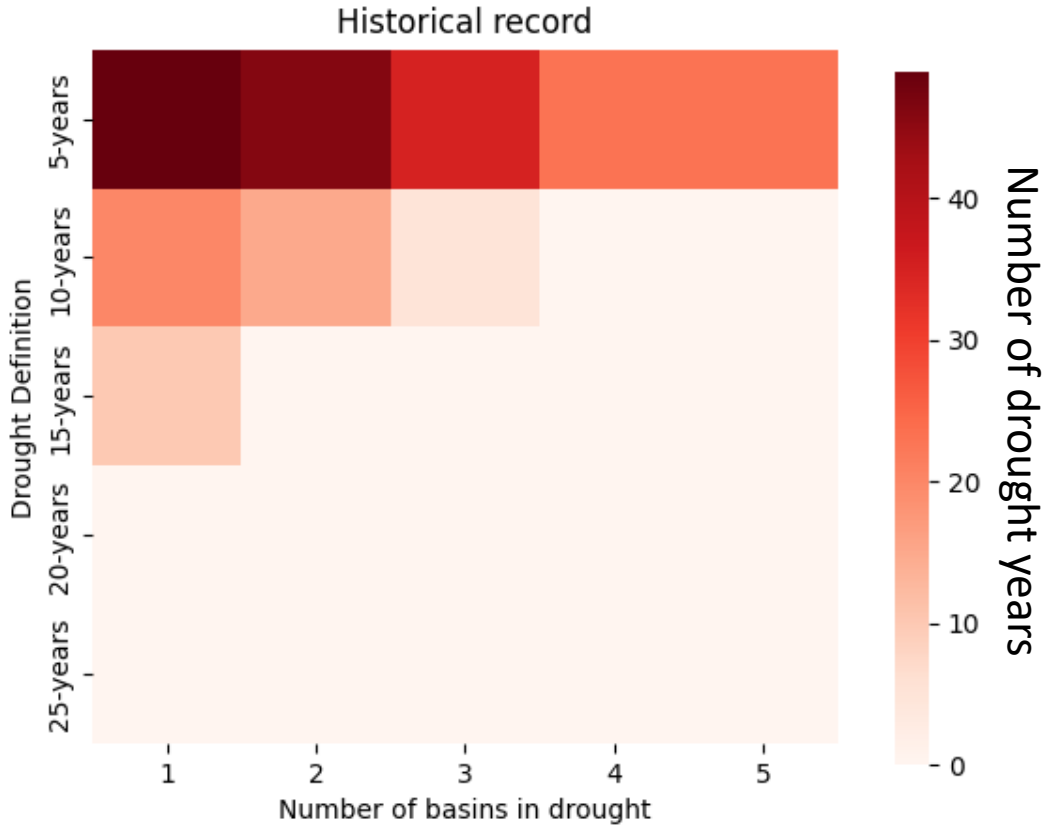


DELIVERIES TO LAKE POWELL

The ‘optimistic’ climate-adjusted ensemble yields a ***regime change to persistently severe dry periods***



CHANGES IN SPATIALLY COMPOUNDING DROUGHT?



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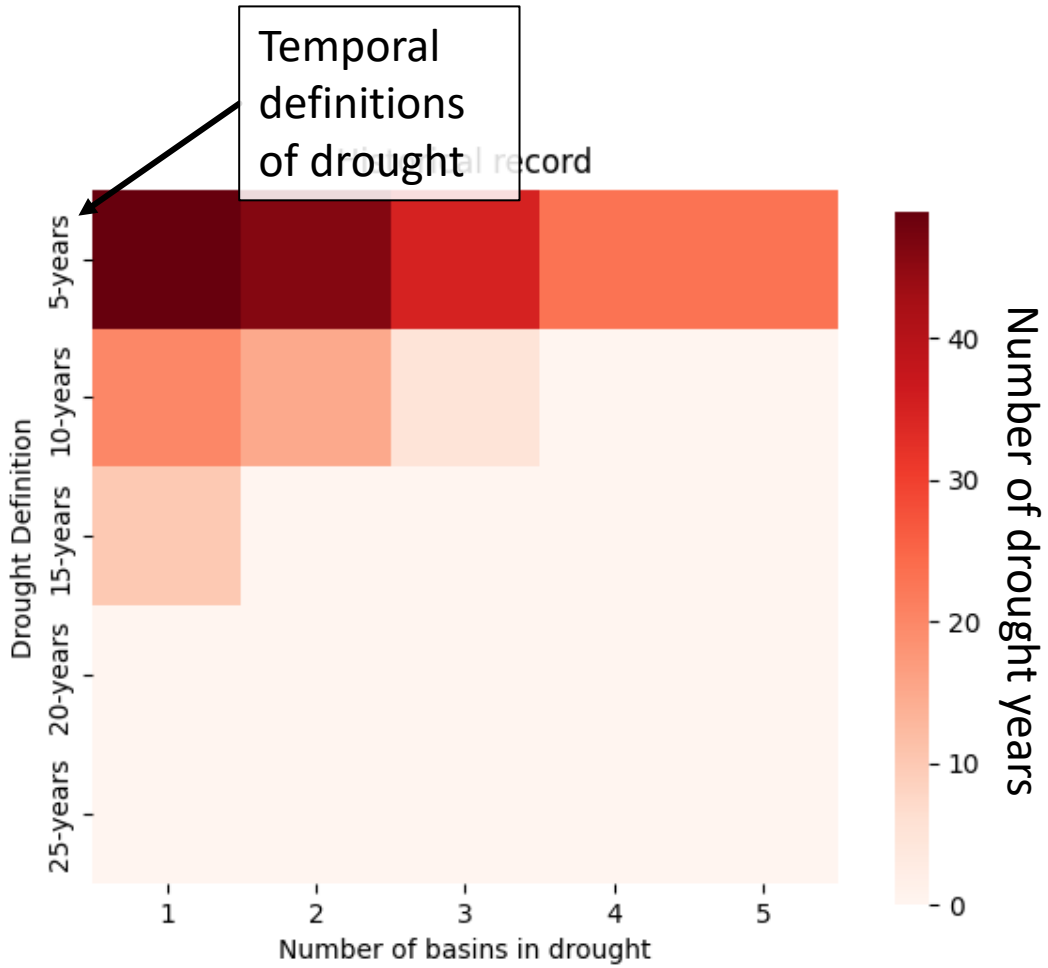

