Climate and Weather Advisory Committee Meeting

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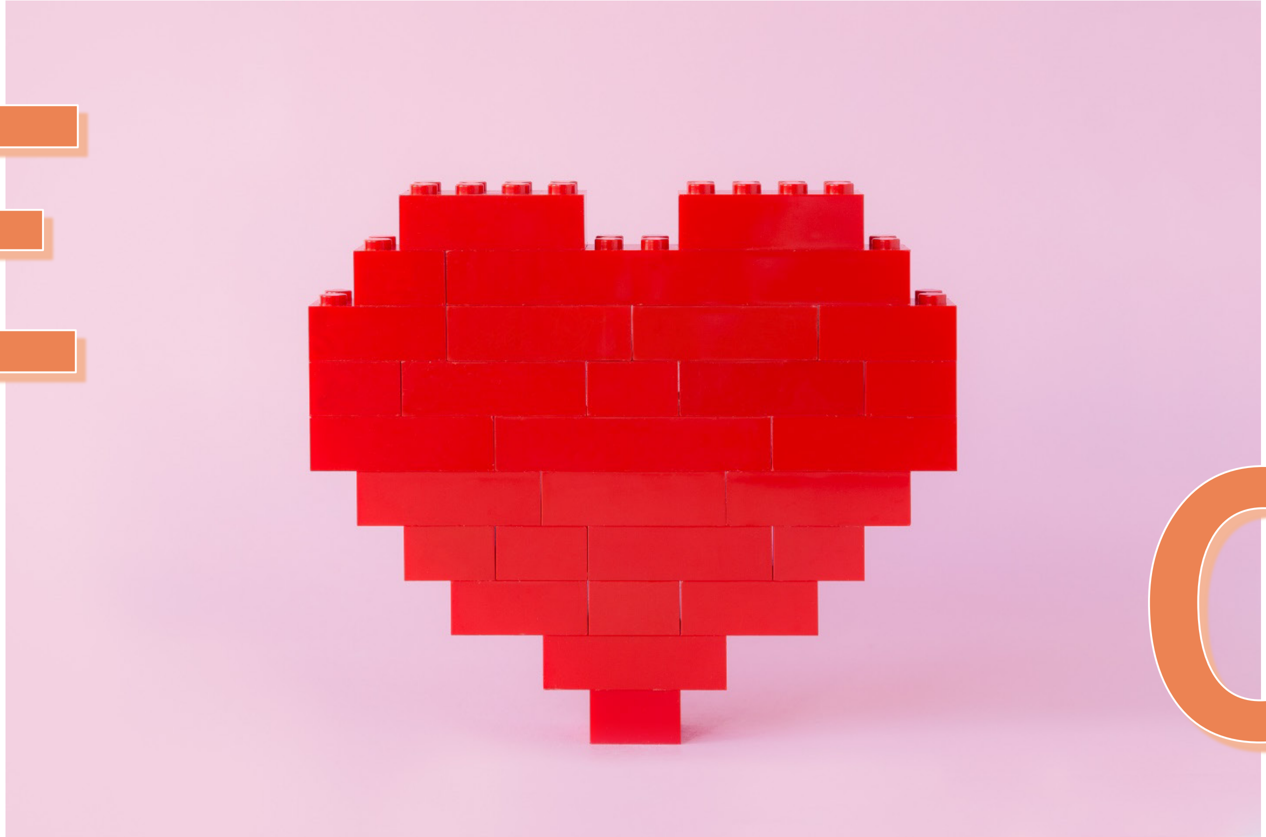
August 1, 2024

Northwest Power and Conservation Council

WE



OUR

COMMITTEE MEMBERS!

Agenda (I)

- Meeting logistics

- Climate data used in the Power Plan
  - 2021 Power Plan
    - Streamflow data - RMJOC
    - Temperature data – RMJOC (4 cities)
    - Wind data – Climatology Lab (3 locations)
    - Solar data – historical (2 locations)
  - Upcoming Power Plan
    - Streamflow data – RMJOC (*no change*)
    - Temperature data – RMJOC (*among 29 locations*)
    - Wind data – climatology Lab (*same 3 locations and additional locations, work in progress*)
    - Solar data – climatology Lab (*same 2 locations and additional locations, work in progress*)

Agenda (II)

- Extreme regional weather in historical and climate scenario data
  - Extreme temperatures at 4 cities
  - Very low seasonal streamflows

- Preview of topics for the next Climate and Weather Advisory Committee

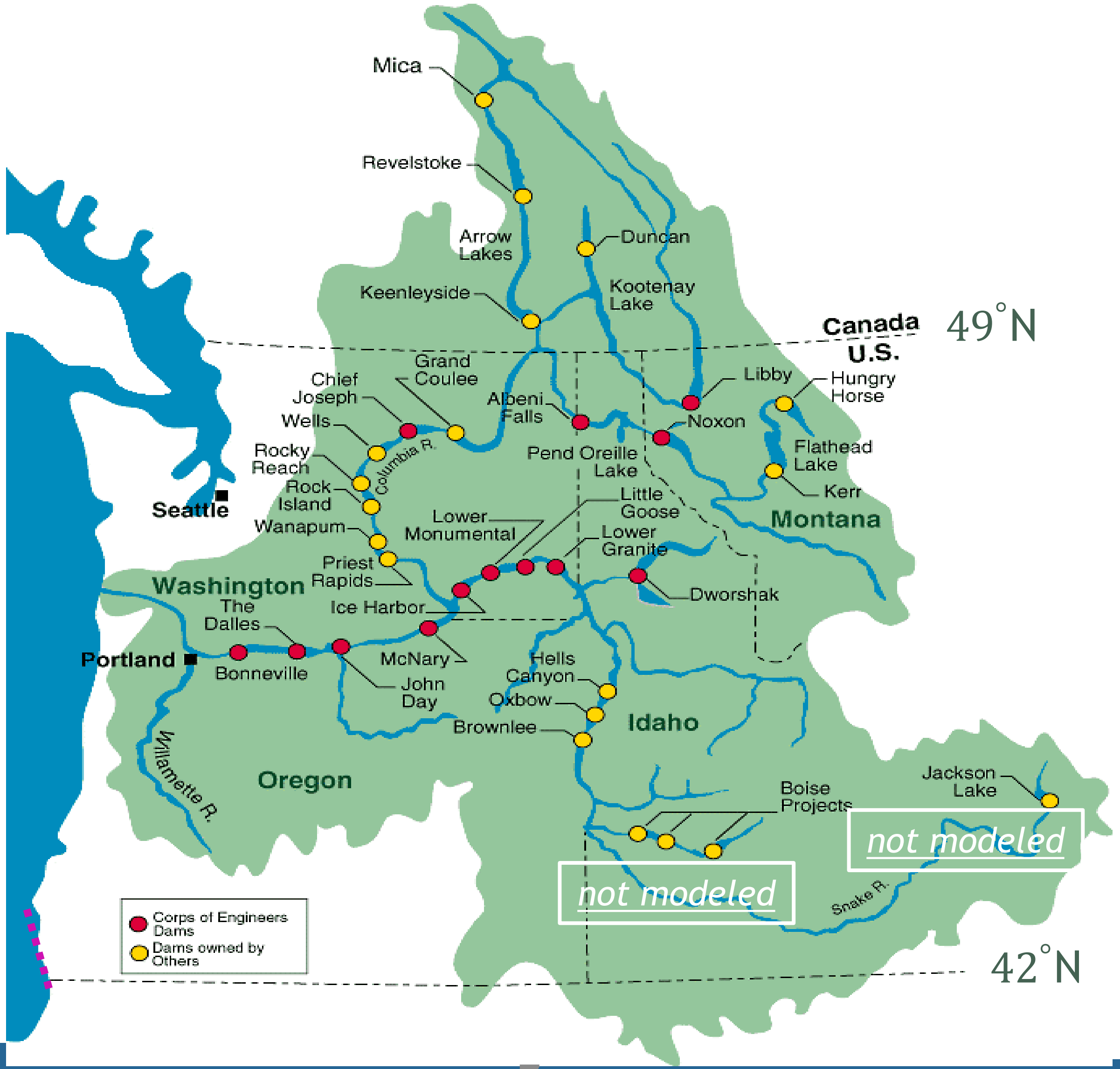
- Discussions and inputs on
  - climate scenarios selection (add scenario J?)
  - climate scenario years (2020 to 2049?)
  - topics of interests

Climate Scenario Streamflows

Climate Scenario Streamflows

- Climate scenario modified daily streamflows available for 76 hydro-projects and gauging stations
- They are used directly in the Council's resource adequacy models

A Sample List of Hydro-Projects



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Climate Trends in Streamflow

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

https://www.nwcouncil.org/2021powerplan_trends-in-historical-and-climate-change-river-flows/

