



Projecting Water Availability and Drought Risk for Hydropower

ESIG 2025 Forecasting & Markets Workshop

Presented by: **Shih-Chieh Kao** (kaos@ornl.gov)

Shih-Chieh Kao¹, Moetasim Ashfaq¹, Deeksha Rastogi¹, Sudershan Gangrade¹, Rocio Uría Martínez¹, Ganesh Ghimire¹, Nathalie Voisin², Dan Broman², Alisha Fernandez²

¹ Oak Ridge National Laboratory, ² Pacific Northwest National Laboratory



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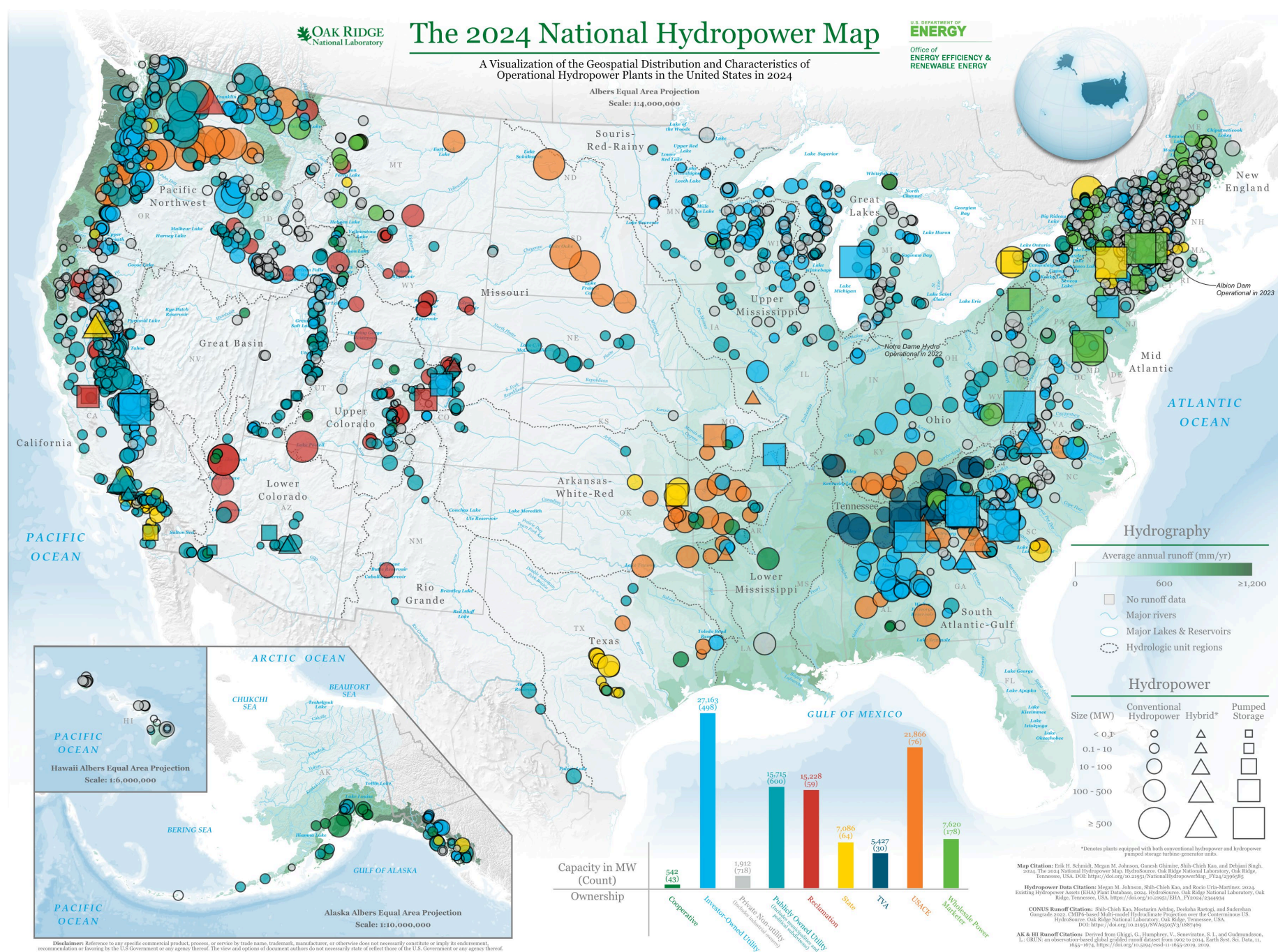
Hydropower in the United States

Over 2200 US hydropower plants

- 80.5 GW conventional hydro, 6% generation
- 22 GW pumped storage, 93% energy storage
- 132 (40% capacity) federal

Highly affected by hydrologic variability

- Extreme events (droughts and floods)
- Changing timing of supply and demand



Projecting Water Availability for Hydropower Production

Provide hydrologic and hydropower projections for 132 US federal hydropower plants.

- Close collaboration with Power Marketing Administrations, Reclamation, USACE, USGS, and other agencies

Identify risks impacting the resilience of future hydropower generation.

- Intensifying droughts and floods
- Conflicting timing of supply and demand changes

Produce downscaled and bias-corrected future water availability projections over the CONUS.

- Provide public dataset supporting long-term planning

Serve as technical basis of the DOE SECURE Water Act Section 9505 Report to Congress.



Driven by SECURE Water Act

Congress authorized the SECURE (Science and Engineering to Comprehensively Understand and Enhance) Water Act, Pub. L. 111-11, in 2009

Section 9501. Findings

Section 9502. Definitions

Section 9503. Reclamation Climate Change and Water Program

– Reclamation Report to Congress

Section 9504. Water Management Improvement

Section 9505. Hydroelectric Power Assessment

– DOE Report to Congress

Section 9506. Climate Change and Water Intragovernmental Panel

Section 9507. Water Data Management by the U.S. Geological Survey

Section 9508. National Water Availability and Use Assessment Program

– USGS Report to Congress

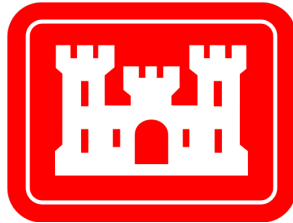
Section 9509. Research Agreement Authority

