Water resource-relevant hot-dry compound events in the Western US

Flavio Lehner[1,2,3]

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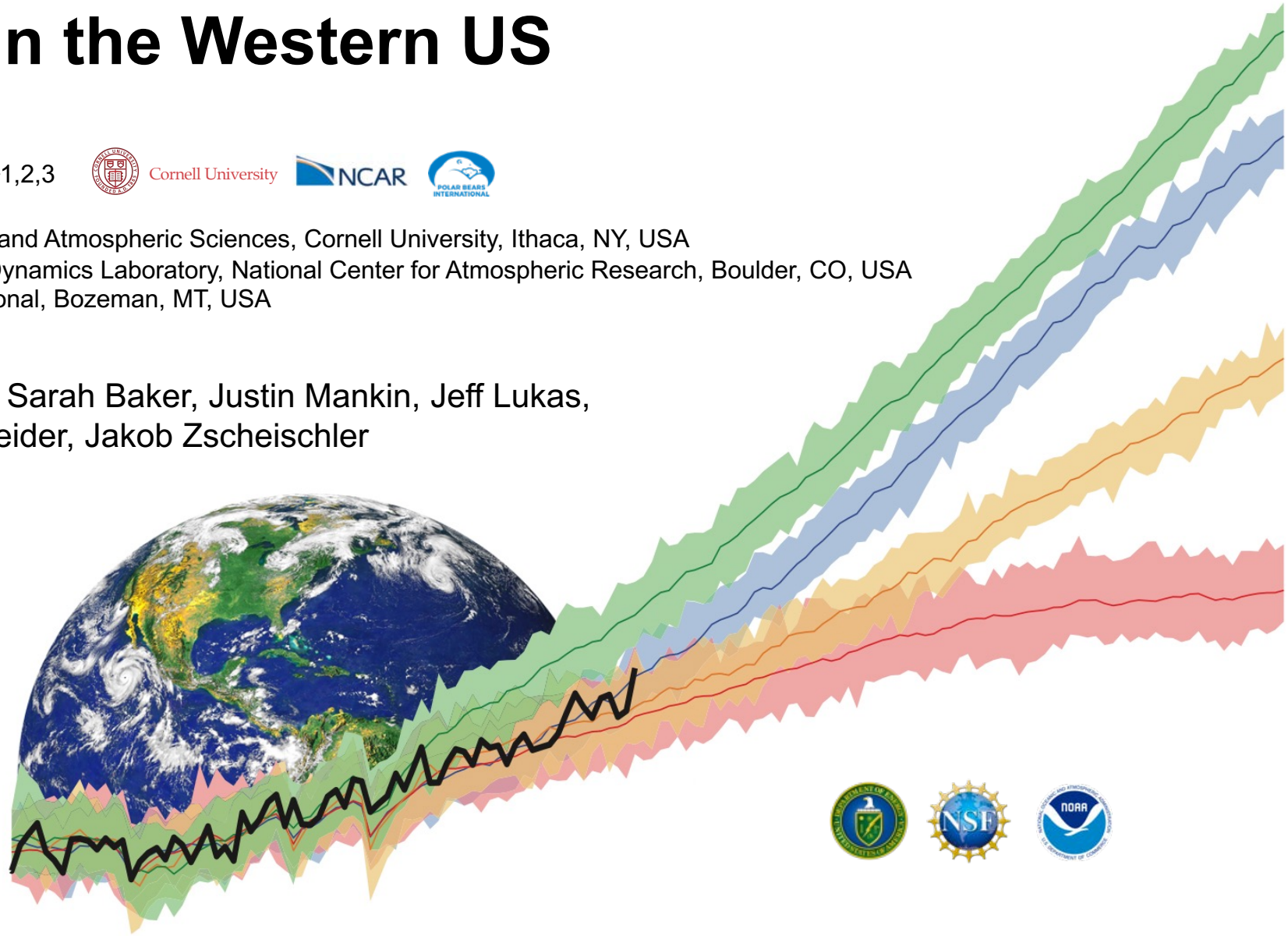
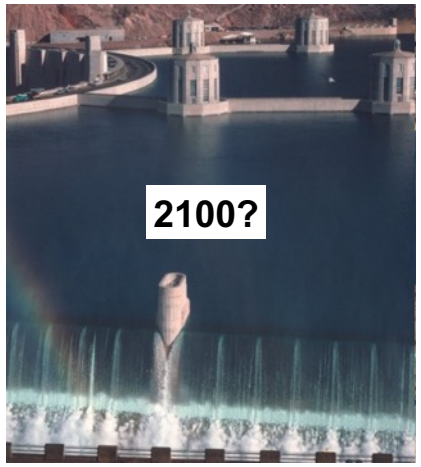
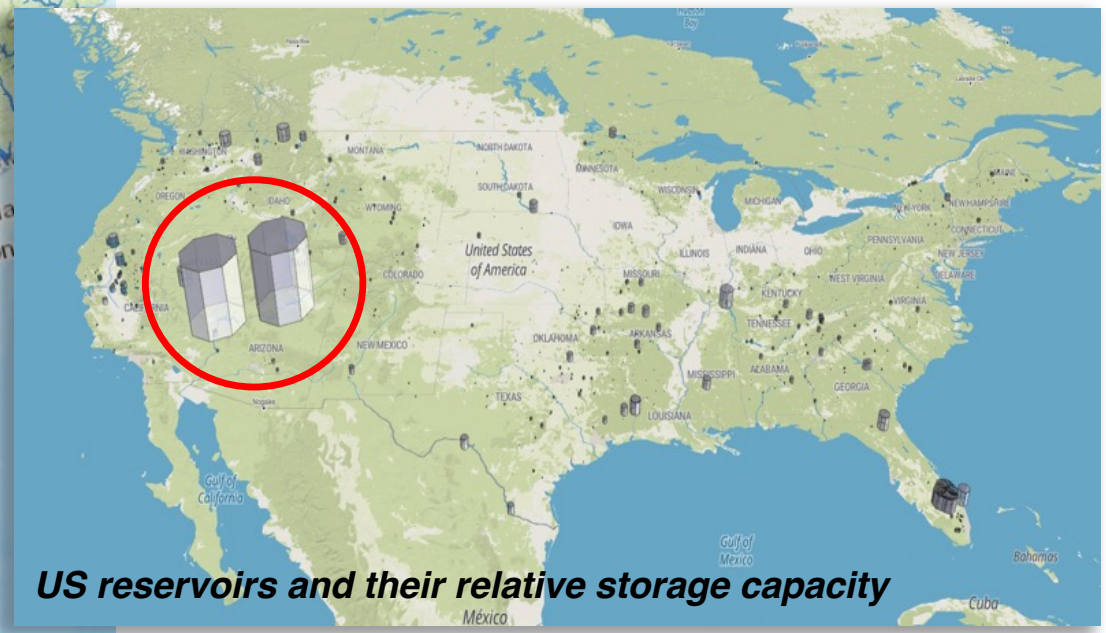
[2]Climate and Global Dynamics Laboratory, National Center for Atmospheric Research, Boulder, CO, USA
[3]Polar Bears International, Bozeman, MT, USA

with thanks to
Rebecca Smith, Sarah Baker, Justin Mankin, Jeff Lukas,
Scott Steinschneider, Jakob Zscheischler



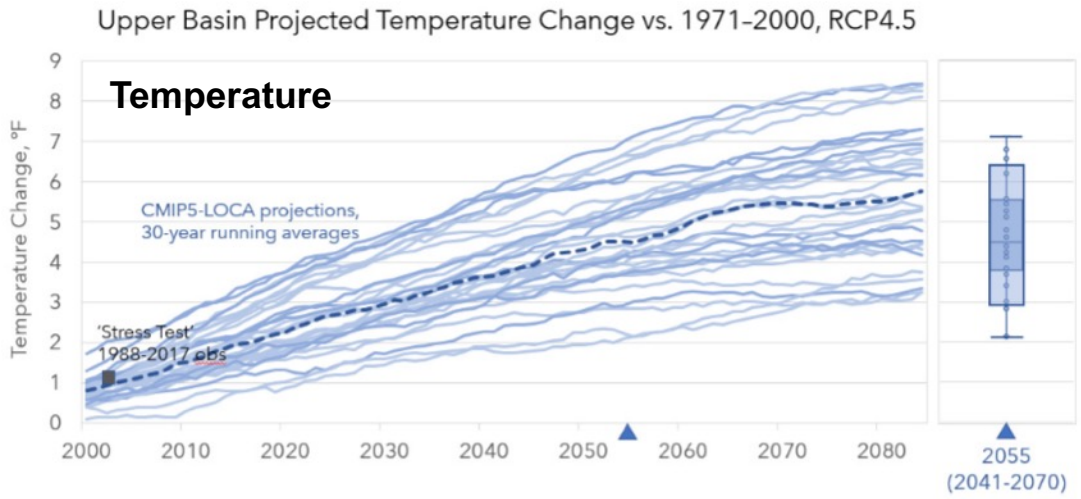


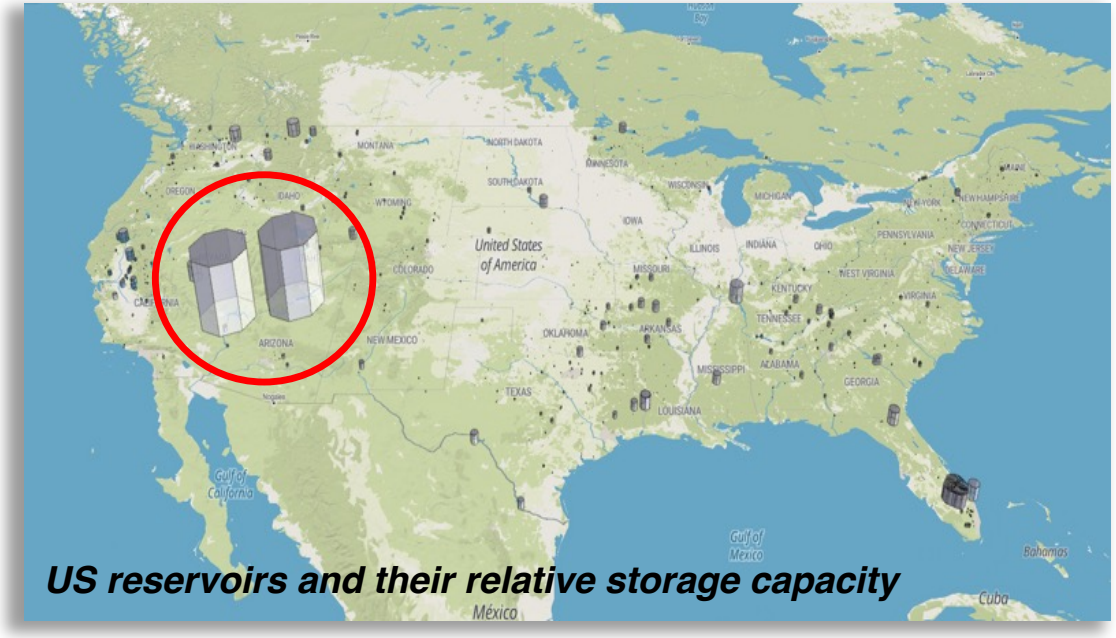
Sources of uncertainty in Upper Colorado River Basin climate projections



US reservoirs and their relative storage capacity

Sources of uncertainty in Upper Colorado River Basin climate projections





US reservoirs and their relative storage capacity

Lukas and Payton (2020, *Western Water Assessment*)

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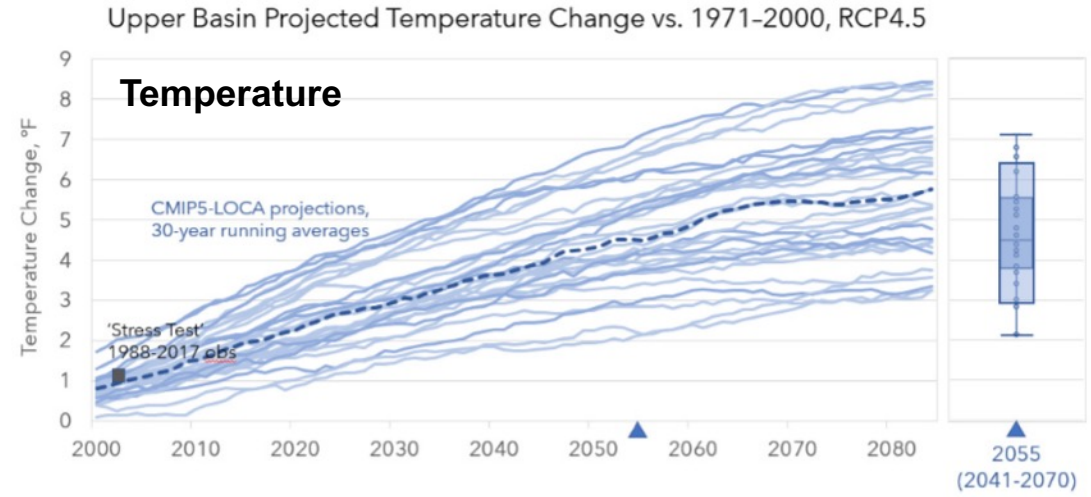
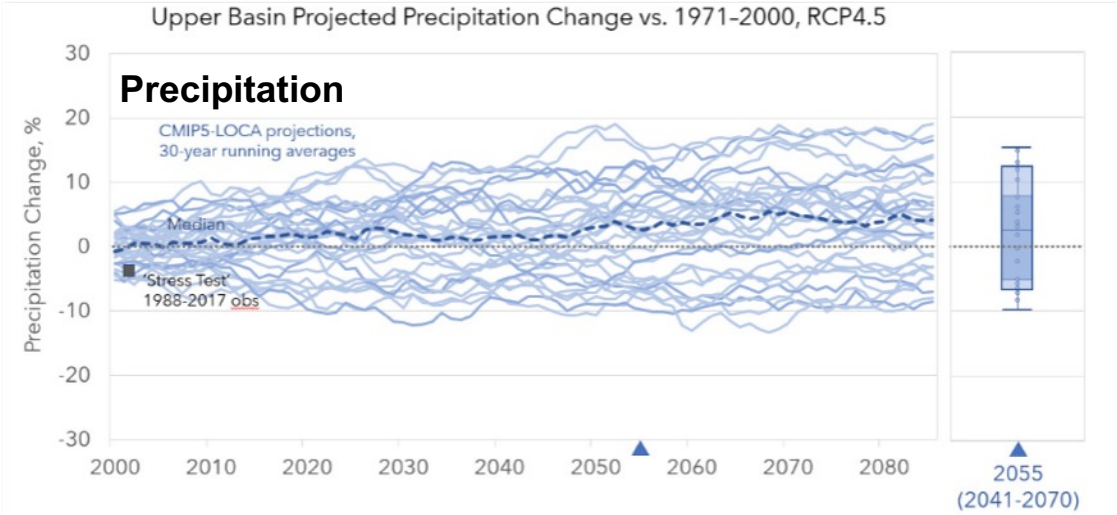
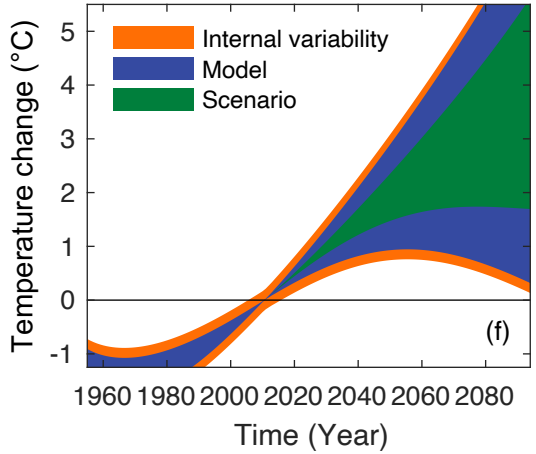




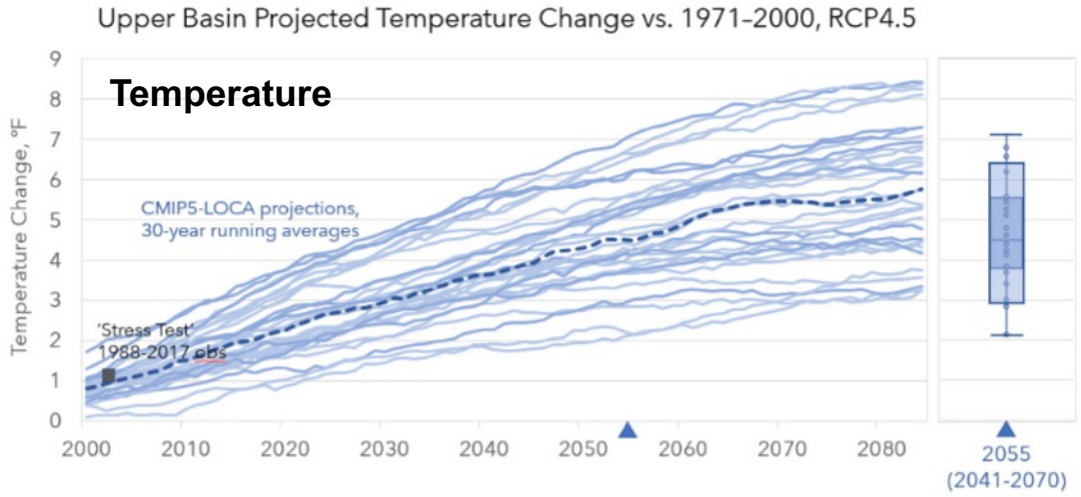
CMIP6 projections and uncertainty sources

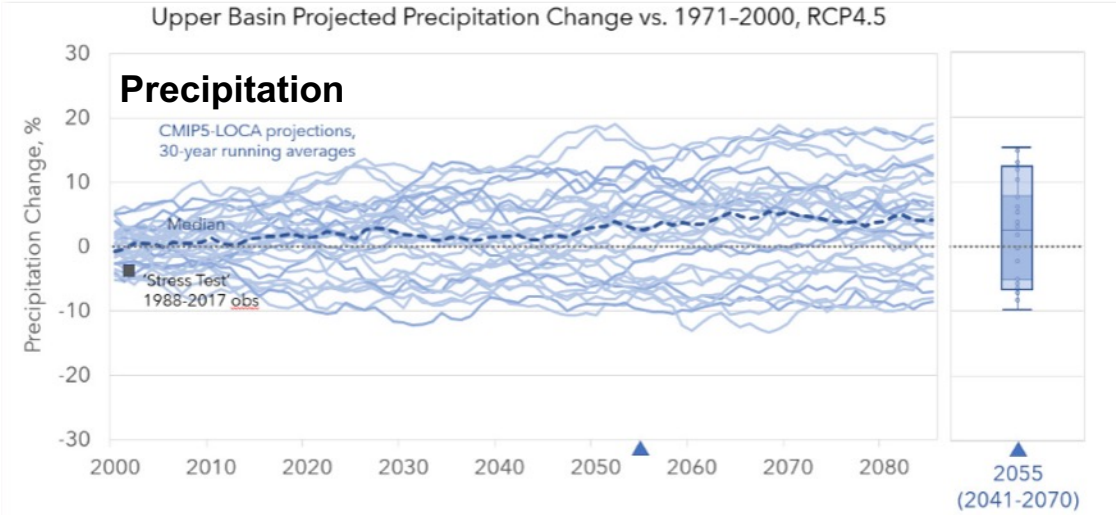


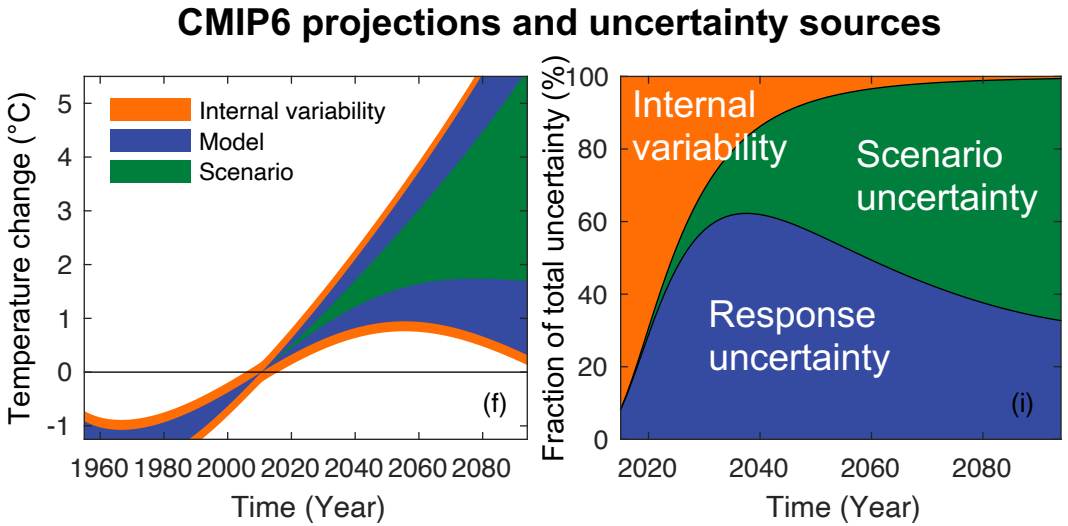
Lukas and Payton (2020, *Western Water Assessment*)