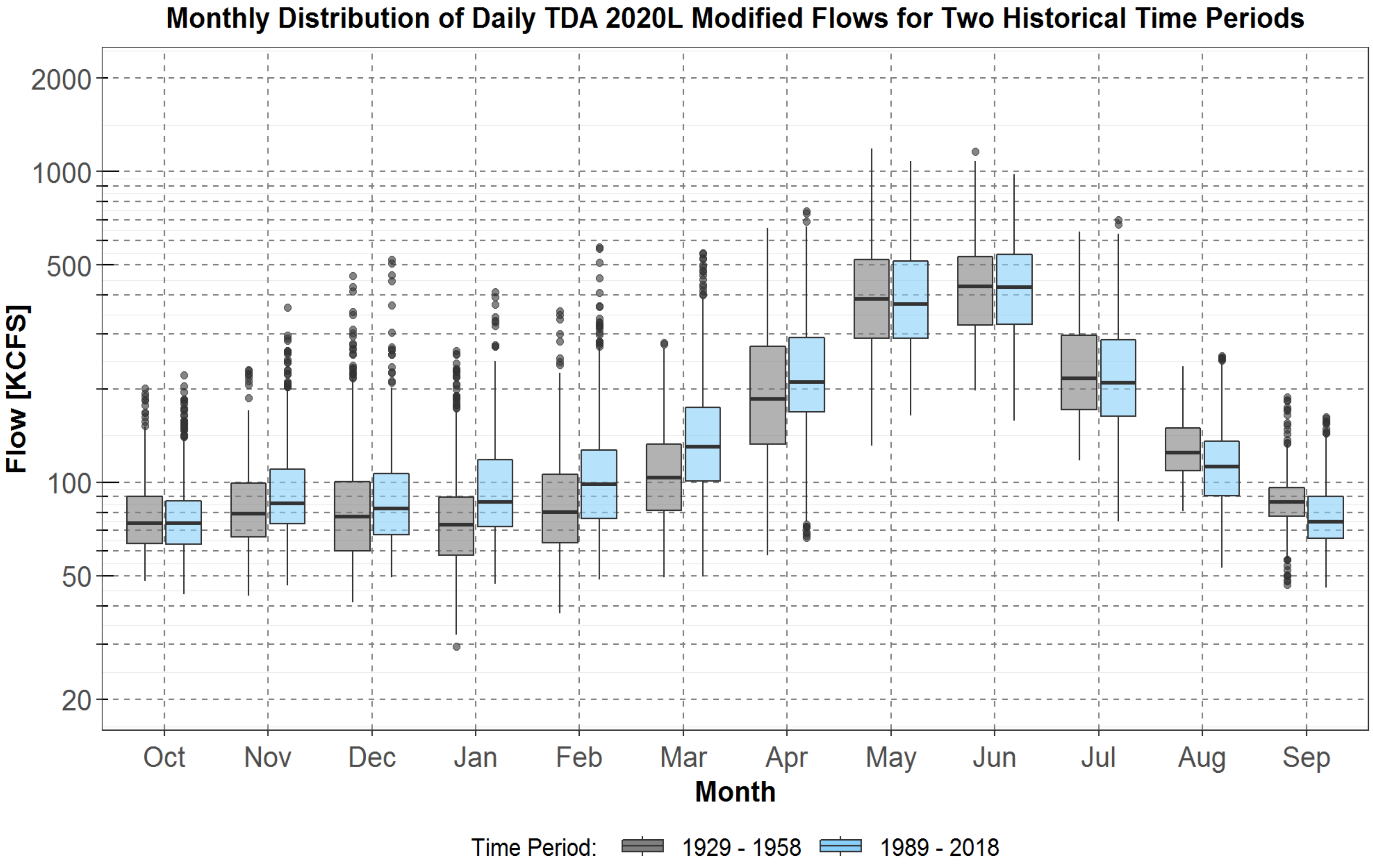
Climate Trends in Streamflow

- Compare daily 2020 Level modified streamflows at The Dalles (TDA)
  - First 30-years, 1929 to 1958, of historical streamflows
  - Last 30-years, 1989 to 2018, of historical streamflows
  - 2020 – 2049 climate scenarios A, C, and G streamflows

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

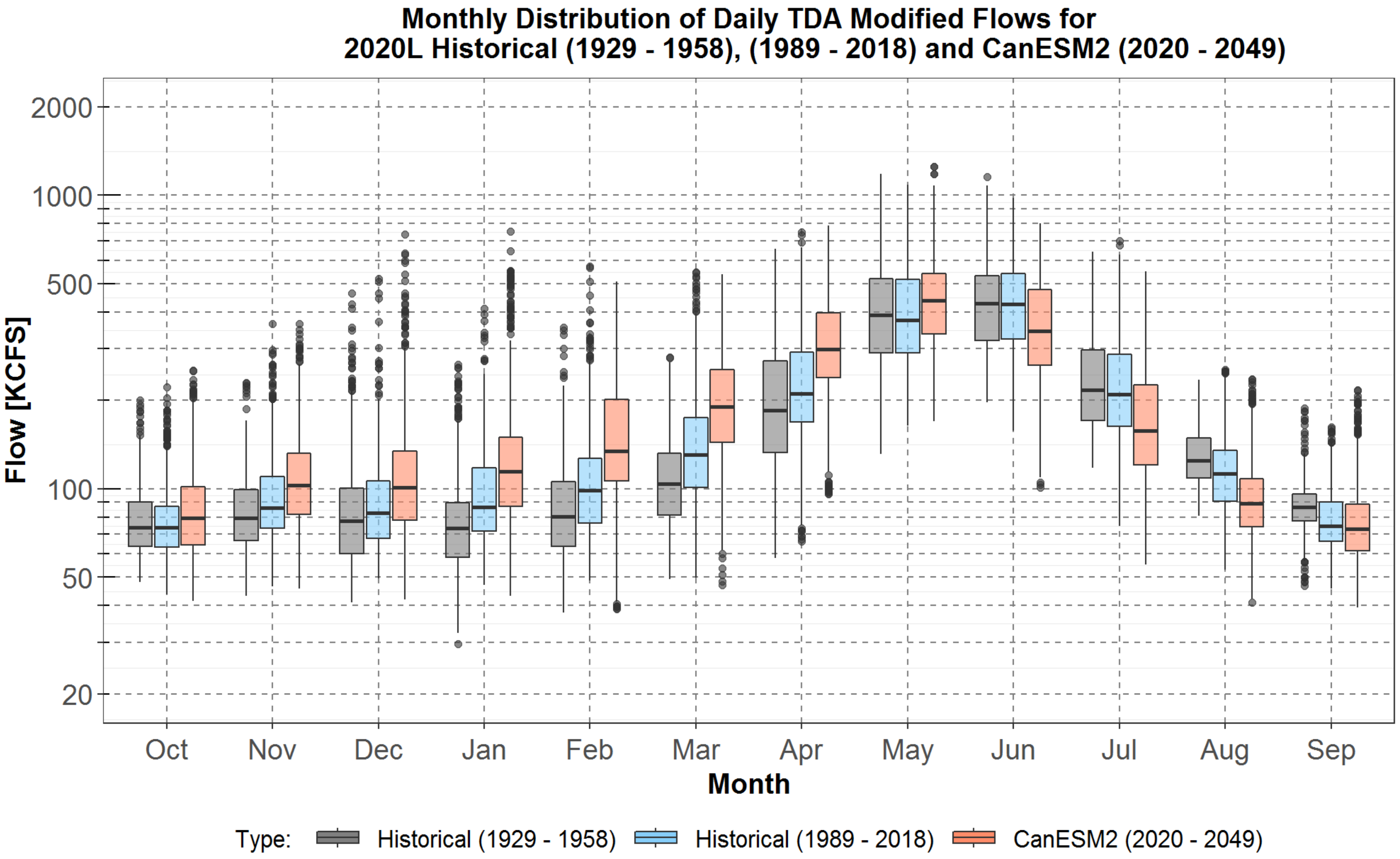
First 30-years vs Last 30-years of Historical Streamflow

- Comparisons of the boxes
- For Nov to Apr
- Streamflows for the *last 30-years* are *higher* than streamflows for the *first 30-years*
- For May, Jul, Aug and Sep
- Streamflows for the *last 30-years* are *lower* than streamflows for the *first 30-years*



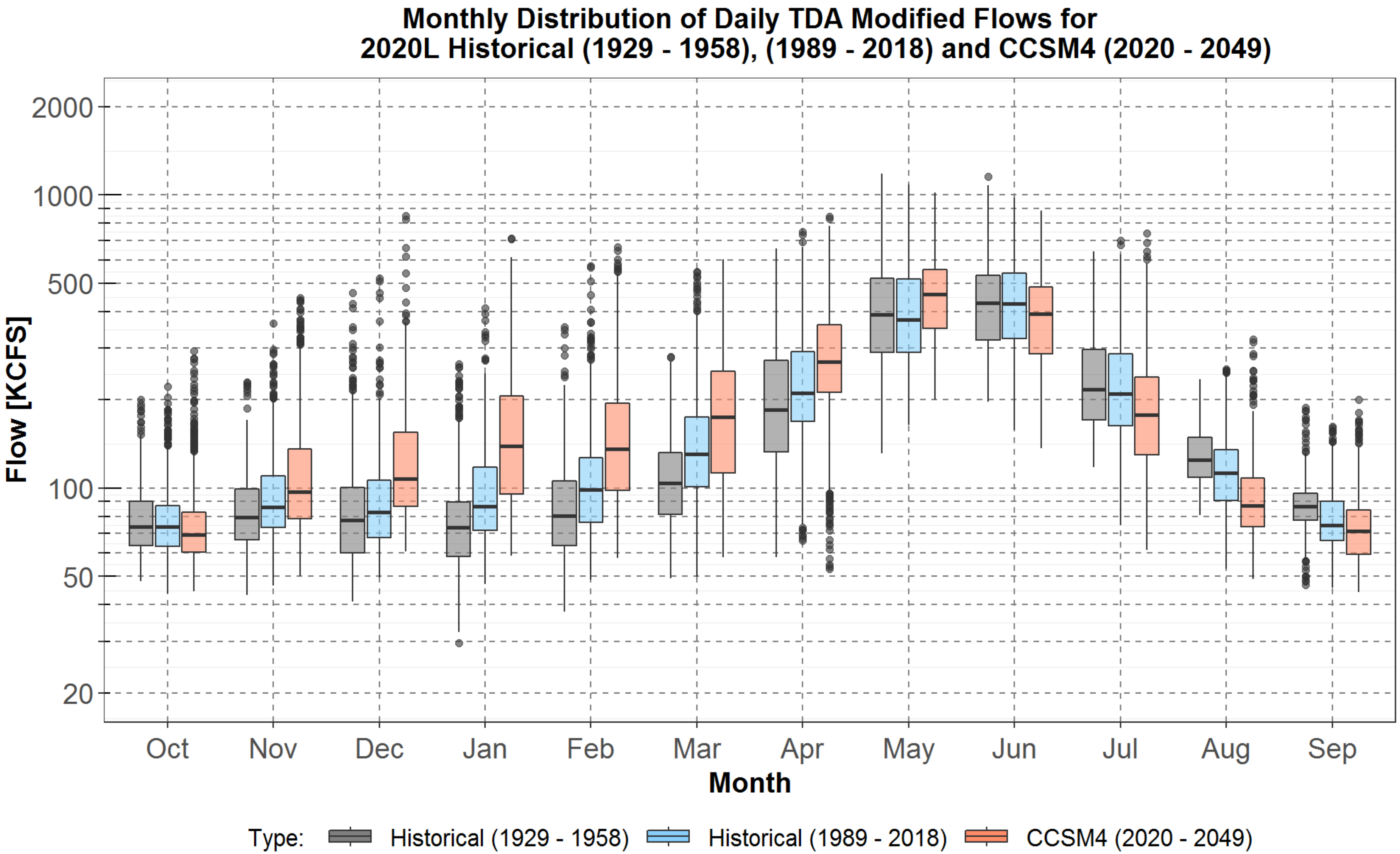
First 30-years, Last 30-years And Climate Scenario A

- Comparisons of the boxes
- For Oct to May
- Streamflows for climate *scenario A* are *higher* than streamflows for the *last 30-years*
- For Jun to Sep
- Streamflows for climate *scenario A* are *lower* than streamflows for the *last 30-years*



First 30-years, Last 30-years And Climate Scenario C

- Comparisons of the boxes
- For Nov to May
- Streamflows for climate *scenario C* are *higher* than streamflows for the *last 30-years*
- For Jun to Oct
- Streamflows for climate *scenario C* are *lower* than streamflows for the *last 30-years*