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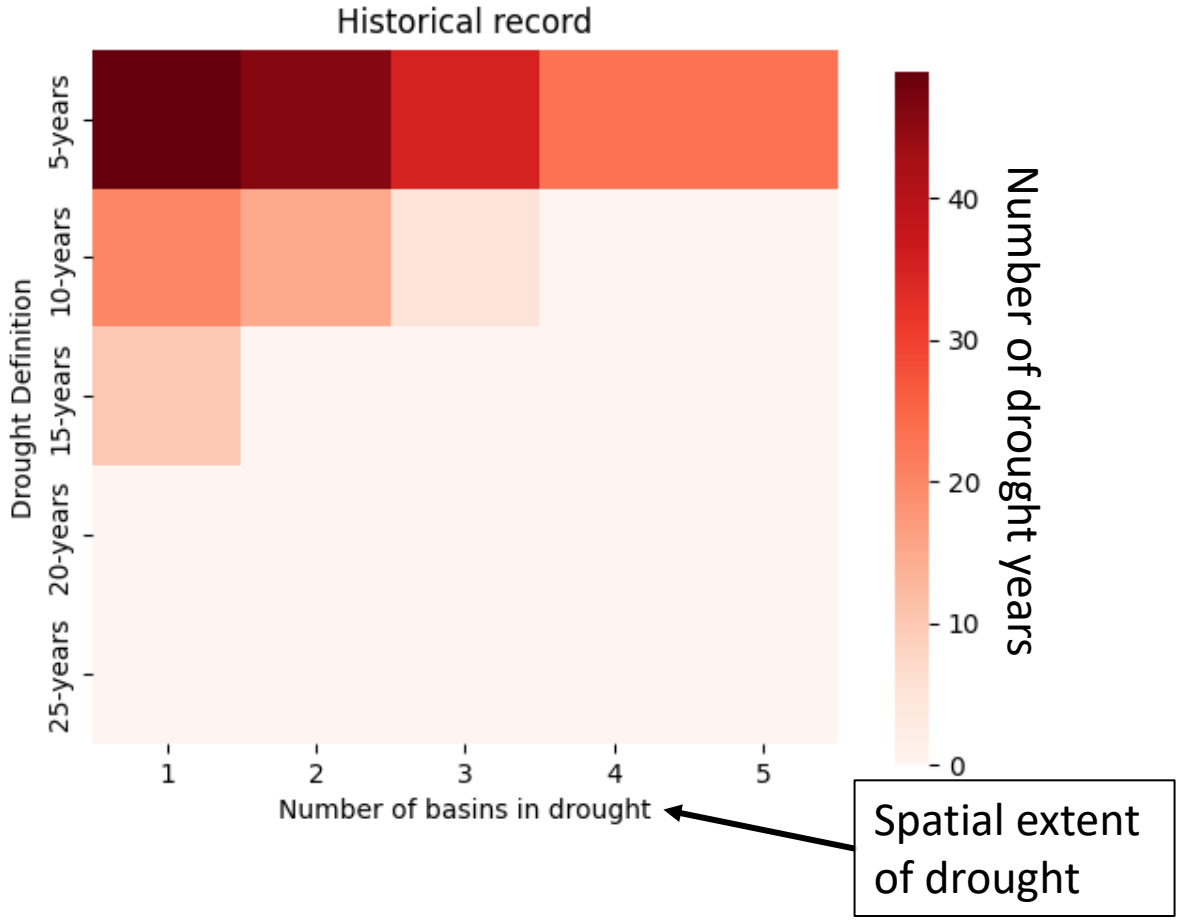

