Northwest **Power** and
Conservation Council

October 1, 2024

MEMORANDUM

TO: **Council Members**

FROM: **Daniel Hua**

SUBJECT: **Primer on Climate Data in the Ninth Plan**

BACKGROUND:

Presenter: Daniel Hua

Summary: For the previous 2021 Power Plan, the Council used a set of climate data for analysis and as inputs into various simulation models. The climate data were selected from a larger set of climate scenario data provided by the River Management Joint Operating Committee (RMJOC) which consists of future projected river flows and temperatures. Due to time limitation, Council staff were not able to use the entire set of RMJOC data. Nevertheless, the subset of data was selected to cover representative ranges in river flows and temperatures. In addition, the climate data also included a consistent set of climate scenario wind, solar radiation and humidity data downloaded from the Climatology Lab and the Northwest Knowledge Network. For the upcoming Ninth Power Plan, Council staff recommend continuing to use data from the same set of climate scenarios. Staff feel these climate scenarios continue to reflect the range of potential climate futures. At this meeting, staff will brief the Council on the overall trends in the climate data and on the selection methodology, as well as feedback from the Climate and Weather Advisory Committee on the proposed approach.

Relevance: The Council is required to prepare a power plan for new resources that looks out into the future and includes a demand forecast of at least 20

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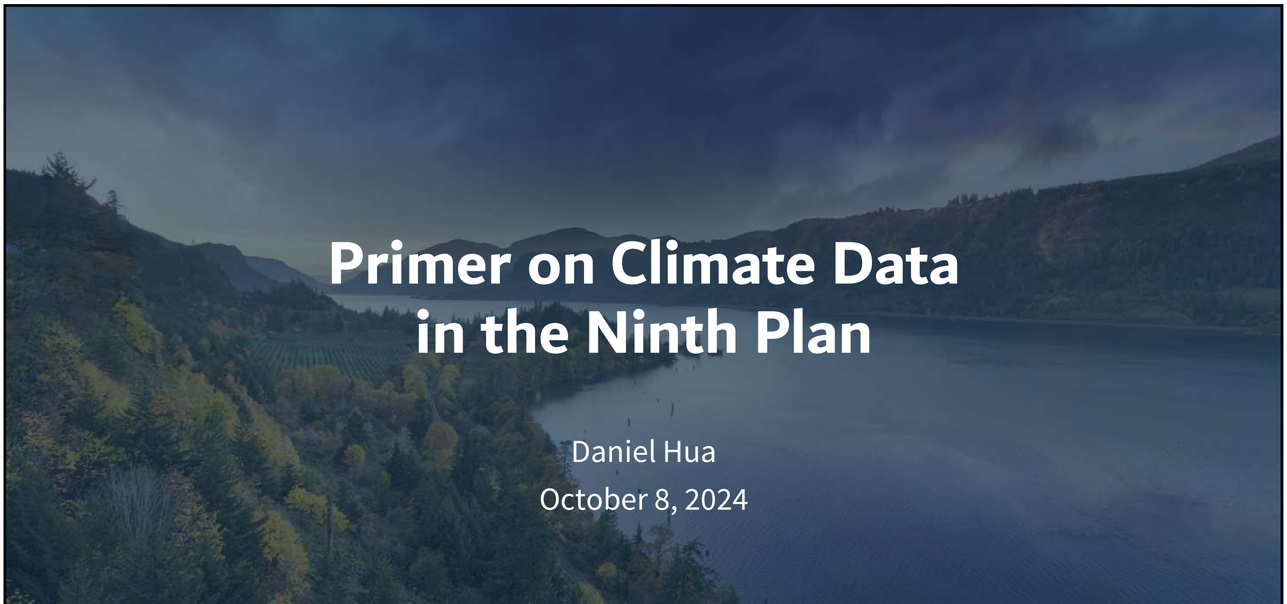
years. All the RMJOC climate scenarios generally forecast higher winter river flows (leading to higher hydro generation), and higher winter temperatures (resulting in lower load with all else being equal). In contrast, projections for summer go in the opposite direction, with generally lower hydroelectric generation, and higher electricity demand (due to higher summer temperatures). Accounting for the forecasted climate changes is important to best reflect the anticipated loads and resource availability, which will lead to a more robust regional resource strategies that ensures an adequate, efficient, economical, and reliable power supply.

Workplan: B.2.6 Maintaining climate change data to ensure it remains relevant and improve analysis for loads and resources in the ninth power plan and ensure appropriate modeling of extreme weather.

More Info: This document, in the Support Material section of the 2021 Power Plan, and the links within, contain more information on the climate data and their analyses in the 2021 Power Plan.



Primer on Climate Data in the Ninth Plan

Daniel Hua

October 8, 2024

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Areas of Power Plan Affected by Climate Data

- Hydro-system modeling
- Wind generation modeling
- Solar generation modeling
- Energy efficiency (EE) and demand response (DR) modeling
- Load forecasting
- Power System adequacy modeling
- Power System expansion modeling

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Outline

- Climate Data used in the 2021 Power Plan
  - The Global Climate Models (GCMs)
  - Transformation of the GCMs into climate scenarios
  - Selection of a subset of the climate scenarios
  - Climate trends in the selected climate scenarios
- Climate data for the Ninth Power Plan
  - Same set of climate scenarios as in the 2021 Power Plan
  - Additional locations for temperature, wind and solar data
  - Feedback and comments from the Climate and Weather Advisory Committee

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Temperatures and Streamflow

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Climate Data Working Group

- Funded by the River Management Joint Operating Committee (RMJOC):
- Climate data research performed by RMJOC staff and scientists at

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The CMIP5 Global Climate Models

- In 2013, the RMJOC initiated analysis of the **C**oupled **M**odel **I**ntercomparison **P**roject Phase **5** (***CMIP5***) data
- The RMJOC selected 10 GCMs that better replicate historical climate data for the Pacific Northwest region and the larger western North America and northeast Pacific
- The set of GCMs undergo 2 emission levels: *RCP 4.5* and *RCP 8.5*
- At the beginning stages of the 2021 Power Plan, the *RCP 8.5* emission seems more likely

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The Council selected only the RCP8.5 GCMs for the Power Plan

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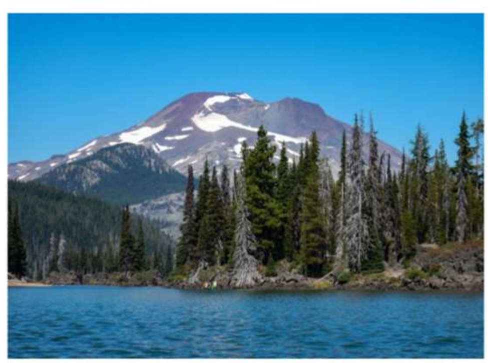
- The RMJOC published a report on the climate data in 2018

Climate and Hydrology Datasets for RMJOC Long-Term Planning Studies: Second Edition (RMJOC-II)

Part I: Hydroclimate Projections and Analyses

June 2018



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https://www.bpa.gov/-/media/Aep/power/hydropower-data-studies/rmjoc-ll-report-part-l.pdf

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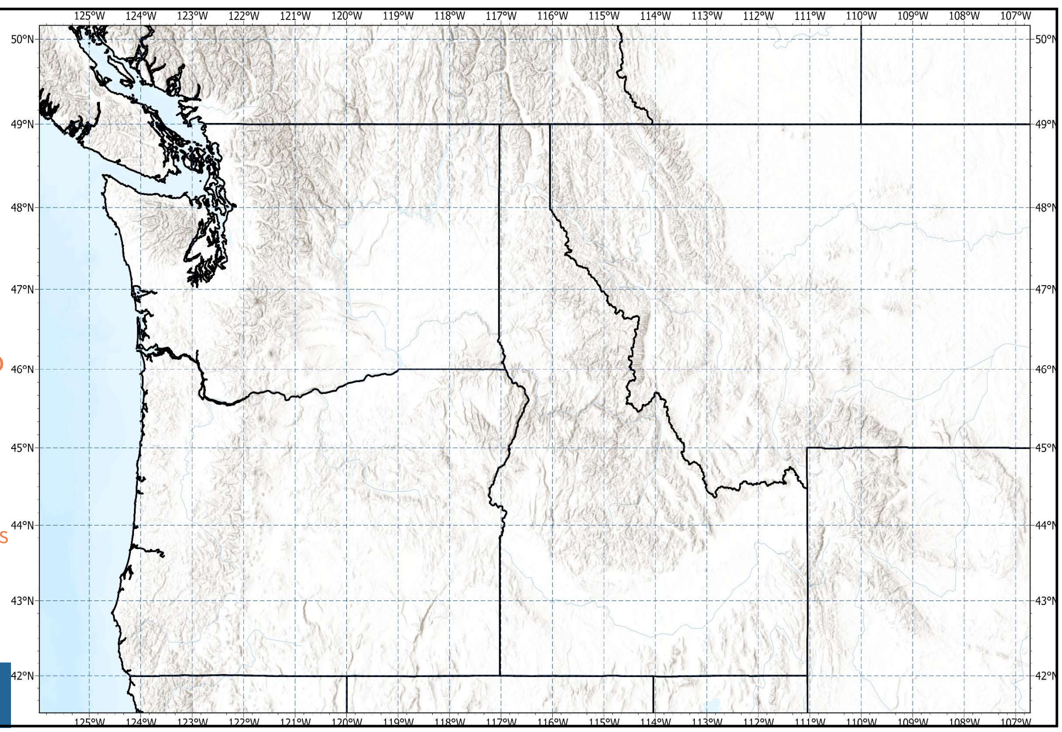
The RMJOC GCMs

- The 10 GCMs
  - *CanESM2* *(CAN)*
  - *CCSM4* *(USA)*
  - *CNRM-CM5* *(FR)*
  - *CSIRO-Mk3-6-0* *(AUS)*
  - *GFDL-ESM2M* *(USA)*
  - *HadGEM2-CC* *(UK)*
  - *HadGEM2-ES* *(UK)*
  - *inmcm4* *(RUS)*
  - *IPSL-CM5-MR* *(FR)*
  - *MIROC5* *(JP)*

- Spatial scales of CMIP5 GCMs over the Northwest: from 1° to 2° longitude and latitude grids, or about 46 miles to 186 miles grids