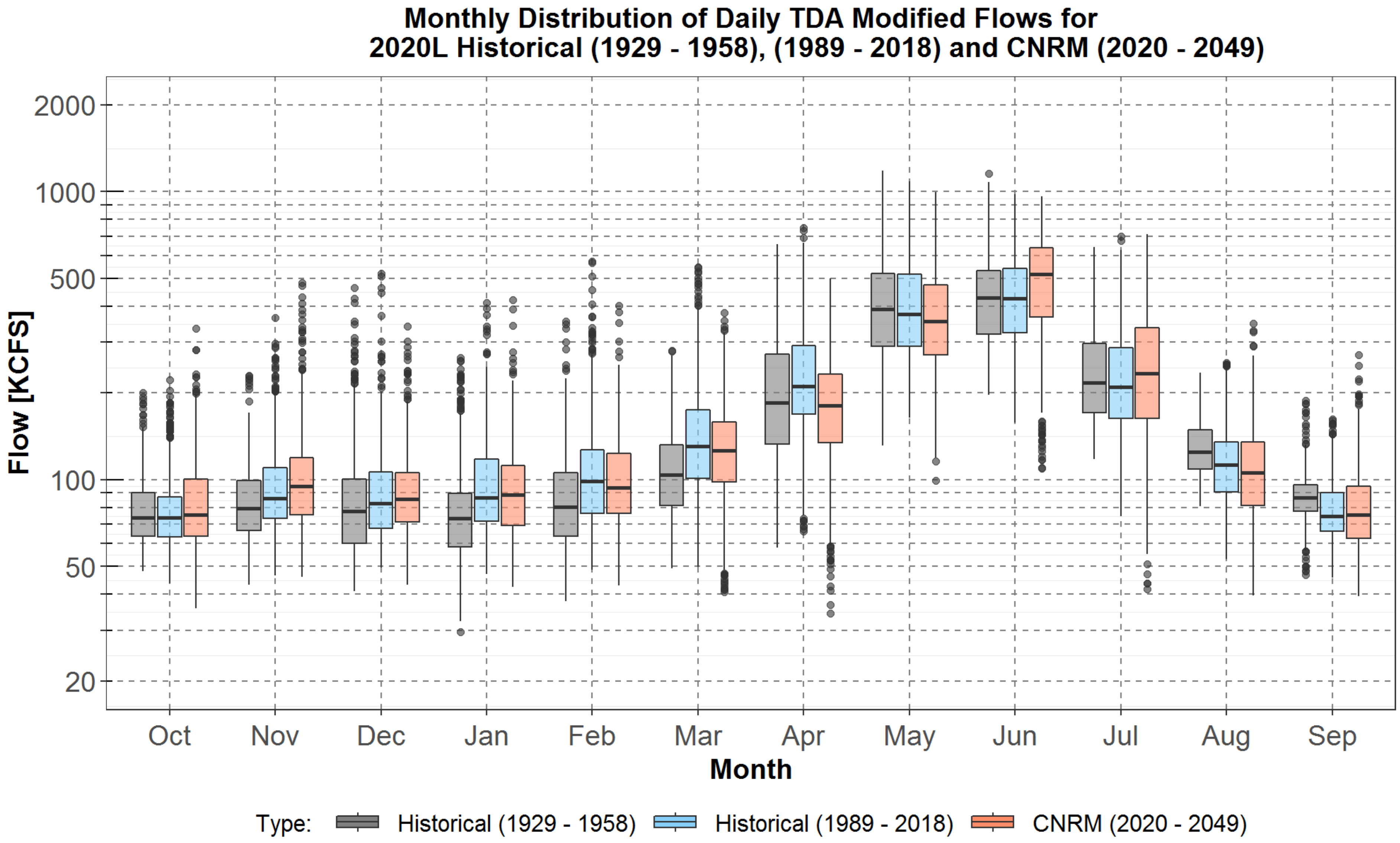


First 30-years, Last 30-years And Climate Scenario G

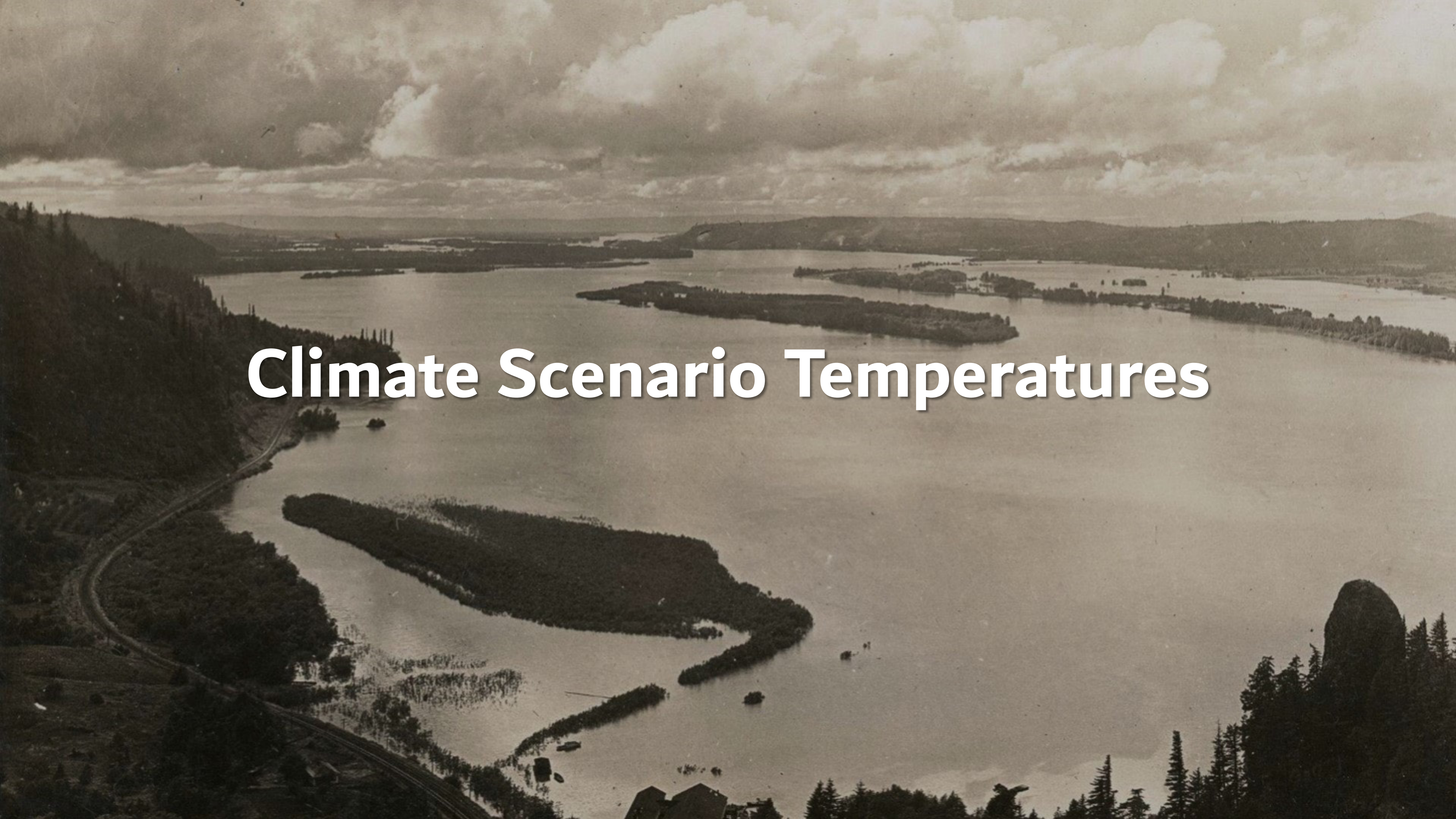
- Comparisons of the boxes

- For Oct to Jan, *Jun* and *Jul*
- Streamflows for climate *scenario G* are *higher* than streamflows for the *last 30-years*

- For *Feb to May*, and Aug
- Streamflows for climate *scenario G* are *lower* than streamflows for the *last 30-years*



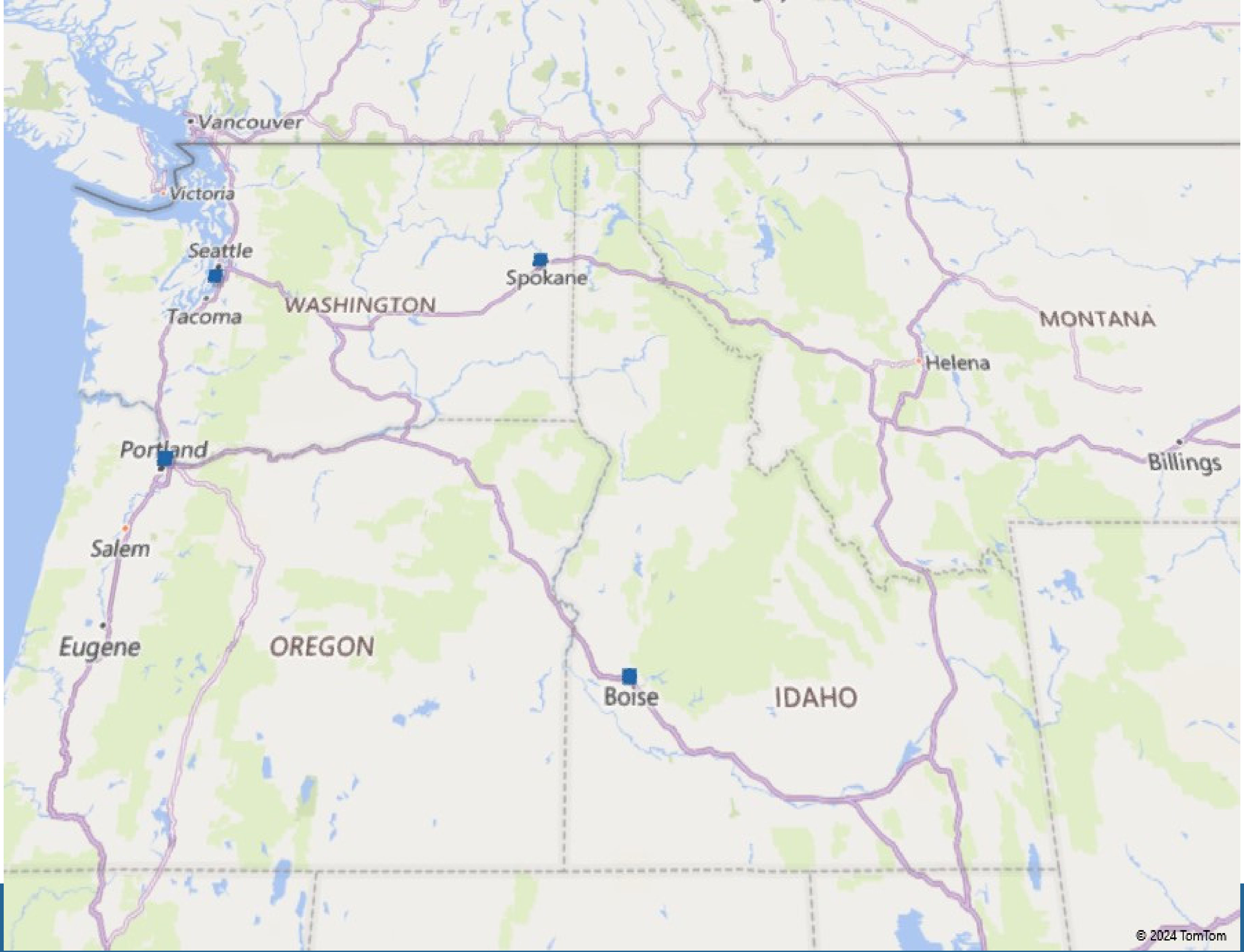
Climate Scenario Temperatures



Previous Power Plan

Climate Scenario Temperatures

- Airport at
  - Boise
  - Portland
  - Seattle
  - Spokane



Climate Scenario Regional Temperature

- RMJOC Climate scenario temperatures $T_{Seattle}$, $T_{Portland}$, $T_{Spokane}$, T_{Boise} are daily minimum and maximum temperatures from