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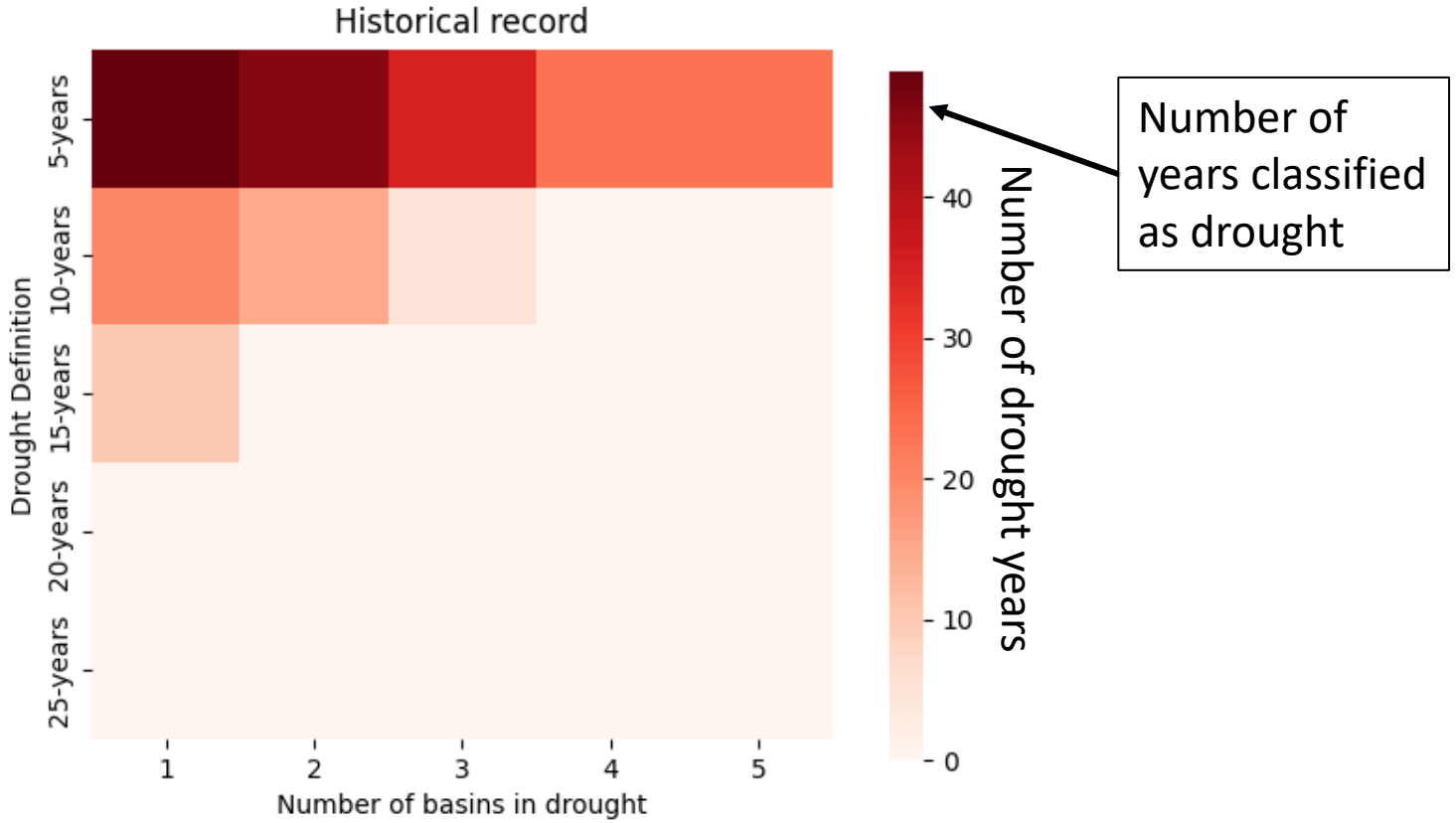