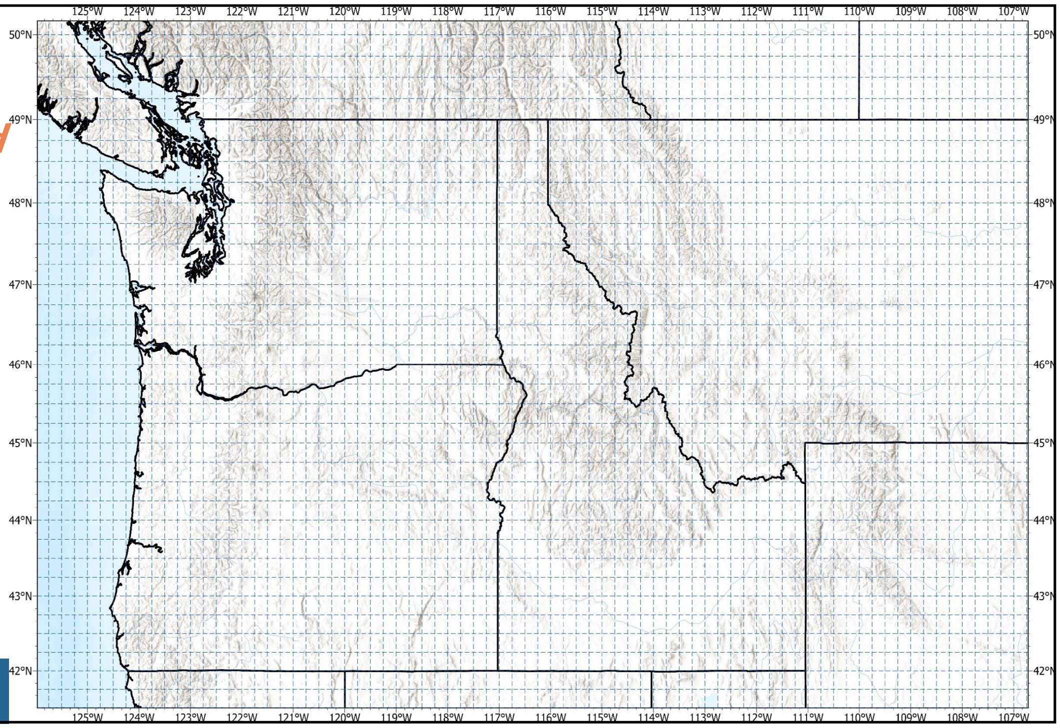
Illustrative GCM Grid

- 1° × 1° grids
- Too sparse to calculate
  - streamflows of interest along rivers
  - temperatures at cities of interest



Illustrative *Downscaled* Grids

- 1/4° × 1/4° grids
- RMJOC used 1/16° × 1/16° grids



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Transforming GCM data

I. To make GCM data more useful, 2 statistical downscaling methods (*BCSD, MACA*) were applied to reduce grid size to: ~ 3.5 miles × 3.5 miles

II. After statistical downscaling, GCMs *precipitation* data undergo 4 hydrological models to become *streamflow*

- 3 **V**ariable **I**nfiltration **C**apacity (*VIC*) Models
- **P**recipitation **R**unoff **M**odeling **S**ystem (*PRMS*)

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BCSD: Bias Corrected Spatial Disaggregation
MACA: Multivariate Adaptive Constructed Analog

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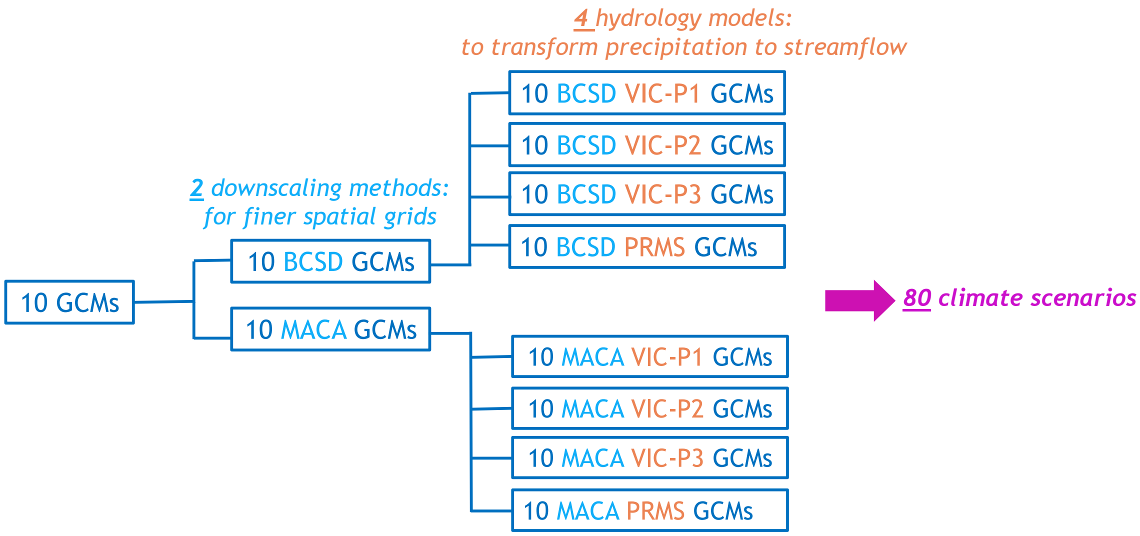
GCMs to Climate Scenarios



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RMJOC Climate Data Map

RMJOC Climate Scenario Data for the Northwest region covers the Columbia River Basin (green) and coastal areas (pink)

RMJOC Scenario Data are temperature and streamflow

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Climate Trends in Winter Seasonal Averages

(Winter: Dec, Jan, Feb)

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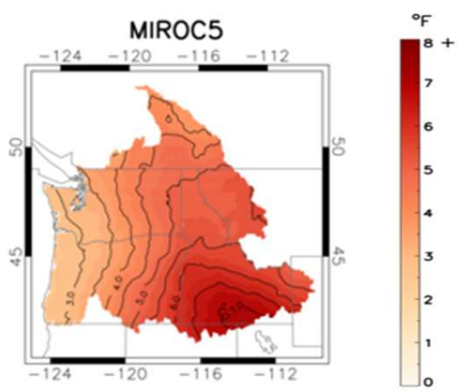
Average Winter Temperature Warming by the 2040s (2030 to 2059)

Relative to historical period (1970 to 1999)

MACA downscaling



courtesy of David Rupp at Oregon State University

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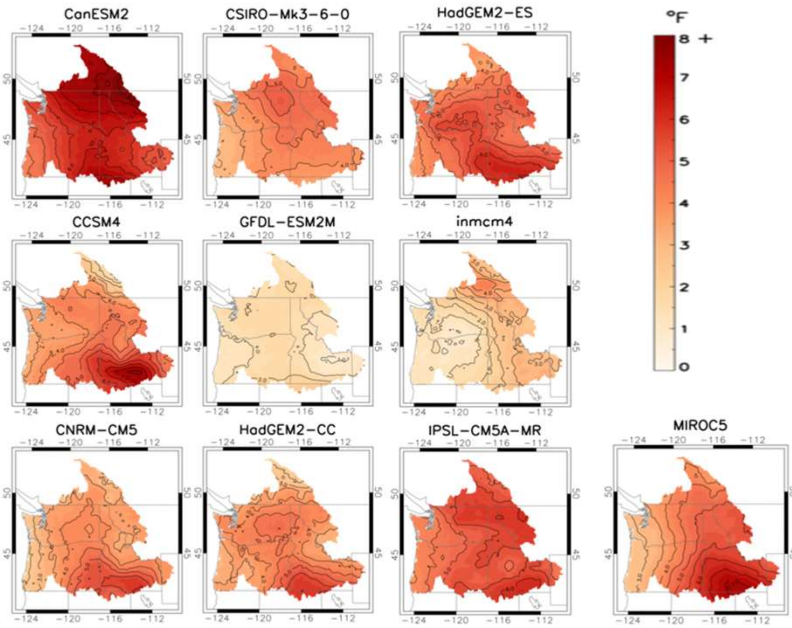
Average Winter Temperature Warming by the 2040s

(MACA downscaling)



- *Warming over most of northwest*
- *Interior tend to have more warming than coast*
- *Winter loads tend to decrease*

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courtesy of David Rupp at Oregon State University

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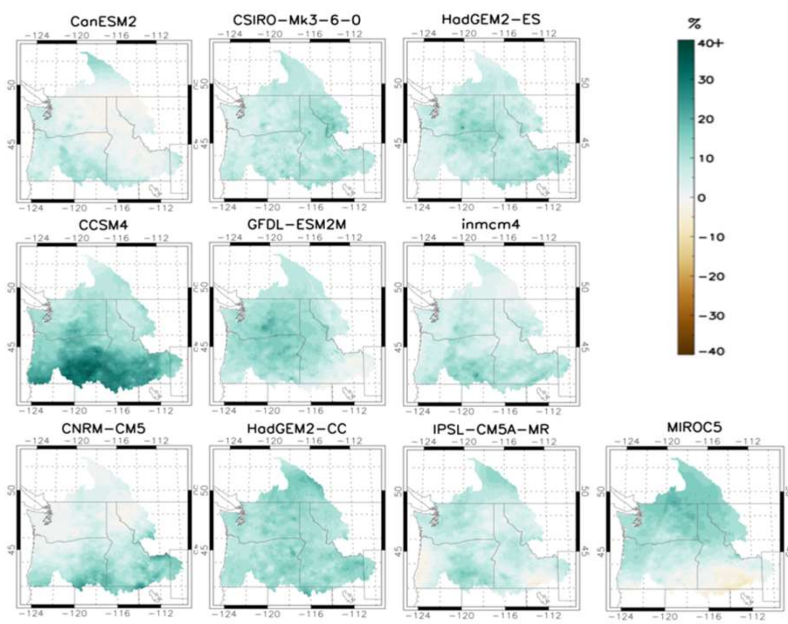
Average Winter Precipitation Changes by the 2040s

(MACA downscaling)



- *Precipitation increases over much of northwest, in US likely falling as rain instead of snow*
- *Likely to have higher winter flows*
- *Winter snowpack likely to decline over time*

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courtesy of David Rupp at Oregon State University

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Climate Trends in Summer Seasonal Averages

(Summer: Jun, Jul, Aug)

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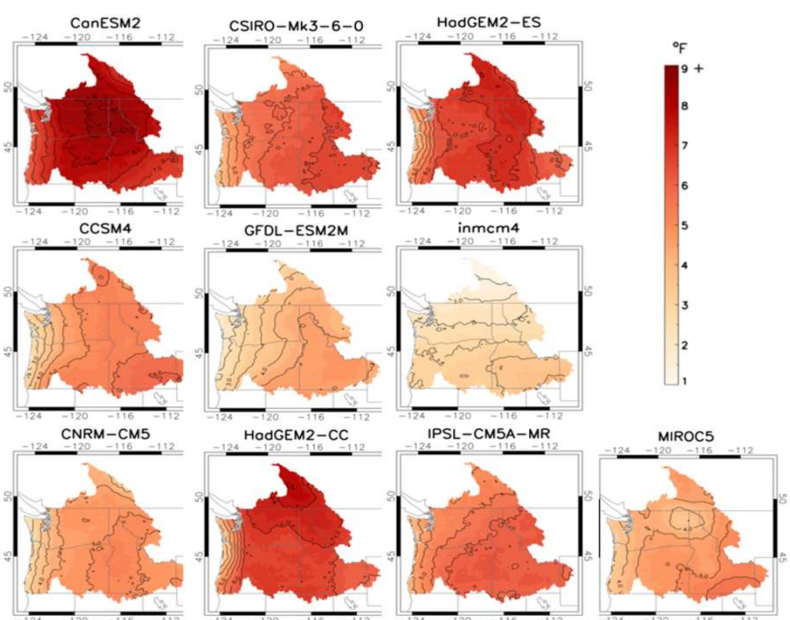
Average Summer Temperature Warming by the 2040s