Lehner et al. (2020, *Earth Sys. Dyn.*)

Sources of uncertainty in Upper Colorado River Basin climate projections







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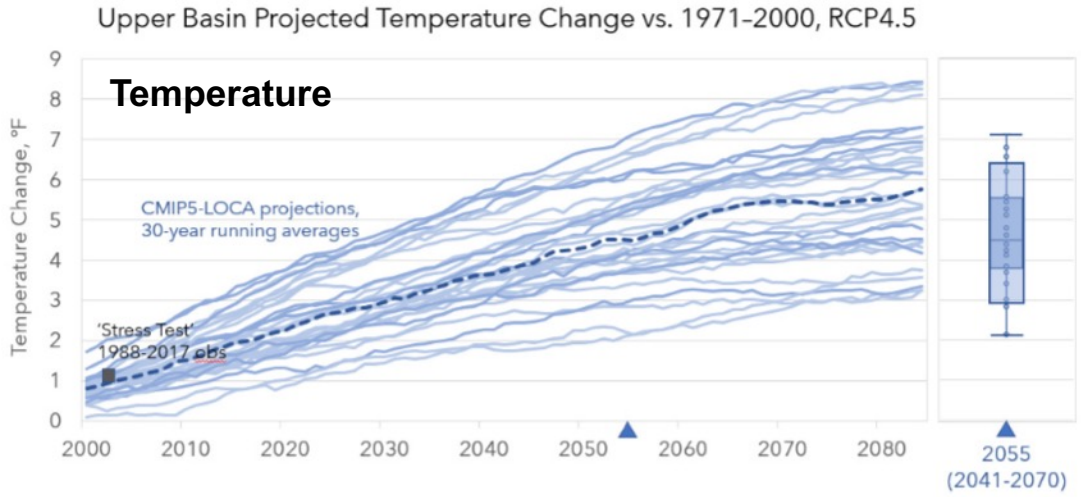
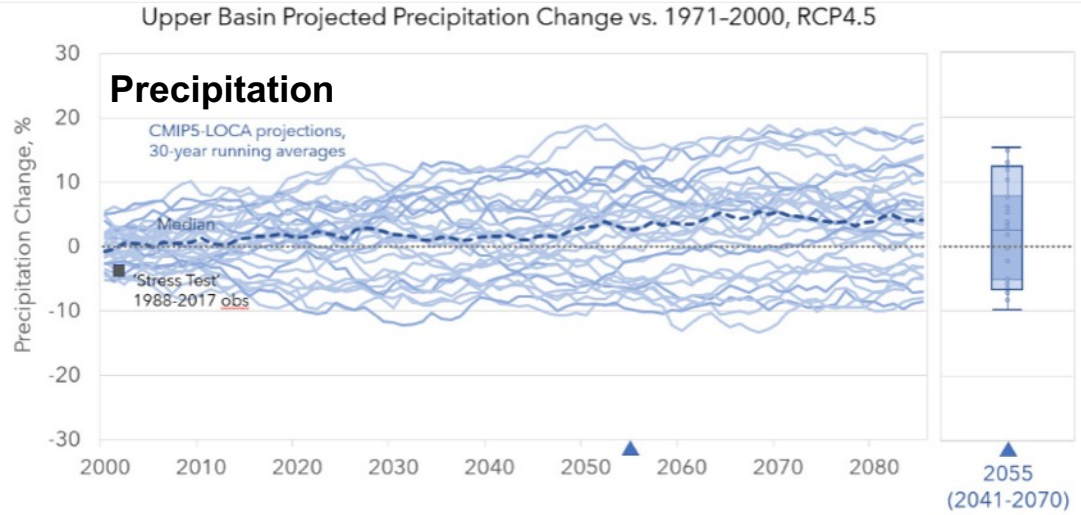
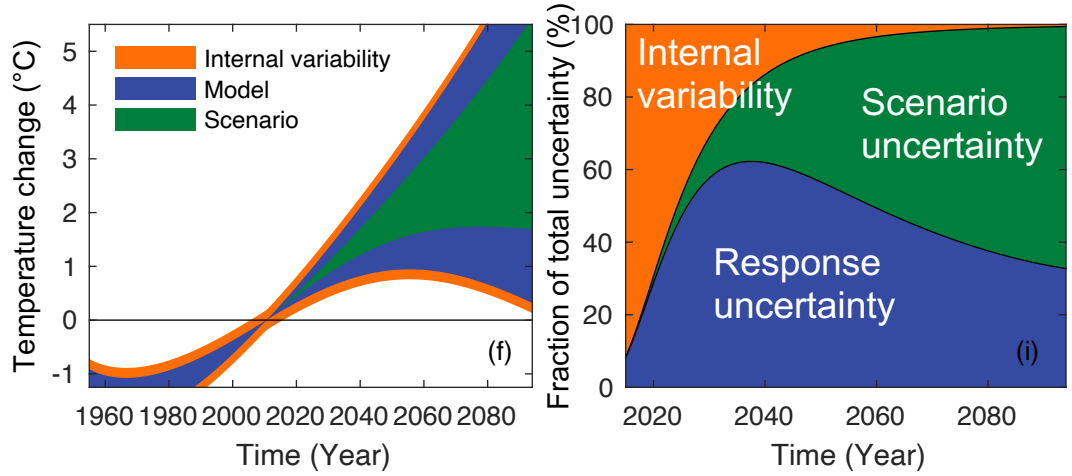
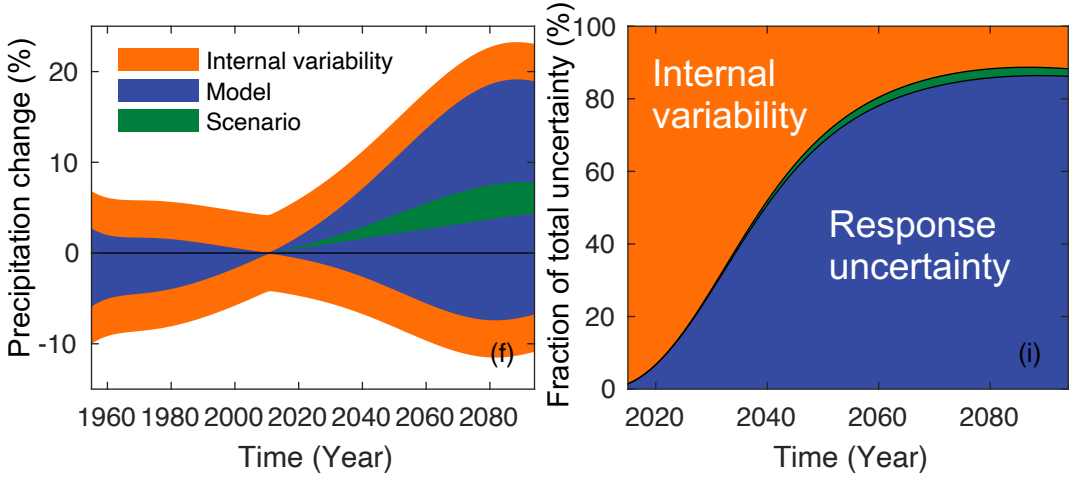
Sources of uncertainty in Upper Colorado River Basin climate projections





CMIP6 projections and uncertainty sources





Scenario uncertainty

Lukas and Payton (2020, *Western Water Assessment*)

Lehner et al. (2020, *Earth Sys. Dyn.*)

Prospects of model weighting

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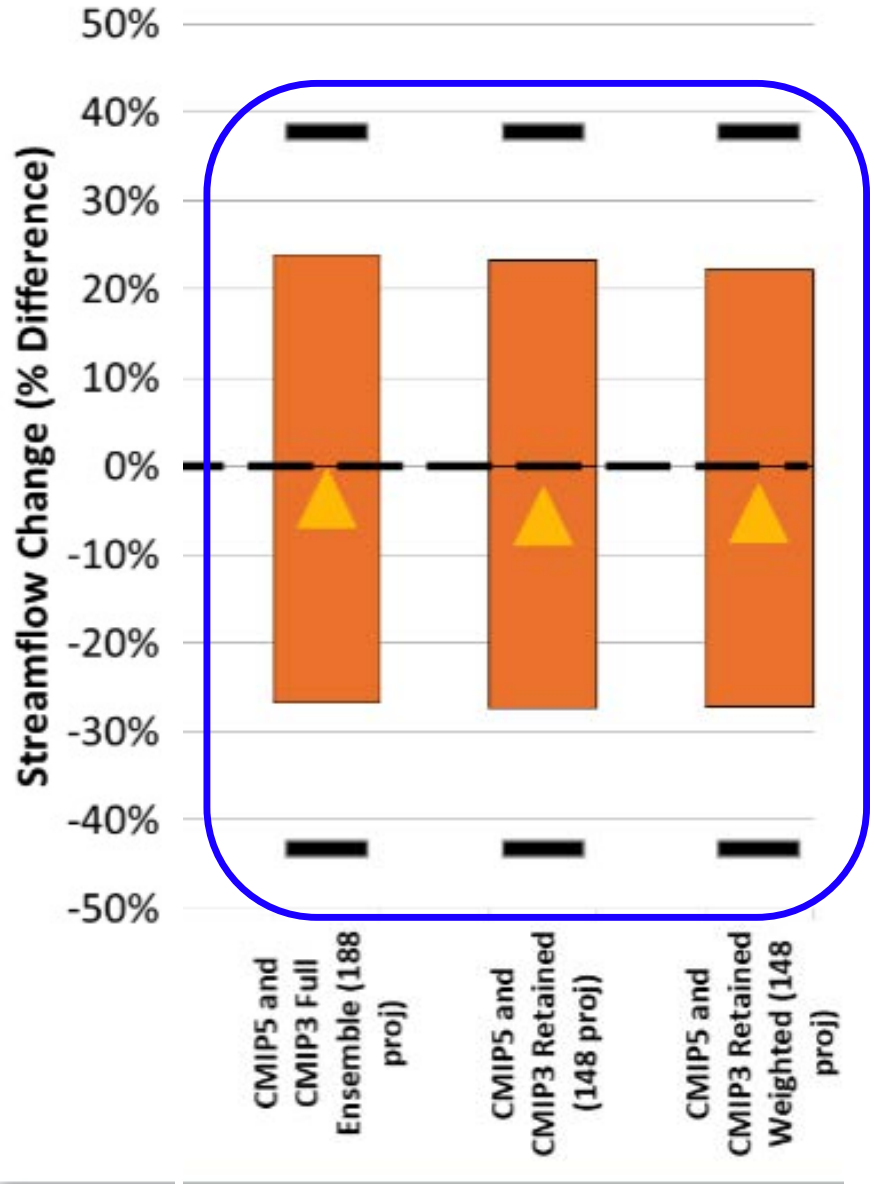
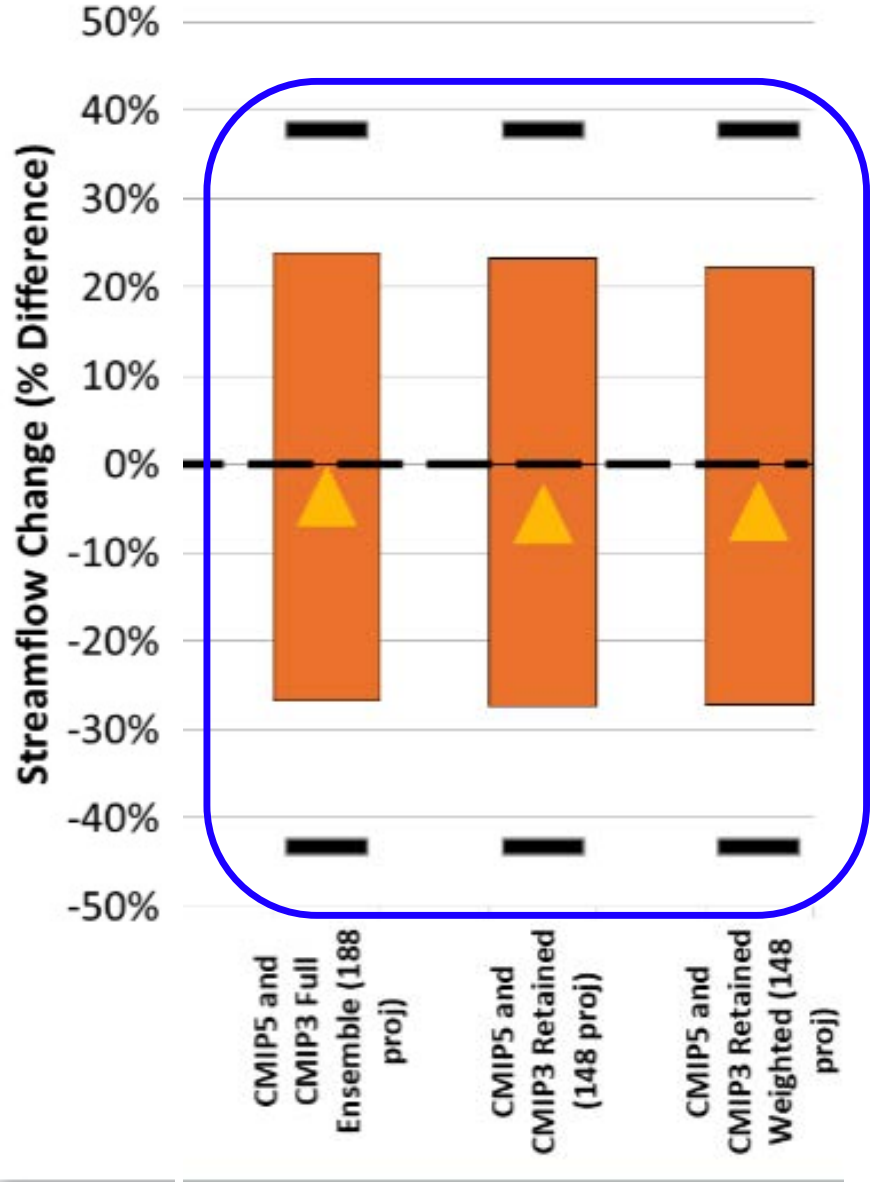


Model weighting didn't change things a lot

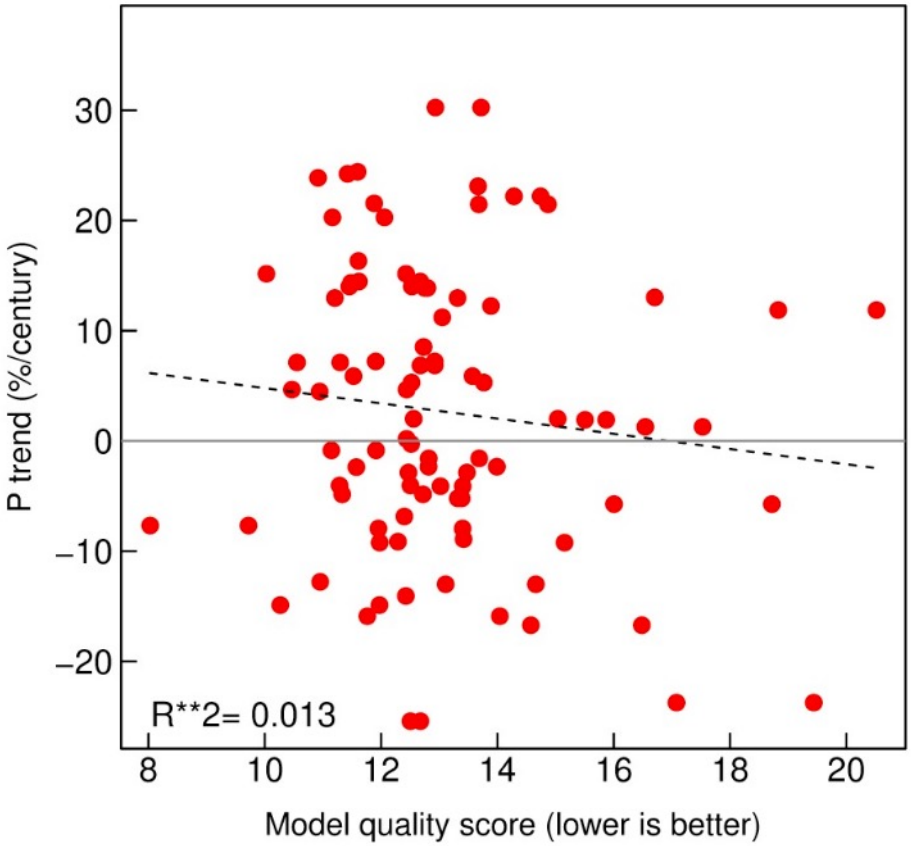
Lukas and Payton (2020, *Western Water Assessment*)

Prospects of model weighting



Model weighting didn't change things a lot

CMIP6: evaluation of mostly ***climatological*** biases

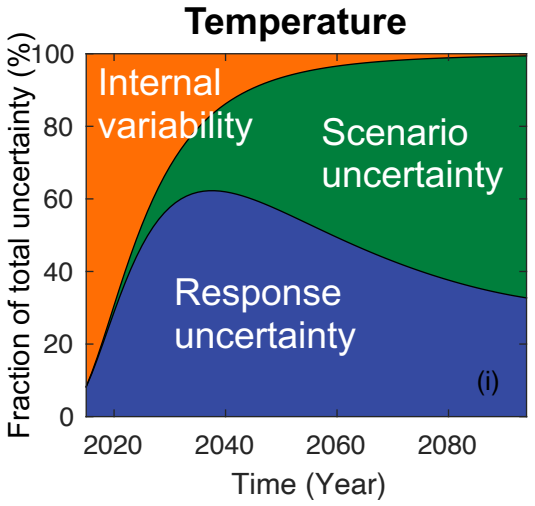


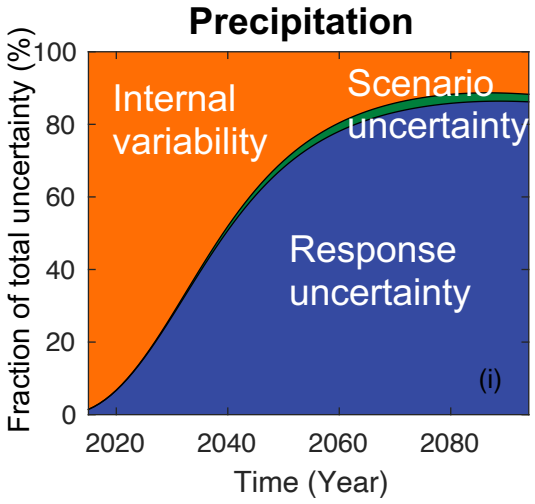
No relationship between model bias and future projections

Lukas and Payton (2020, *Western Water Assessment*)