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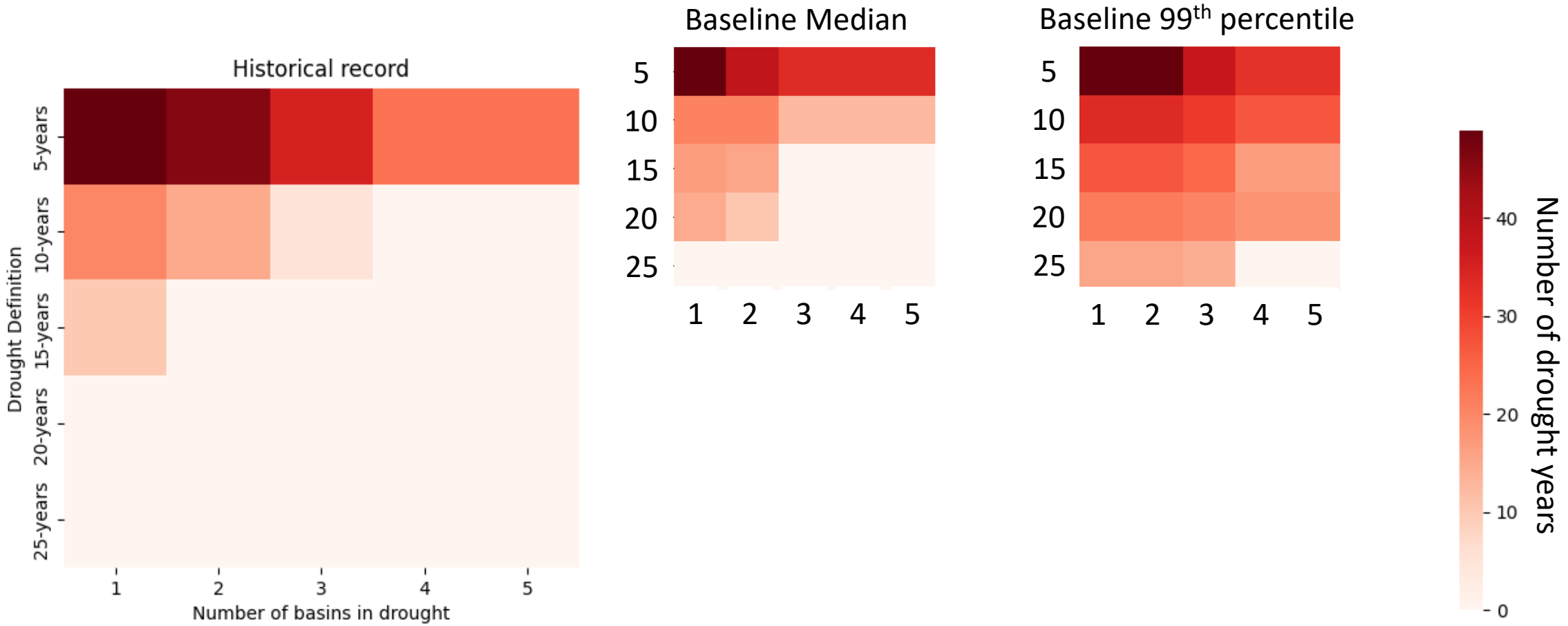