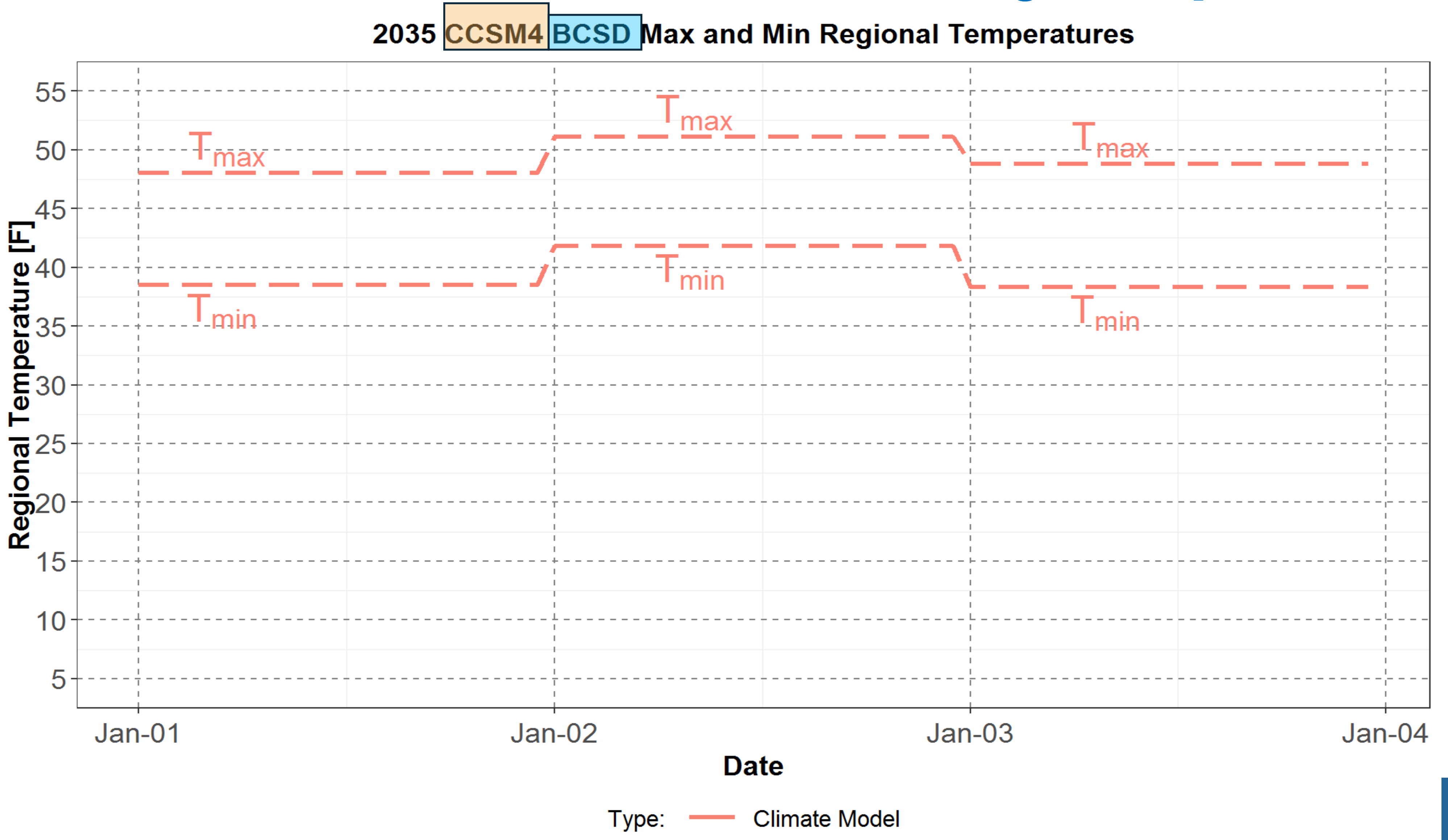
- Define a *regional* temperature T:

$$T = a \times T_{Seattle} + b \times T_{Portland} + c \times T_{Spokane} + d \times T_{Boise} + constant$$

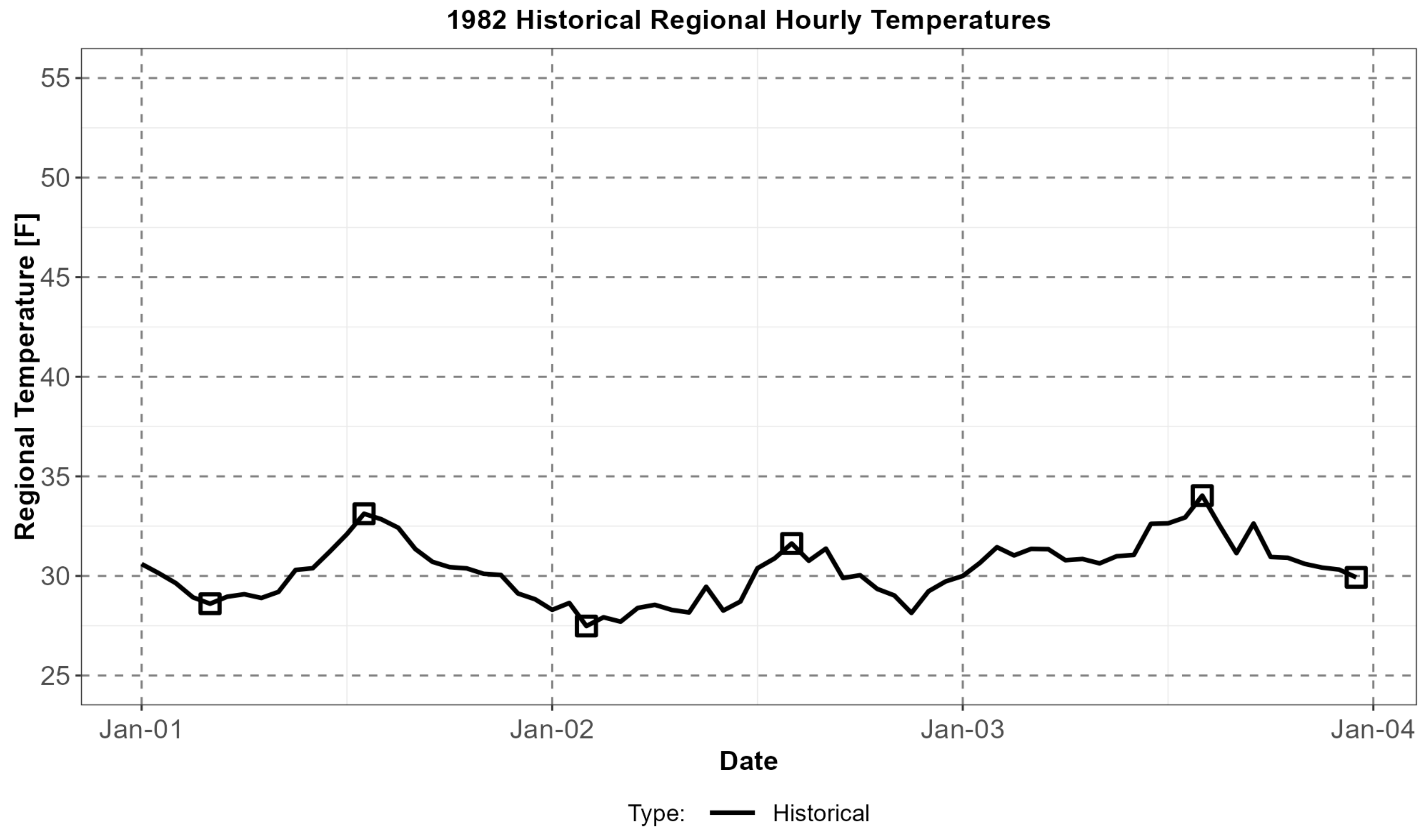
(a, b, c, d, vary by month. For example, a = 0.49, b = 0.26, c = 0.22, d = 0.06, constant = -2.54, for Jan to Apr)