(MACA downscaling)

- *Warming over most of northwest*
- *Interior more warming than coast*
- *Summer loads tend to increase*



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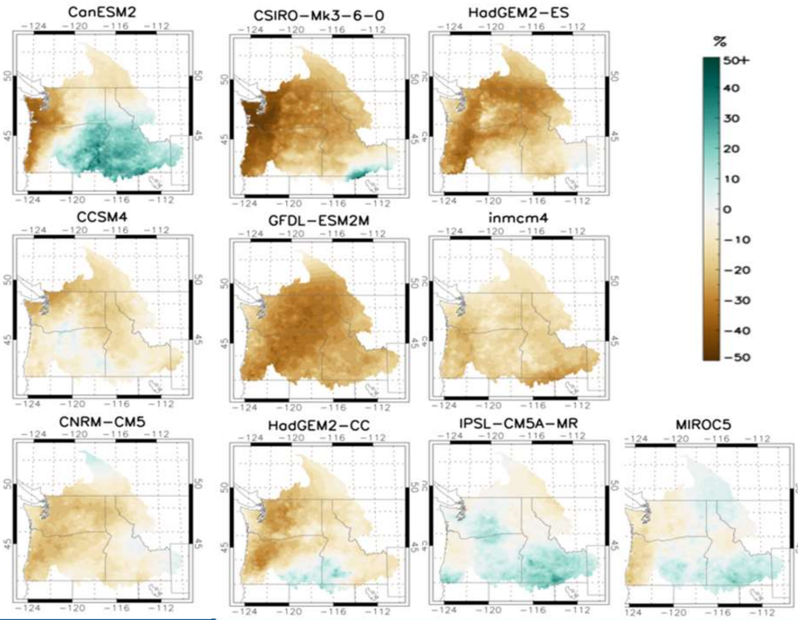
courtesy of David Rupp at Oregon State University

Average Summer precipitation changes by the 2040s

(MACA downscalng)

- *Precipitation decreases for many areas of basin*
- *Likely to have longer periods of low summer flows*



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courtesy of David Rupp at Oregon State University

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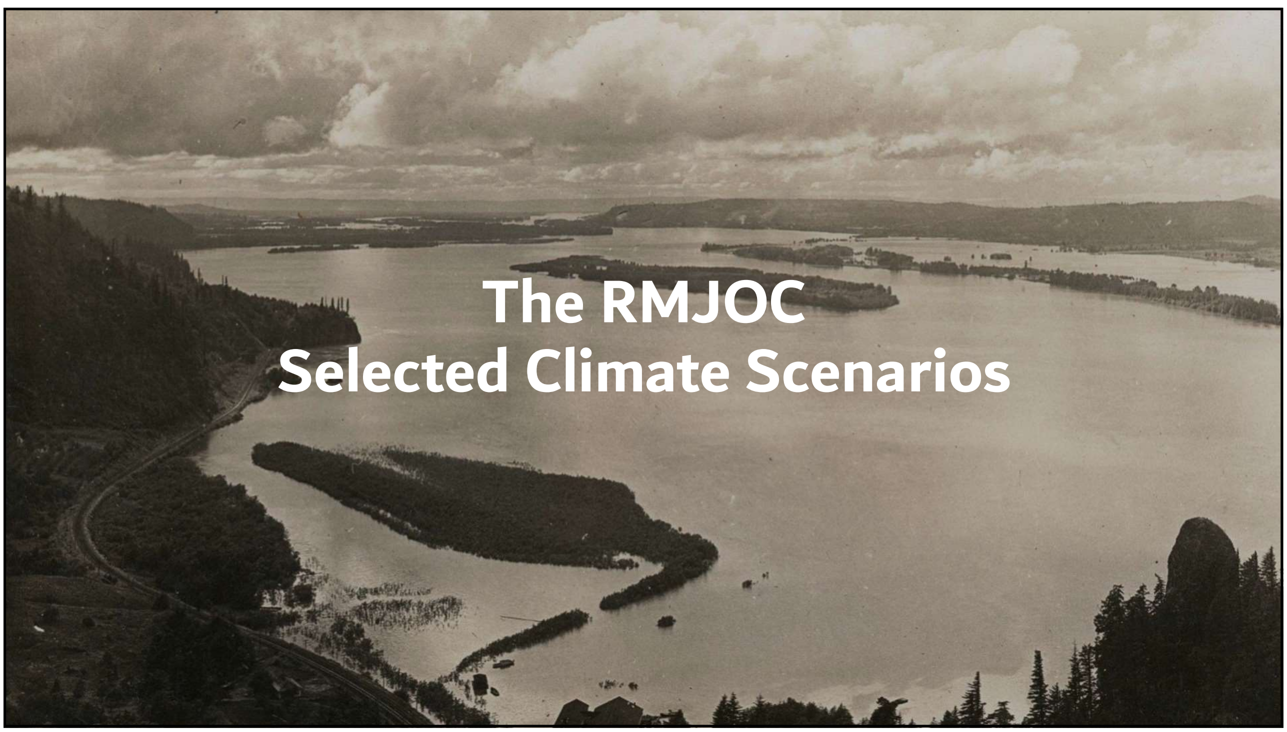

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RMJOC Report Summary

- Temperature has warmed by $1.5°F$ since 1970s
- And expected to further increase by $1°F$ to $4°F$ by 2030s
- Warming is likely to be greatest in the interior
- General upward trend in precipitation, particularly in winter months
- Dry summer months could become drier
- Average winter snowpacks are very likely to decline over time as more winter precipitation falls as rain instead of snow
- By the 2030s, higher average fall and winter flows, earlier peak spring runoff; and longer periods of low summer flows are very likely

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RMJOC Selection of Climate Scenarios

- Differences in these **6** streamflow metrics*:
  - annual volume
  - winter volume
  - spring volume
  - summer volume
  - (winter-volume) / (spring-volume)
  - annual half-volume timing
- At these **14** hydro-projects:

*metrics are used to measure vulnerabilities in hydro-generation, flood risk management, water supply, ecosystem, recreation, biological operations, etc.,

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The 19 RMJOC Climate Scenarios

- These ***19*** climate scenarios (out of 80) could encompass sufficient ranges of streamflow changes at 14 hydro-projects of interests:

A: *CanESM2_RCP85_BCSD_VIC_P1*
B: *CanESM2_RCP85_MACA_PRMS_P1*
C: *CCSM4_RCP85_BCSD_VIC_P1*
D: *CCSM4_RCP85_MACA_VIC_P3*
E: *CNRM-CM5_RCP85_BCSD_VIC_P2*
F: *CNRM-CM5_RCP85_MACA_VIC_P1*
G: *CNRM-CM5_RCP85_MACA_VIC_P3*
H: *CSIRO-Mk3-6-0_RCP85_BCSD_PRMS_P1*
I: *GFDL_ESM2M_RCP85_BCSD_VIC_P2*
J: *GFDL_ESM2M_RCP85_MACA_VIC_P1*
K: *GFDL_ESM2M_RCP85_MACA_VIC_P2*
L: *HadGEM2-CC_RCP85_BCSD_VIC_P1*
M: *HadGEM2-CC_RCP85_MACA_VIC_P1*
N: *inmcm4_RCP85_BCSD_PRMS_P1*
O: *inmcm4_RCP85_BCSD_VIC_P2*
P: *inmcm4_RCP85_MACA_VIC_P3*
Q: *IPSL-CM5A-MR_RCP85_MACA_VIC_P2*
R: *MIROC5_RCP85_BCSD_PRMS_P1*
S: *MIROC5_RCP85_BCSD_VIC_P3*

- The RMJOC staff then developed *modified streamflow** data and hydro-regulation rule curves and constraints for these 19 scenarios

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****modified streamflow includes effects of irrigation and evaporation***

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https://www.nwcouncil.org/2021powerplan_climate-change-scenario-selection-process/

Why did the Council Select a Subset of Climate Scenarios?

- The Council's various models required significant run-time and analyses
  - Resource adequacy model
  - Capital Expansion model
  - Load Forecast model
- Thus, it was not practical to use all 19 RMJOC climate scenarios in the previous 2021 Power Plan
- Resource Adequacy Analysis of the Northwest power system is a part of the Power Plan
  - Select climate scenarios that encompass the boundaries of adequacy
  - "high" and "low" levels of hydro-generation
  - "high" and "low" levels of loads

Climate Scenarios Selection Criteria (I)

- Selection of the subset will be based on distributions of
  - Monthly *winter* hydro generations and *summer* hydro generations for the 19 scenarios
  - Monthly *winter heating-degree days* (HDDs) and *summer cooling-degree days* (CDDs) for the 19 scenarios (to serve as proxies for the winter loads and summer loads)

Climate Scenarios Selection Criteria (II)

- Select scenarios to represent *high* and *low levels* of:
  - *winter hydro-generation*
  - *summer hydro-generation*
  - *winter HDDs*
  - *summer CDDs*

Levels / Data	Winter Hydro-Generation	Summer Hydro-Generation	Winter HDDs	Summer CDDs
High	S_1	S_2	S_3	S_4
Low	S_5	S_6	S_7	S_8

- Apriori, up to 8 climate scenarios could be selected, but that is *still too many*
  - Try to select scenarios that could encompass more than one data type (e.g., both low winter HDDs and high summer CDDs)

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Selection Methodology for High and Low Winter & Summer Hydro-Generations

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Comparing Winter and Summer Hydro-Generations

- Winter months (3): Dec, Jan, Feb
- Summer months (3): Jun, Jul, Aug
- Climate scenario water-years (30): 2020 to 2049
- Historical water-years (80): 1929 to 2008

- Climate scenario winter or summer generations:
  - *(3 months) × (30 water-years) × (19 climate scenarios) = 1,710 data points*

- Historical winter or summer generations:
  - *(3 months) × (80 water-years) = 240 data points*

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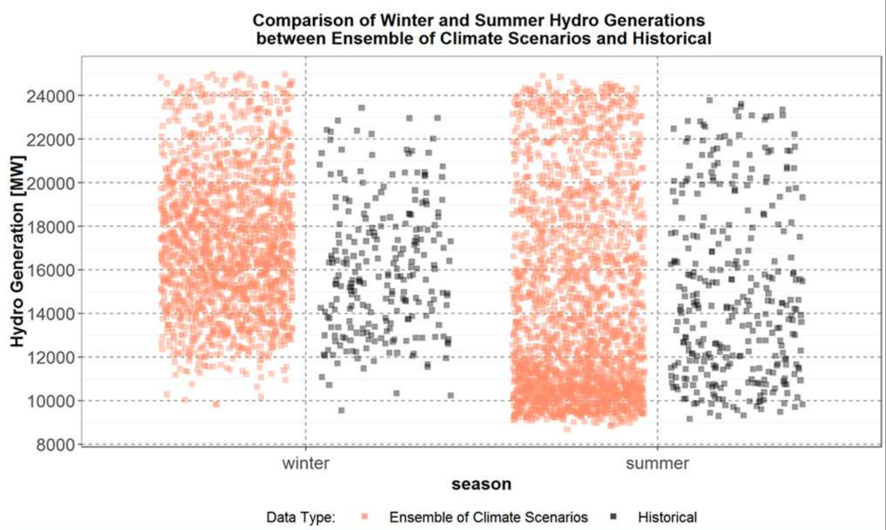
Winter and Summer Hydro-Generation (A)