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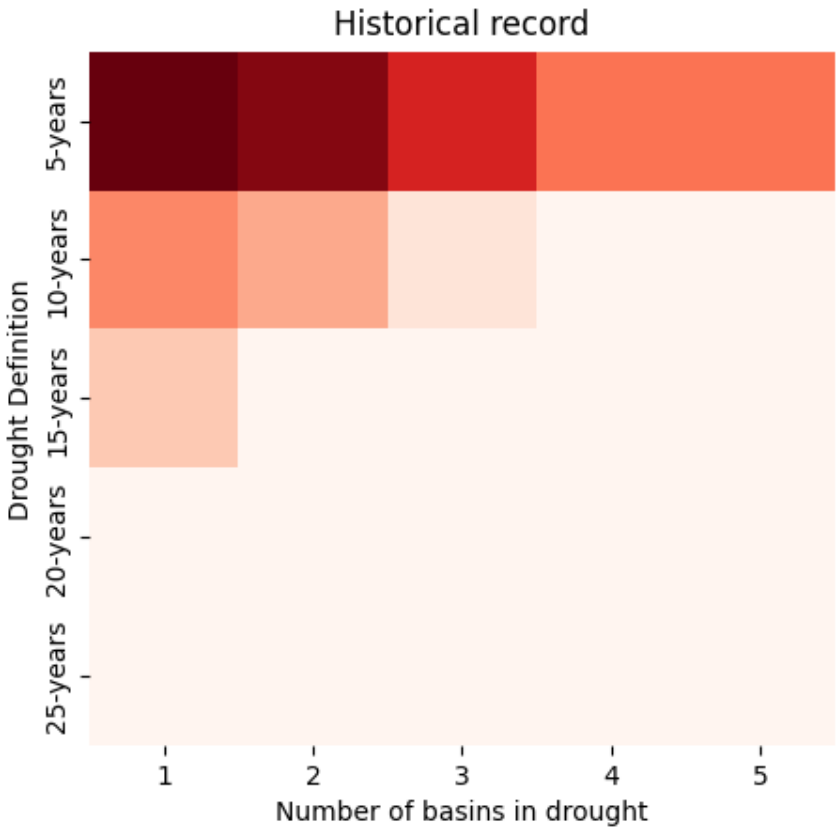
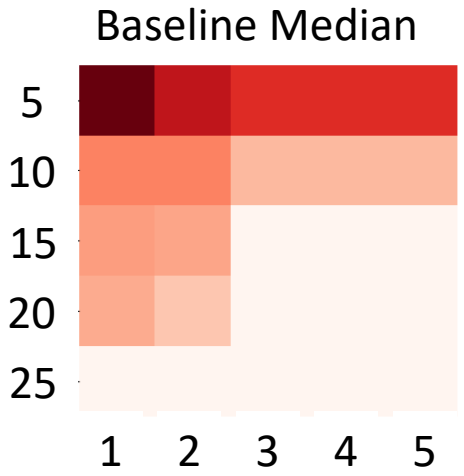
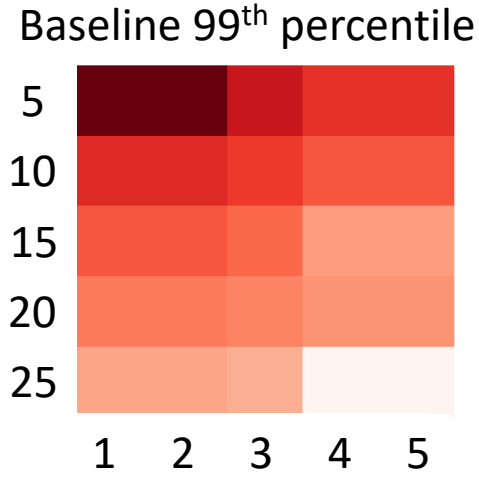
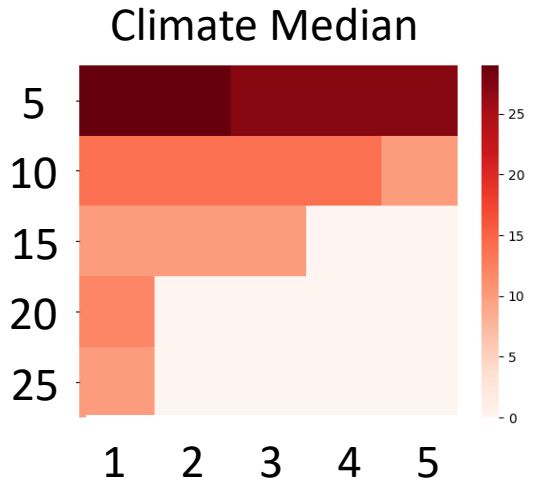
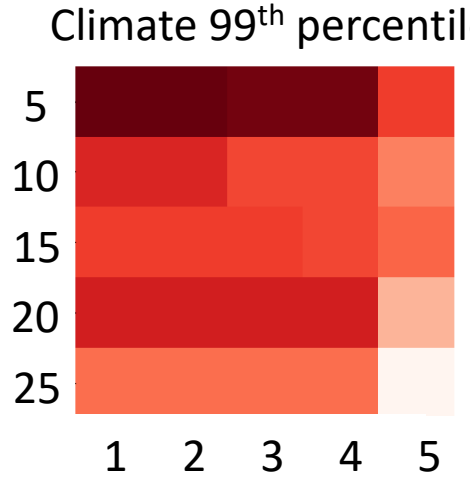
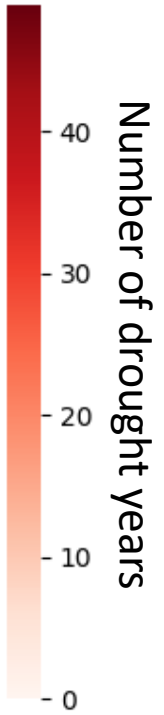