- Therefore, T is daily minimum and maximum

CCSM4 BCSD Climate Scenario Daily Temperatures

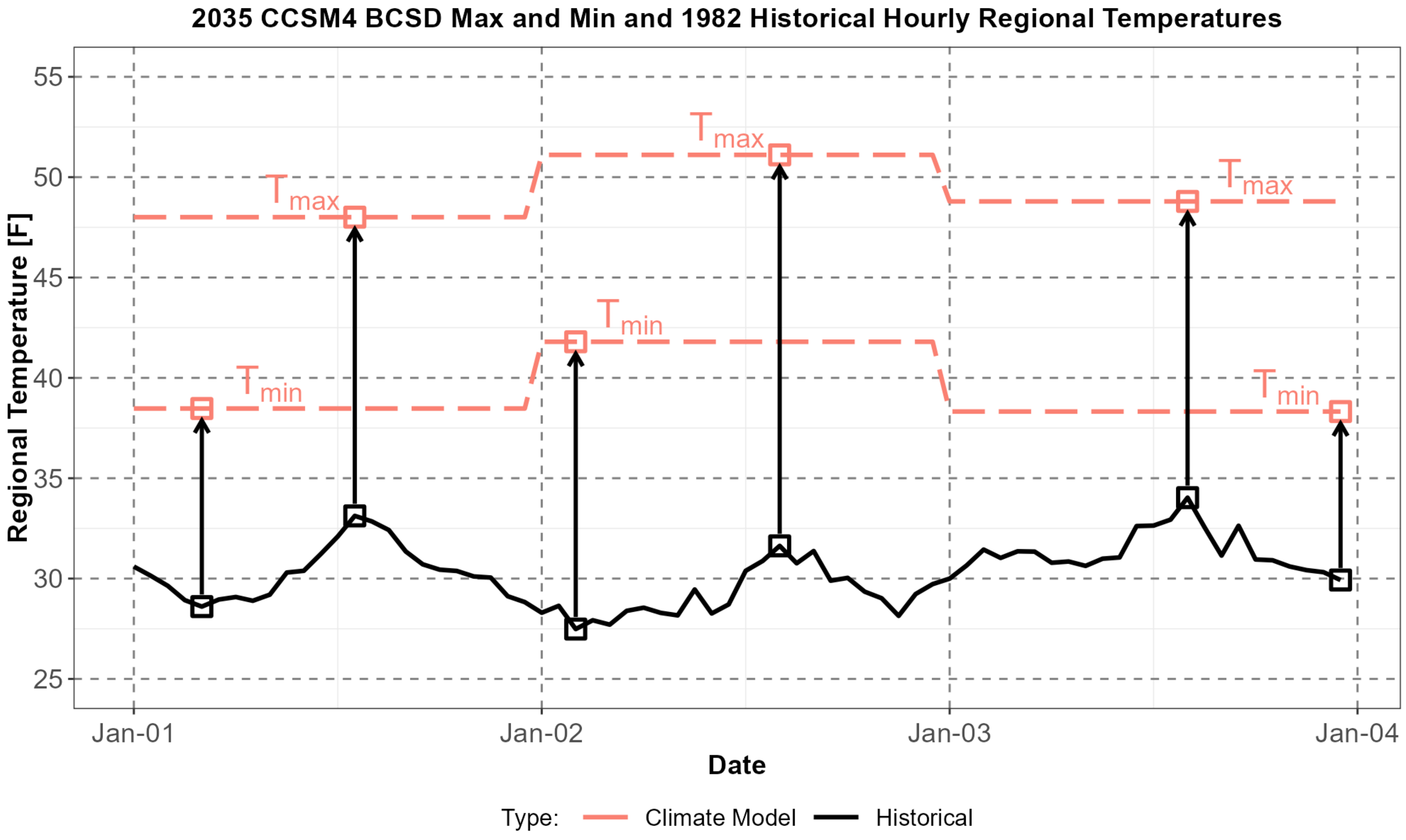


The Historical 1982 Hourly Temperatures



Mapping Historical 1982 Temperatures to Climate Scenario Daily Temperatures

- historical T_{min} is transformed to *scenario C* T_{min} at the same historical hour
- historical T_{max} is transformed to *scenario C* T_{max} at the same historical hour



Transforming Historical 1982 Temperatures to Climate Scenario Daily Temperatures

- For January 1st,

$$\alpha_{Jan-1} \times (28.60) + \beta_{Jan-1} = 38.47$$
$$\alpha_{Jan-1} \times (33.12) + \beta_{Jan-1} = 48.01$$

So $\alpha_{Jan-1} \cong 2.110$ and $\beta_{Jan-1} \cong -21.88$

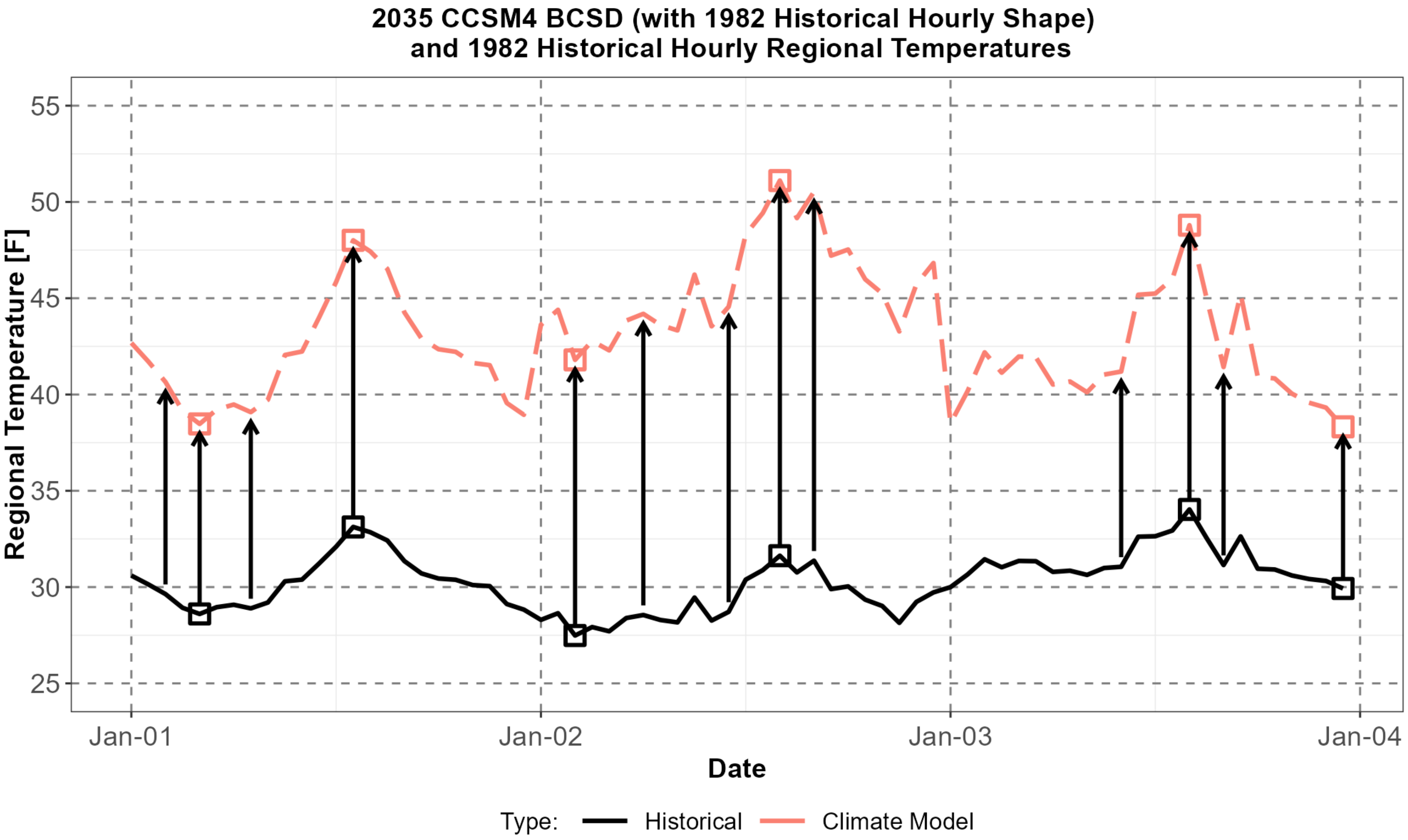
- For January 2nd,

$$\alpha_{Jan-2} \times (27.48) + \beta_{Jan-2} = 41.80$$
$$\alpha_{Jan-2} \times (31.63) + \beta_{Jan-2} = 51.11$$

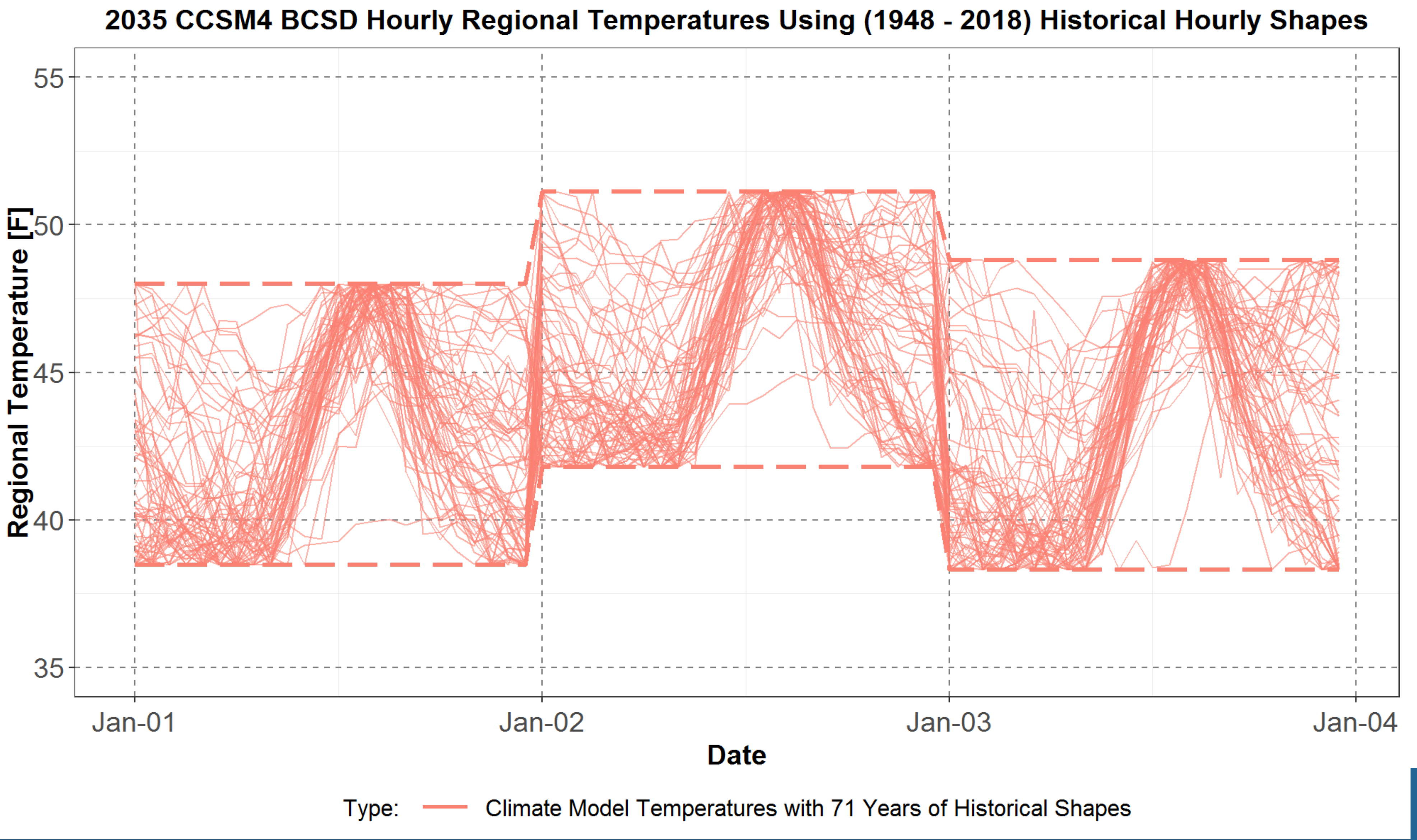
So $\alpha_{Jan-2} \cong 2.246$ and $\beta_{Jan-2} \cong -19.95$