Pierce et al. (2021, *J. American Water Res. Assoc.*)

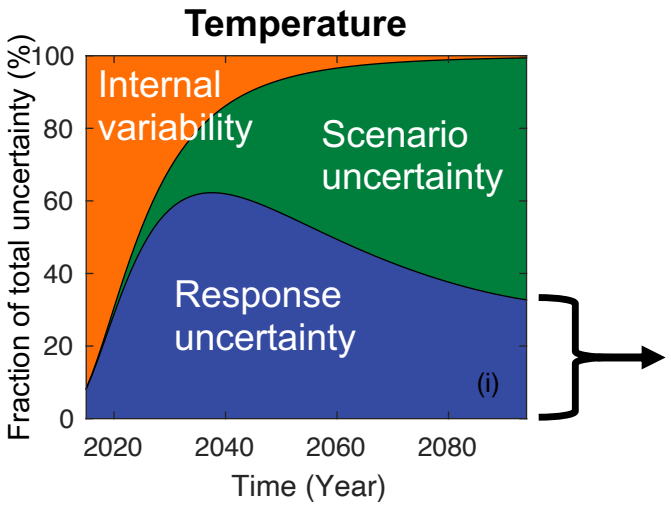
Prospects of model weighting





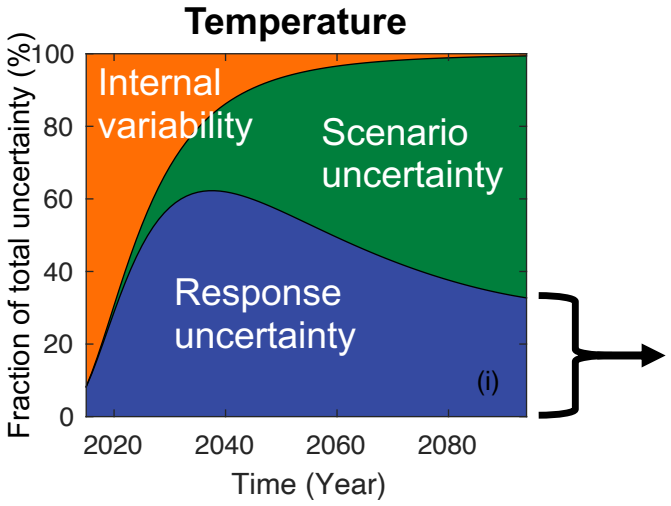
Lehner et al. (2020, *Earth Sys. Dyn.*)

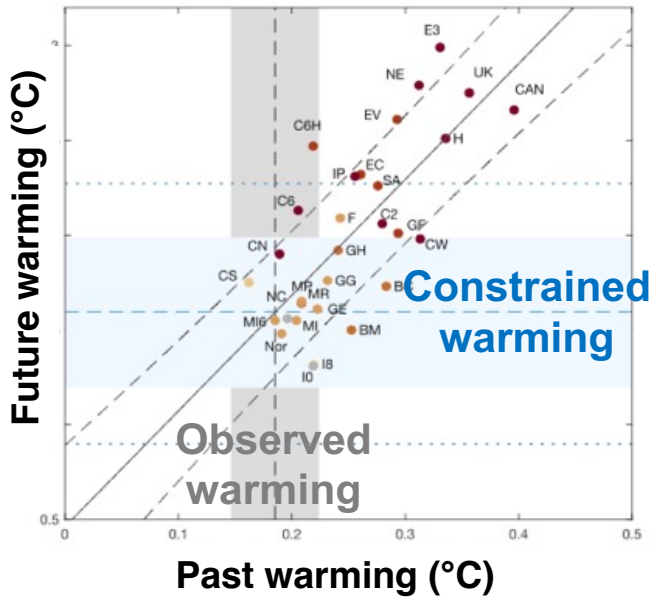
Prospects of model weighting: temperature



Lehner et al. (2020, *Earth Sys. Dyn.*)

Prospects of model weighting: temperature



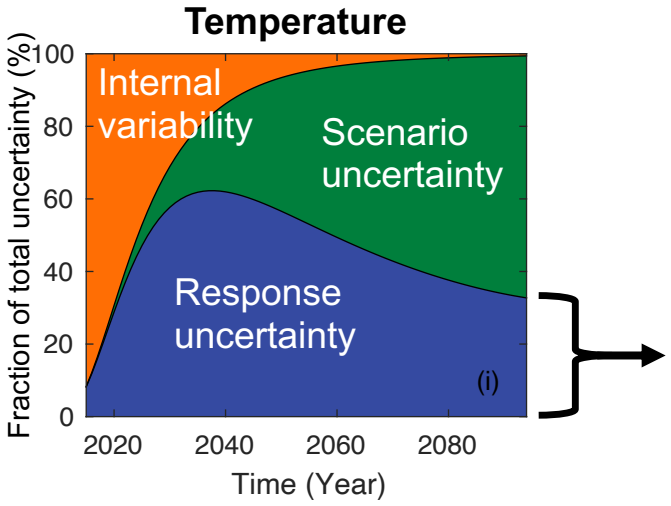


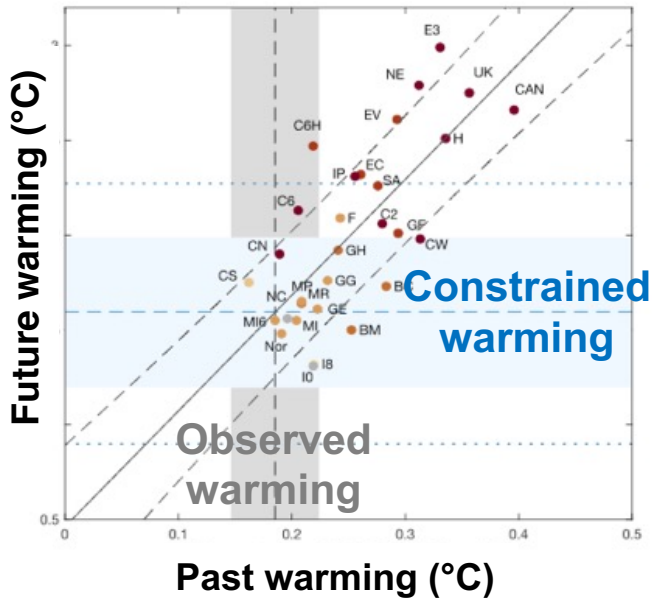
Tokarska et al. (2020, *Science Advances*)

Models that warm too much today also warm more (too much?) in the future

Lehner et al. (2020, *Earth Sys. Dyn.*)

Prospects of model weighting: temperature





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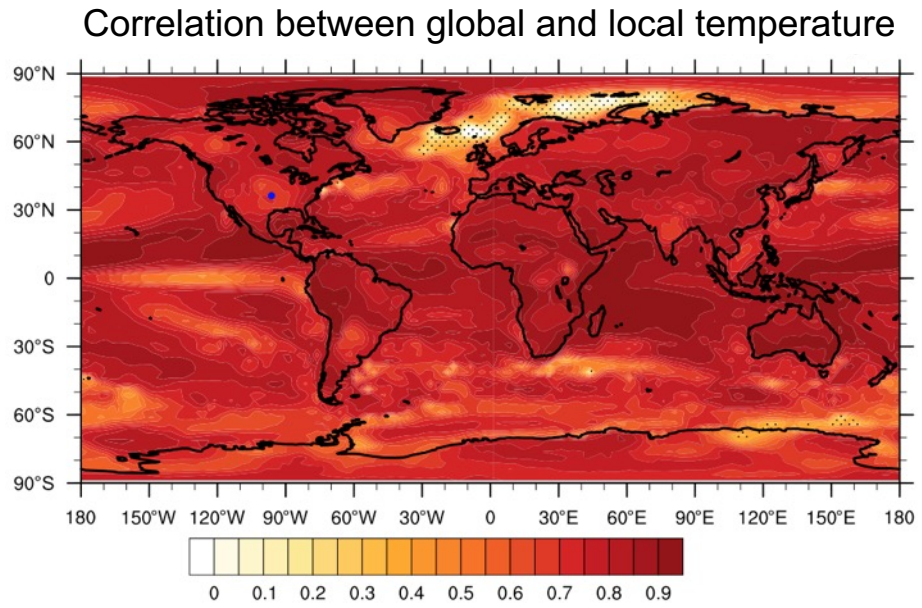

Qasmi & Ribes (2022, *Science Advances*)

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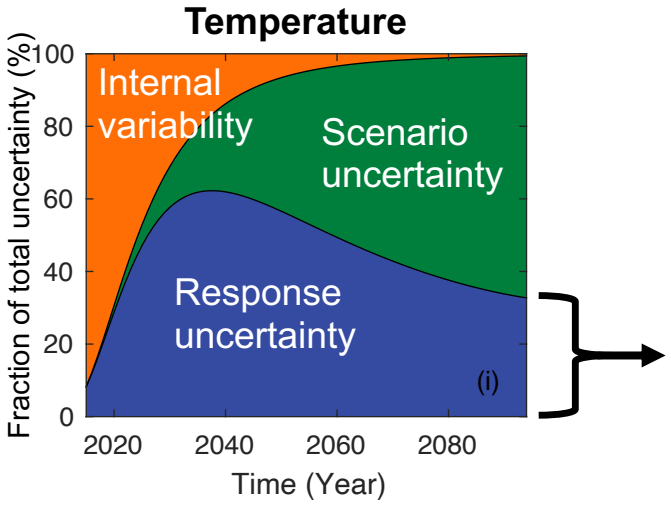
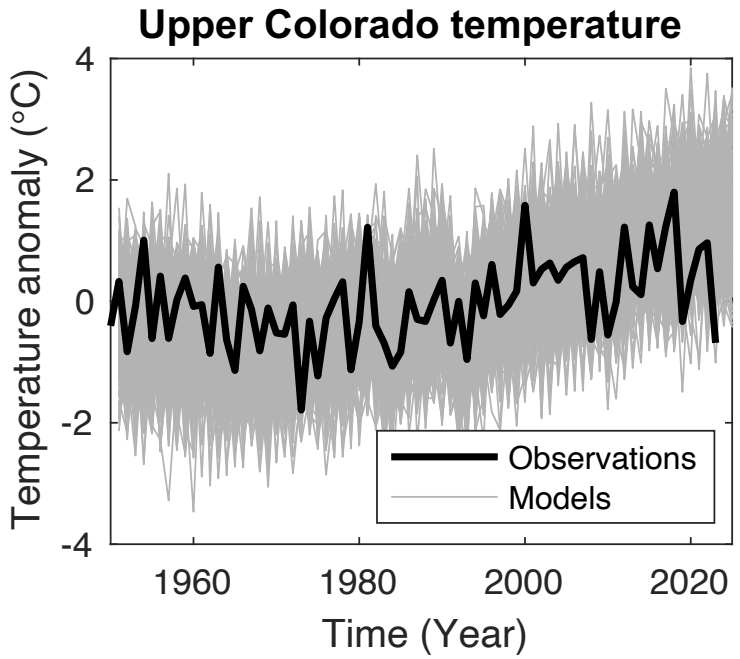
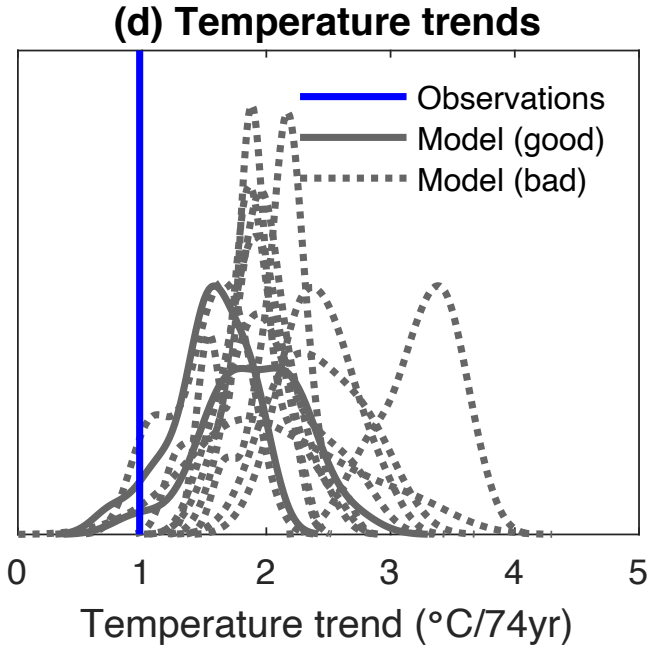
That's also true locally

Lehner et al. (2020, *Earth Sys. Dyn.*)

Prospects of model weighting: temperature







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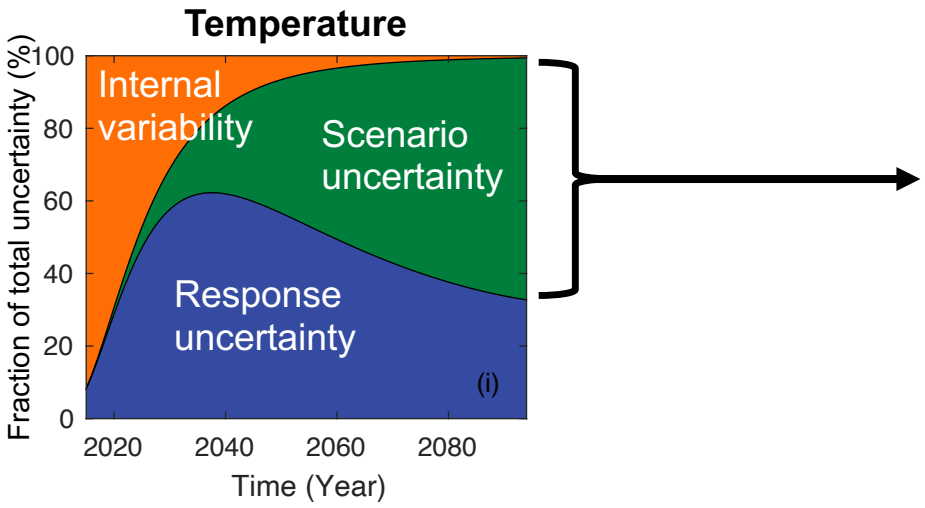
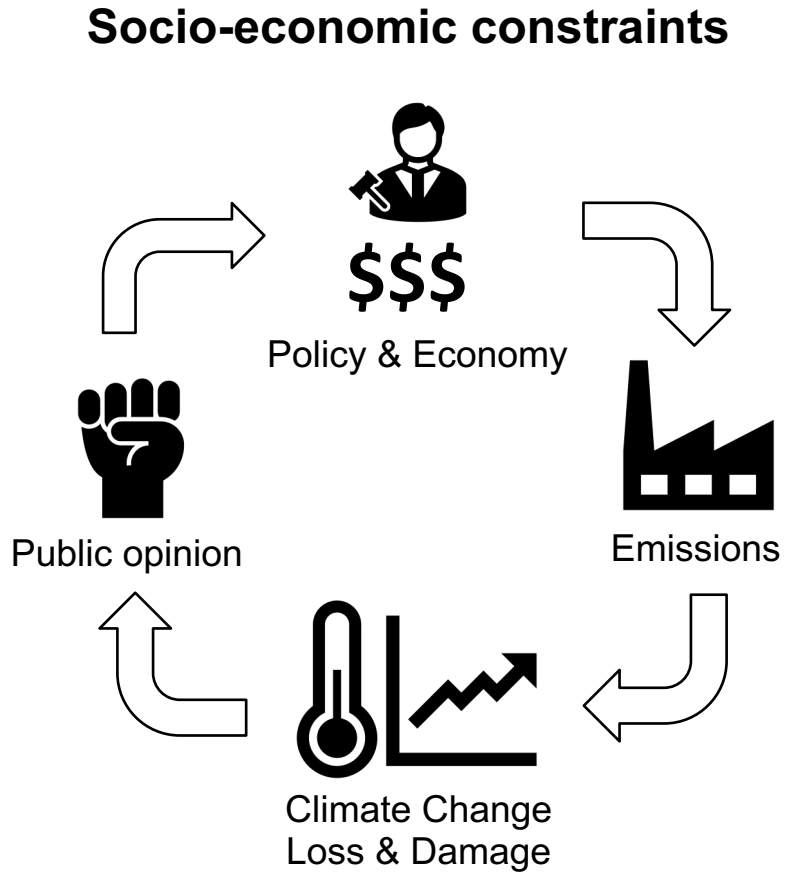


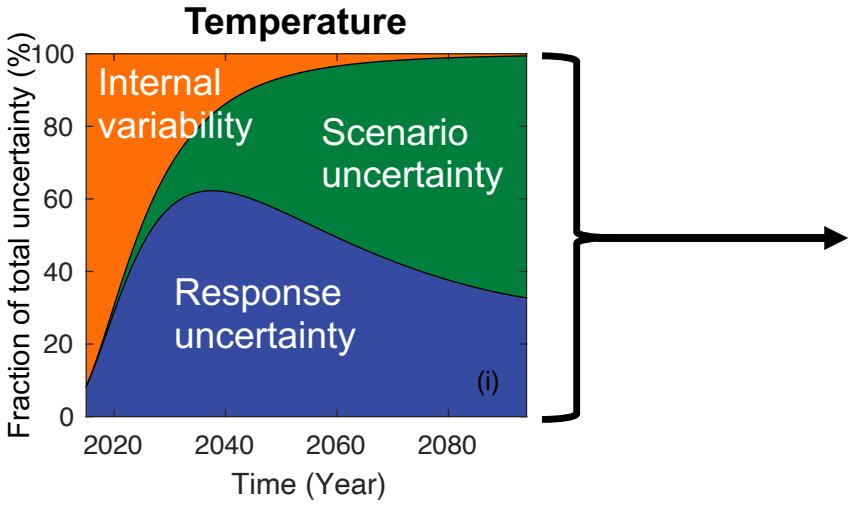


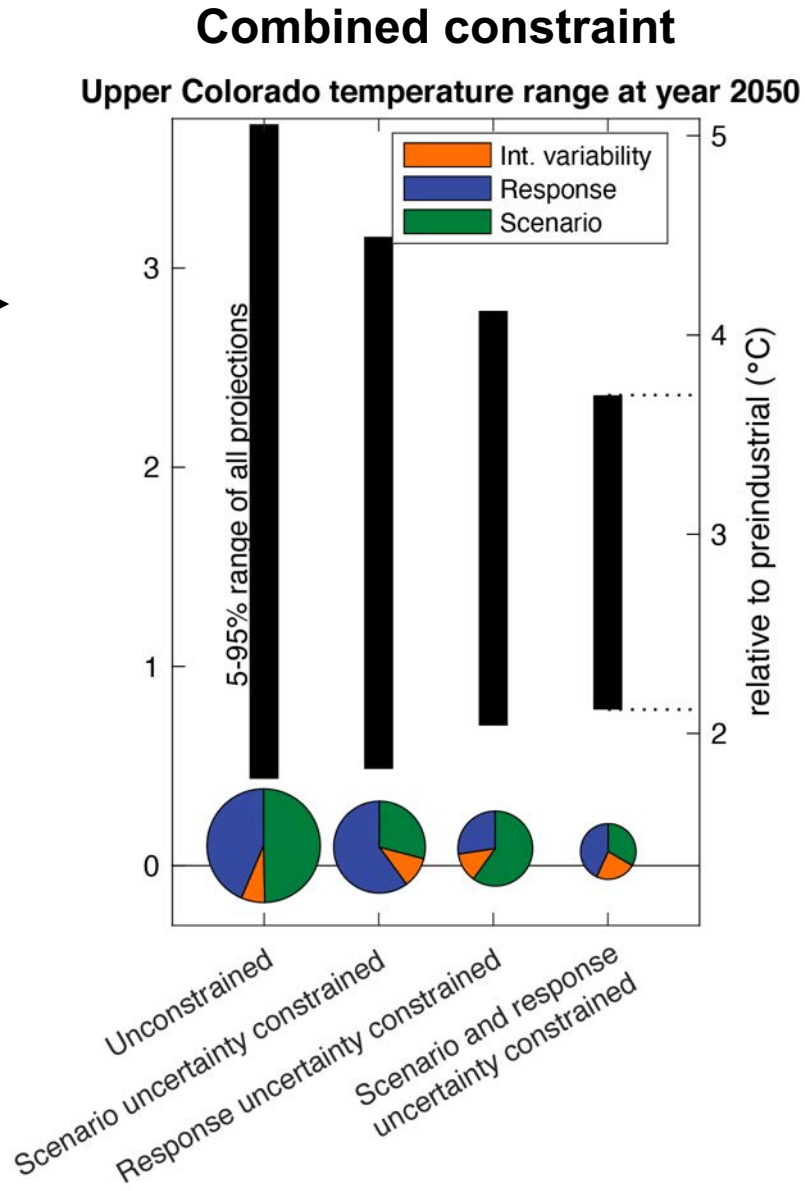
after Moore et al. (2022, *Nature*)