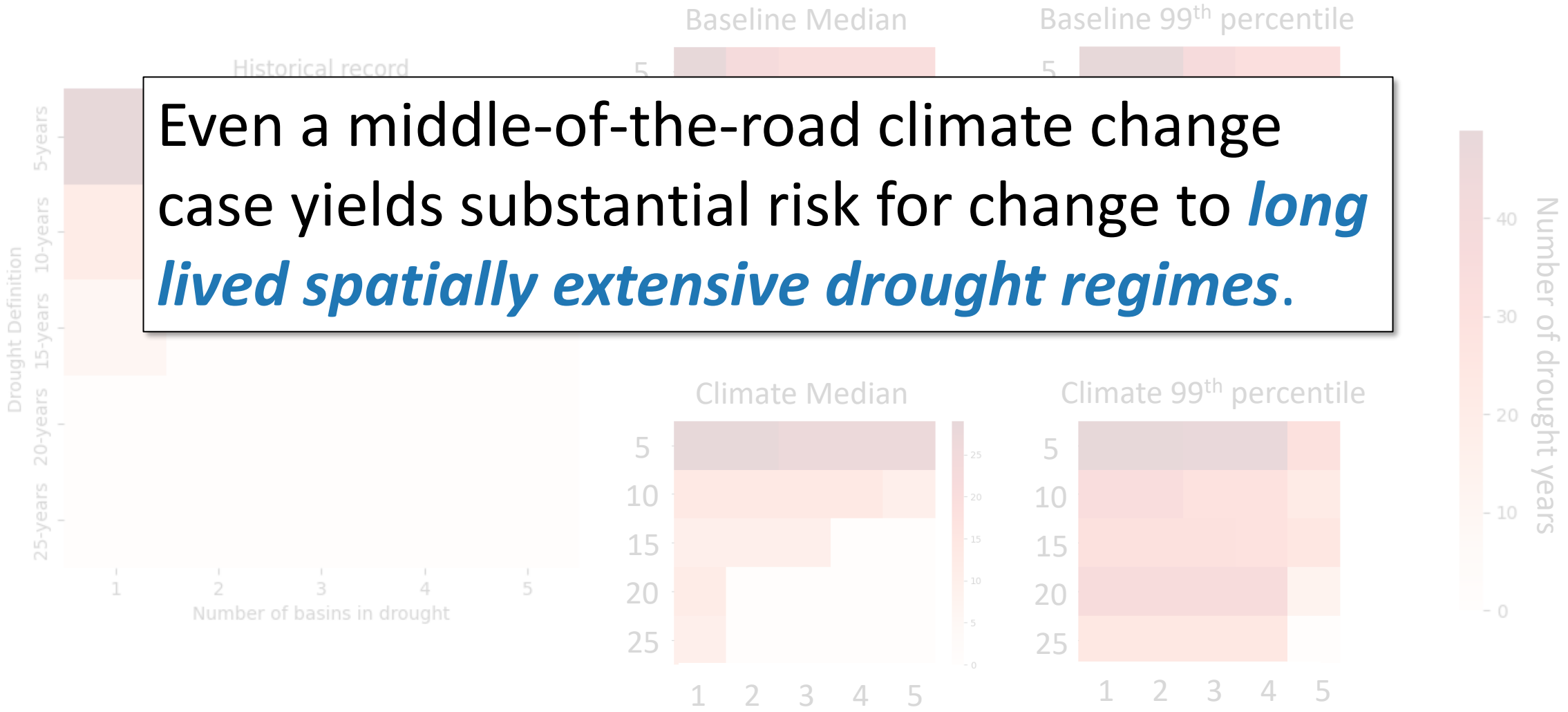








CHANGES IN SPATIALLY COMPOUNDING DROUGHT?



Even a middle-of-the-road climate change case yields substantial risk for change to ***long lived spatially extensive drought regimes***.

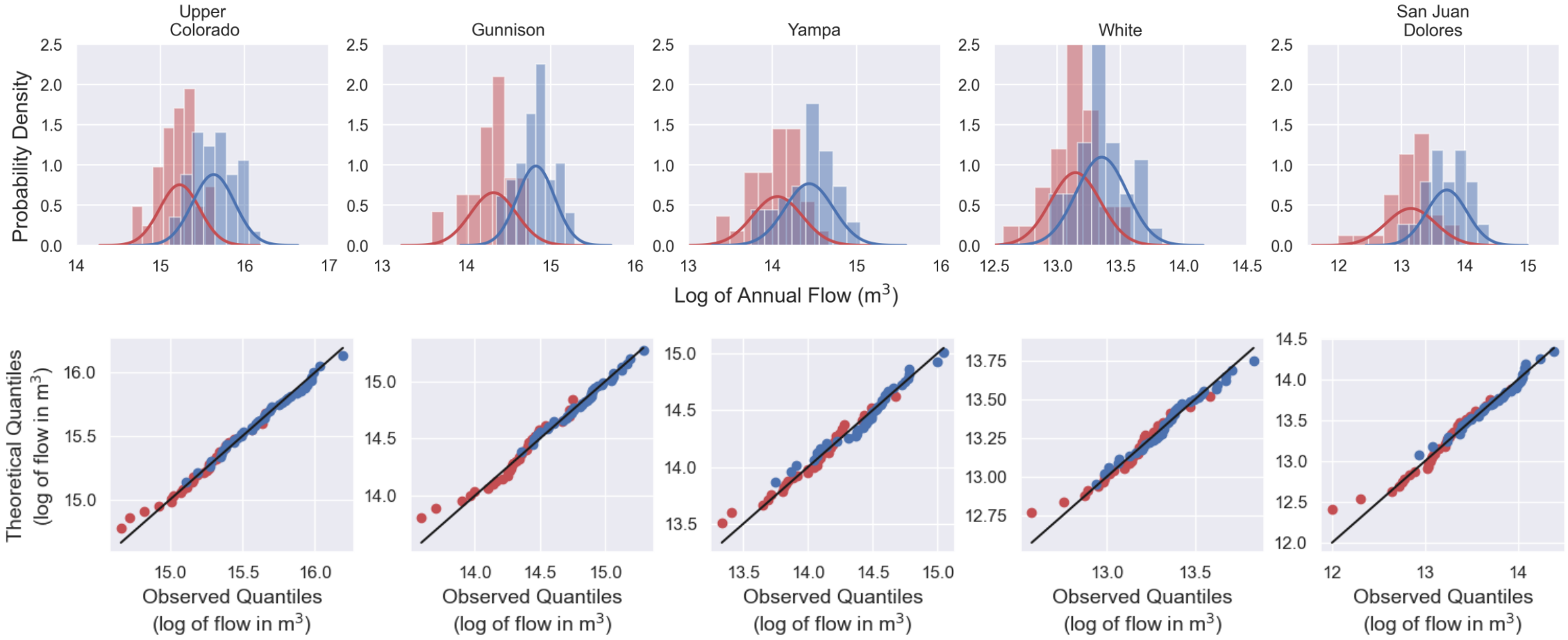
THEME 2 RISKS & IMPACTS – WHAT IS NEEDED