Section 9510. Effect

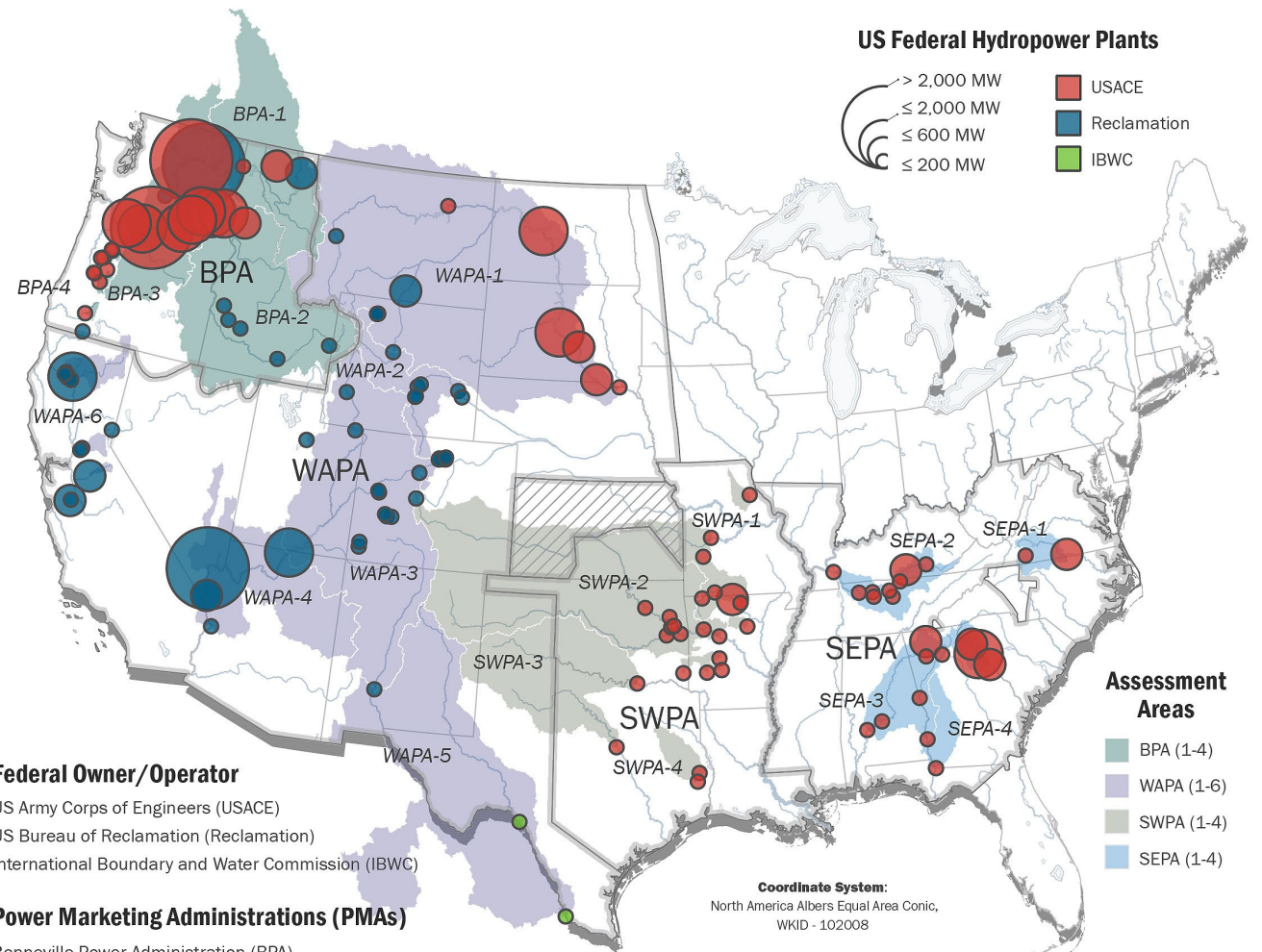
132 Power Plants in 18 Study Areas



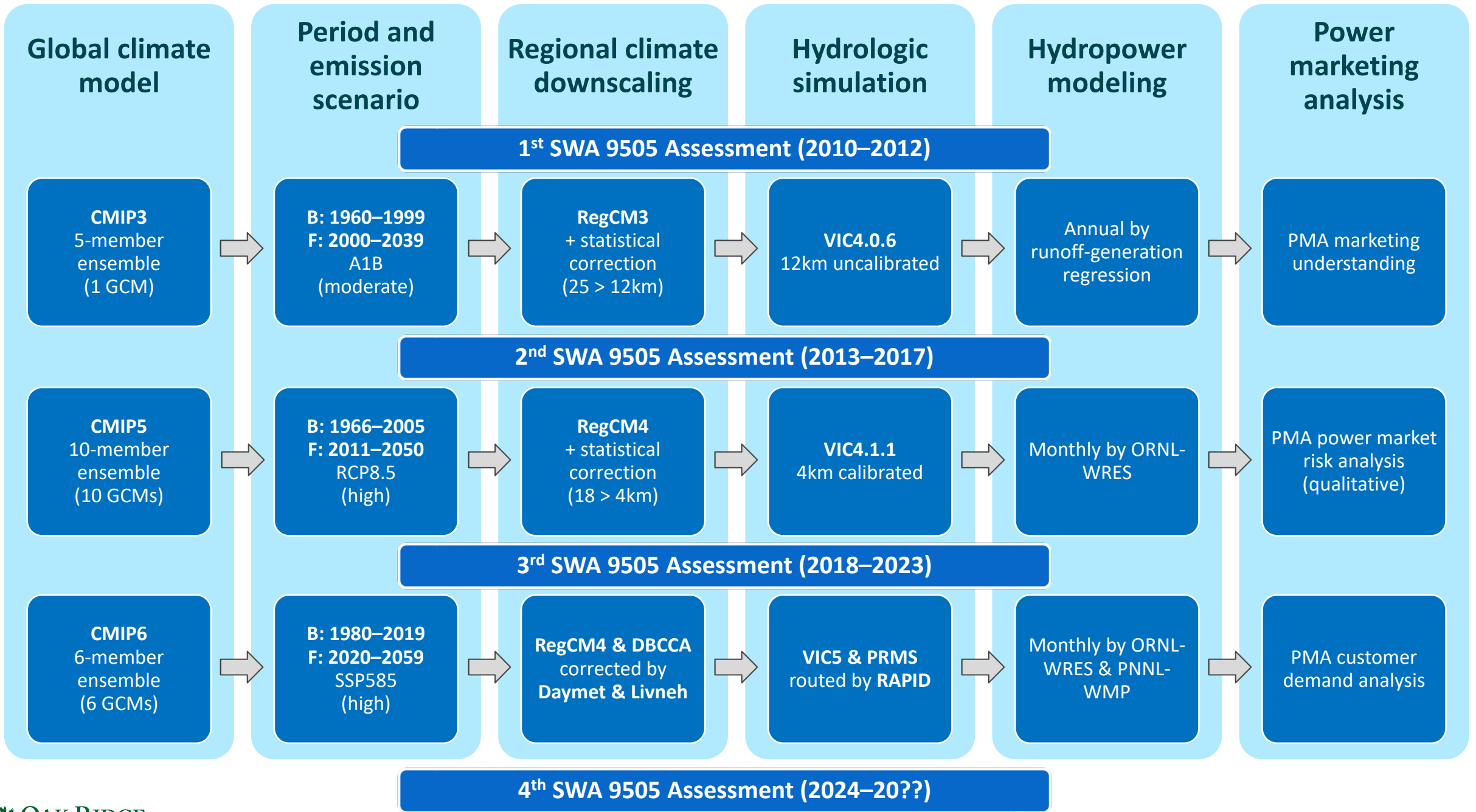
Western Area Power Administration



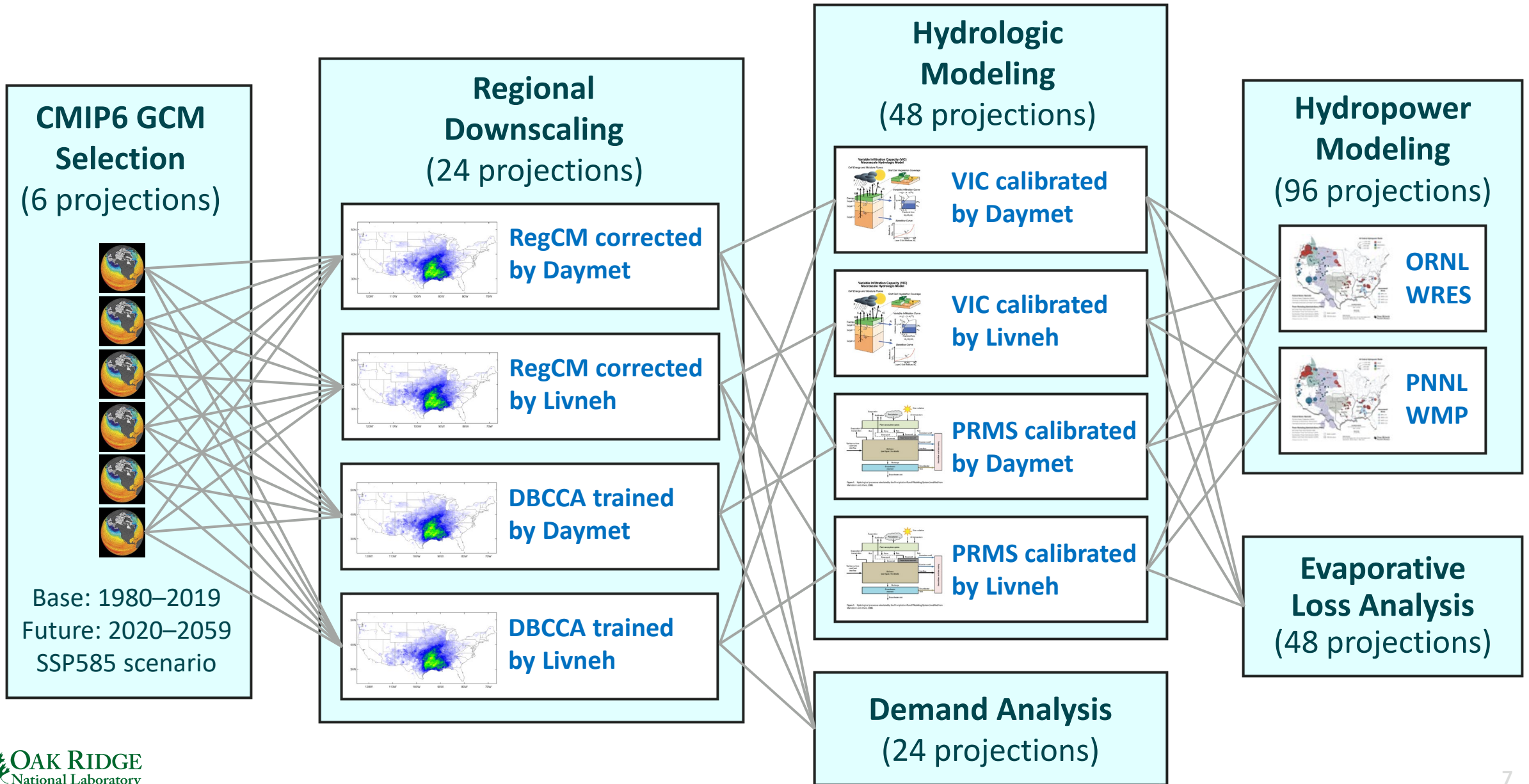
PMA	# of Plants	Capacity (GW)
BPA	31	20.5
WAPA	55	10.2
SWPA	24	2.2
SEPA	22	4.1
Total	132	37.0



Cartographer: Nicole Samu - 12/4/2018



Use A Multi-Model Framework to Help Reveal Uncertainty

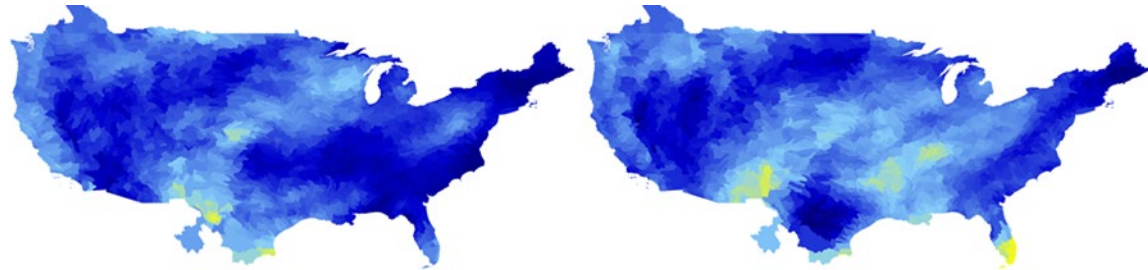


Projected Changes in Annual Precipitation and Temperature

Change in Precipitation (%)

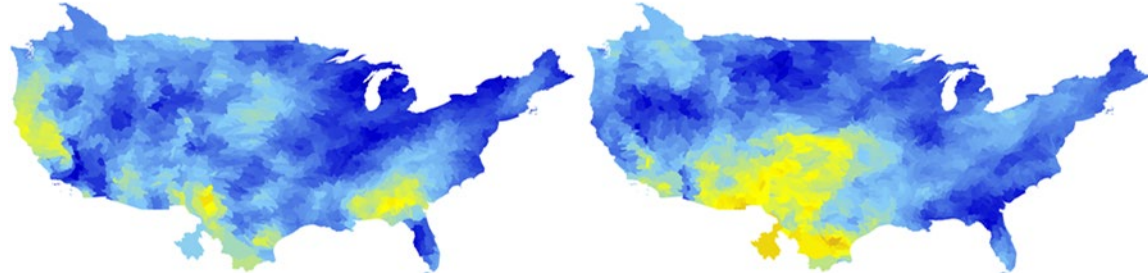