- Use HYDSIM model to produce monthly hydro-generation
- Winter months (*Dec, Jan, Feb*)
- Summer months (*Jun, Jul, Aug*)
- Ensemble of 19 climate scenarios
- Climate water-years: 2020 to 2049
- Historical water-years: 1929 to 2008



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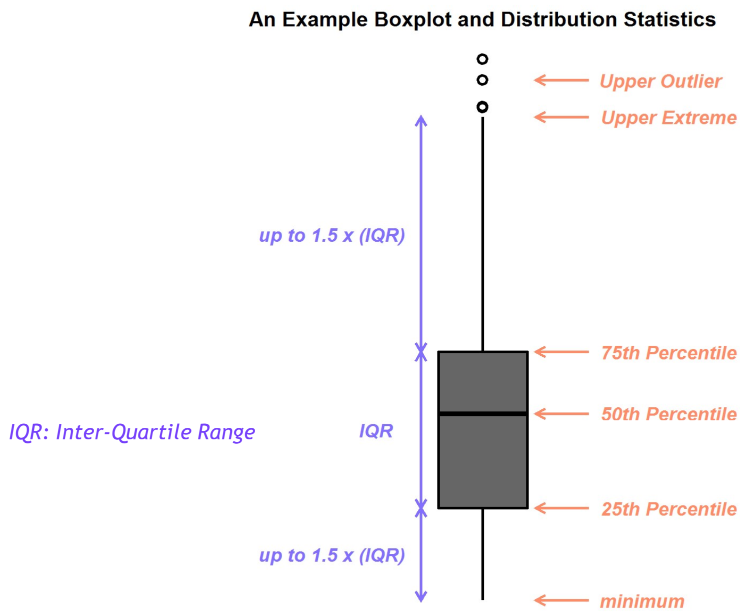
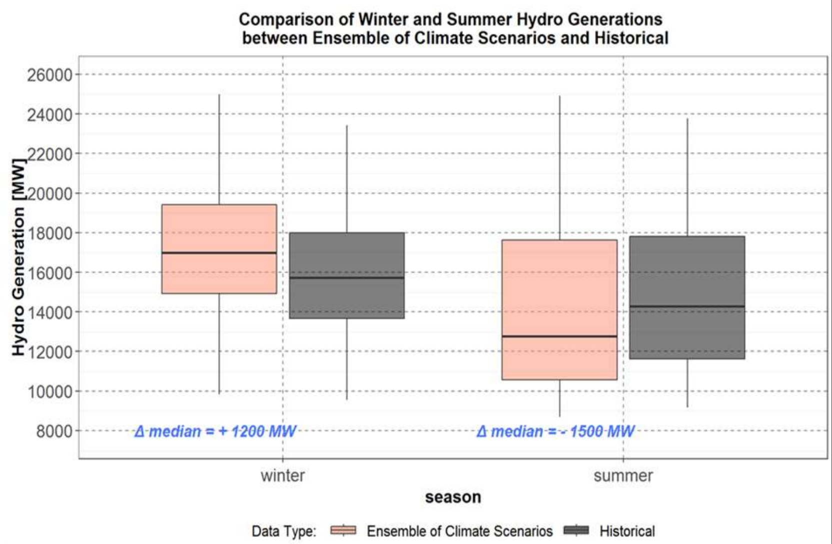


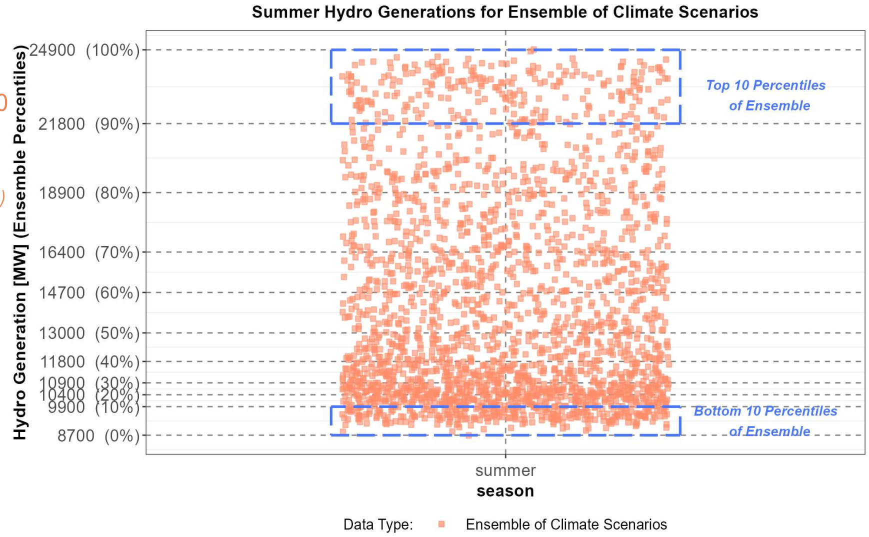
Winter and Summer Hydro-Generation

- Comparisons with historical hydro-generations
  - Median winter generation: climate ensemble is 1,200 MW higher than historical
  - Median summer generation: climate ensemble is $-$ 1,500 MW lower than historical



Summer Hydro-Generation Population Slices

- Slice the climate ensemble summer hydro-generation into 10 equal slices
  - 0% to 10% *(bottom 10th percentile)*
  - ⋮
  - 90% to 100% *(top 10th percentile)*
- Consider hydro-generations in the lowest slice (0% to 10%) to be represent low generation
- Consider hydro-generations in the highest slice (90% to 100%) to be represent *high* generation



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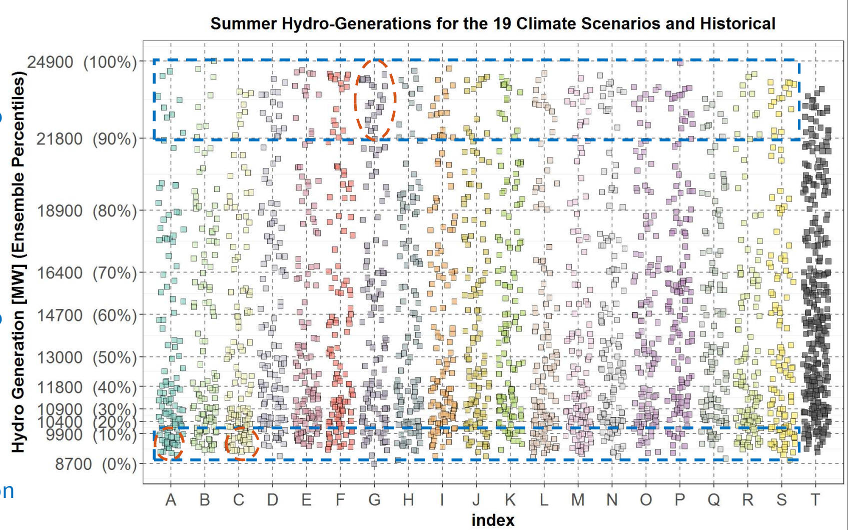
Selecting Climate Scenarios to represent "High" and "Low" Ensemble Summer Generation

- Select the climate scenario with the largest population in the *lowest 10 percentiles* of ensemble distribution to represent the *low ensemble summer generation*
- Select the climate scenario with the largest population in the *highest 10 percentiles* of ensemble distribution to represent the *high ensemble summer generation*
- Scenario *"T"* is winter generation with historical streamflows – for comparison



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Select Scenarios to Represent High and Low Summer Hydro-Generation

- For "high" summer hydro-generation, ***G*** was selected where
  - ***G*** has the most data points: **20** in the top-10 percentile box
- For "low" summer hydro-generation, either ***A*** or ***C*** could be selected where
  - ***A*** and ***C*** are tied with the most data points: **22** in the bottom-10 percentile box

Select Scenarios to Represent High and Low Winter Hydro-Generation

- A similar selection process was performed for winter hydro-generations

Selection Methodology for High and Low Winter HDDs and Summer CDDs

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Cooling and Heating Degree Days

- Calculate a *regional average* daily temperature:
  - for example, for Jan to Apr

    $$\overline{T_d} = 0.49 \times \bar{T}_{Seattle} + 0.26 \times \bar{T}_{Portland} + 0.22 \times \bar{T}_{Spokane} + 0.06 \times \bar{T}_{Boise} - 2.54$$

  - for other months, the coefficients are different
- For a single day, the cooling degree-day (CDD) exists
  - if the average daily temperature $\overline{T_d} > 65°F$
  - Monthly cooling degree-days is the sum of all cooling degree-days for all days in the month
- For a single day, the heating degree-day (HDD) exists
  - If the average daily temperature $\overline{T_d} < 65°F$
  - Monthly heating degree-days is the sum of all heating degree-days for all days in the month

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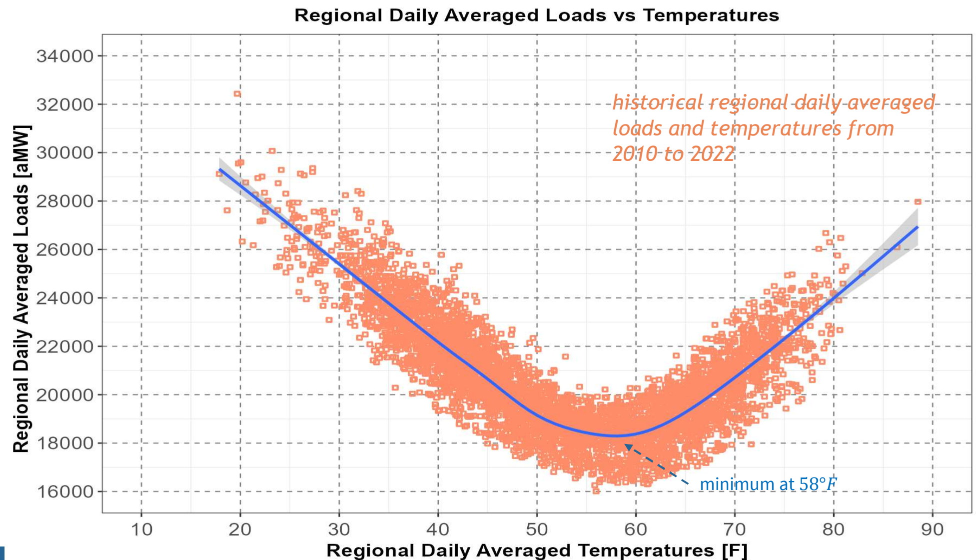
Why Reference to $65°F^*$?