Highest and lowest emissions scenarios are less likely

Lehner et al. (2020, *Earth Sys. Dyn.*)

Prospects of model weighting: temperature

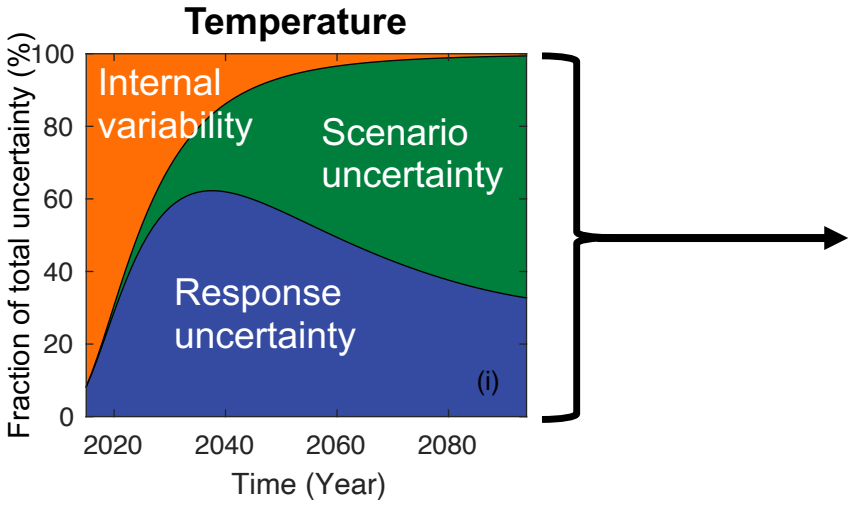




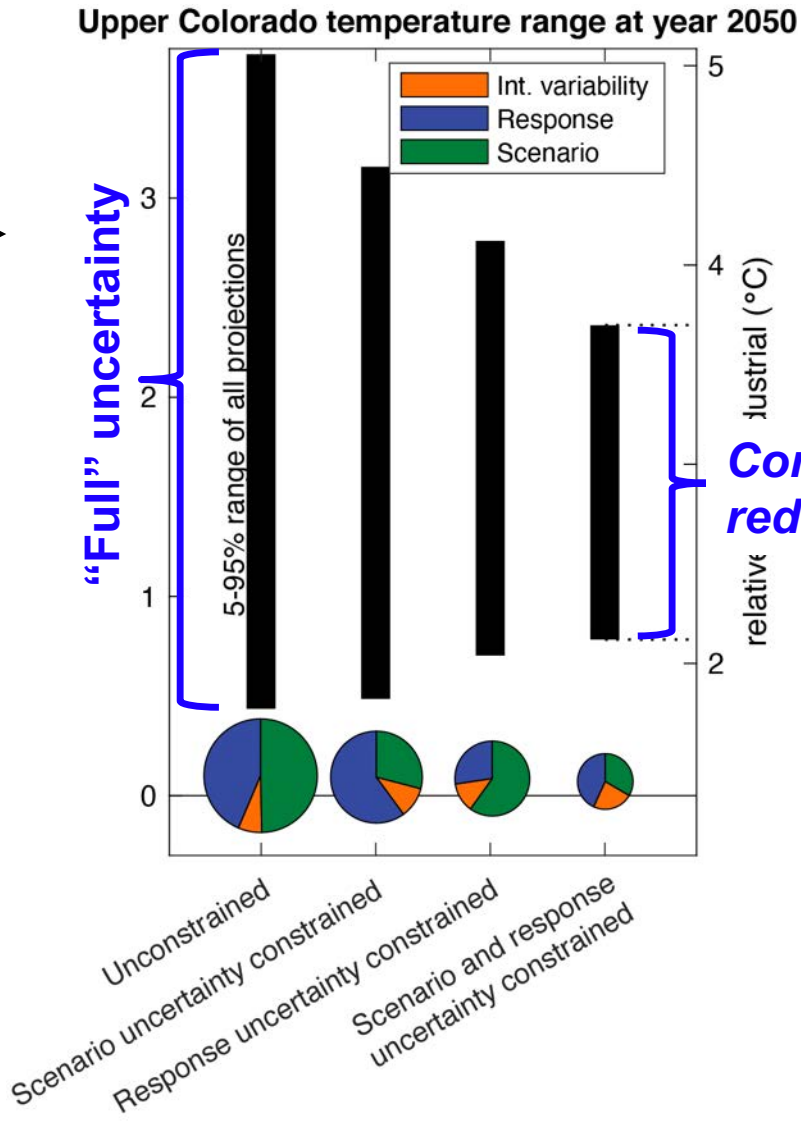
Lehner et al. (2020, *Earth Sys. Dyn.*)

Lehner et al. (2023, *AGU Advances*)

Prospects of model weighting: temperature



Combined constraint

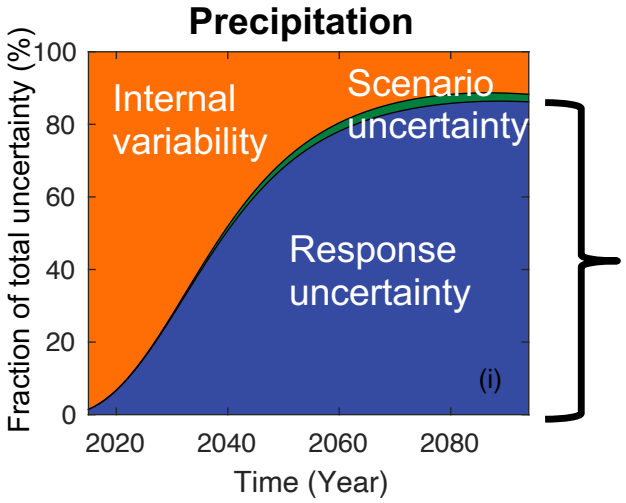


Combined uncertainty reduction of >50%

Lehner et al. (2020, *Earth Sys. Dyn.*)

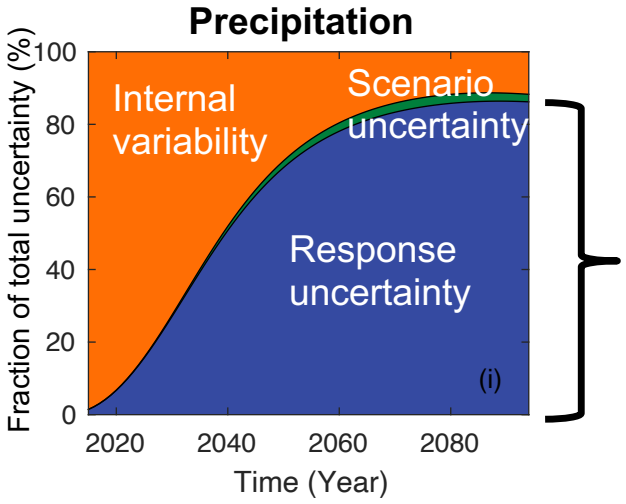
Lehner et al. (2023, *AGU Advances*)

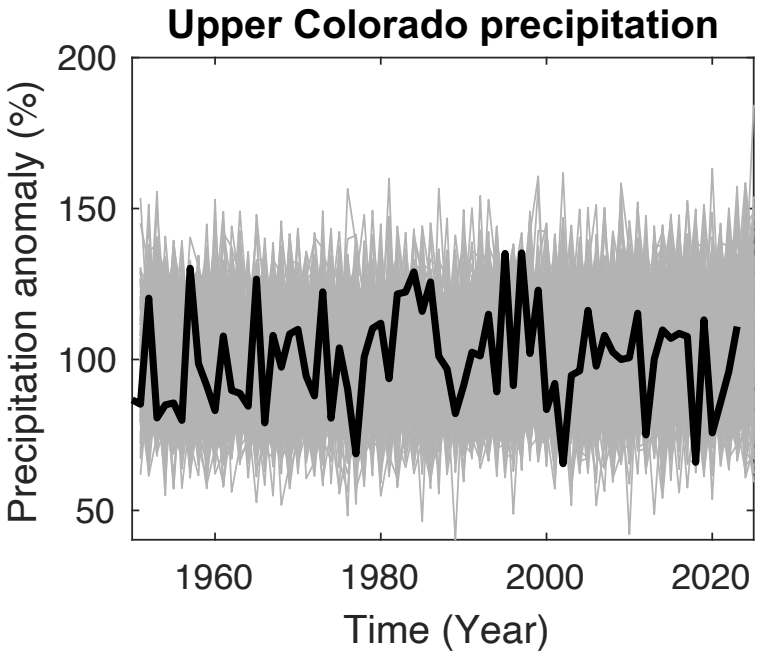
Prospects of model weighting

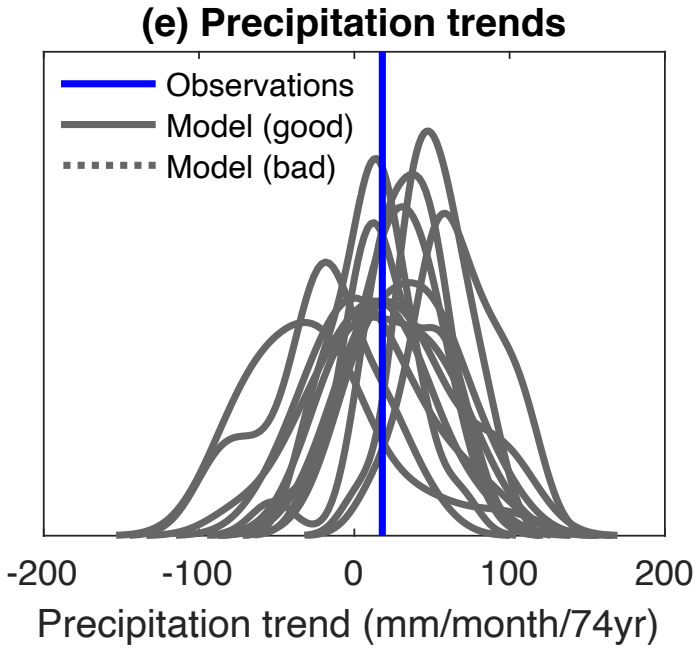


Lehner et al. (2020, *Earth Sys. Dyn.*)

Prospects of model weighting: precipitation



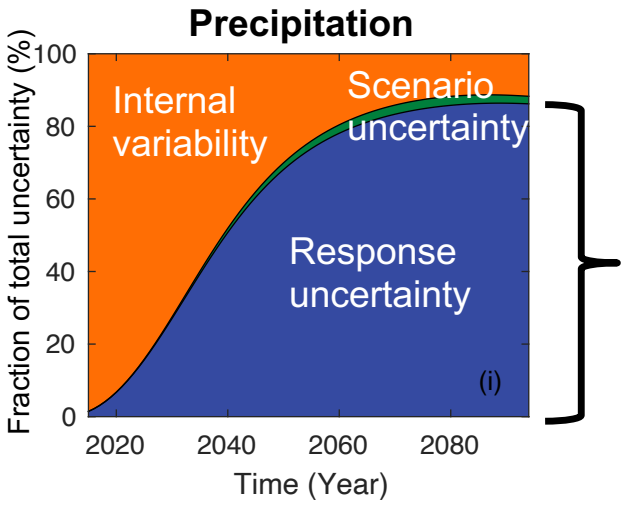




Observed precipitation trend within model spread

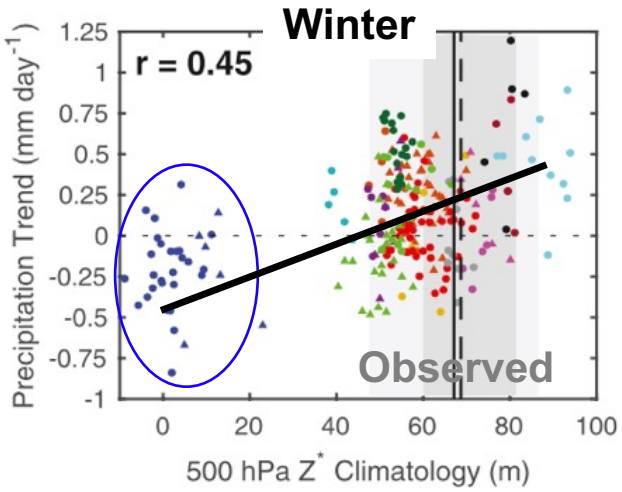
Lehner et al. (2020, *Earth Sys. Dyn.*)

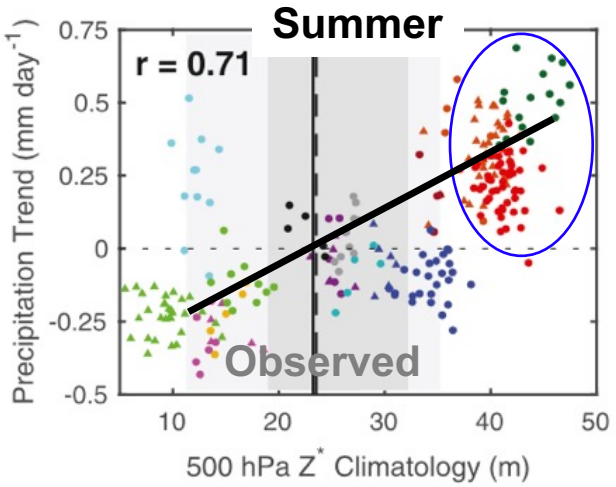
Prospects of model weighting: precipitation



Physical constraints

(dynamics)



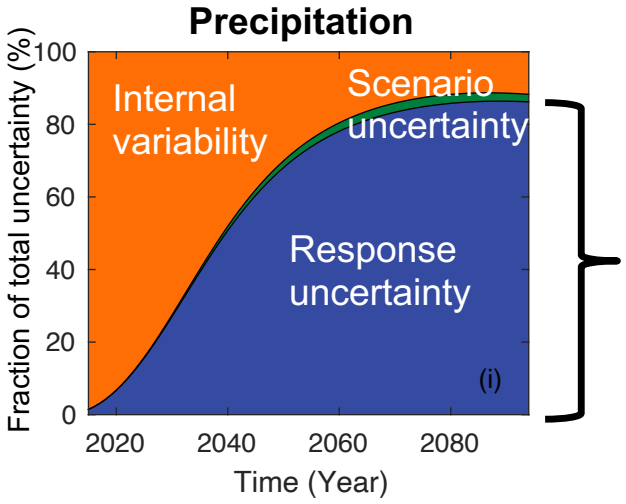


Models with the most extreme winter drying and summer wetting are less realistic

Lehner et al. (2020, *Earth Sys. Dyn.*)

Grise (2022, *Geophys. Res. Letters*); see also Simpson et al. (2015, *Nat. Clim. Change*)

Prospects of model weighting: precipitation

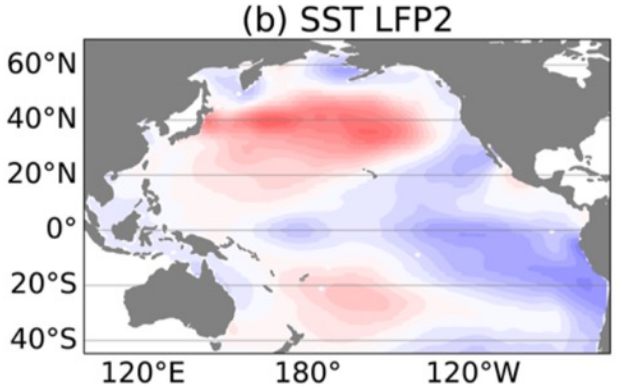


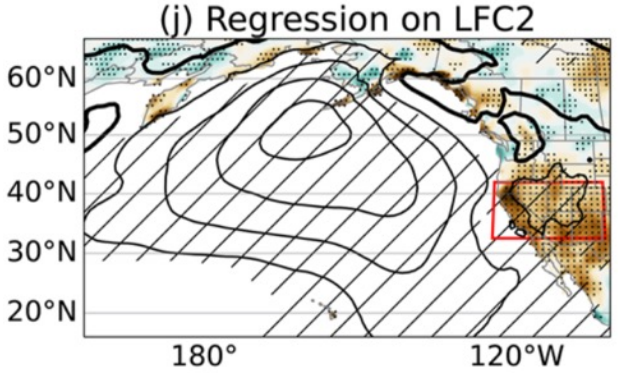
Anthropogenic Aerosols Contribute to the Recent Decline in Precipitation Over the U.S. Southwest

post-1980

Yan-Ning Kuo[1], Hanjun Kim[1], and Flavio Lehner[1,2,3]

Observations

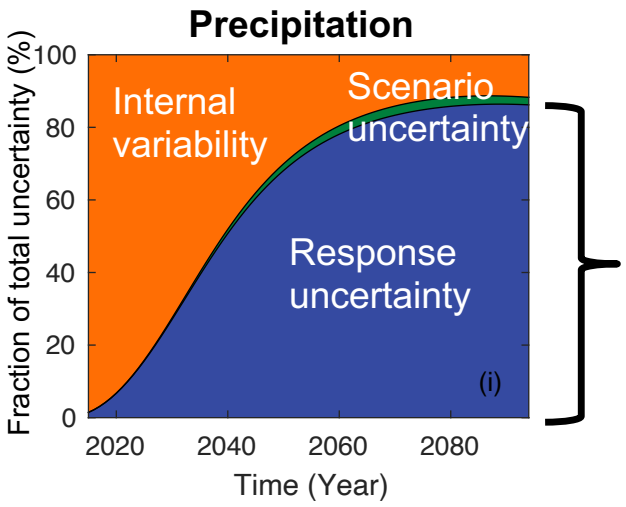




Lehner et al. (2020, *Earth Sys. Dyn.*)

Kuo et al (2023, *Geophys. Res. Letters*); see also Wills et al. (2018, *Geophys. Res. Letters)*