F(2020–2059) - B(1980–2019)

Change in Temperature (C)



(c) CNRM-ESM2-1 ssp585 r1i1p1f2

(d) MPI-ESM1-2-HR ssp585 r1i1p1f1



(e) MRI-ESM2-0 ssp585 r1i1p1f1

(f) NorESM2-MM ssp585 r1i1p1f1

Percent Change - Mean Annual Precipitation



(c) CNRM-ESM2-1 ssp585 r1i1p1f2

(d) MPI-ESM1-2-HR ssp585 r1i1p1f1



(e) MRI-ESM2-0 ssp585 r1i1p1f1

(f) NorESM2-MM ssp585 r1i1p1f1

Mean Annual Temperature Change (°C)



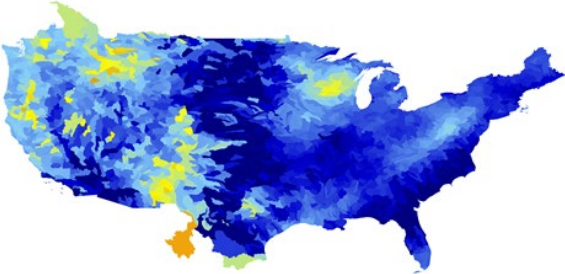
Projected Changes in Annual Runoff

VIC

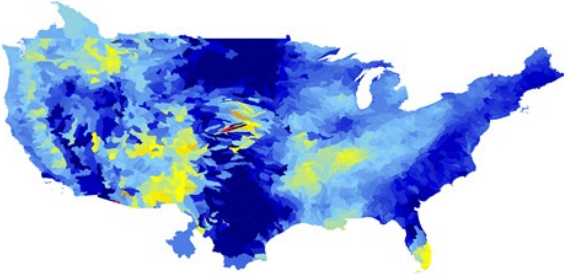
F(2020–2059) - B(1980–2019)