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*Standard definition: see National Weather Service (https://www.weather.gov/key/climate_heat_cool)

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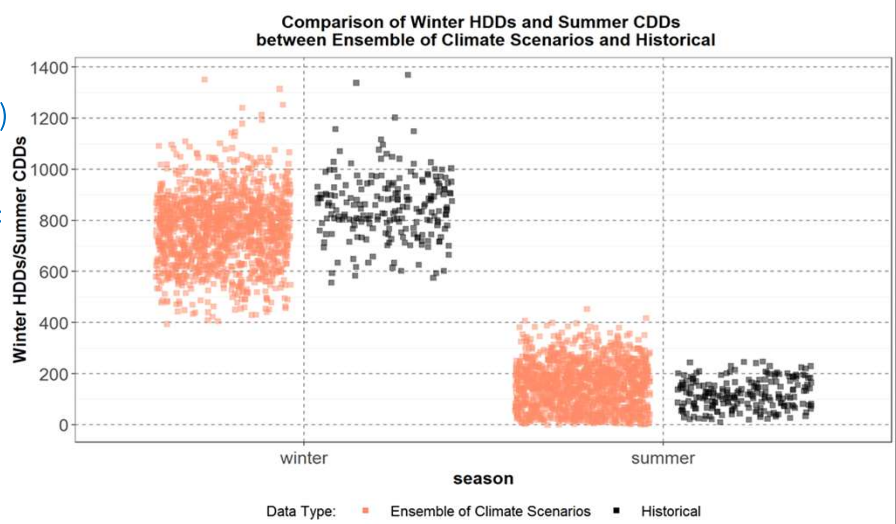
Winter HDDs and Summer CDDs (A)

- Winter months (*Dec, Jan, Feb*)
- Summer months (*Jun, Jul, Aug*)
- Ensemble of climate scenarios: climate temperature-years 2020 to 2049
- Historical temperature-years (1929 to 2008)



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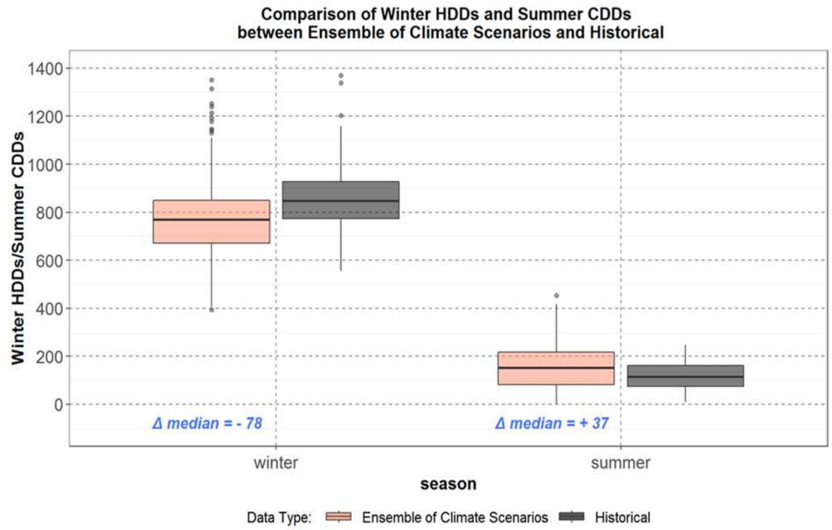
Winter HDDs and Summer CDDs (B)

- Median winter HDDs: climate ensemble is 78 HDDs lower than historical – *lower winter loads*
- Median summer CDDs: climate ensemble is 37 CDDs higher than historical – *higher summer loads*



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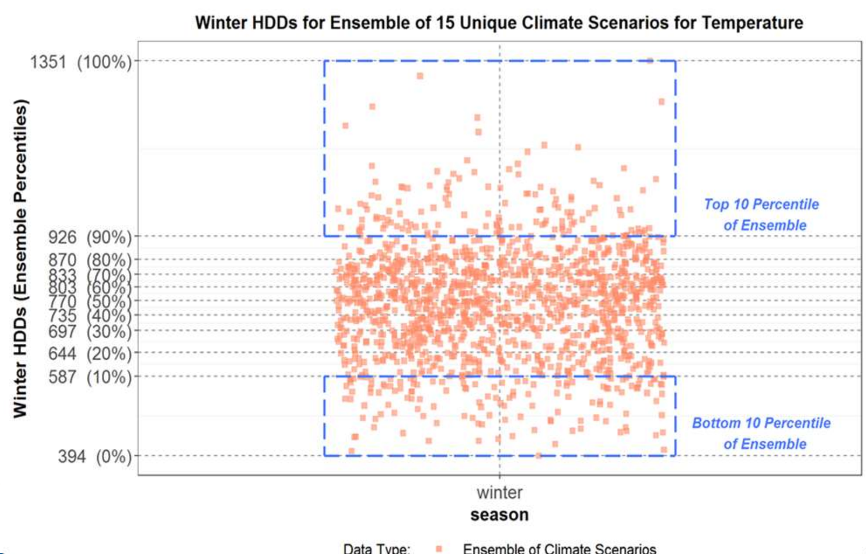
Winter HDDs Population Slices

- Slice the climate ensemble winter hydro-generation into 10 equal slices
  - 0% to 10% *(bottom 10th percentile)*
  - ⋮
  - 90% to 100% *(top 10th percentile)*
- Consider HDDs in the lowest slice (0% to 10%) to be represent low HDDs
- Consider HDDs in the highest slice (90% to 100%) to be represent *high* HDDs



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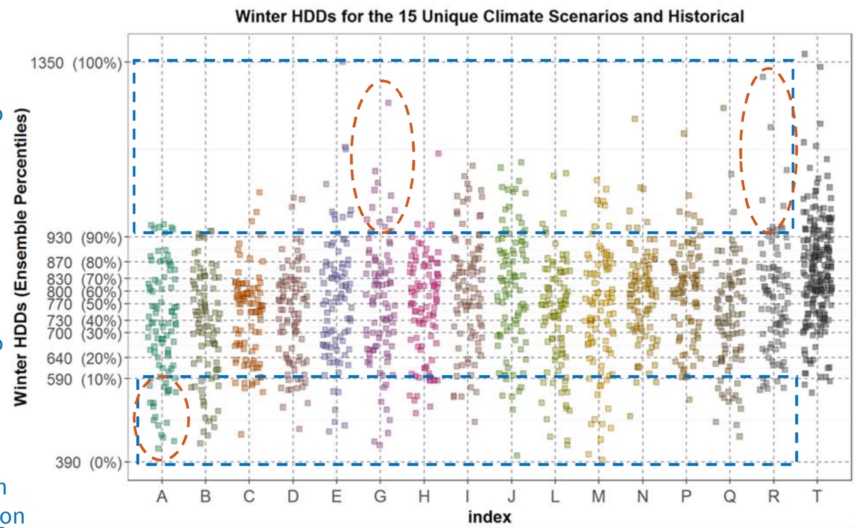
Selecting Climate Scenarios to represent "High" and "Low" Ensemble Winter HDDs

- Select the climate scenario with the largest population in the *lowest 10th percentile* of ensemble distribution to represent the *low ensemble winter HDDs*
- Select the climate scenario with the largest population in the *highest 10th percentile* of ensemble distribution to represent the *high ensemble winter HDDs*
- Scenario *"T"* is winter generation with historical streamflows – for comparison



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C and G were selected for winter and summer hydro-generation

Select Scenarios to Represent High and Low Winter HDDs

- For "high" winter HDDs, either ***G*** or ***R*** could be selected where
  - ***G*** and ***R*** are tied with the most data points: **14** in the top-10 percentile box
- For "low" winter HDDs, ***A*** was selected where
  - ***A*** has the data points: **18** in the bottom-10 percentile box

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Select Scenarios to Represent High and Low Summer CDDs

- A similar selection process was performed for summer CDDs

The Selected Climate Scenarios

Selected Scenarios

Scenario\Metric	Winter Generation	Summer Generation	Winter HDD	Summer CDD
A			low	high
C	high	low	-	-
G	low	high	high	low

A: *CanESM2_RCP85_BCSD_VIC_P1*
C: *CCSM4_RCP85_BCSD_VIC_P1*
G: *CNRM-CM5_RCP85_MACA_VIC_P3*

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Temperatures

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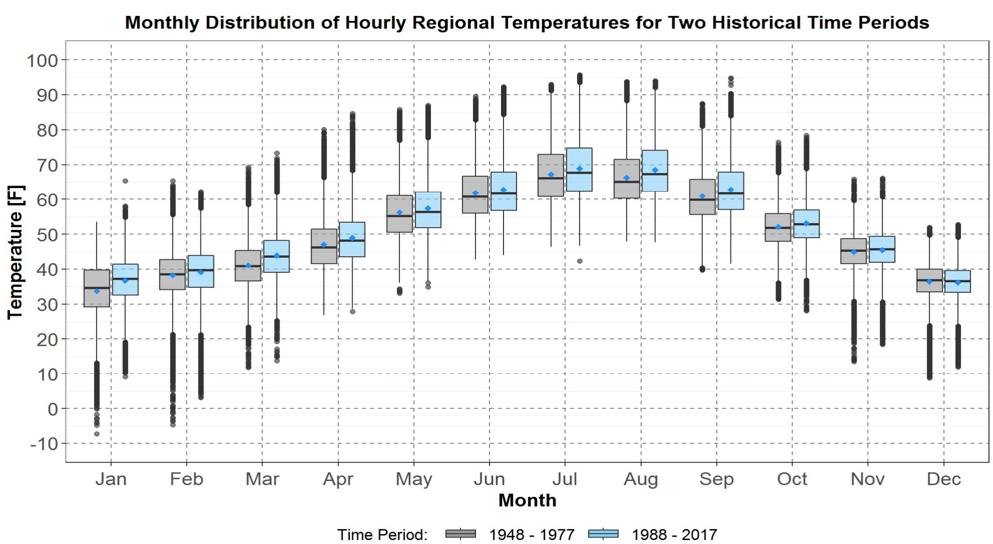
Warming Trends in Historical Time Periods



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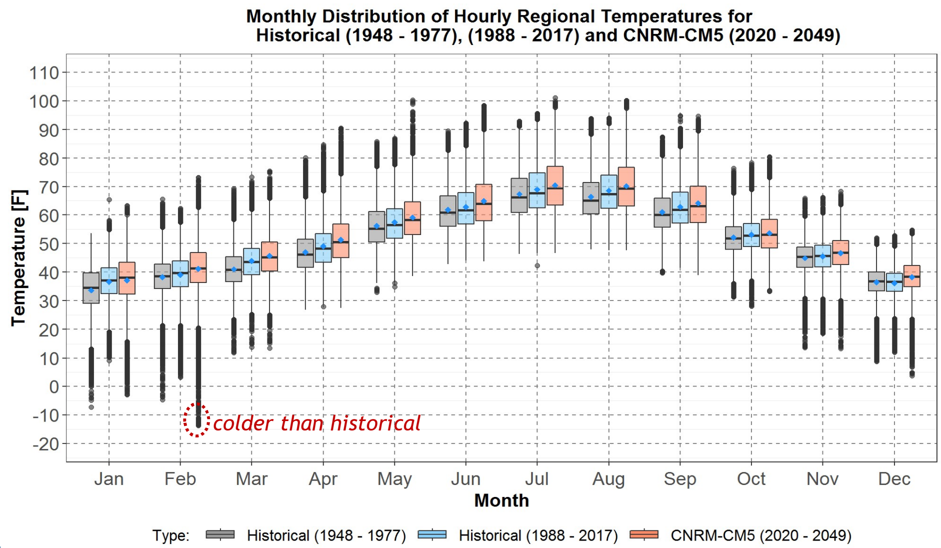
Warming Trends of Scenario G



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Climate scenario G has the lowest warming.
Climate scenarios A and C have higher warming.