Prospects of model weighting: precipitation



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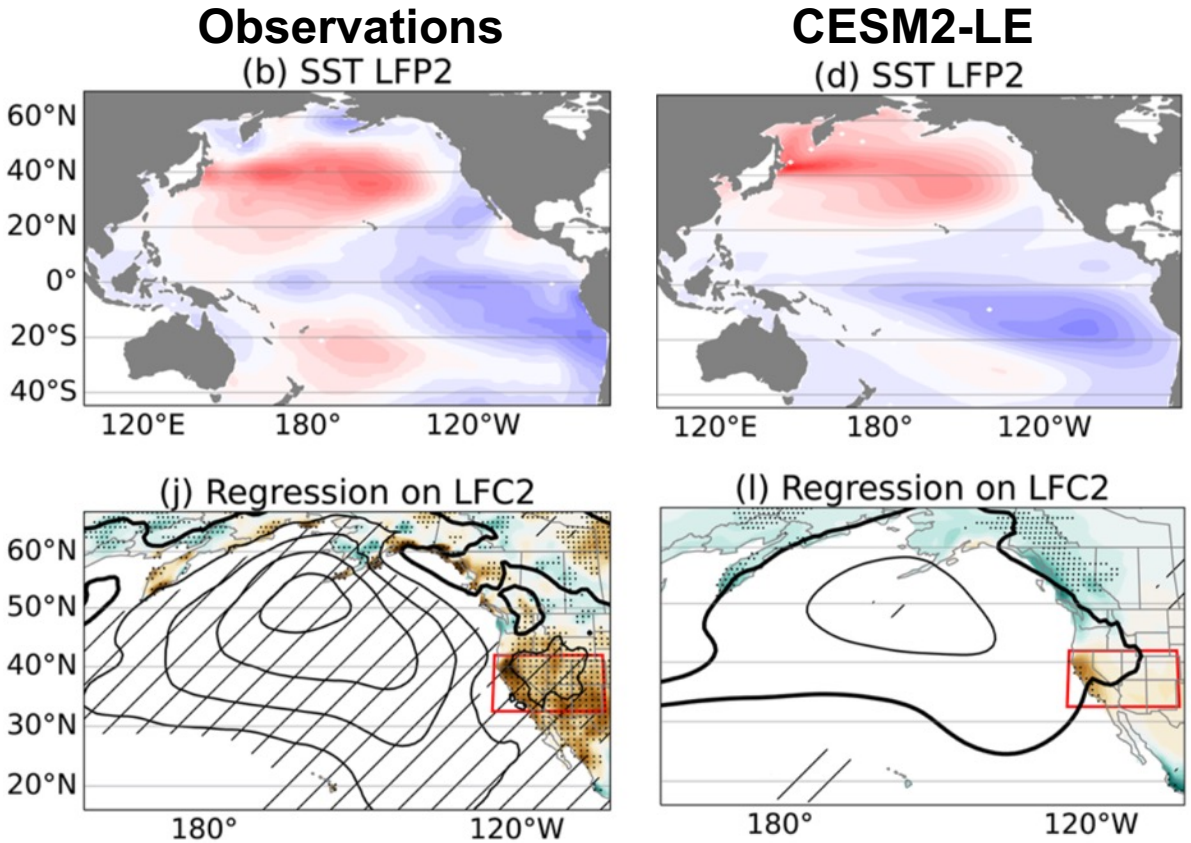

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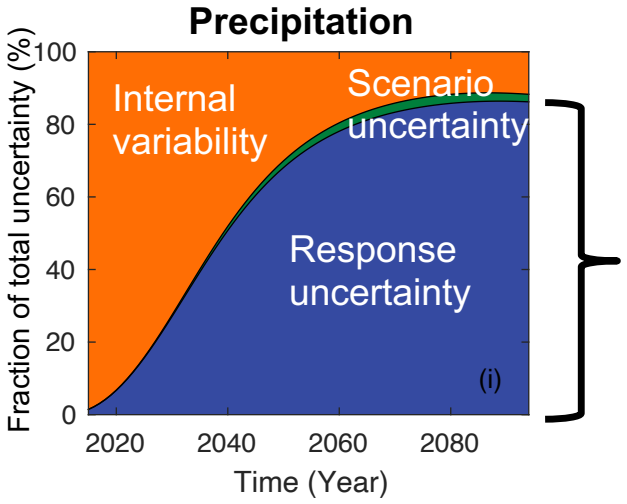
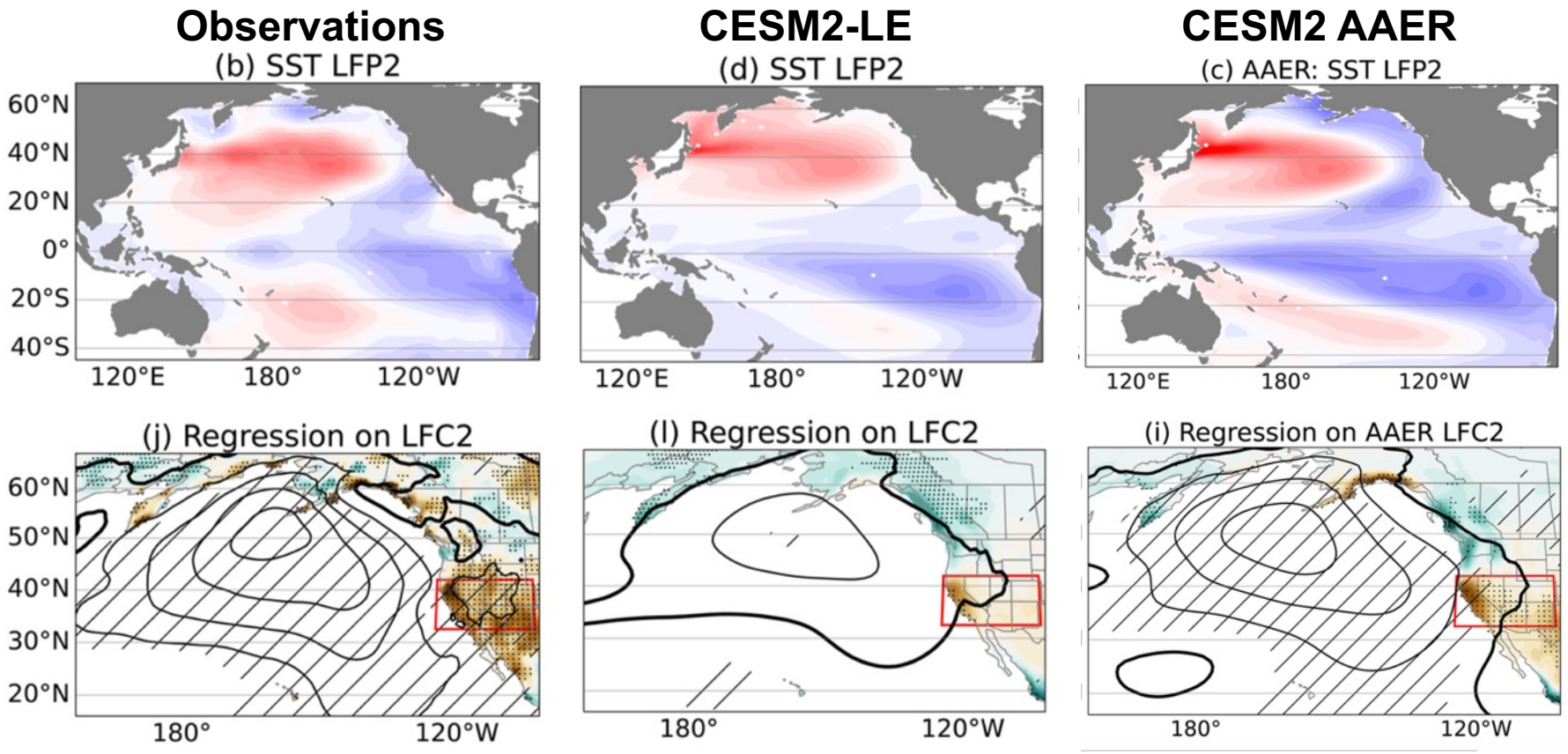


Anthropogenic Aerosols Contribute to the Recent Decline in Precipitation Over the U.S. Southwest ↳ *post-1980*

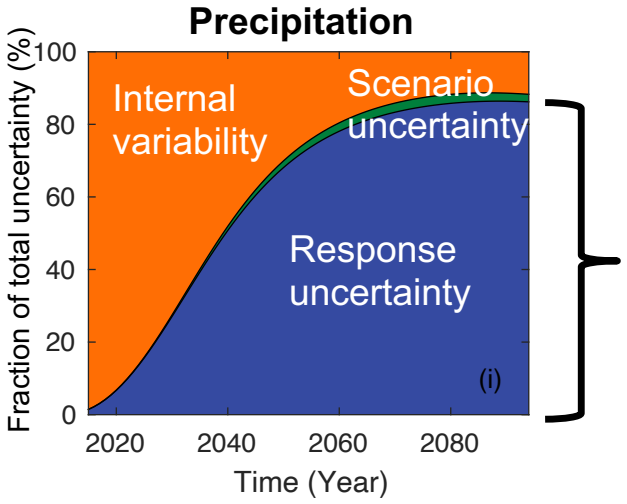
Yan-Ning Kuo[1], Hanjun Kim[1], and Flavio Lehner[1,2,3]

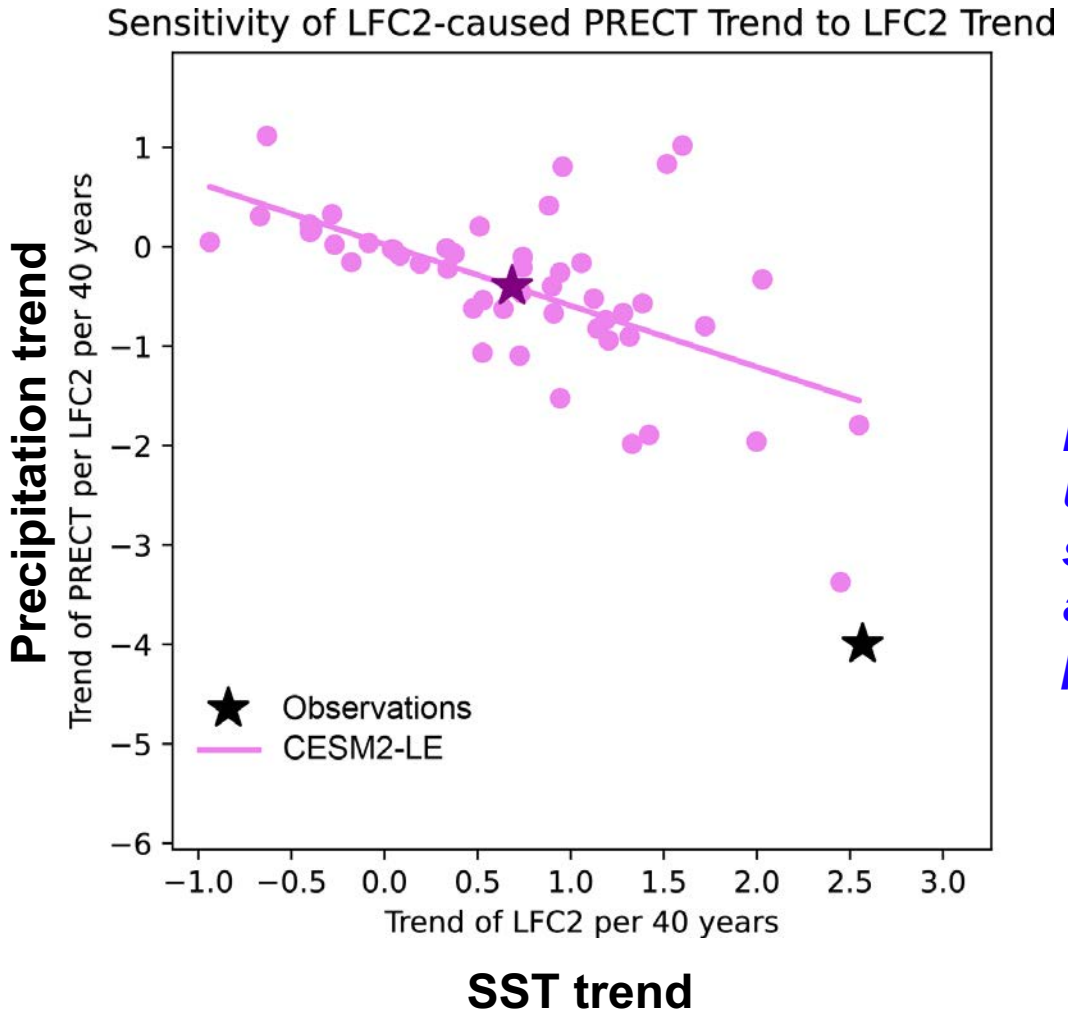


Lehner et al. (2020, *Earth Sys. Dyn.*)

Kuo et al (2023, *Geophys. Res. Letters*); see also Wills et al. (2018, *Geophys. Res. Letters)*

Prospects of model weighting: precipitation





Models might underestimate the strength of the aerosol-SST-precipitation link

Lehner et al. (2020, *Earth Sys. Dyn.*)

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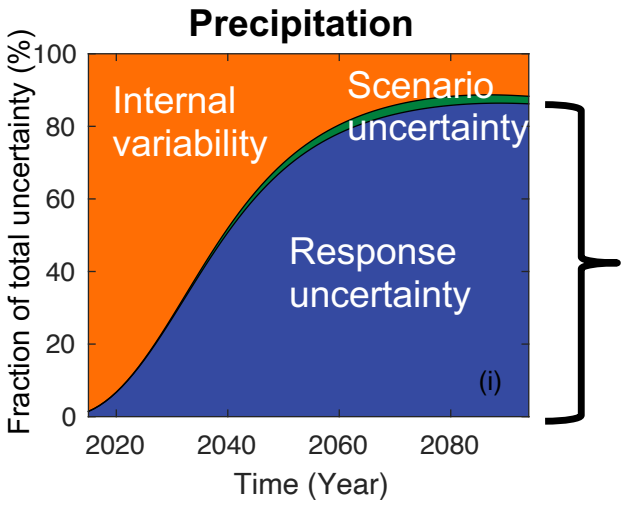
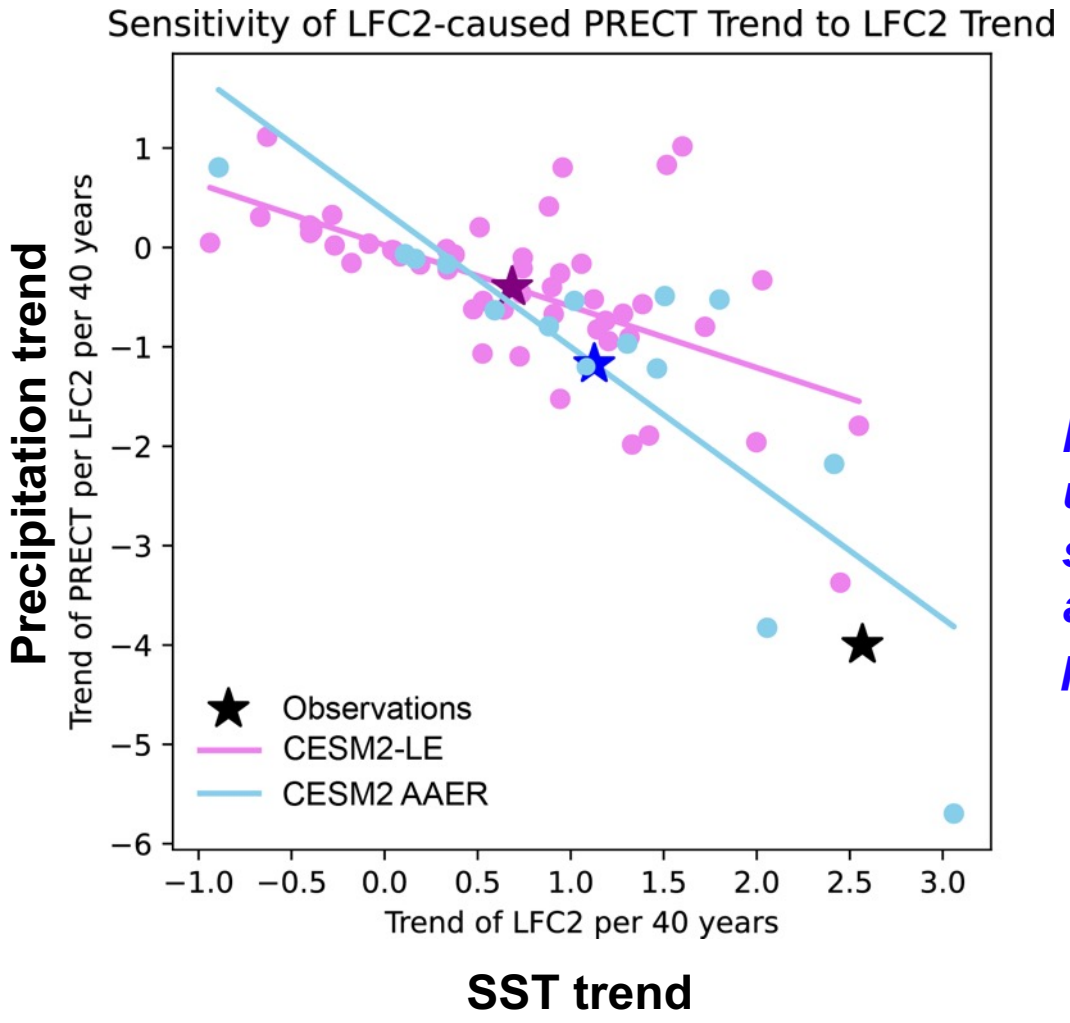
Prospects of model weighting: precipitation





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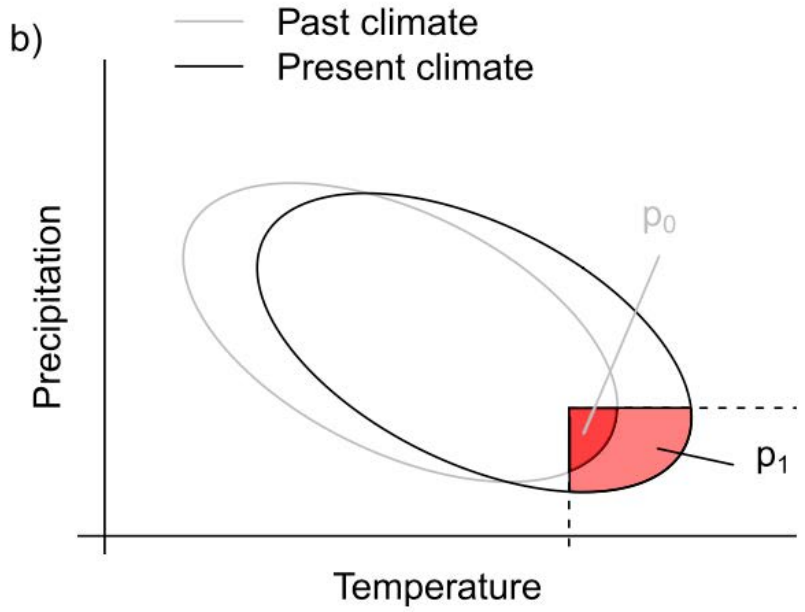
Prospects of model weighting: compound statistics

Attributing Compound Events to Anthropogenic Climate Change

Jakob Zscheischler and Flavio Lehner



Several proposed tests to determine "fit for purpose" of models

Zscheischler and Lehner (2021, *Bull. Am. Met. Soc.*); see also Zscheischler and Fischer (2020, *Weather & Climate Extremes*)

Prospects of model weighting: compound statistics

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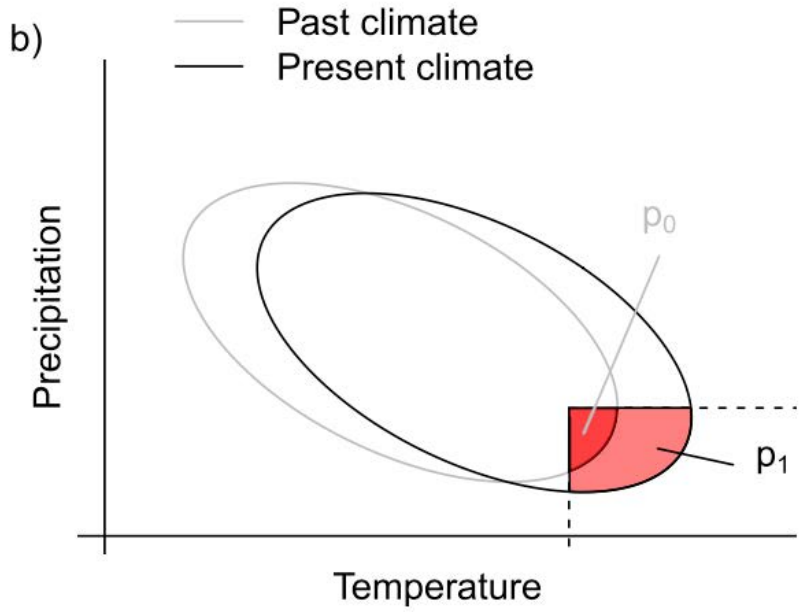
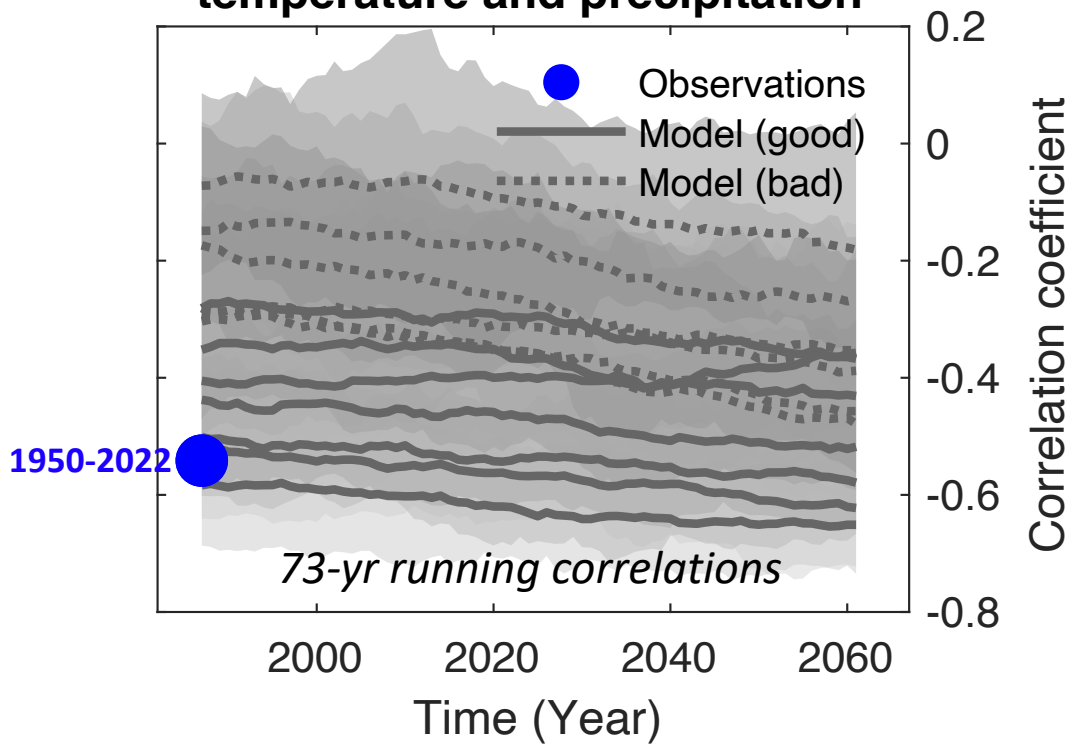


(c) Correlation of detrended temperature and precipitation



Models tend to have a weak correlation between temperature and precipitation

Zscheischler and Lehner (2021, *Bull. Am. Met. Soc.*)

Lehner et al. (in prep.)