PRMS

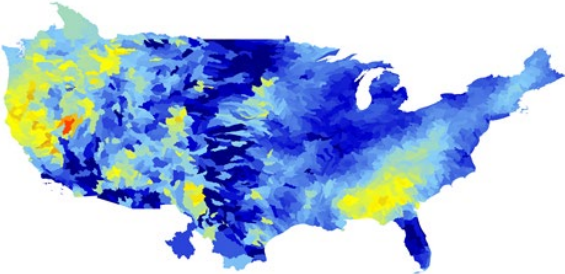
(a) ACCESS-CM2 ssp585 r1i1p1f1



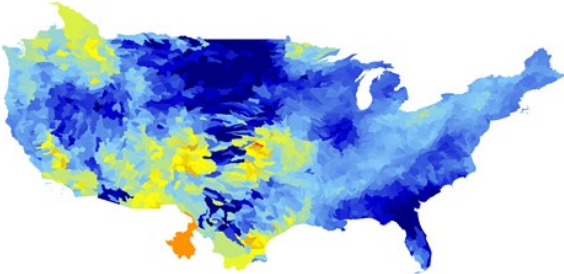
(b) BCC-CSM2-MR ssp585 r1i1p1f1



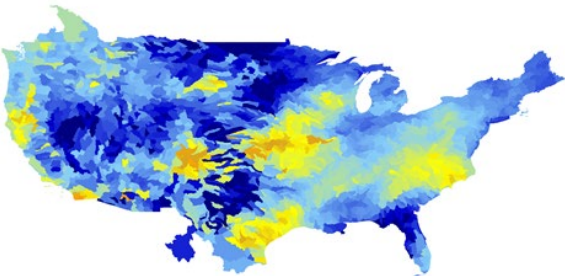
(c) CNRM-ESM2-1 ssp585 r1i1p1f2



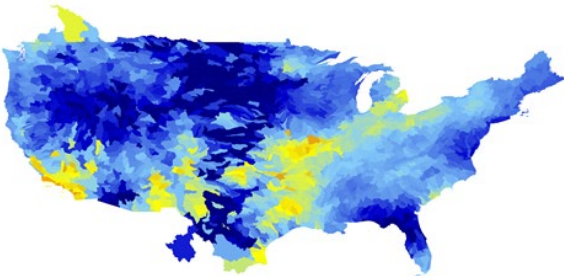
(d) MPI-ESM1-2-HR ssp585 r1i1p1f1



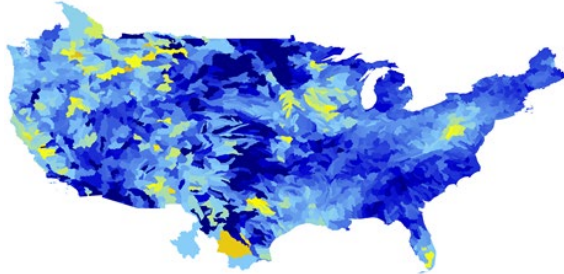
(e) MRI-ESM2-0 ssp585 r1i1p1f1



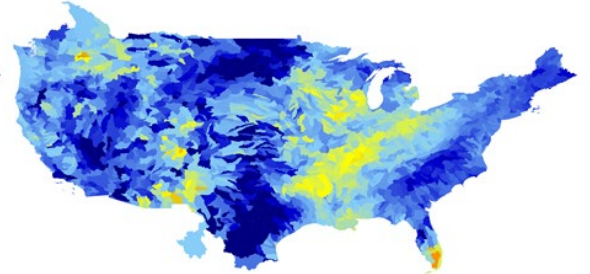
(f) NorESM2-MM ssp585 r1i1p1f1



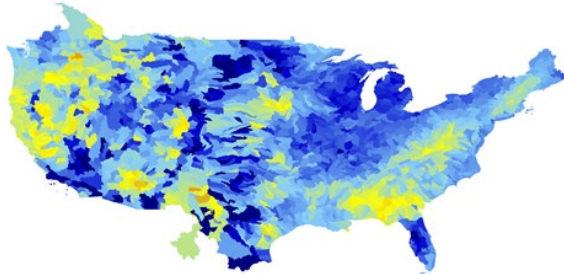
(a) ACCESS-CM2 ssp585 r1i1p1f1



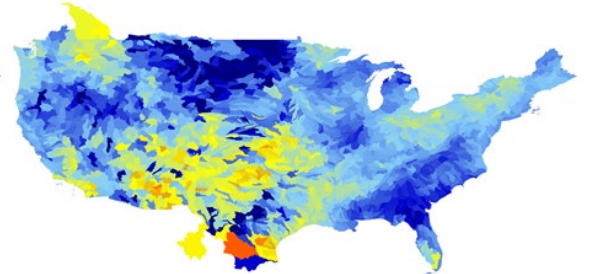
(b) BCC-CSM2-MR ssp585 r1i1p1f1



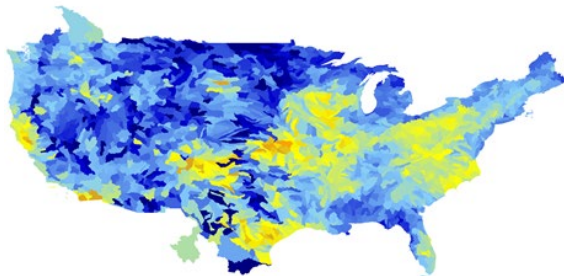
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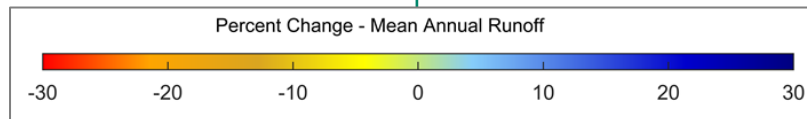
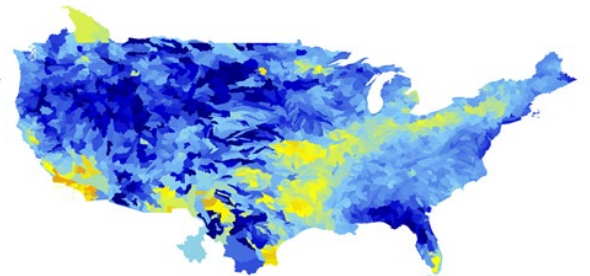
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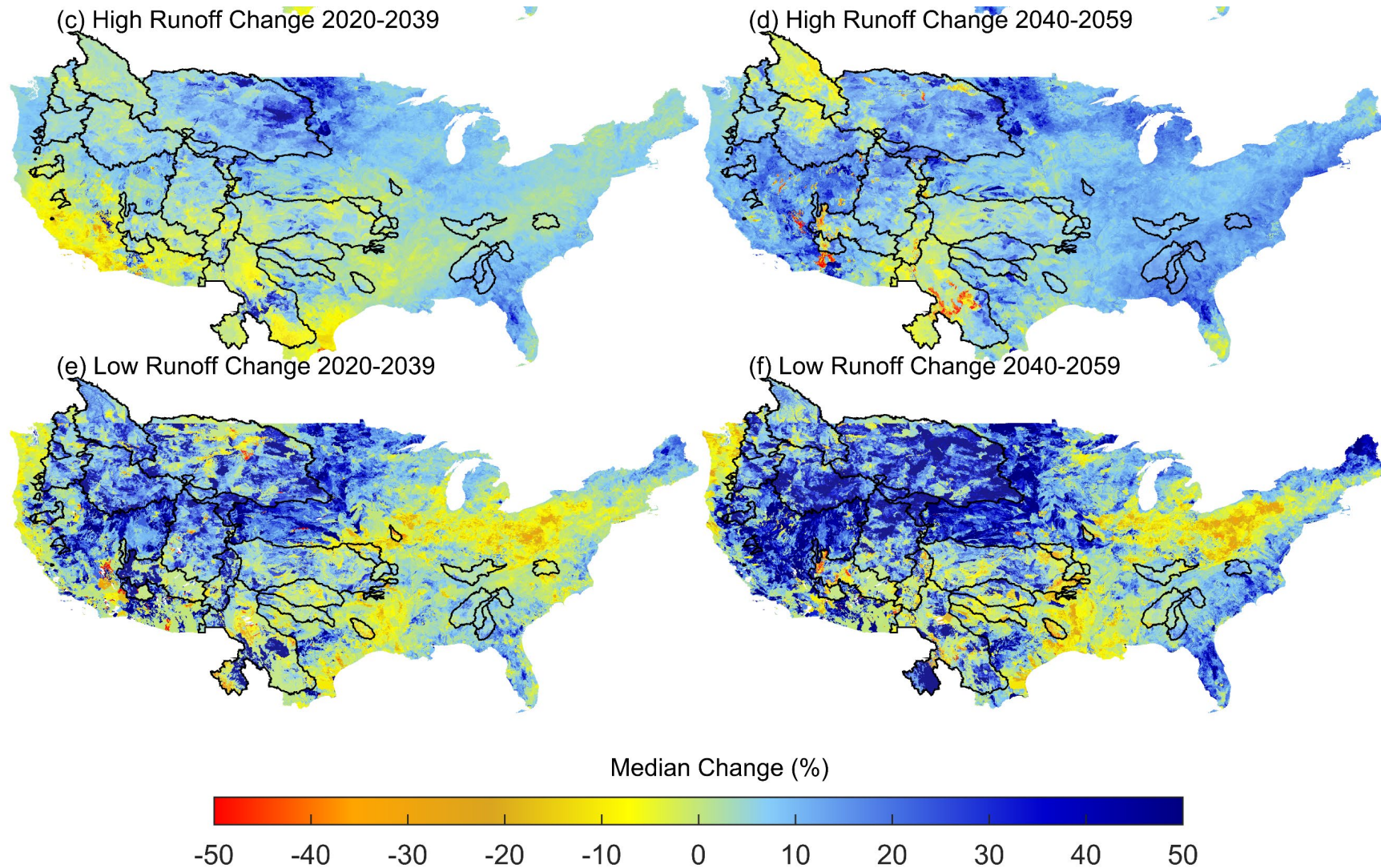
(e) MRI-ESM2-0 ssp585 r1i1p1f1