Climate Scenario Hourly Temperatures with Historical 1982 Hourly Shape

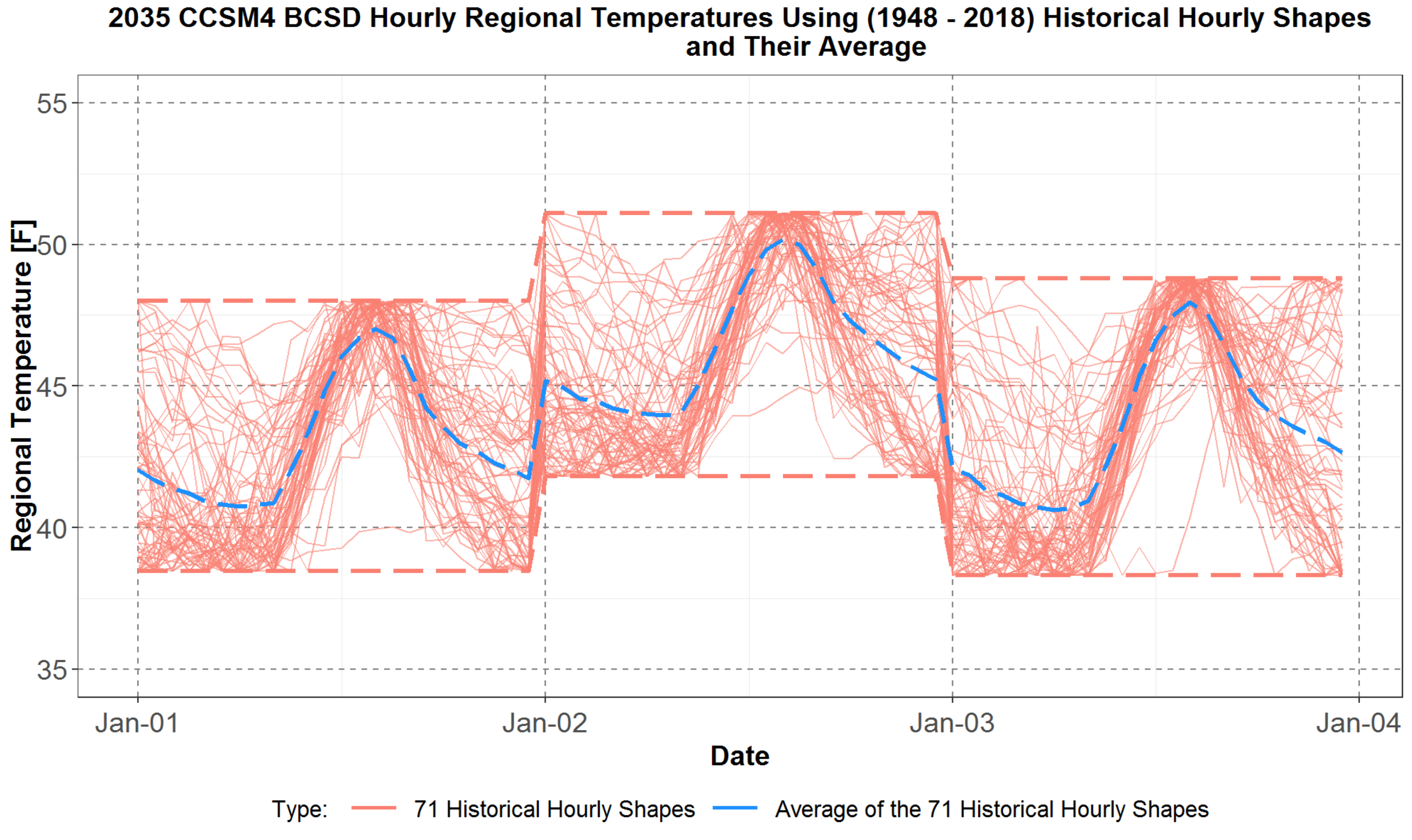
- The equation for Jan 1st that transforms historical T_{min} and T_{max} to *scenario C* T_{min} and T_{max}
- is also used to transform other historical hourly temperatures to scenario C hourly temperatures
- And so on for *Jan 2nd*, *Jan 3rd*, $\cdots$, *etc.*,



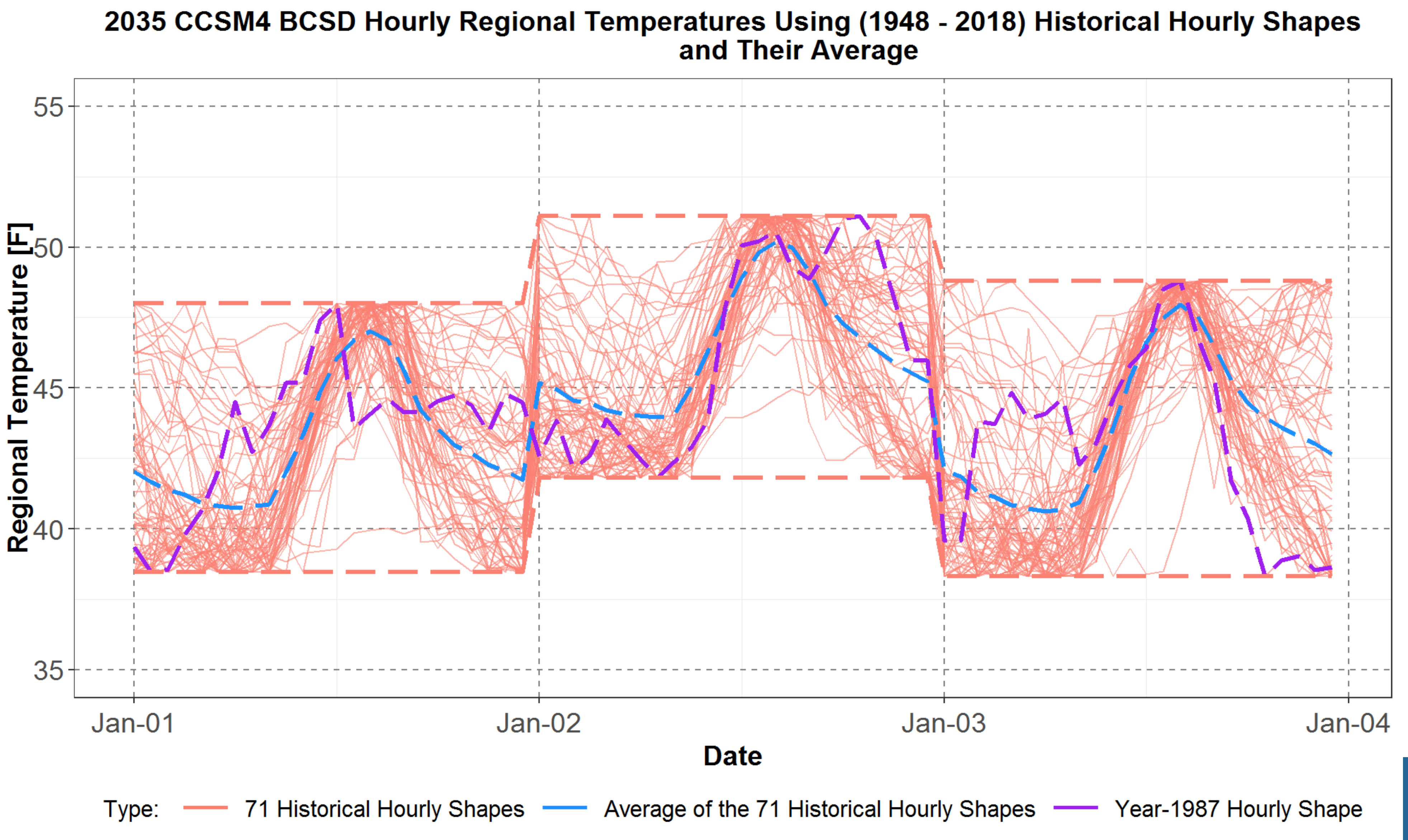
Which Historical Year to Pick for Hourly Shape? (A)



Which Historical Year to Pick for Hourly Shape? (B)



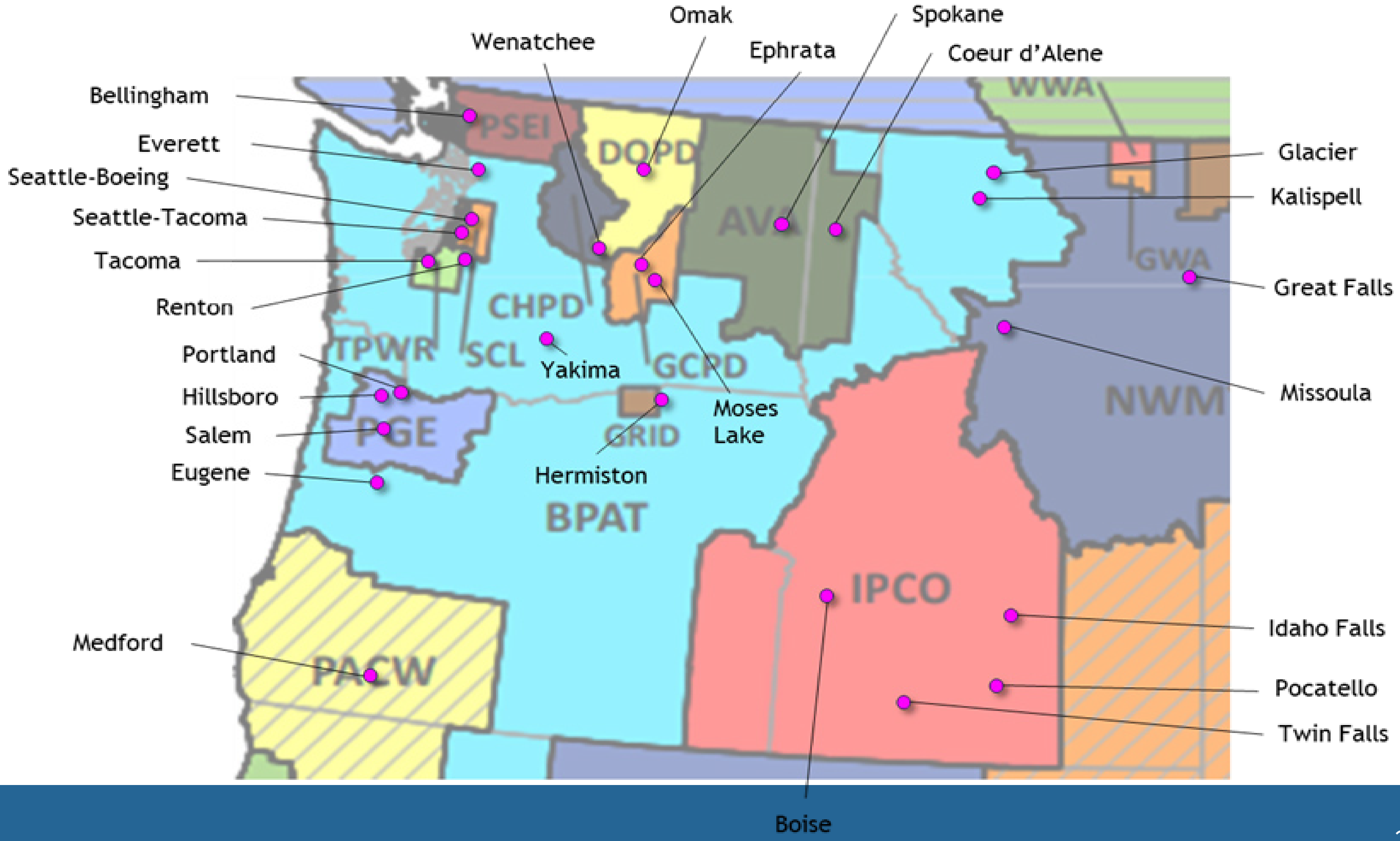
Pick A Historical Year "Closest" to the Average