Prospects of model weighting: compound statistics

Attributing Compound Events to Anthropogenic Climate Change

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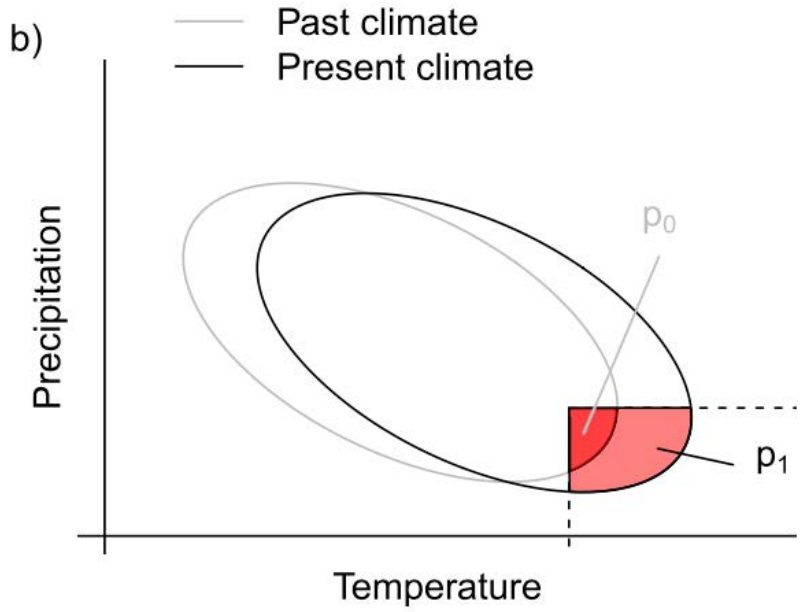
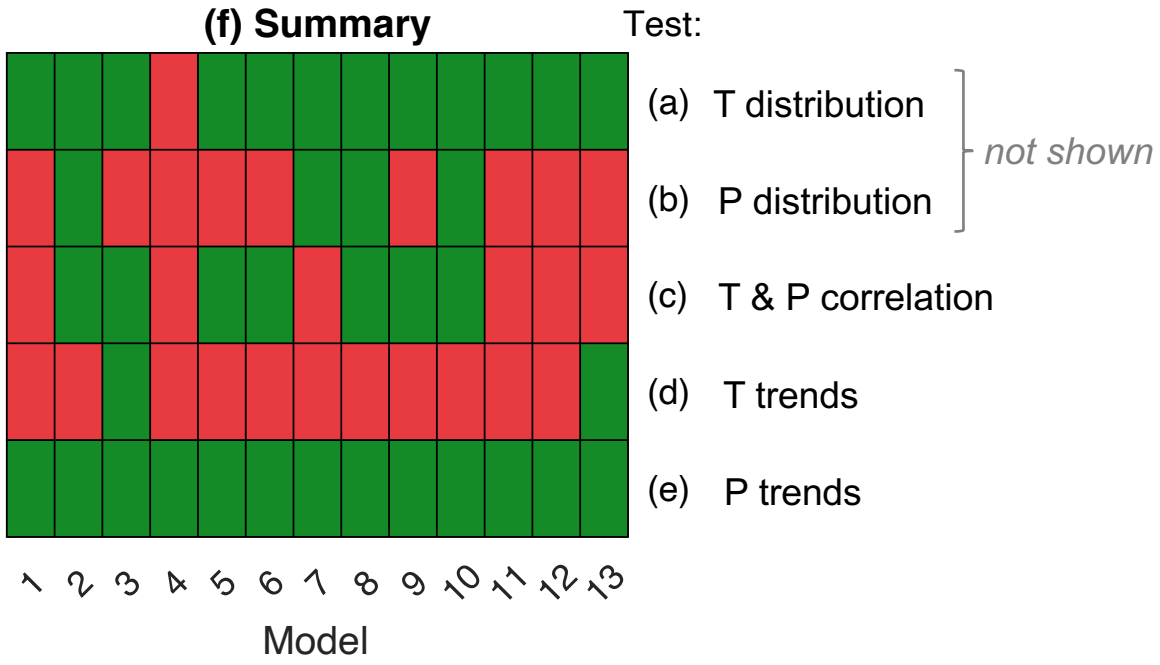
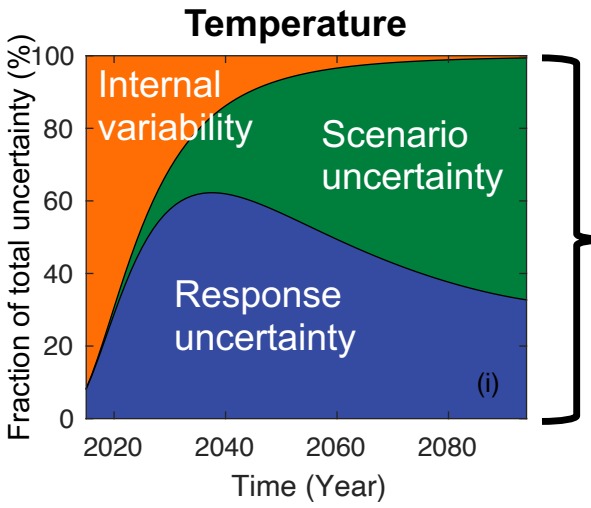
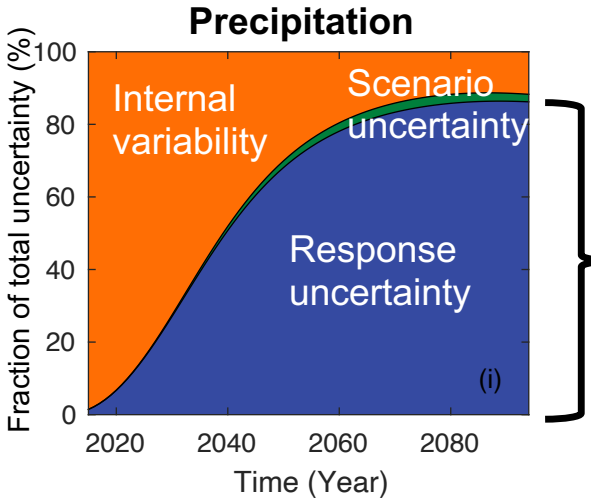




No model passes all tests → model weighting

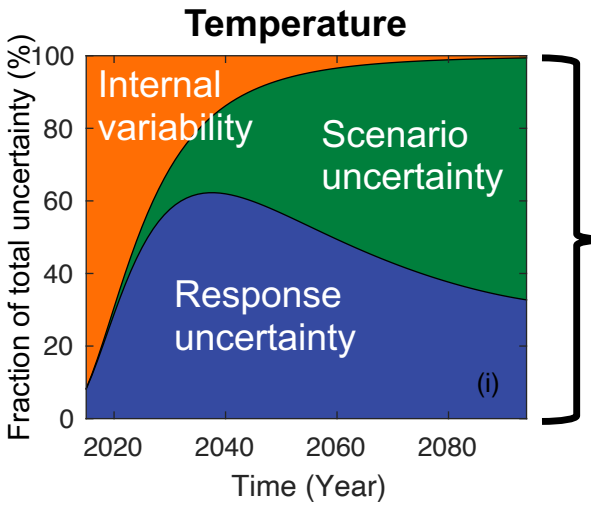
Prospects of model weighting

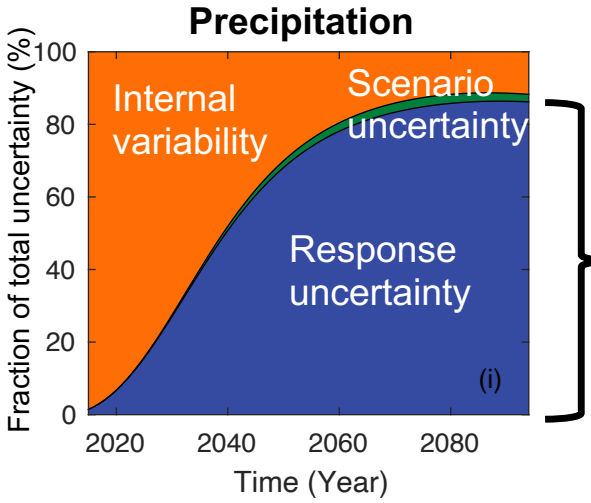




Can we constrain streamflow and reservoir storage projections?

Prospects of model weighting



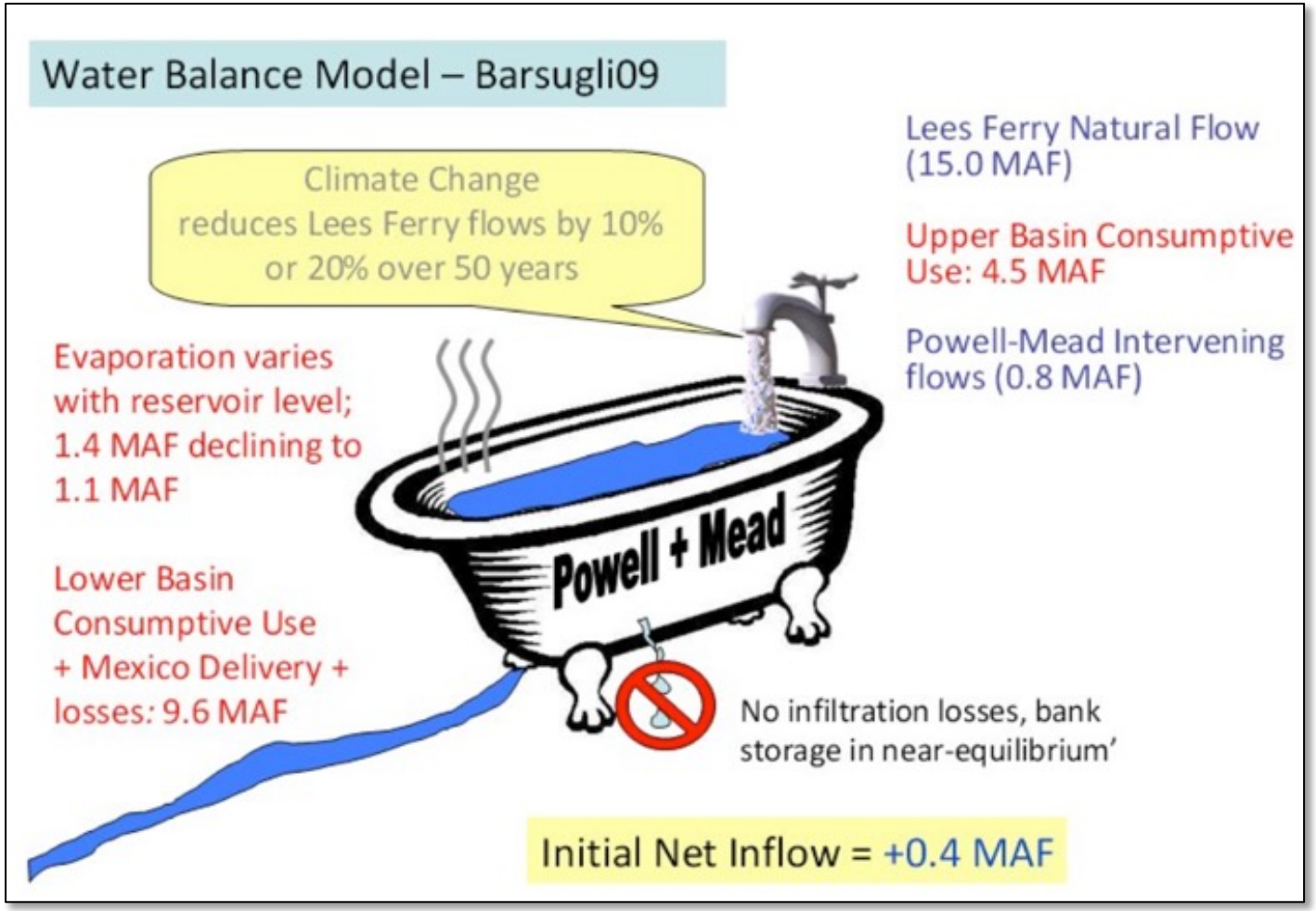


Can we constrain streamflow and reservoir storage projections?

Preliminary!

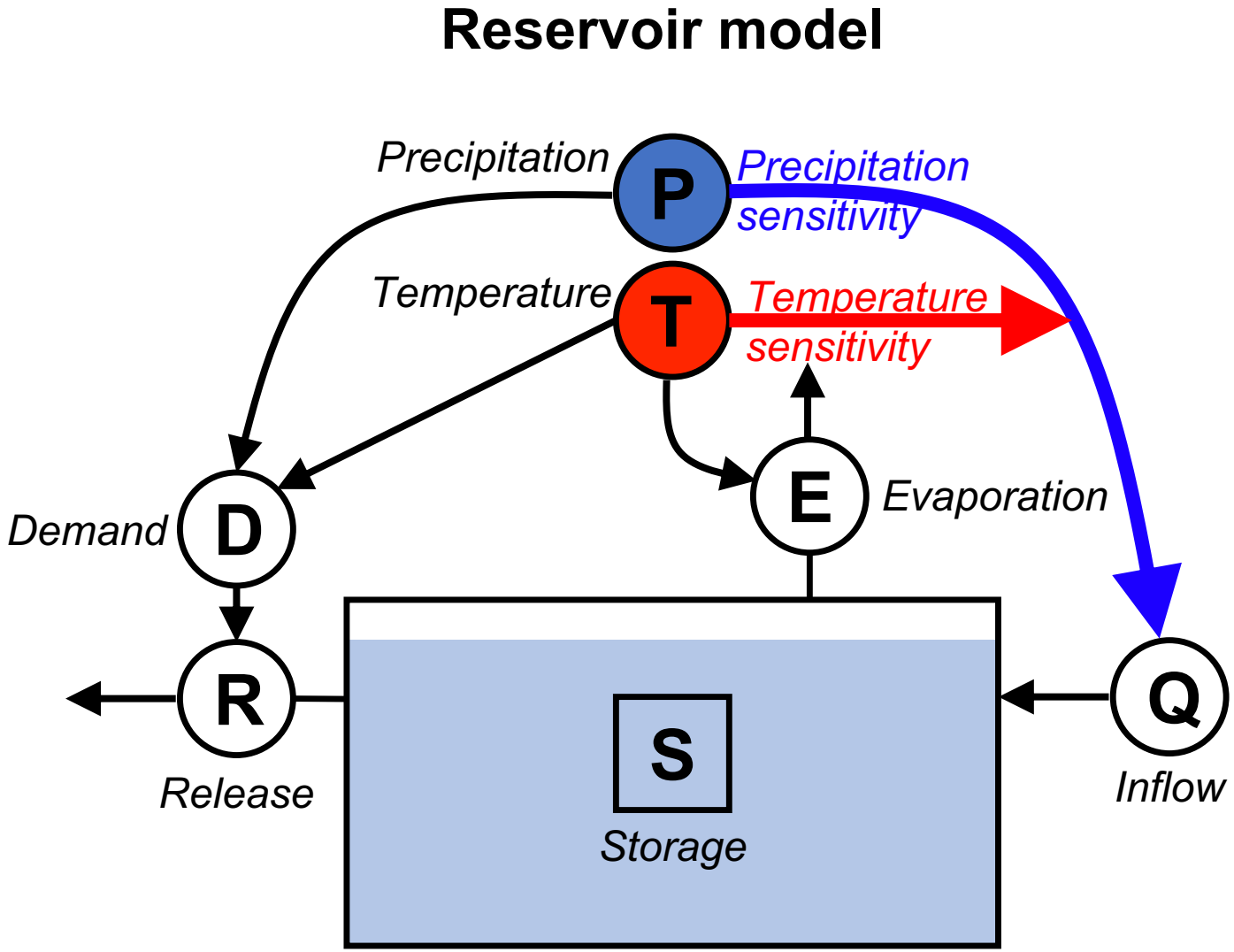
Weighting scheme following
Sanderson et al. (2015, *J. Clim.*)
Knutti et al. (2017, *Geophys. Res. Let.*)

Simple reservoir model application



Barsugli and Lukas (2010, *Western Water Assessment*)