(f) NorESM2-MM ssp585 r1i1p1f1



Changes in High and Low Runoff

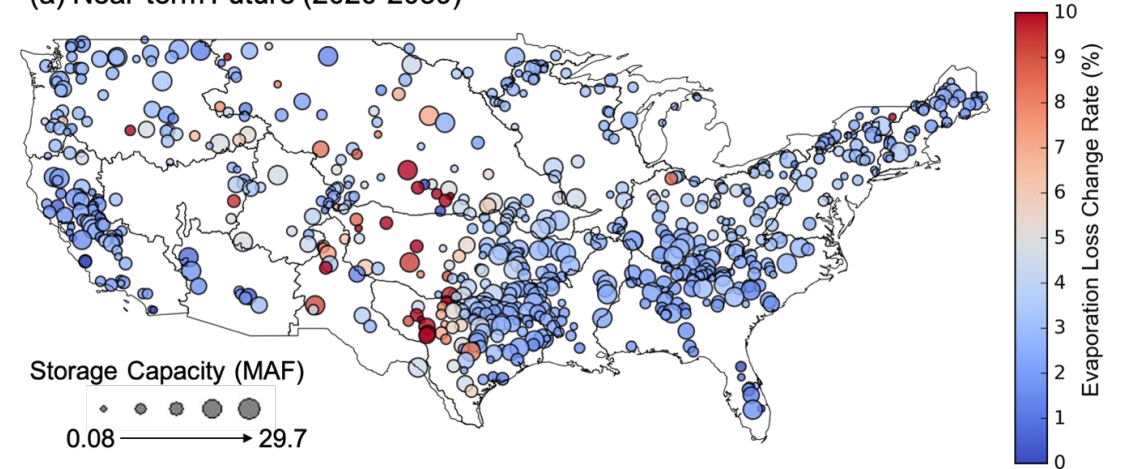


Projected Change in Direct Reservoir Evaporation

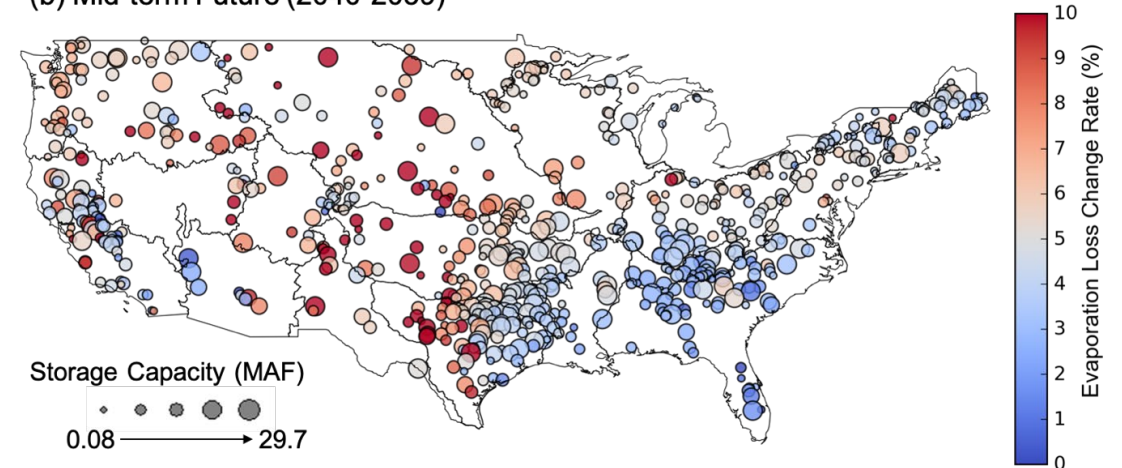
Use projected future climate and hydrology to estimate the increase of direct (open-water) reservoir evaporation.

- The historic monthly reservoir surface area was derived from NASA satellite imageries
- The increase of evaporation loss is more severe in the south-central United States, mainly southern Missouri, western Arkansas–White–Red, and the western Texas-Gulf
- In the mid-term future period, the average evaporation loss growth rate is 5.6%, and the spatial heterogeneity of evaporation loss growth is more significant than near-term future

(a) Near-term Future (2020-2039)



(b) Mid-term Future (2040-2059)