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Streamflows at The Dalles

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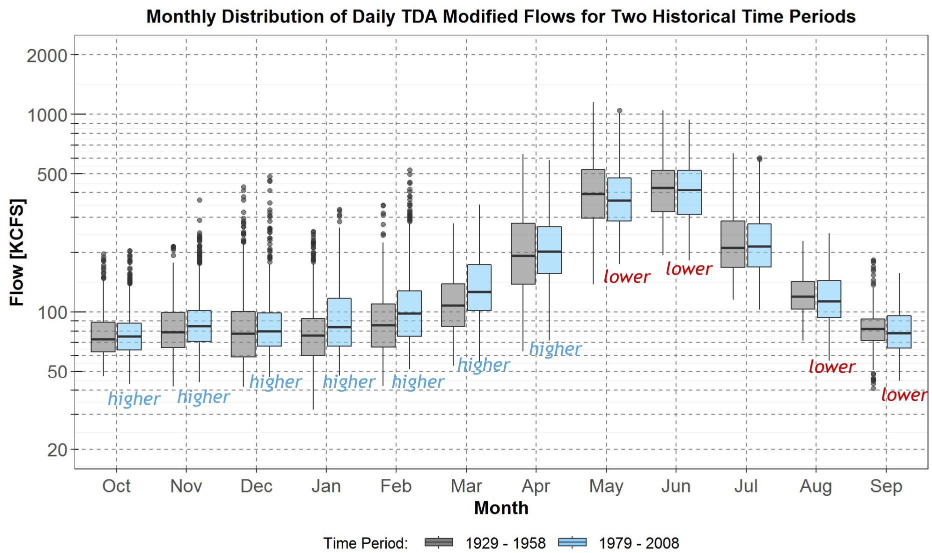
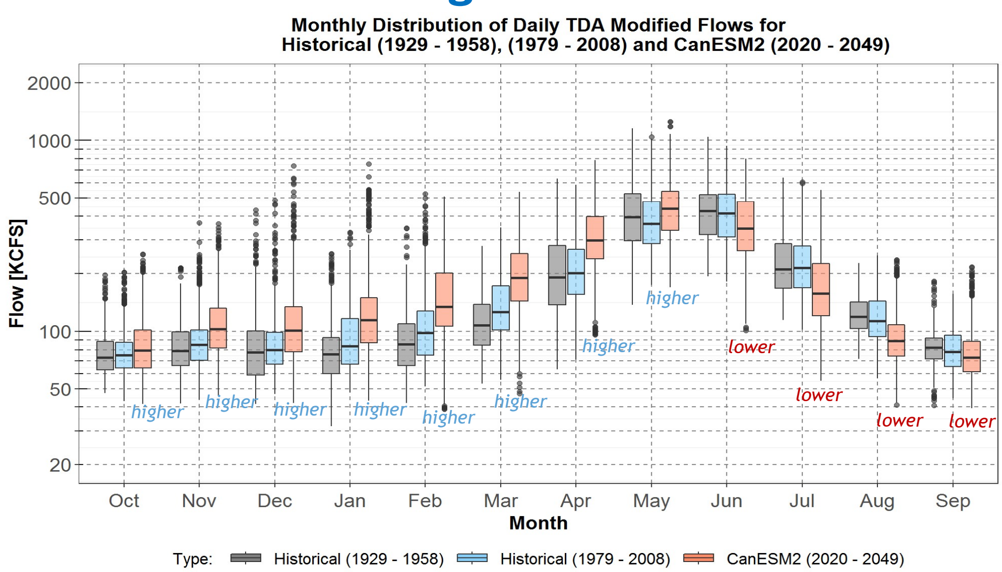
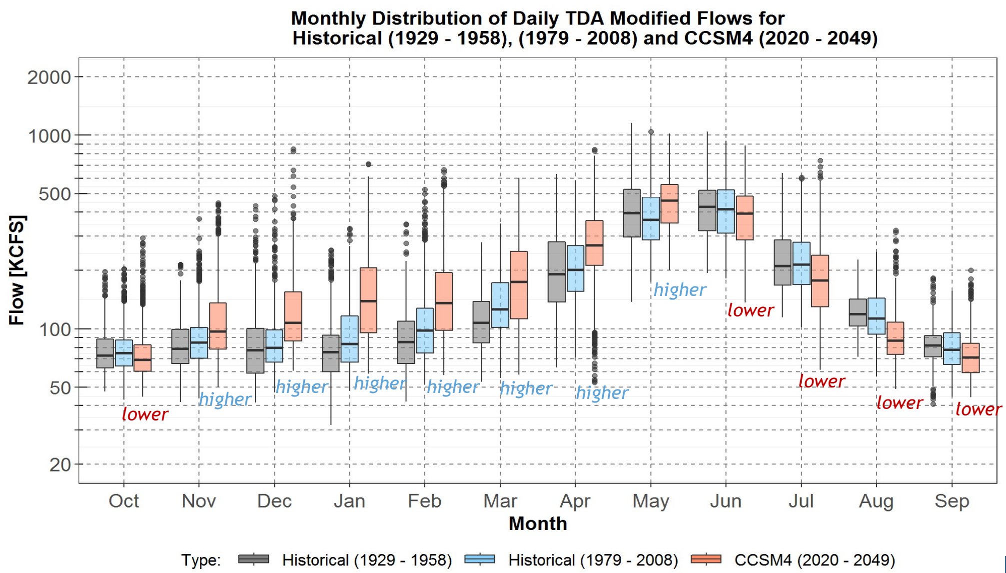
Seasonal-Shifting Trend in Historical Time Periods



Seasonal-Shifting Trend of Scenario A



Seasonal-Shifting Trend of Scenario C



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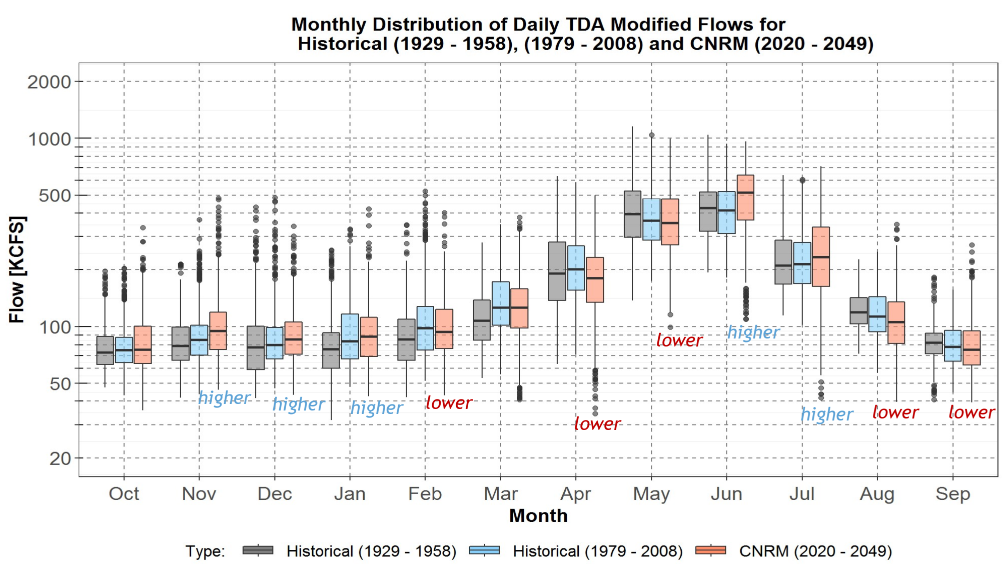
Seasonal-Shifting Trend of Scenario G



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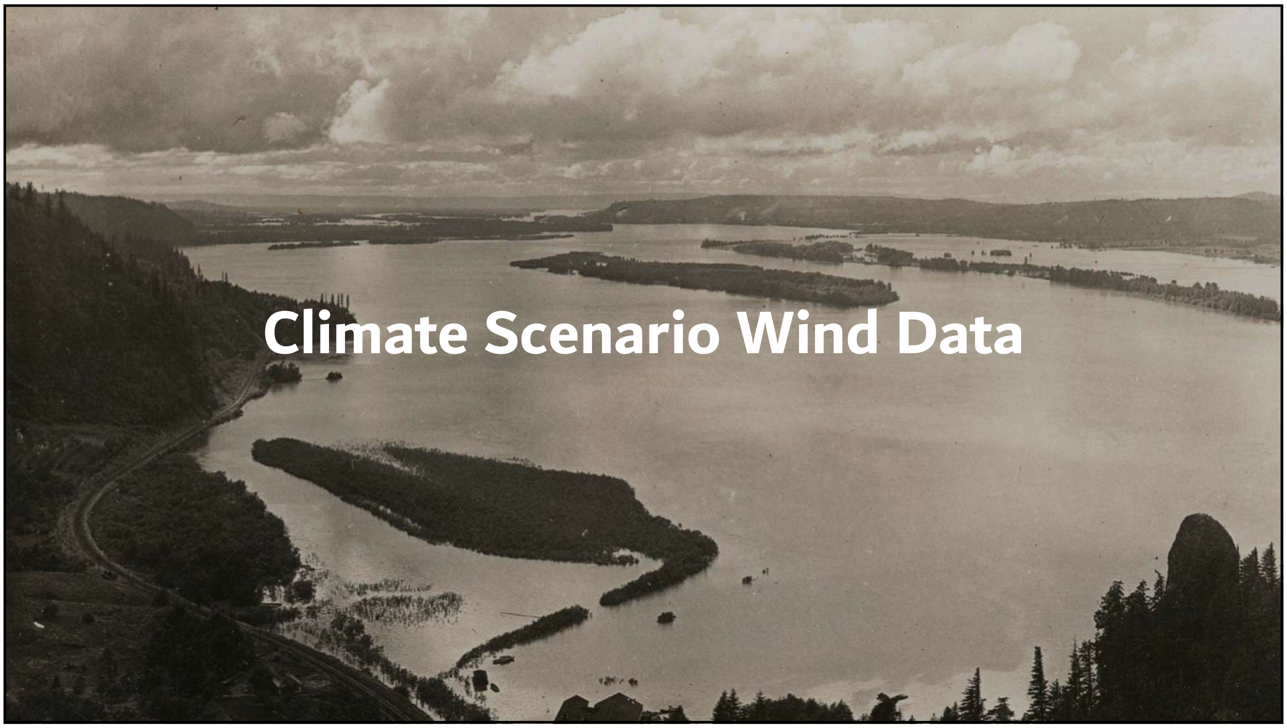