- *What are the bottlenecks for advancing regional modeling to better capture risks and impacts?*
  - *There is a computational bottleneck in utilizing large ensemble ESM and/or regional runs at the scales needed*
  - *It take time and effort to capture 'holistic treatments' of risk beyond characterizing natural hazards*
  - *Decision relevance requires perspectives beyond 'modelers modeling'*
  - *There needs to be a better bridge between the physical and statistical modeling communities in better capturing extremes and risks*

Thank you! Happy to follow up in our discussion.

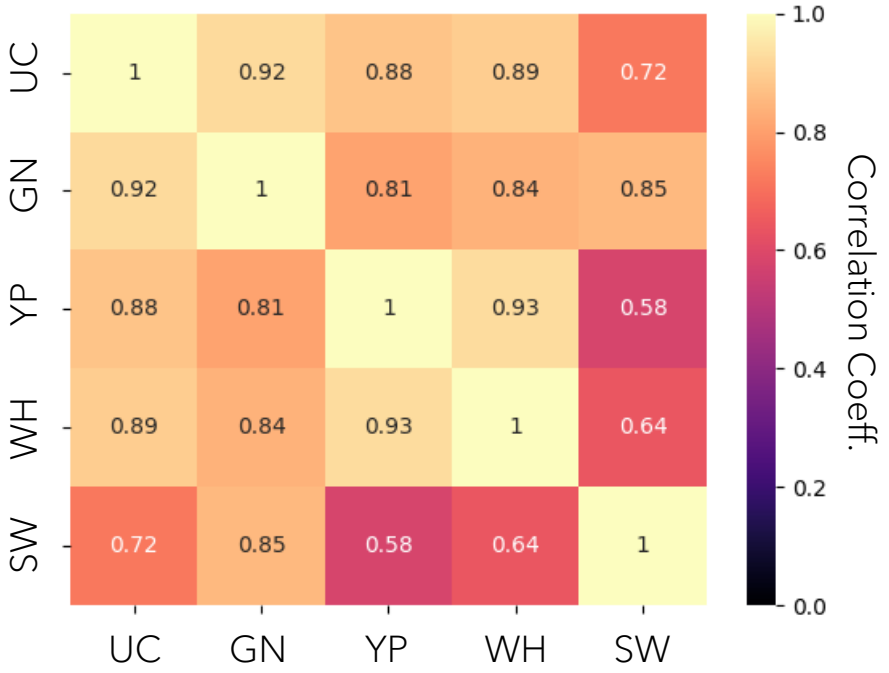
ADDITIONAL SLIDES

FITTING THE HMM