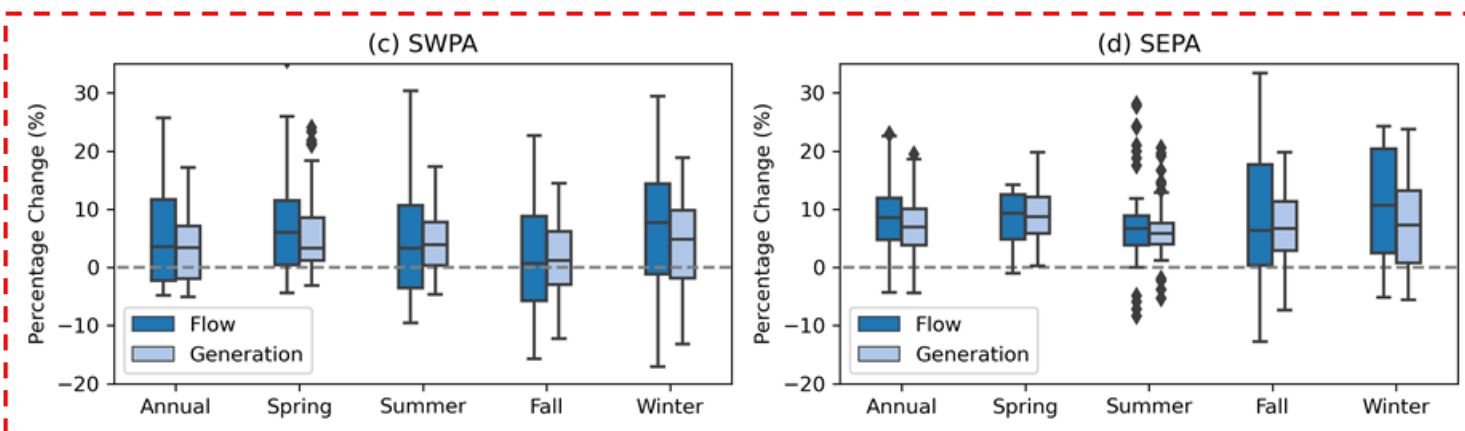
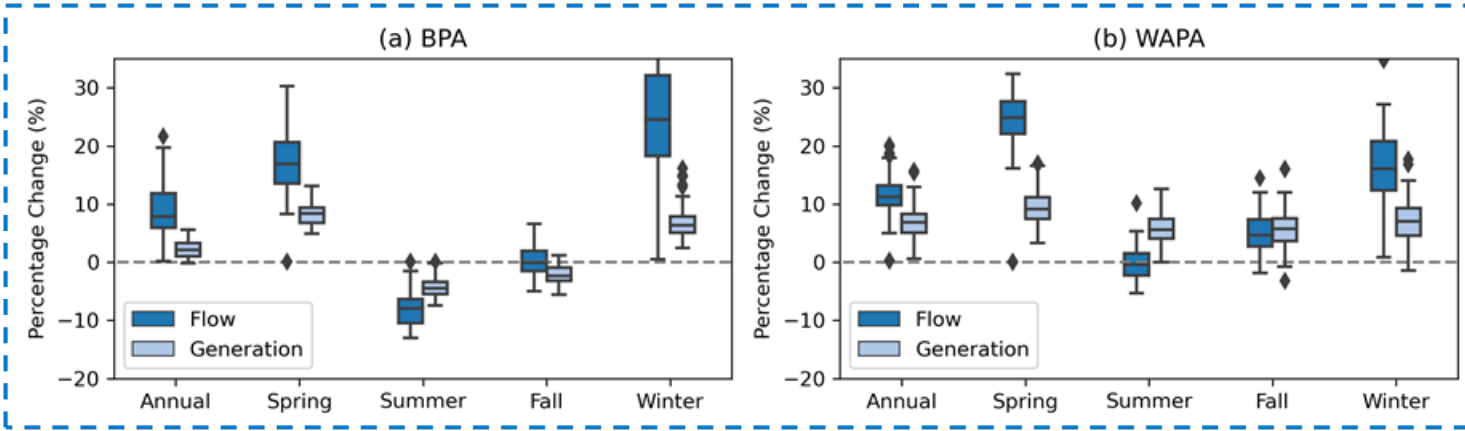


Zhao et al. (2023), Evaluating Enhanced Reservoir Evaporation Losses from CMIP6-Based Future Projections in the Contiguous United States, *Earth's Future*,

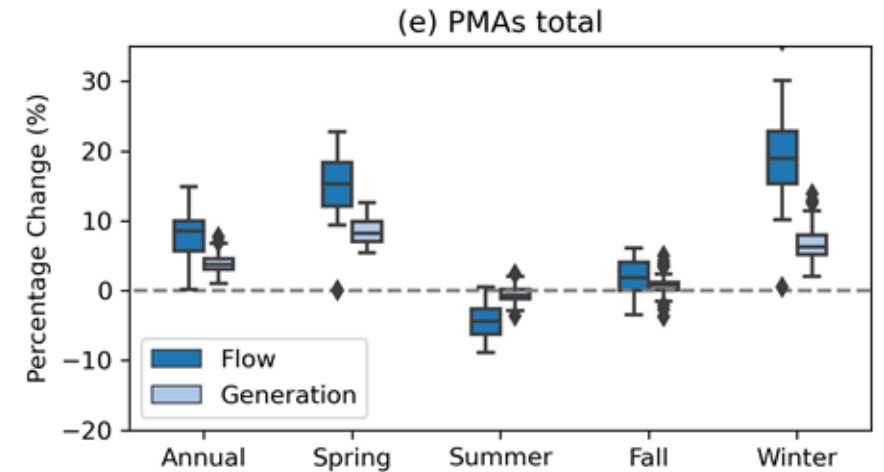
<https://doi.org/10.1029/2022EF002961>.