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Climate Scenario Wind Data

- The CMIP5 *RMJOC* climate scenario data consist of temperature and streamflow
- Very similar CMIP5 climate scenario wind data: download from Climatology Lab
- The climate scenario wind data are transformed into wind generation capacity factors (= generation / nameplate capacity)
- There does not seem to be strong climate trends in wind generation

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https://www.climatologylab.org/maca.html
https://climate.northwestknowledge.net/MACA/data_csv.php

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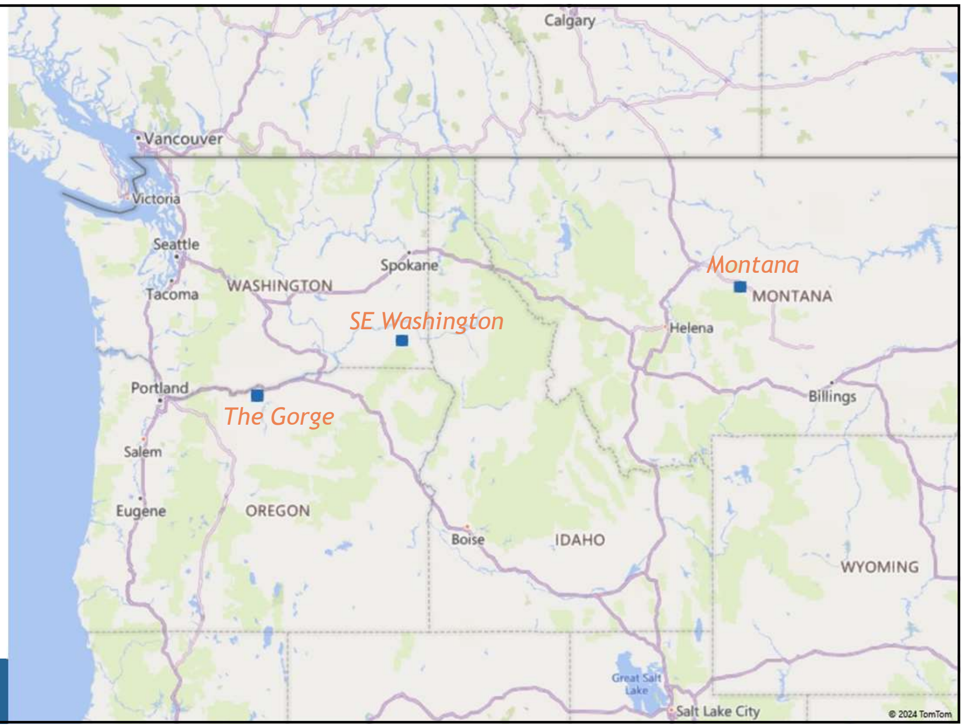
Northwest Wind Fleets

- 3 representative sites
  - The Gorge
  - SE Washington
  - Montana



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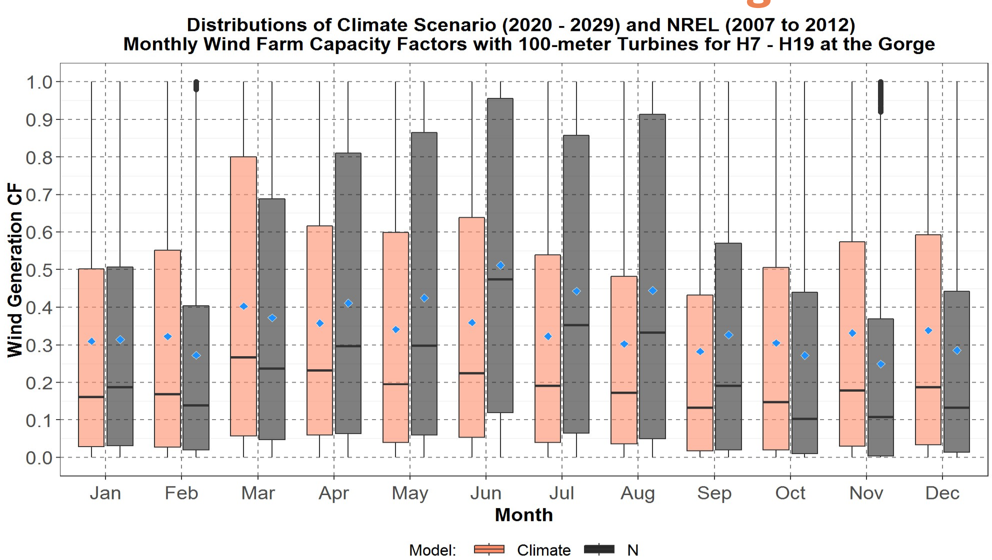
Synthetic Historical and Climate Scenario Wind Generation at the Gorge



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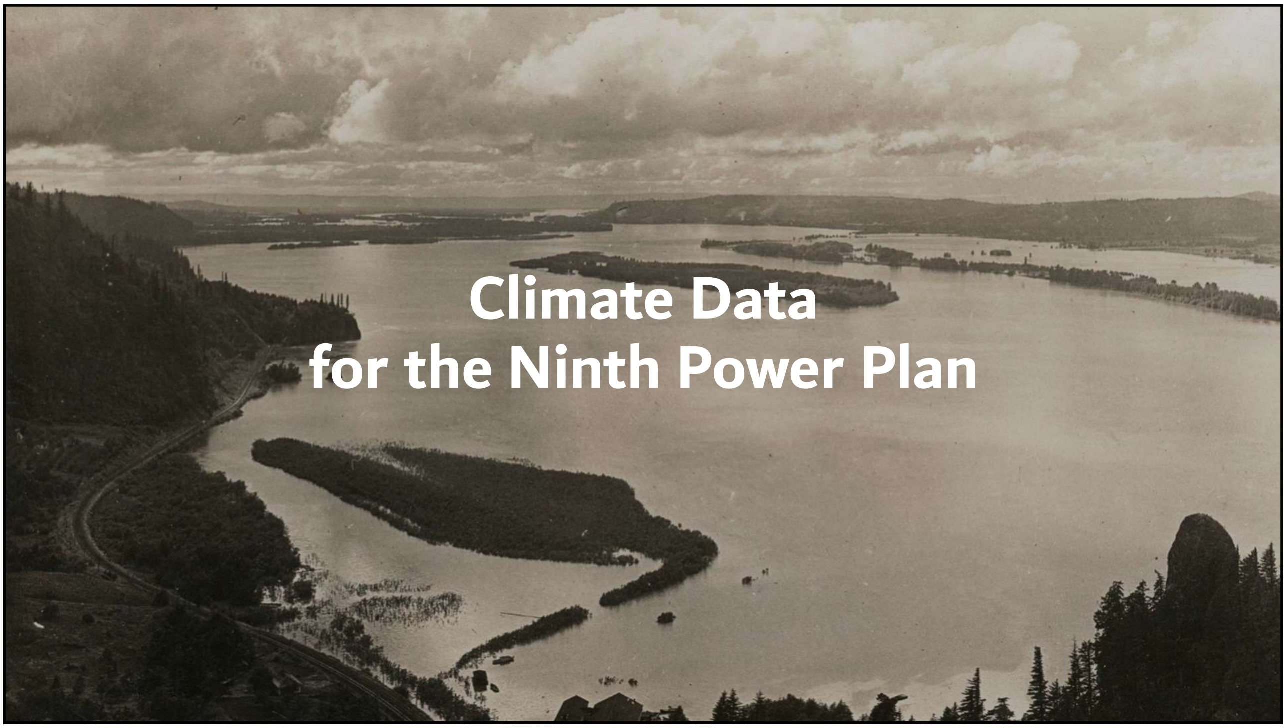

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Proposed Climate Data for the Ninth Power Plan

- Climate scenarios: the same 3 as in the 2021 Power Plan
  - Temperature data: about 25 Northwest locations representing 13 Balancing Authorities
  - Wind data: add 2 additional Northwest locations (*exact locations to be determined*)
  - Solar data: add 3 Northwest locations (*exact locations to be determined*)
  - Streamflow data: about 72 hydro-projects, same as in the 2021 Power Plan

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Power Plan Years and Climate Scenarios Years

- 2021 Power Plan years: 2022 to 2041
- Climate scenario years: 2020 to 2049

- Upcoming Ninth Power Plan years: 2027 to 2046
- Proposed climate scenario years: 2020 to 2049

Notable Feedback and Comments from the Climate and Weather Advisory Committee (I)

- The 3 selected RMJOC climate scenarios, A, C and G, have slightly stronger climate trends than the full ensemble of 19 RMJOC climate scenarios.
- Adding climate scenario J would result in more consistent climate trends as those of the full ensemble of 19 RMJOC climate scenarios.

- Council staff considered adding J:
  - increase by 25% the amount of work in the Ninth Power Plan that involves climate data
  - does not add more extreme temperature data than those in A, C and G already
  - seems to have a discrepancy between seasonal precipitation but seasonal streamflow
  - In the end, council staff would recommend not to include J

Notable Feedback and Comments from the Climate and Weather Advisory Committee (II)

- The RMJOC climate data were calculated from CMIP5 GCMs. Consider using newer the CMIP6 GCMs.
- Currently, the global response to mitigate climate change seems to suggest a smaller emission levels, perhaps RCP6.0. Consider using RCP6.0 climate data instead of RCP8.5.

- Council staff is not able to use either the newer CMIP6 data or the RCP6.0 emission level:
  - Modified streamflow data, needed to run the adequacy model, are not available for either the CMIP6 data or the RCP6.0 emission level
  - The RMJOC transformed precipitation data into modified streamflow only for the CMIP5 data and for the RCP4.5 and RCP8.5 emission levels

Notable Feedback and Comments from the Climate and Weather Advisory Committee (III)

- Some climate models contains extreme cold temperatures that are unrealistic

- Council staff are currently analyzing extreme cold temperatures for the selected A, C and G scenarios, and plan to discuss results with the CWAC.

- Since the Ninth Power Plan covers from 2027 to 2046, consider using additional climate scenario years from 2050 to 2059

- Modified streamflow data are available from 2020 to 2099. However, associated hydro-regulation rule-curves (such as flood-control) are not available for 2050 to 2059.