Simple reservoir model application



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Validation of recent runoff trends in Earth System Models (poster)
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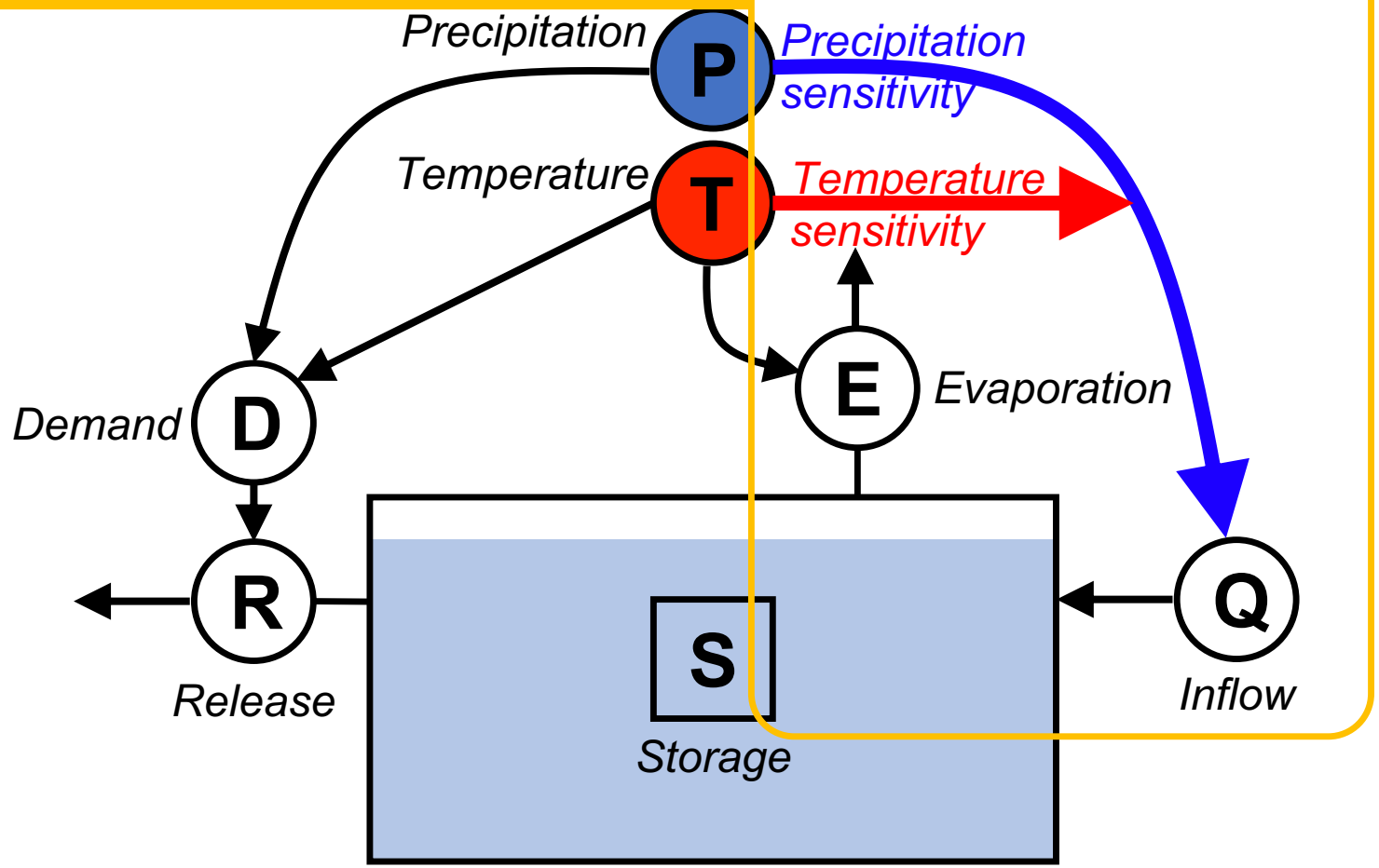
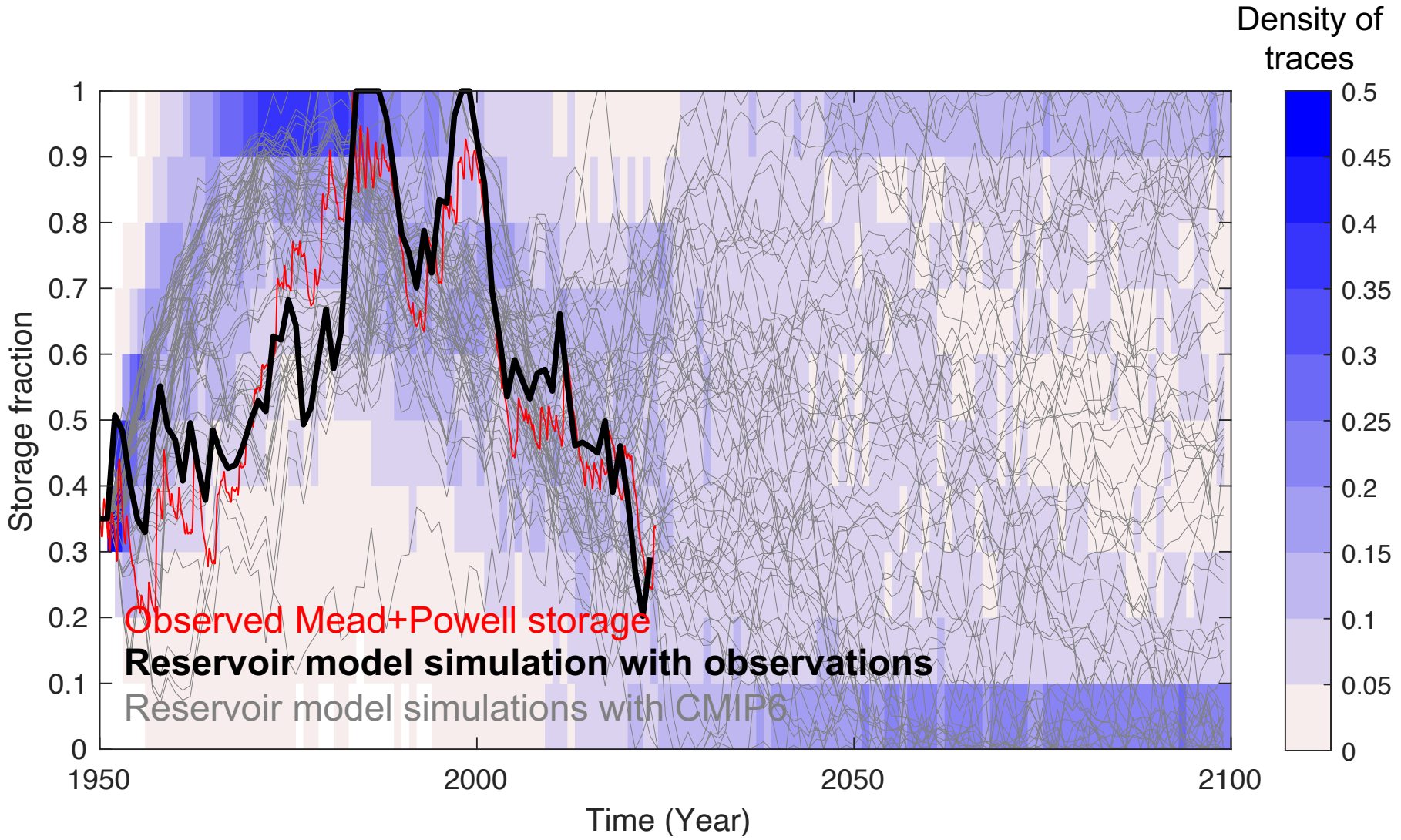
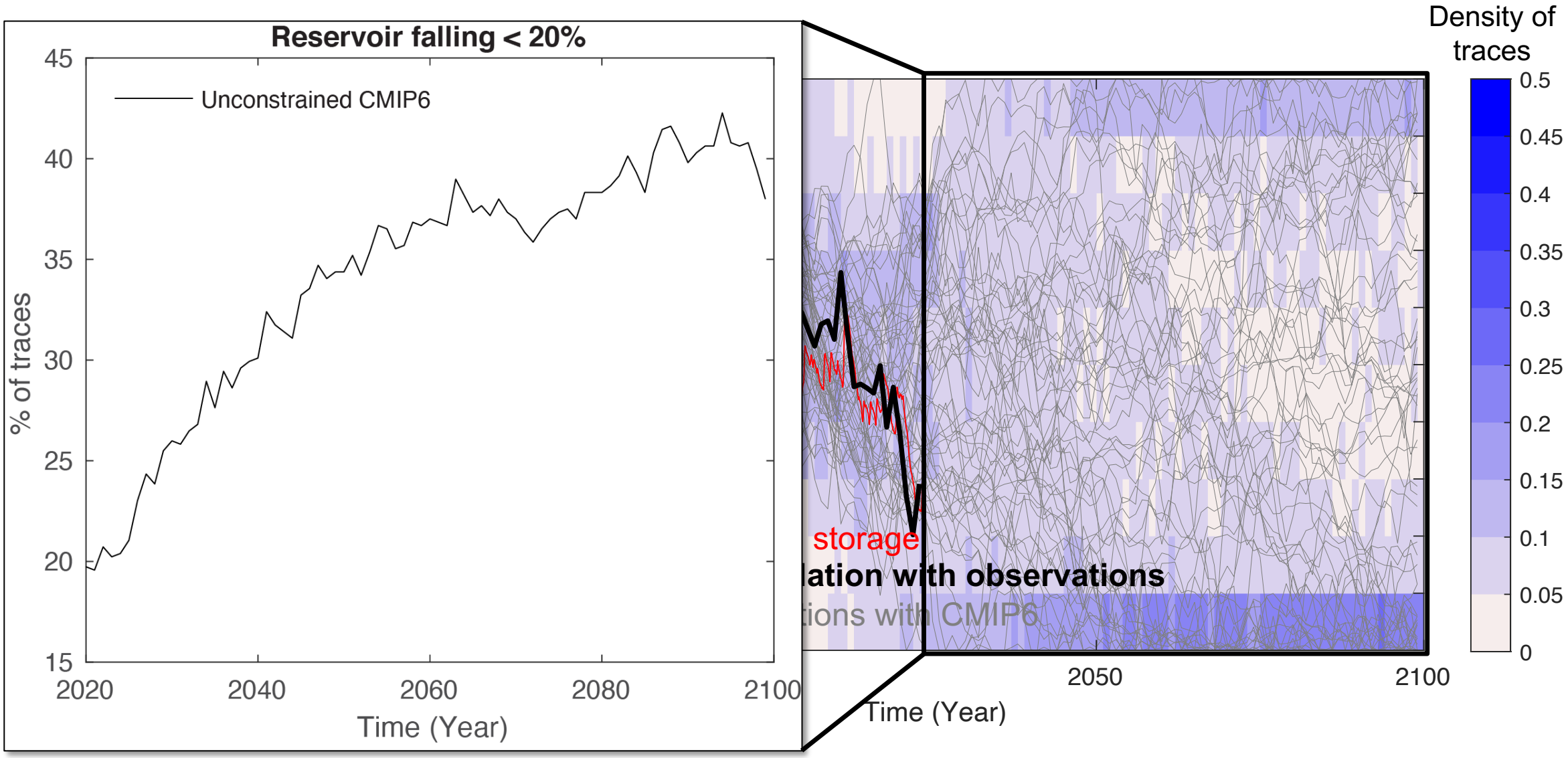


Projections

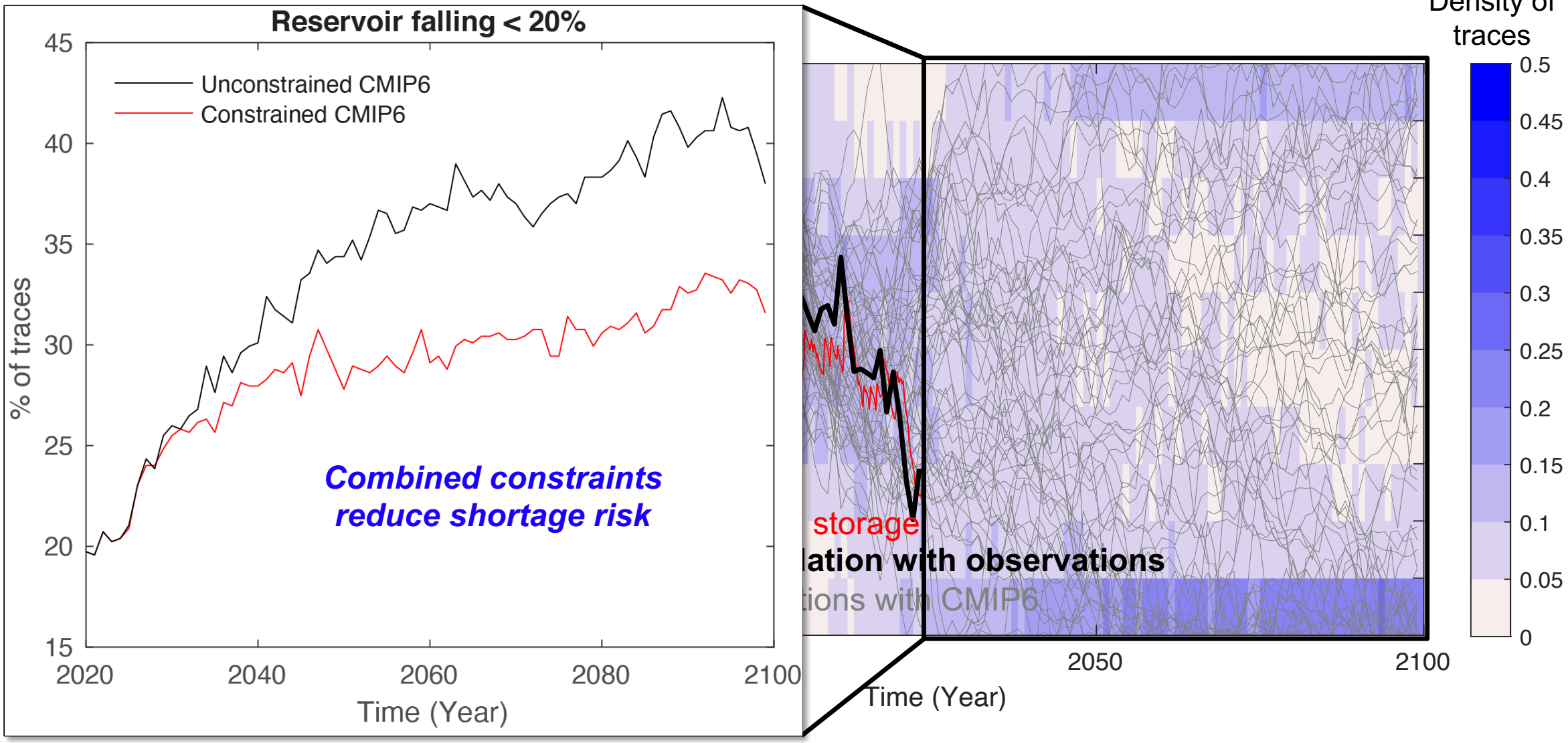
- >600 simulations
- 5 emissions scenarios
- 1 base demand scenario
- 1 set of runoff sensitivities



Projections



Projections



Conclusions

- **Progress on constraints of regional climate change with help of large ensembles**

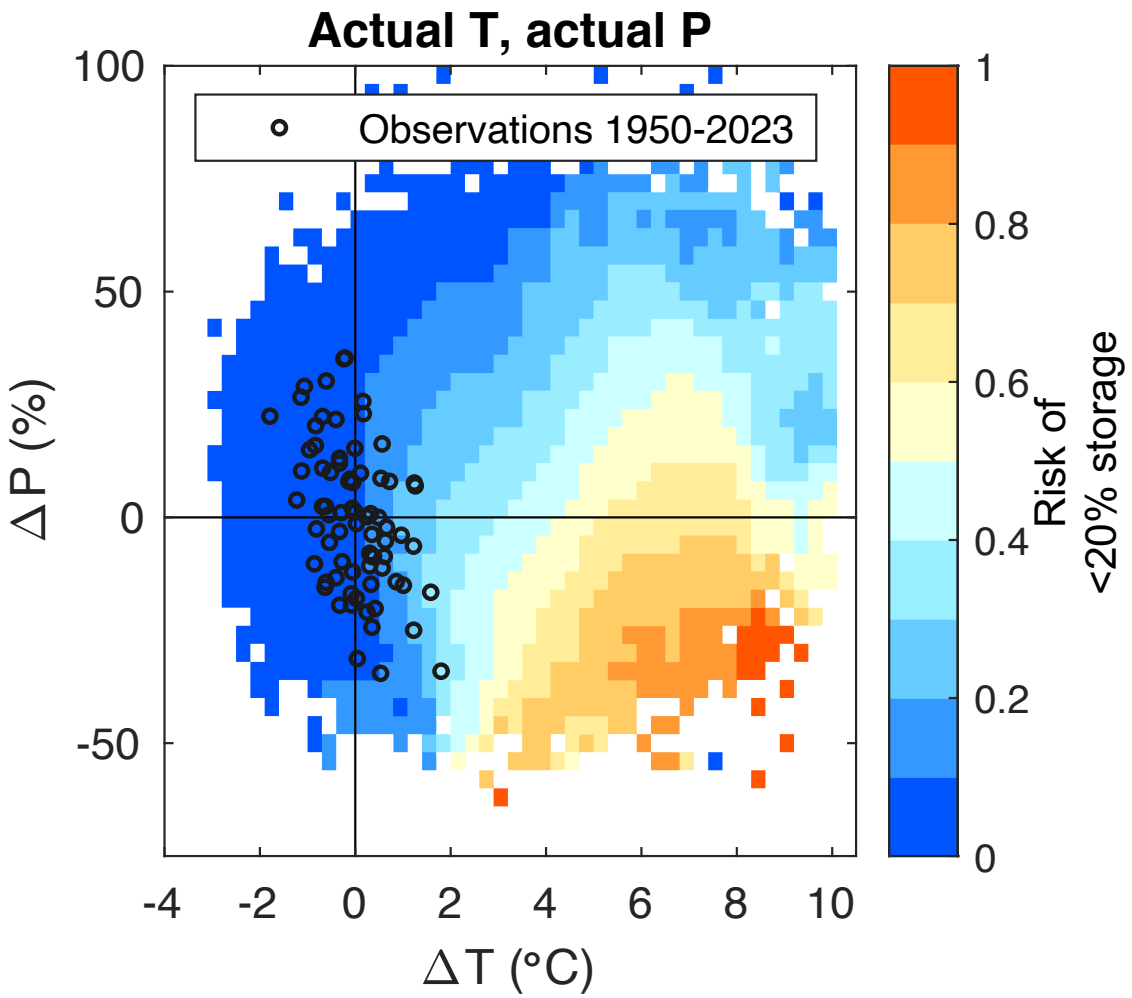
- **Exploring constraints in practical applications**

- **Caveats remain regarding model bias understanding**
  Global temperature trends
  SST-affected teleconnections
  Land-atmosphere coupling
  …

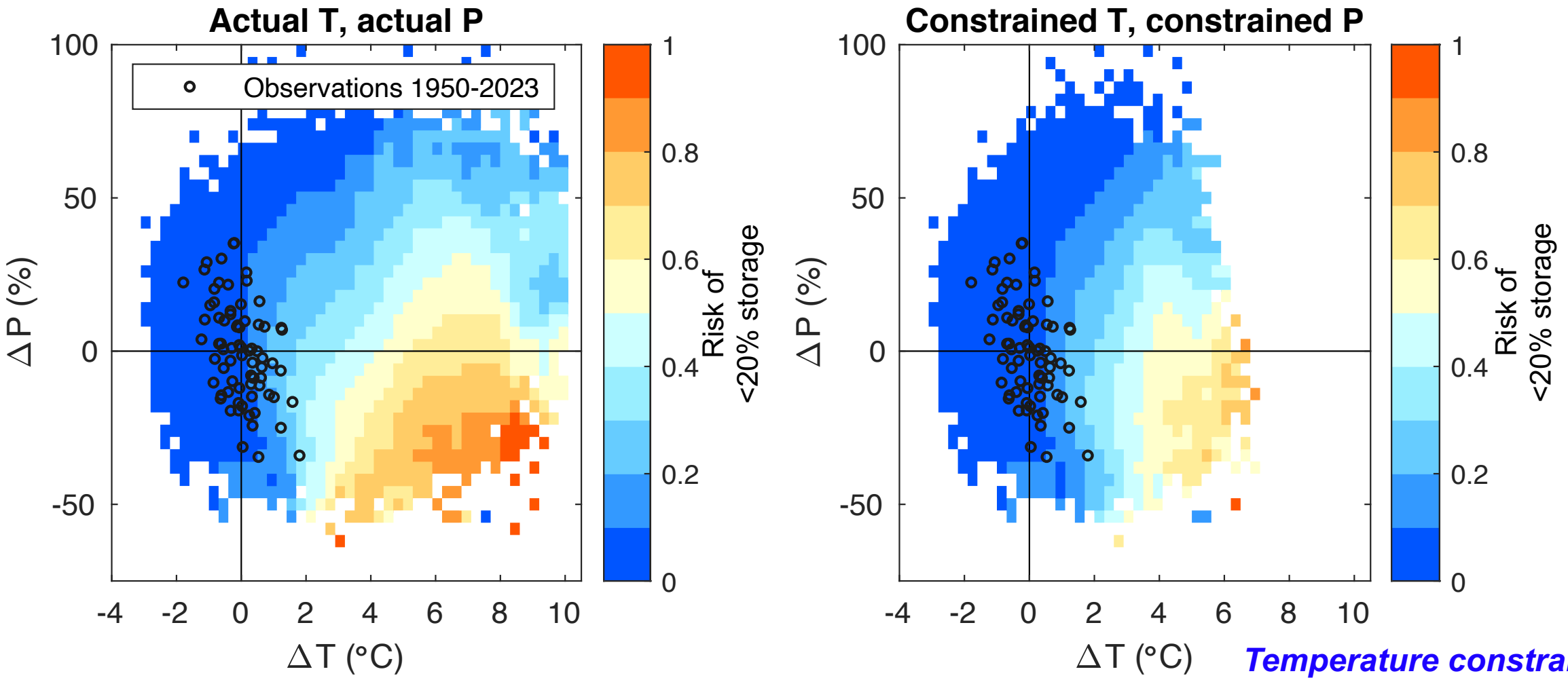
Climate Variability, Change, and Impacts
LEHNER RESEARCH GROUP – EARTH AND ATMOSPHERIC SCIENCES, CORNELL UNIVERSITY
Contact: flavio.lehner@cornell.edu