Projected Changes in Annual and Seasonal Generation

Snow-dominated, larger reservoirs



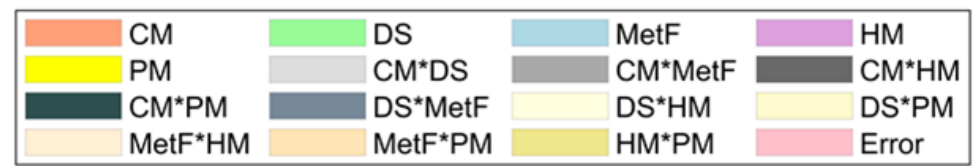
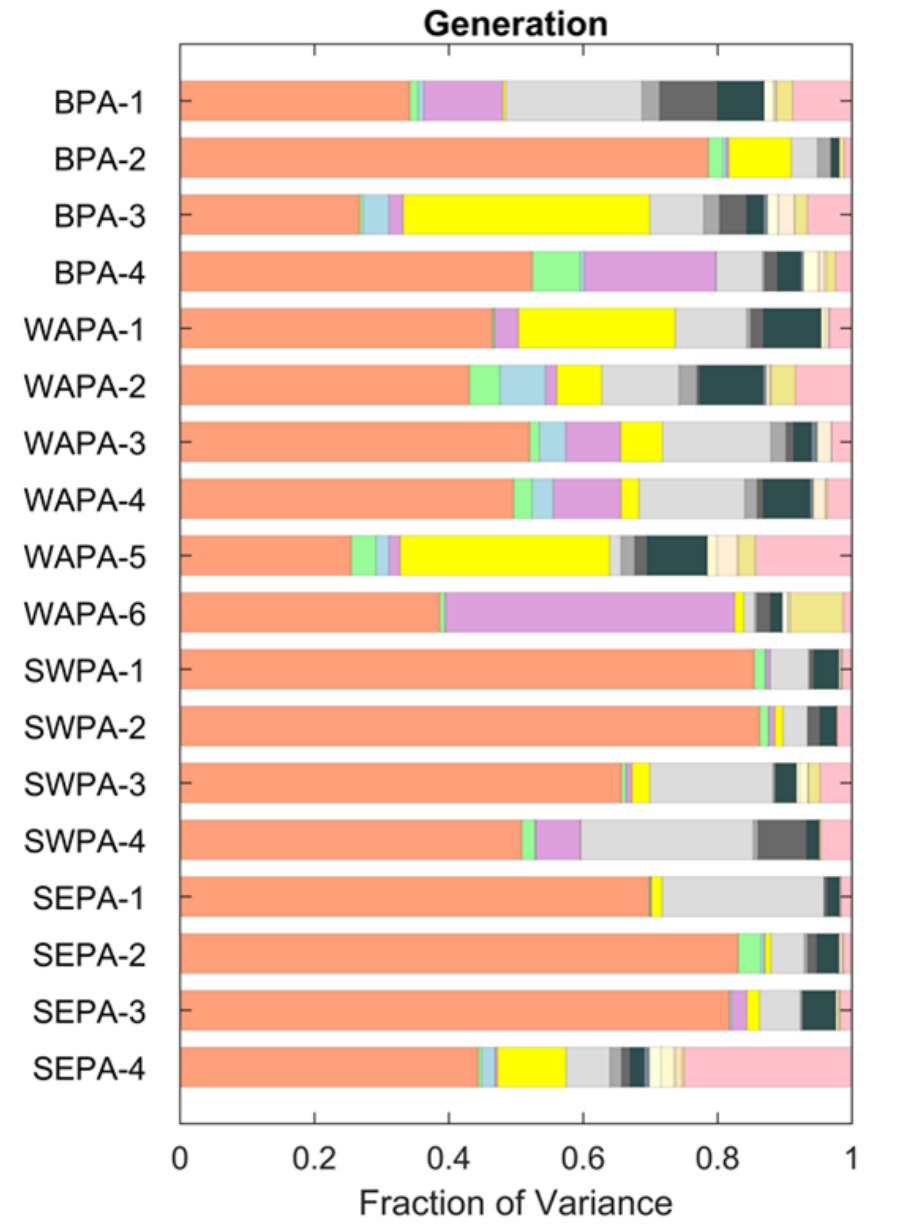
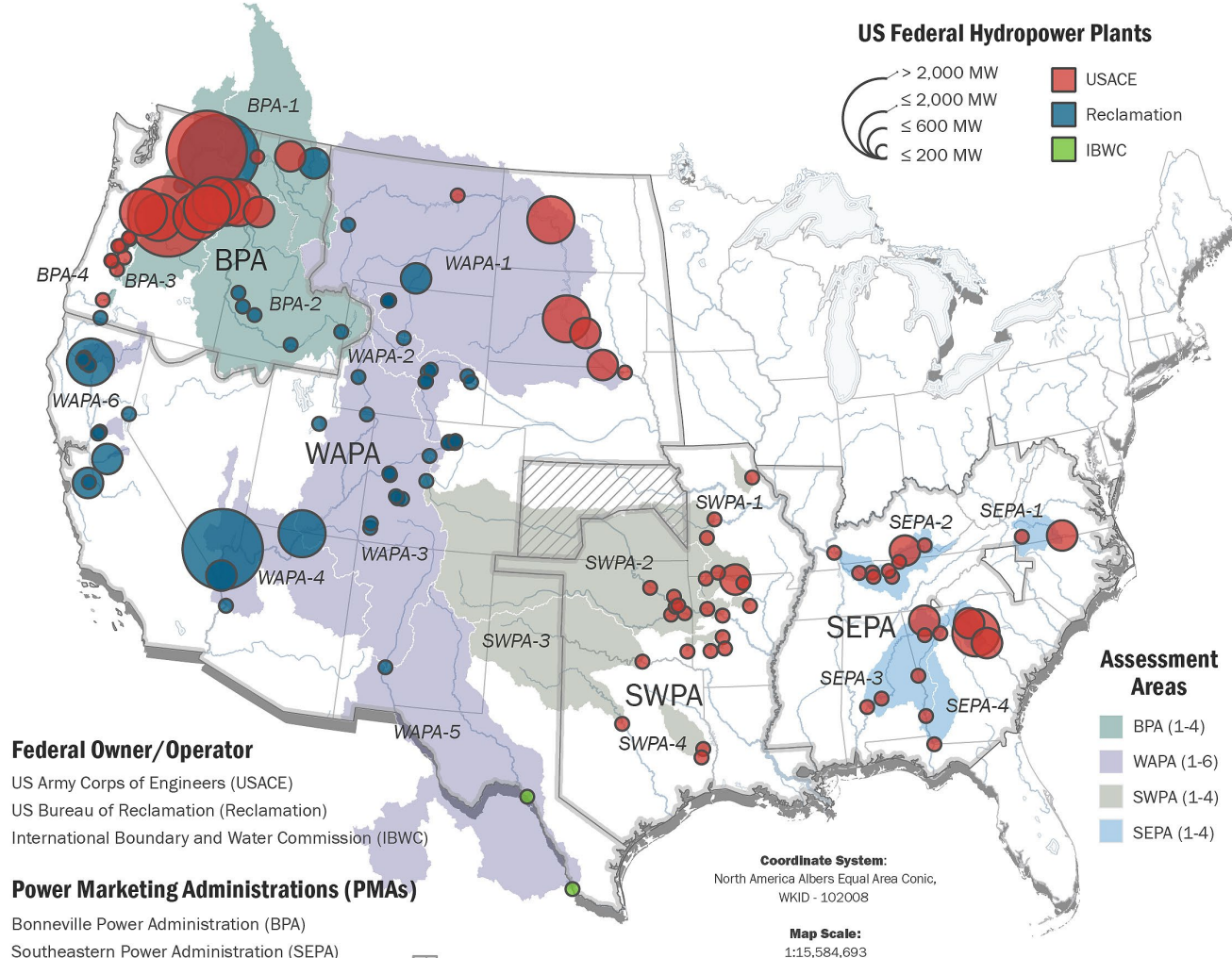
Rainfall-dominated, smaller reservoirs



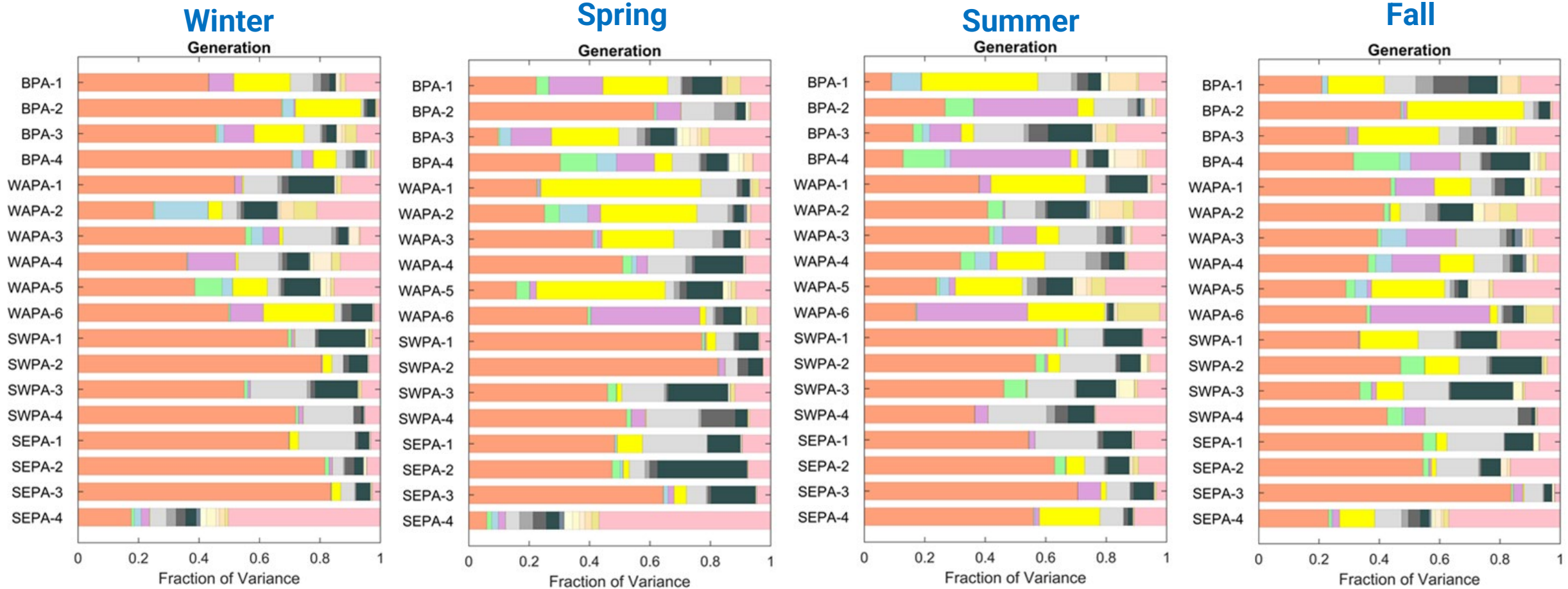
• Main findings

- Differences between snow / rainfall dominated PMAs
- Reservoirs may absorb parts of increasing variabilities
- Not all changes can be mitigated by reservoirs