Upcoming Power Plan

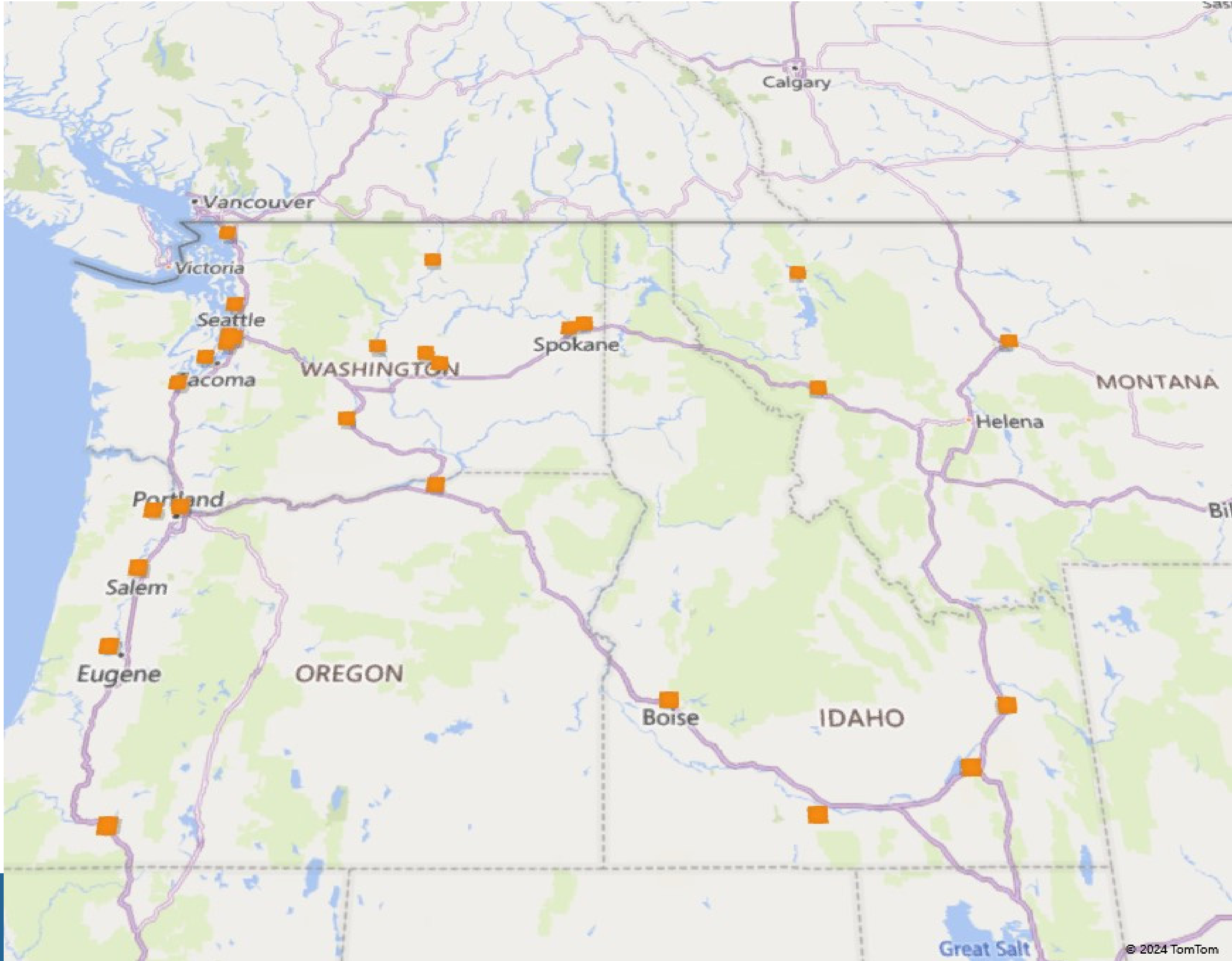
Climate Scenario Temperatures for Upcoming Power Plan

- RMJOC Climate scenario temperatures among 29 locations that represents the 13 Balancing Areas



Climate Scenario Temperatures

- 29 locations



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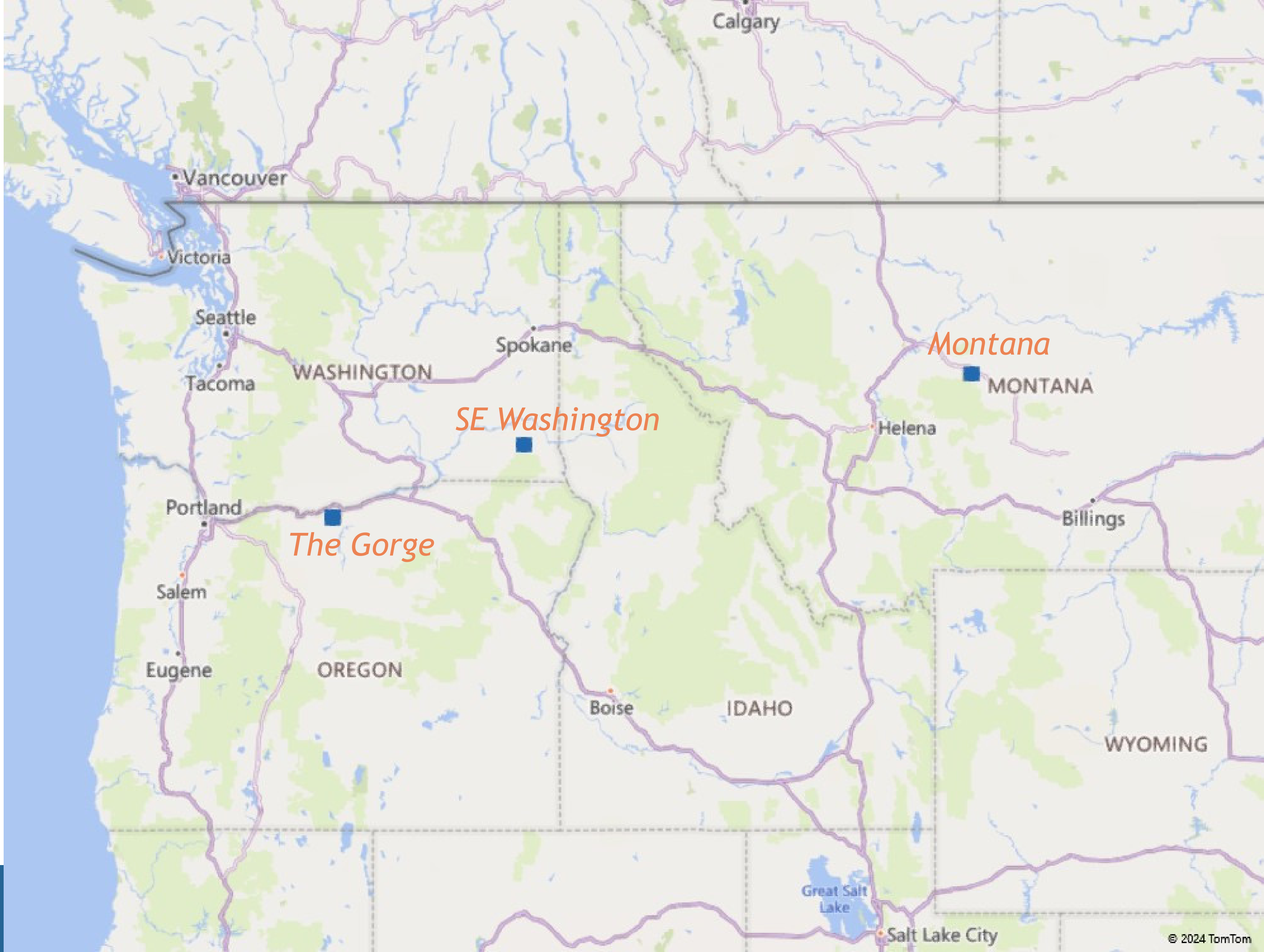
Climate Scenario Wind

Previous Power Plan

Northwest Wind Fleets

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



Climate Scenario Wind Data

- The RMJOC climate scenario data consist of temperature and streamflow
- For CMIP5 climate scenario wind data: download from Climatology Lab
  - at the Gorge, SE Washington and Montana
  - *daily* averaged eastward wind vector
  - *daily* averaged northward wind vector
  - at 10 m height
  - MACA downscaled data only
    - *CanESM2_RCP85_MACA*
    - *CCSM4_RCP85_MACA*
    - *CNRM-CM5_RCP85_MACA*