Extra

Projections

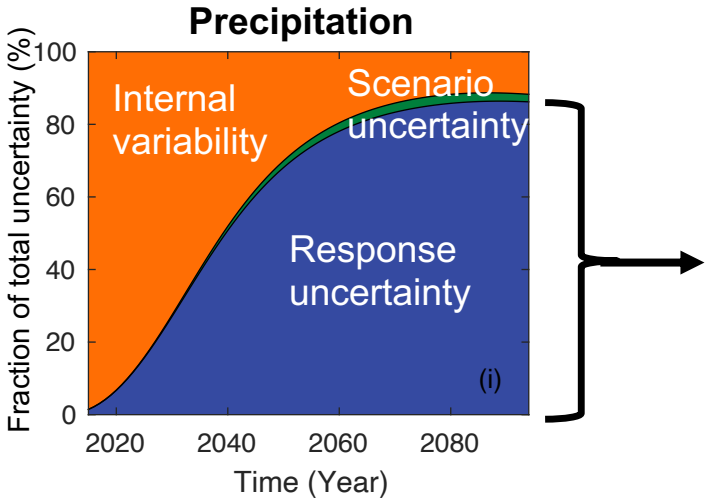


Projections



Temperature constraint is main effect

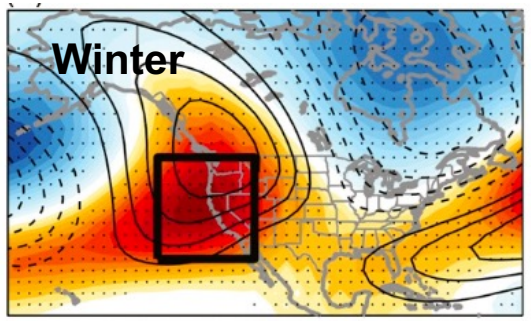
Prospects of model weighting

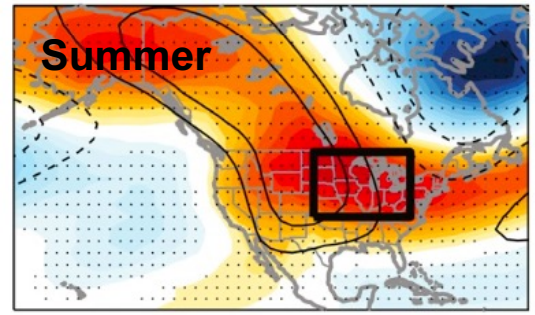


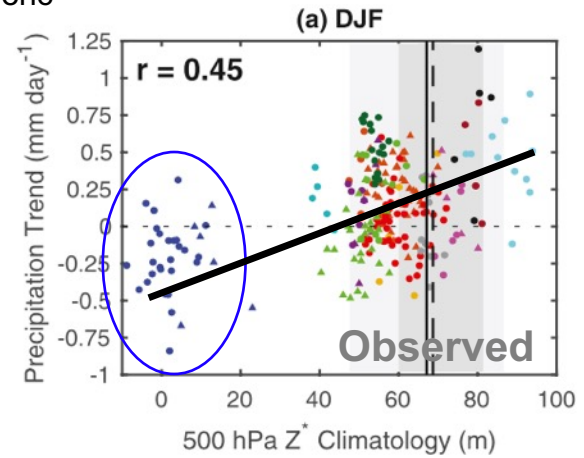
Physical constraints

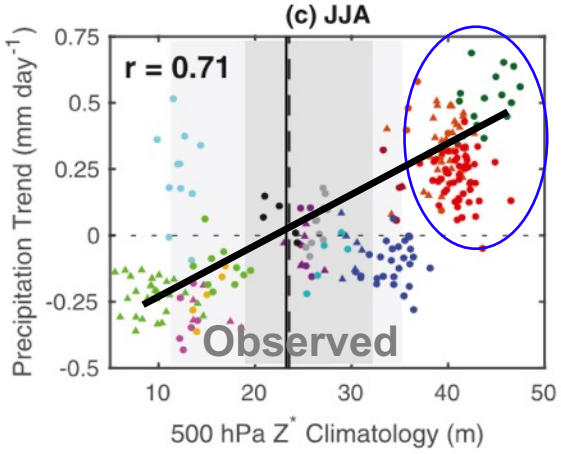
(dynamics)

Present-day representation in mid-tropospheric ridging explains precipitation spread









Models with the most extreme winter drying and summer wetting are less realistic

Lehner et al. (2020, *Earth Sys. Dyn.*)

Grise (2022, *Geophys. Res. Letters*); see also Simpson et al. (2015, *Nat. Clim. Change*)

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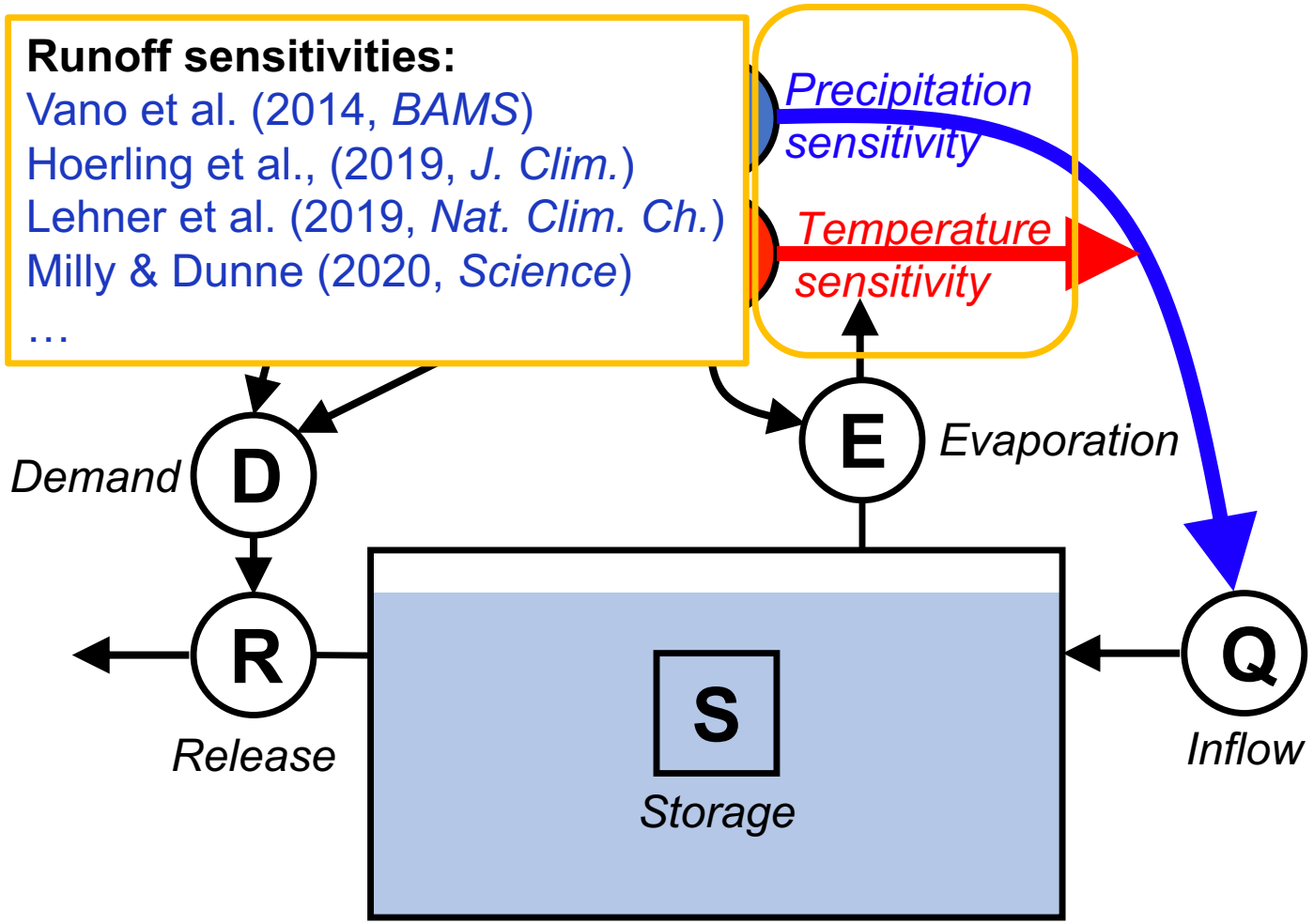
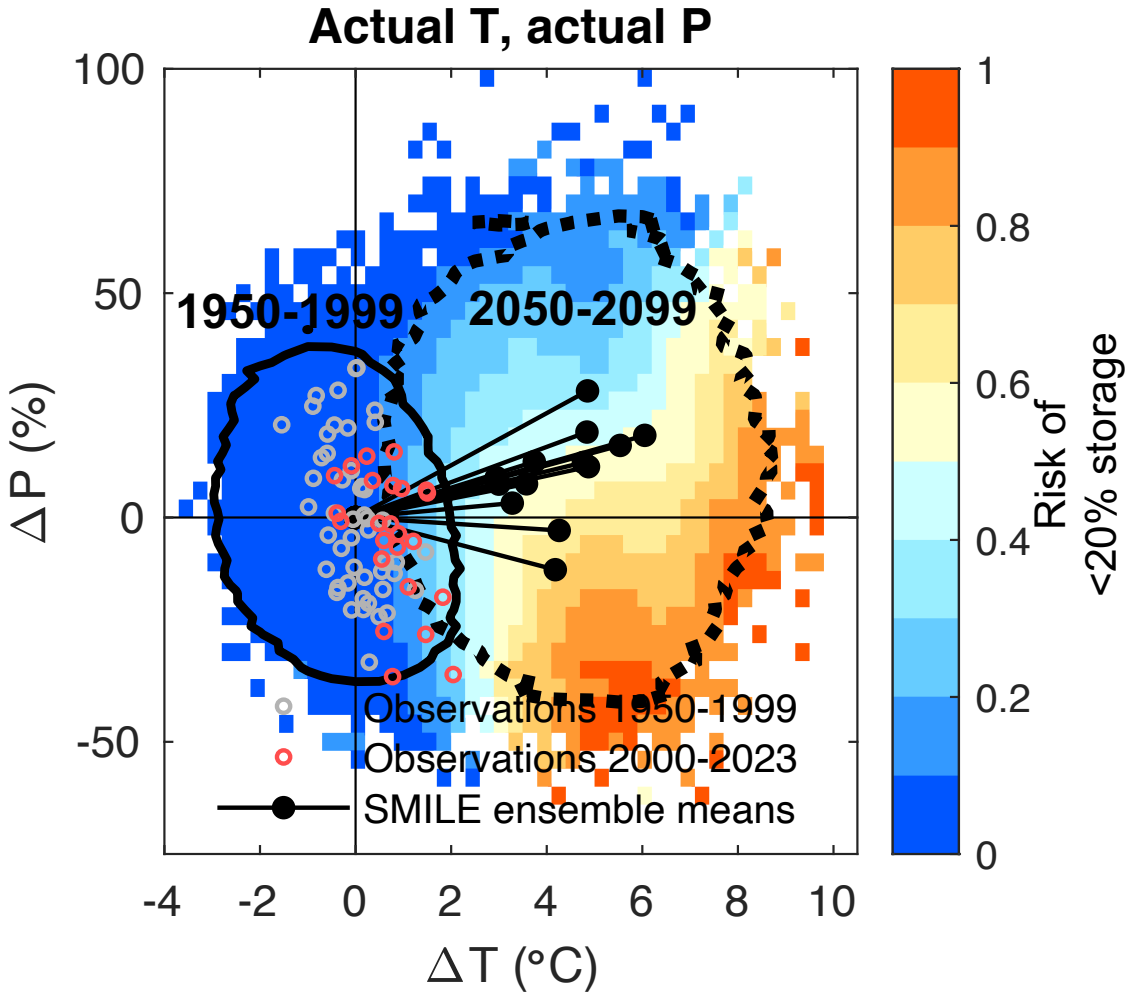
Reservoir model

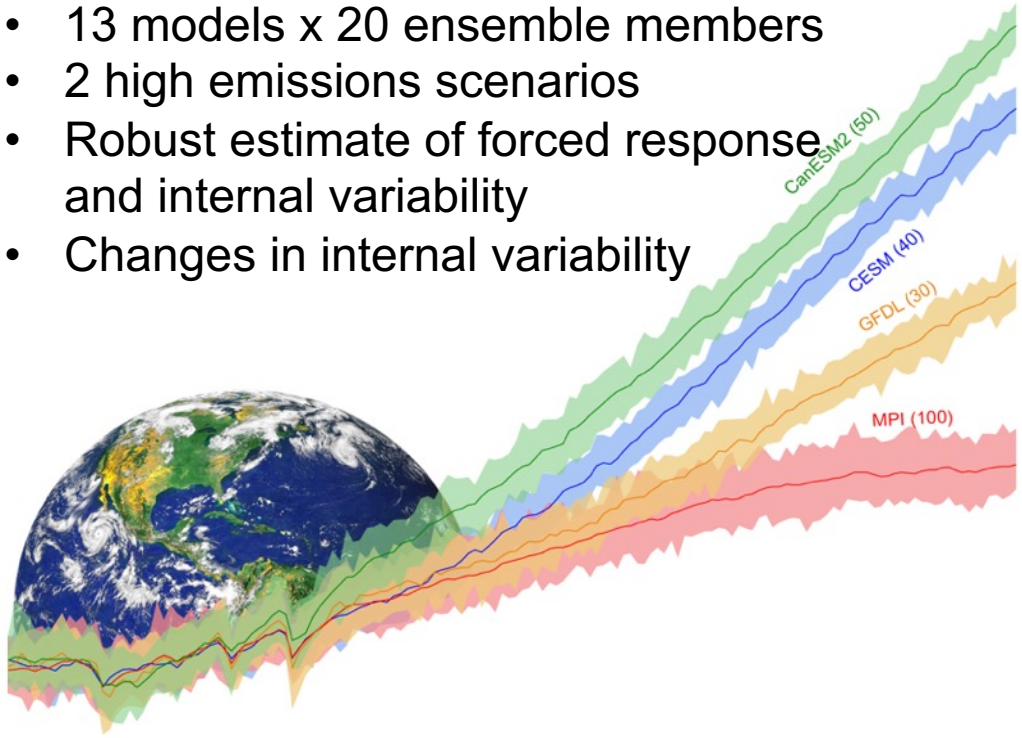
Runoff sensitivities:
Vano et al. (2014, *BAMS*)
Hoerling et al., (2019, *J. Clim.*)
Lehner et al. (2019, *Nat. Clim. Ch.*)
Milly & Dunne (2020, *Science*)
…



Projections with Single Model Initial-Condition Large Ensembles



- 13 models x 20 ensemble members
- 2 high emissions scenarios
- Robust estimate of forced response and internal variability
- Changes in internal variability



Deser et al. (2020, *Nat. Clim. Change*)

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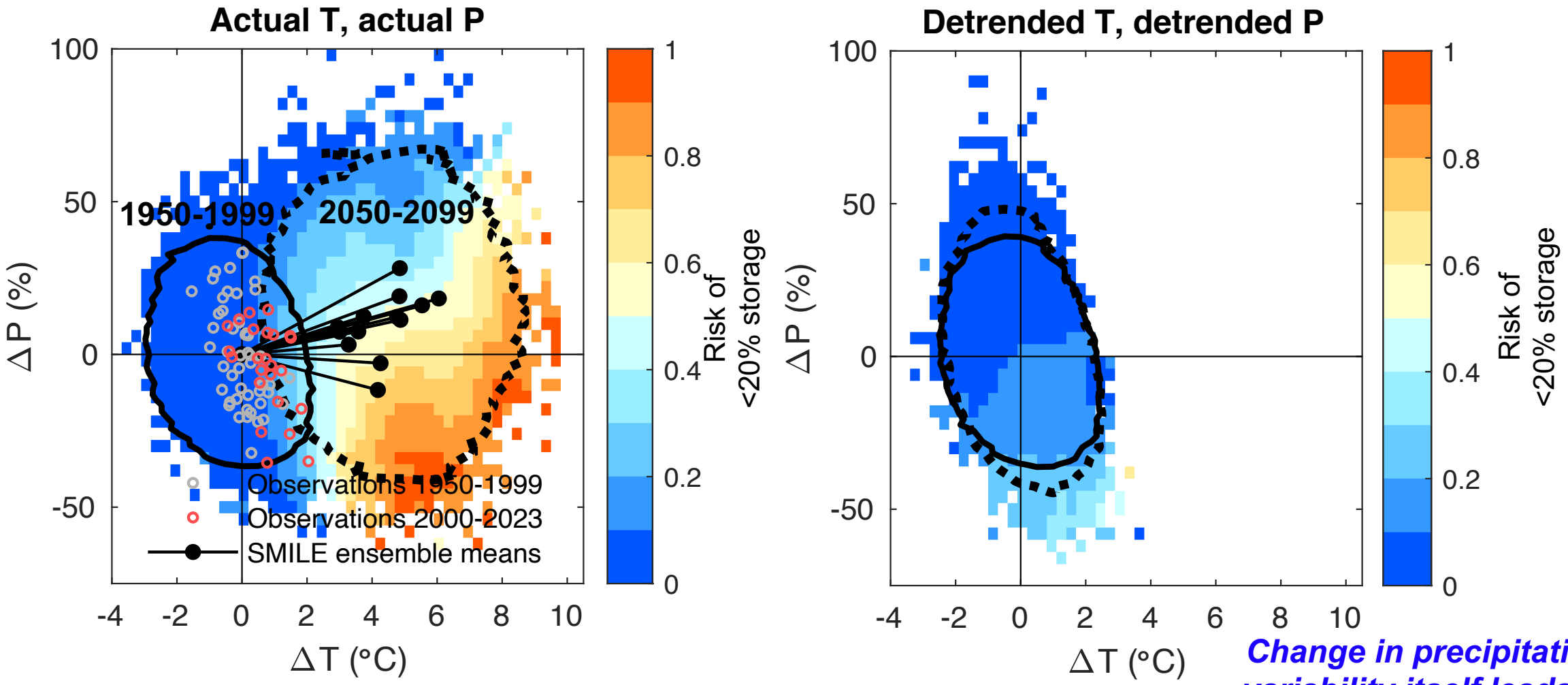

Change in precipitation variability itself leads to changes in risk