Uncertainty – Annual Generation



Uncertainty – Seasonal Generation



CM: climate models; DS: downscaling approach; MetF: meteorological forcing for training; HM: hydrology model ; PM: hydropower model

Access Downscaled Hydroclimate Projections from SWA9505

Outputs from DOE SECURE Water Act Section 9505 Assessment

- 1/24° (~4km), daily time-step
- Use multi-model and observation
- Provide 25 hydroclimate variables
- Available for the conterminous US (CONUS)

Part 1

- 6 GCMs, SSP585, 1980–2059
- Downscaled by 2 methods and 2 observations

Part 2 (new)

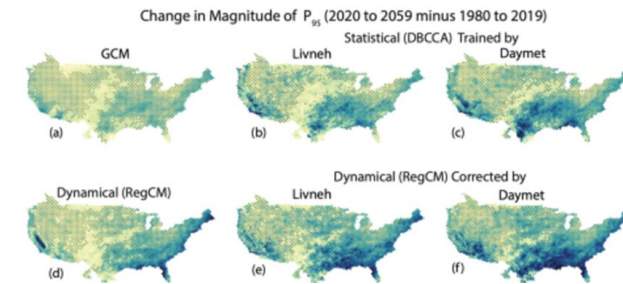
- 7 GCMs, 4 SSPs, 1980–2099
- Downscaled by DBCCA-Daymet

Full dataset is now available through Globus

Additional streamflow & hydropower projections are also available.

CMIP6-based Multi-model Hydroclimate Projection over the Conterminous US, Version 1.1

Publication Date: March 5, 2024



Downloads

10 Downloads

[9505V3_Gridded_Annual_Download_Links \(CSV, 103.2 Kb\)](#)

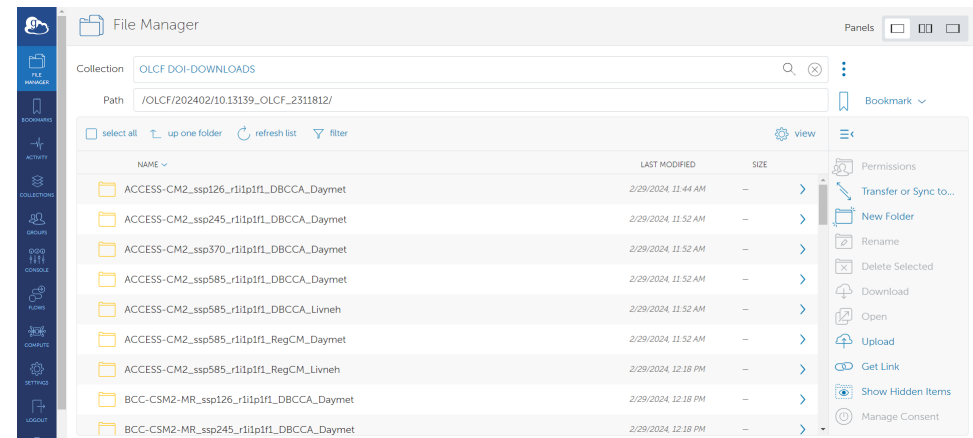
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[9505V3_Gridded_Data_Field_Descriptions \(CSV, 883.0 B\)](#)

[9505V3_Gridded_Monthly_Download_Links \(CSV, 1003.0 Kb\)](#)

[9505V3_SpatialAverage_Download](#)

https://hydrosource.ornl.gov/dataset/9505V3_1



Full download through Globus

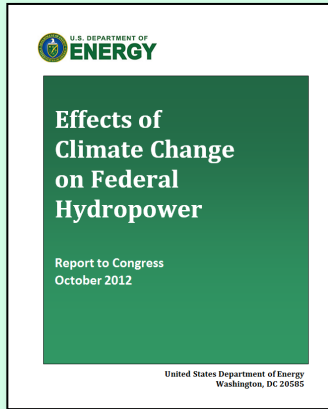
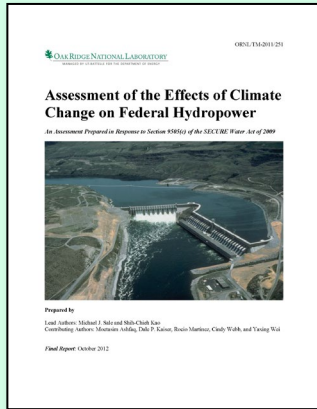
Thank you!

Contact: Shih-Chieh Kao (kaos@ornl.gov)



Three Iterations of SWA 9505 Assessments

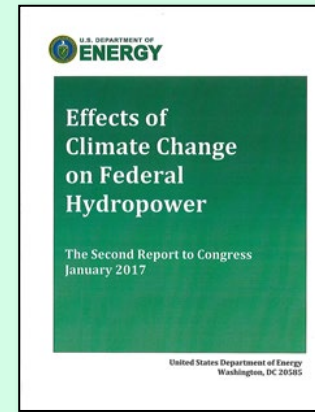
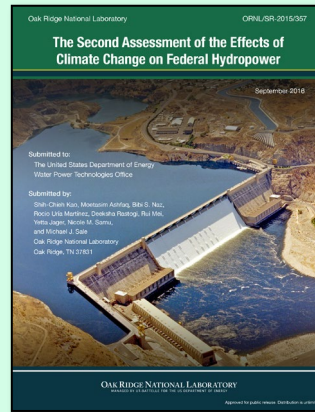
1st Assessment (2010–2012)



- First CONUS-scale hydroclimate impact assessment for hydropower
- Established data and assessment framework for 132 federal plants marketed by four PMAs
- Based on a dynamically downscaled **CMIP3** GCM
- Annual hydropower evaluation based on historic R-G relationship

<https://doi.org/10.2172/1220238>

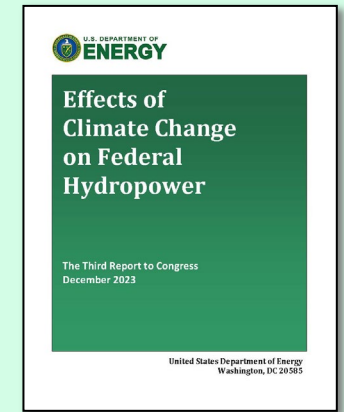
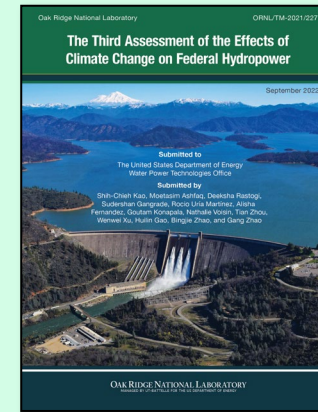
2nd Assessment (2013–2017)



- Based on 10 dynamically downscaled **CMIP5** GCMs
- Conducted CONUS-scale hydrologic model calibration
- Evaluate monthly generation based on a newly developed regional hydropower model
- Provide wet/dry scenarios for DOE Hydropower Vision study

<https://doi.org/10.2172/1340431>

3rd Assessment (2018–2023)



- Used alternative downscaling methods, observations and hydro models to inform uncertainty.
- Evaluated GCM skills to support the selection of 6 **CMIP6** GCMs.
- Analyzed the elevated evaporative loss from major reservoirs.
- Performed energy demand analysis.

<https://doi.org/10.2172/1887712>