Questions?
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Christian Douglass: cdouglass@nwcouncil.org
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Extras

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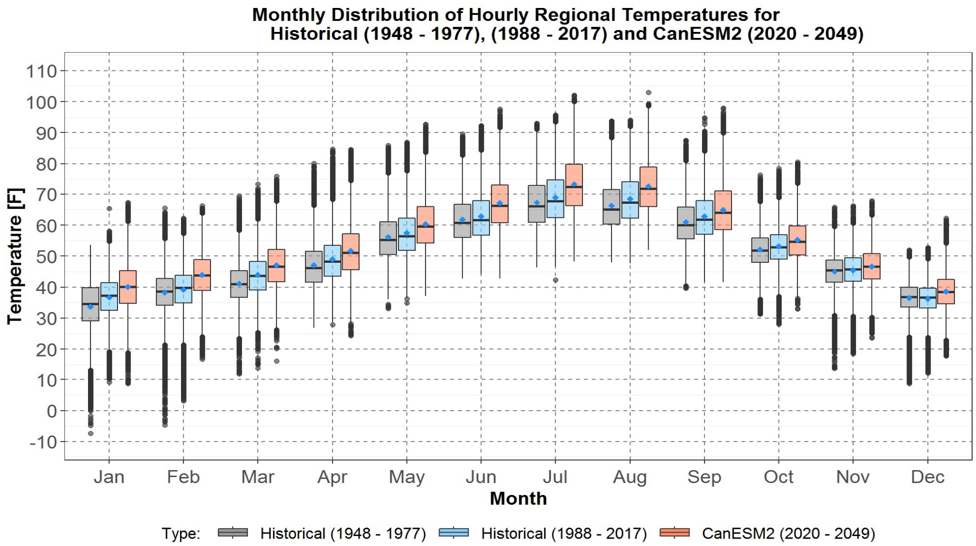
Climate Trends for Scenario A



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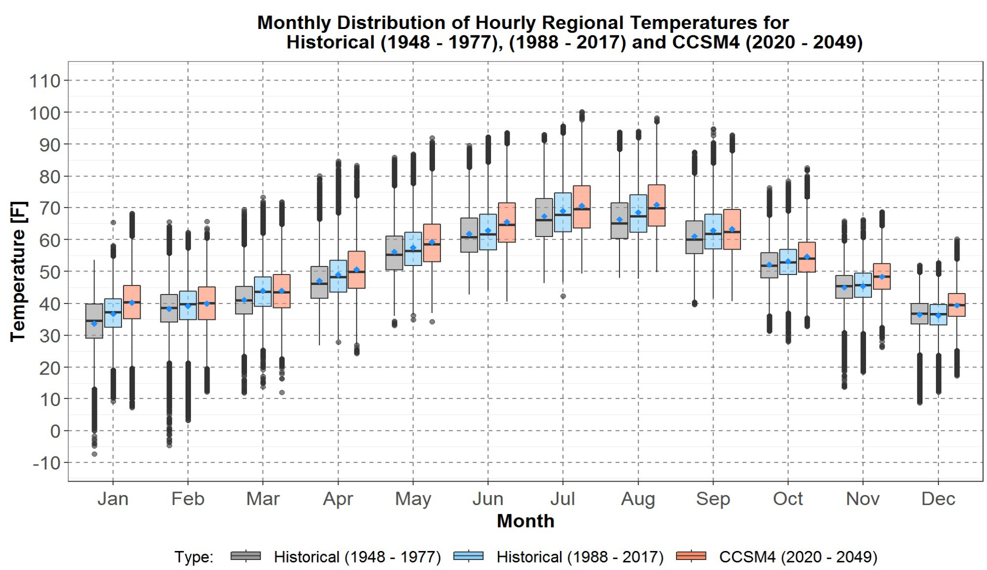
Climate Trends for Scenario C



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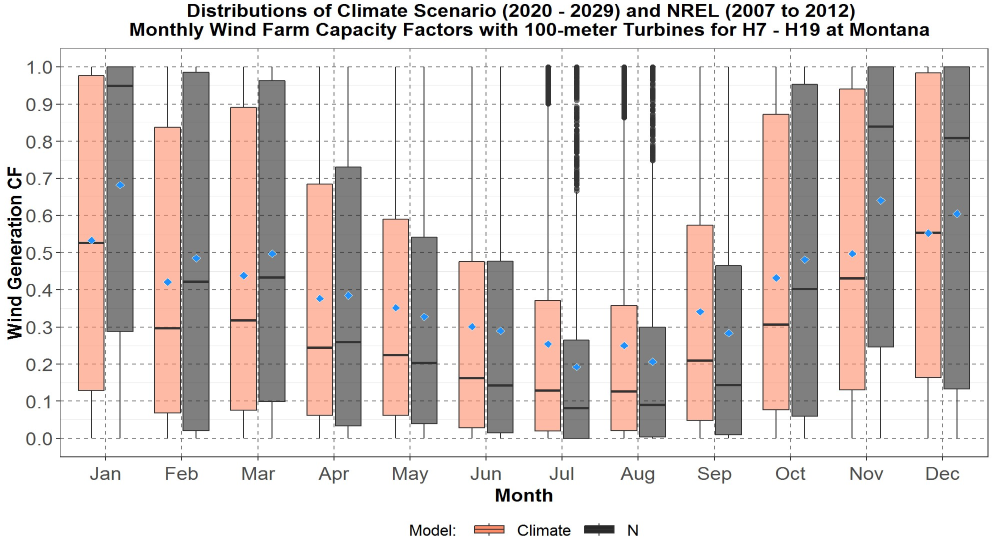
Synthetic Historical and Climate Scenario Wind Generation in Montana



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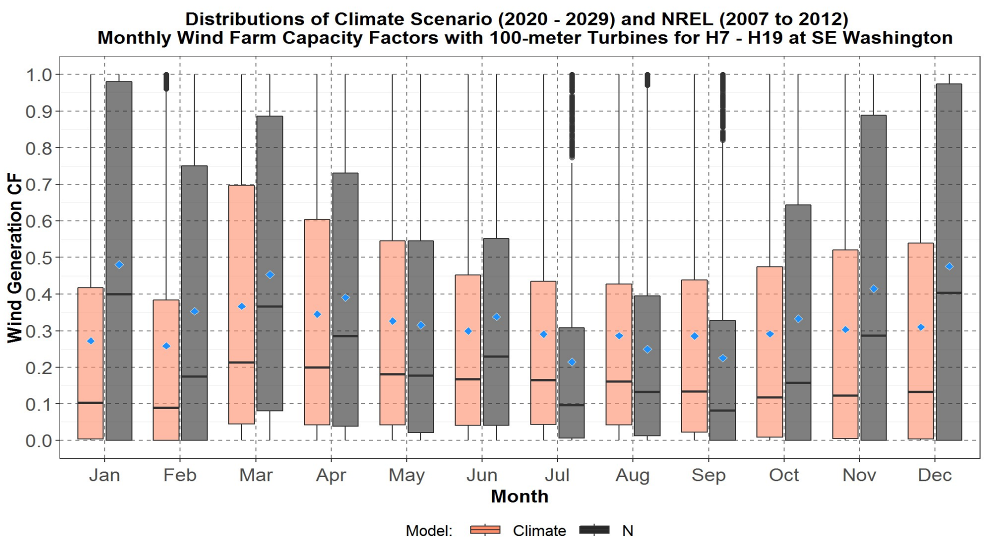
Synthetic Historical and Climate Scenario Wind Generation at SE Washington



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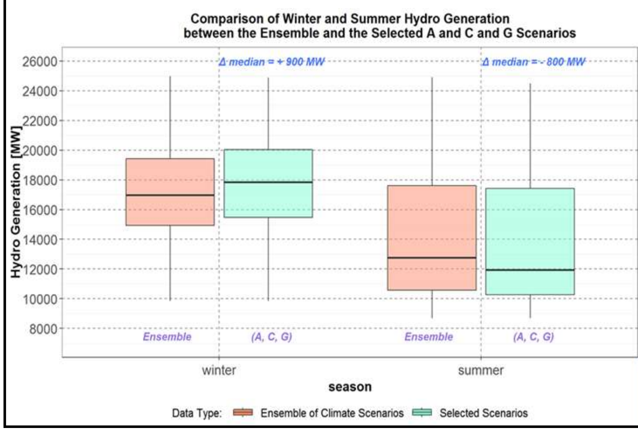
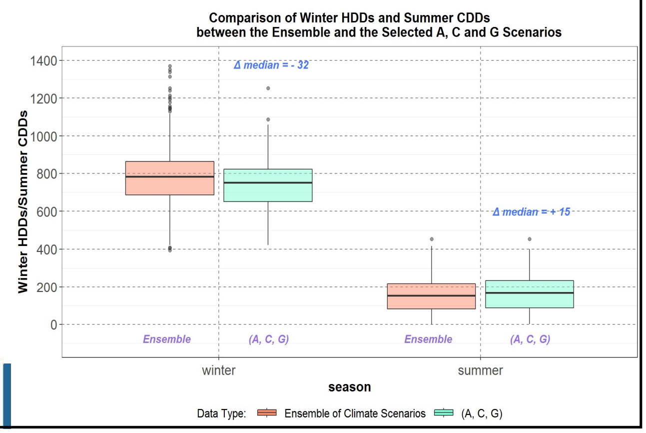
Feedback and Comments from the Climate and Weather Advisory Committee (A1)

- The 3 selected RMJOC climate scenarios, A, C and G, have slightly stronger climate trends than the full ensemble of 19 RMJOC climate scenarios.





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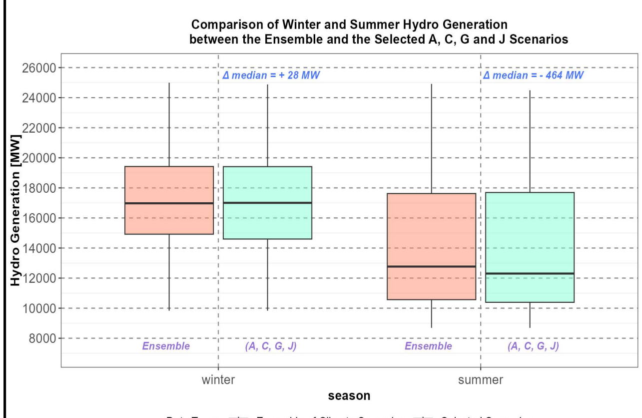
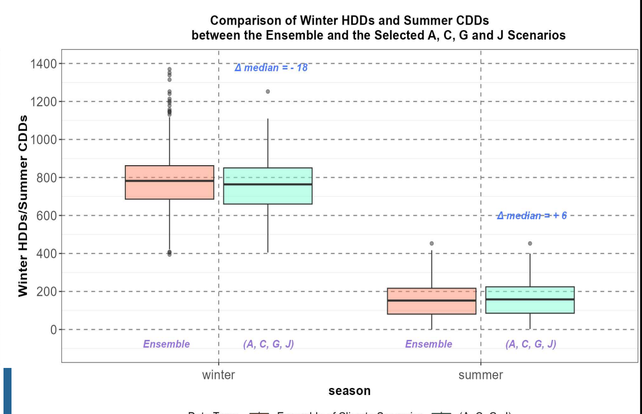
Feedback and Comments from the Climate and Weather Advisory Committee (A2)

- Adding climate scenario J would result in a more consistent distribution with the full ensemble of 19 RMJOC climate scenarios





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