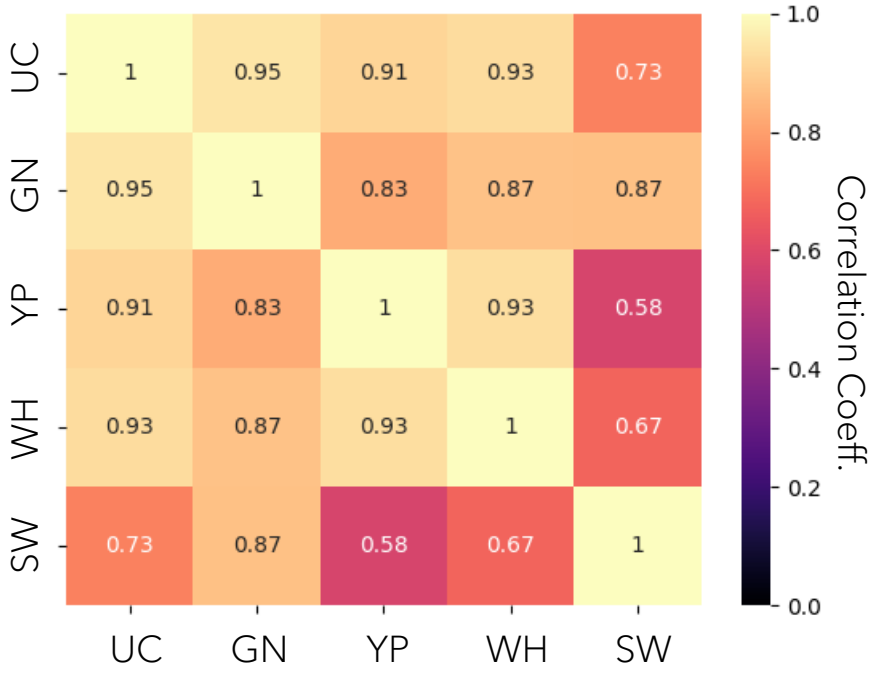


CAPTURING SPATIAL CORRELATION

Historical Correlation Matrix



Synthetic Correlation Matrix

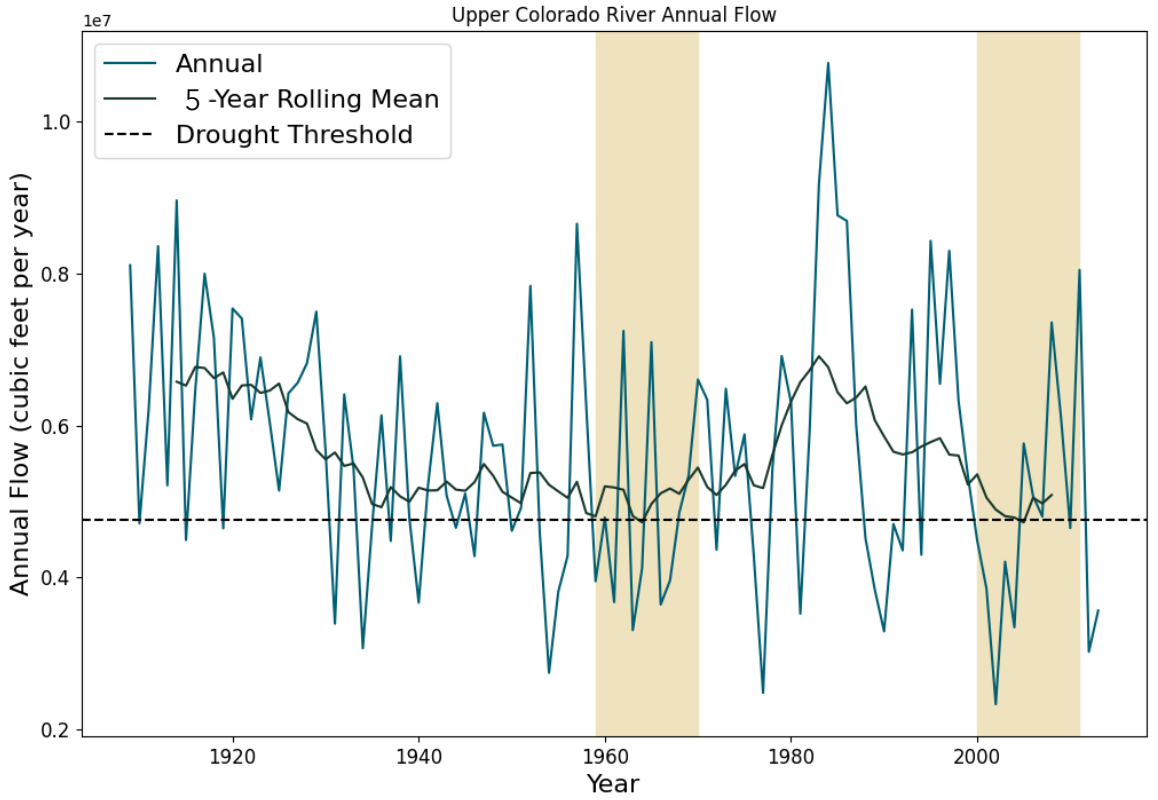


IDENTIFYING DROUGHT

Drought

A period when the **5-year rolling mean** flow drops more than **½ standard deviation** below the **mean of the entire record**

$$\mu_{11} < \mu_{hist} - 0.5\,\sigma_{hist}$$



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Assessing the Risk of Persistent Drought Using Climate Model Simulations and Paleoclimate Data

Toby R. Ault, Julia E. Cole, Jonathan T. Overpeck, Gregory T. Pederson, and David M. Meko

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