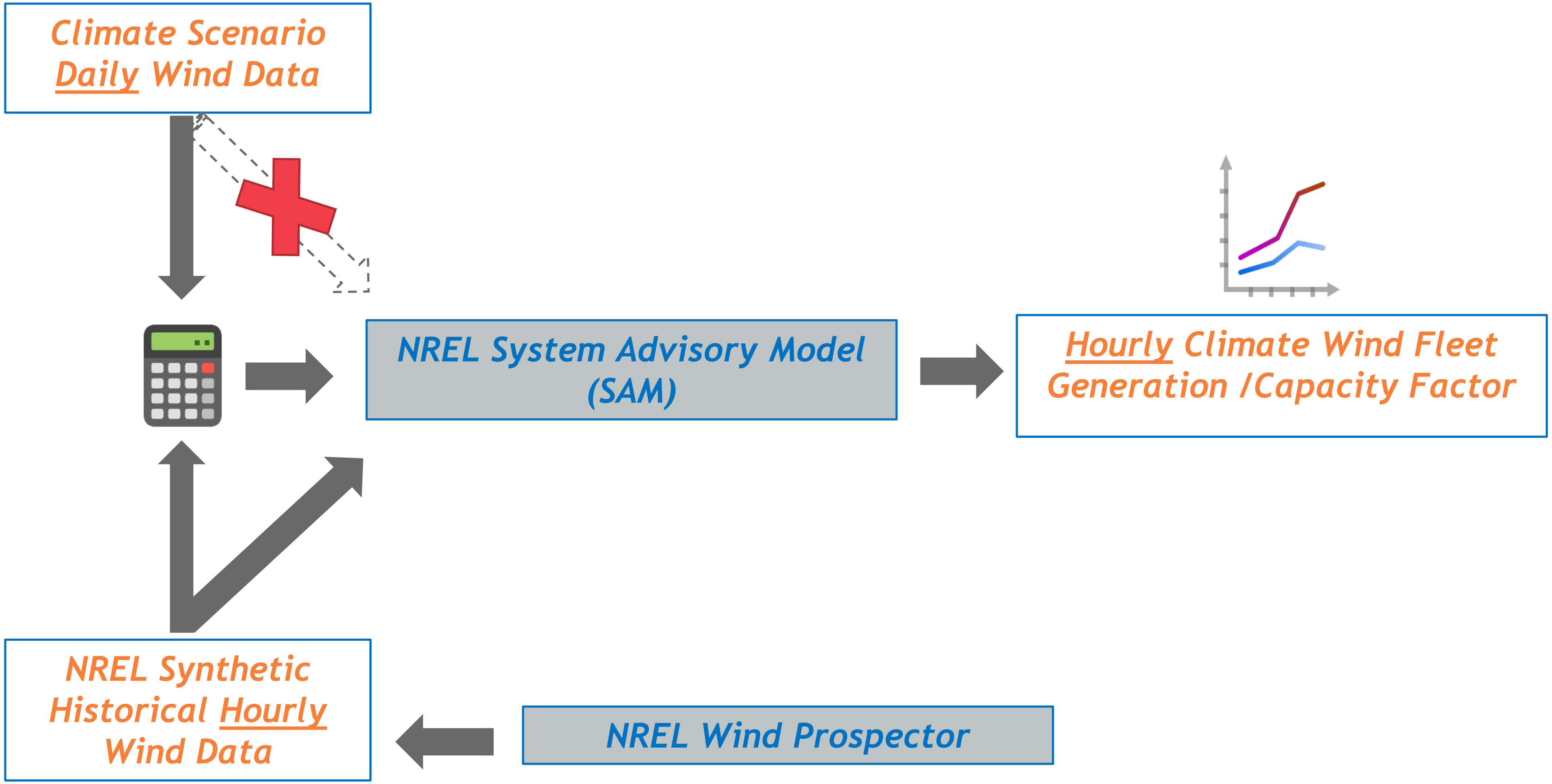
RMJOC

A: *CanESM2_RCP85_BCSD*
C: *CCSM4_RCP85_BCSD*
G: *CNRM-CM5_RCP85_MACA*

- How to use climate wind data to calculate climate wind generation?

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

Climate Wind Data to Wind Generation



NREL Synthetic Historical Hourly Data from Wind Prospector

- Download NREL synthetic historical *hourly* wind data at the Gorge, SE Washington and Montana*
  - *temperature*
  - *pressure*
  - *wind speed*
  - *wind direction*

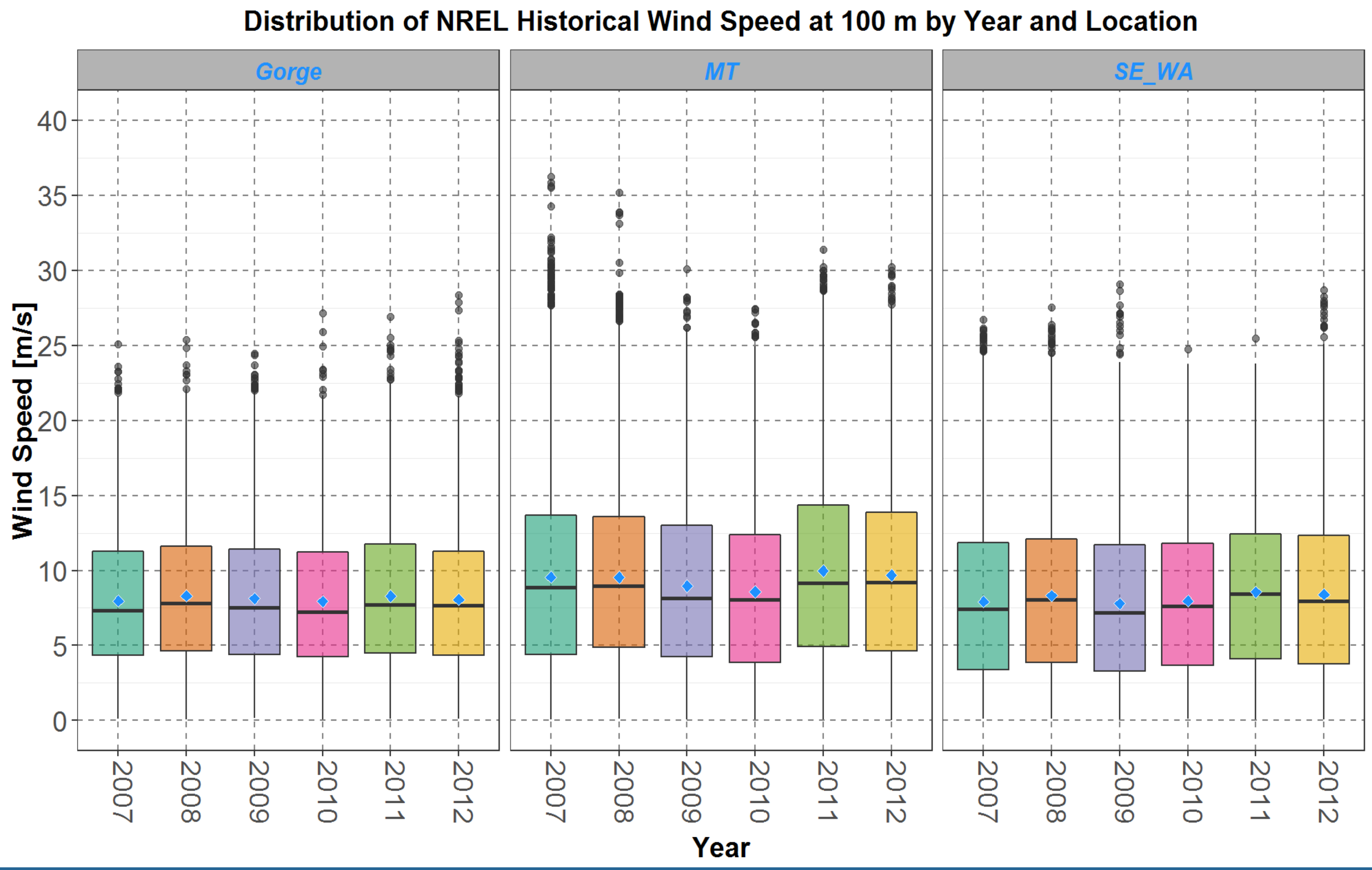
- NREL historical wind data:
  - 2007 to 2012 (6 years)
  - at 100 m height

- These hourly data are in input format for the System Advisory Model (SAM)†

*https://maps.nrel.gov/wind-prospector/
†https://sam.nrel.gov/

NREL Synthetic Historical Wind Speeds

- Wind speeds at the Gorge are similar to those at SE Washington
- Wind speeds at Montana are higher than those at the Gorge and SE Washington



Transformation of Climate Wind Data for SAM

i. *daily* averaged eastward and northward wind vectors transformed to *daily* wind speed and direction

ii. *daily* wind speed at 10 m height transformed to wind speeds at 80 m and 100 m heights (two types of turbine hub heights)

iii. At 100 m height, calibrate climate daily wind speed data for a historical period with NREL's synthetic historical daily wind speeds

iv. calibrated *daily* wind speed transformed to *hourly* wind speed

v. calibrated *daily* wind direction transformed to *hourly* wind directions

vi. Input wind direction and calibrated climate hourly wind speed data into SAM

Transformation of Climate Wind Data (i)

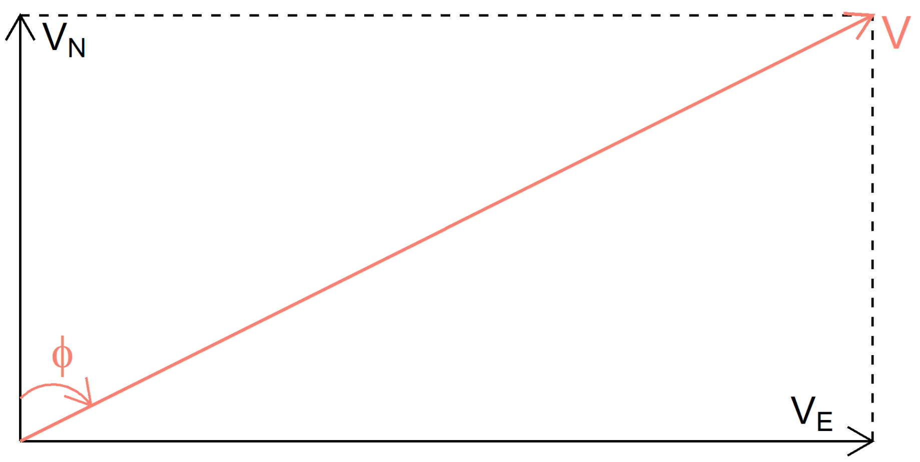
- The climate model daily wind data
  - *northward wind vector* V_N
  - *eastward wind vector* V_E

are transformed into

  - *wind speed* V,
  - *wind direction* φ,
    measured with respect to north, clockwise

$$V = \sqrt{V_N^2 + V_E^2}$$

$$\phi = \tan^{-1}(V_E/V_N)$$



Transformation of Climate Wind Data (ii A)

- Transform wind speed data from 10 m height to 80 m and 100 m heights

“Methodologies Used in the Extrapolation of Wind Speed Data at Different Heights and Its Impact in the Wind Energy Resource Assessment in a Region”

by

Francisco Bañuelos-Ruedas, César Angeles-Camacho and Sebastián Rios-Marcuello

DOI: 10.5772/20669

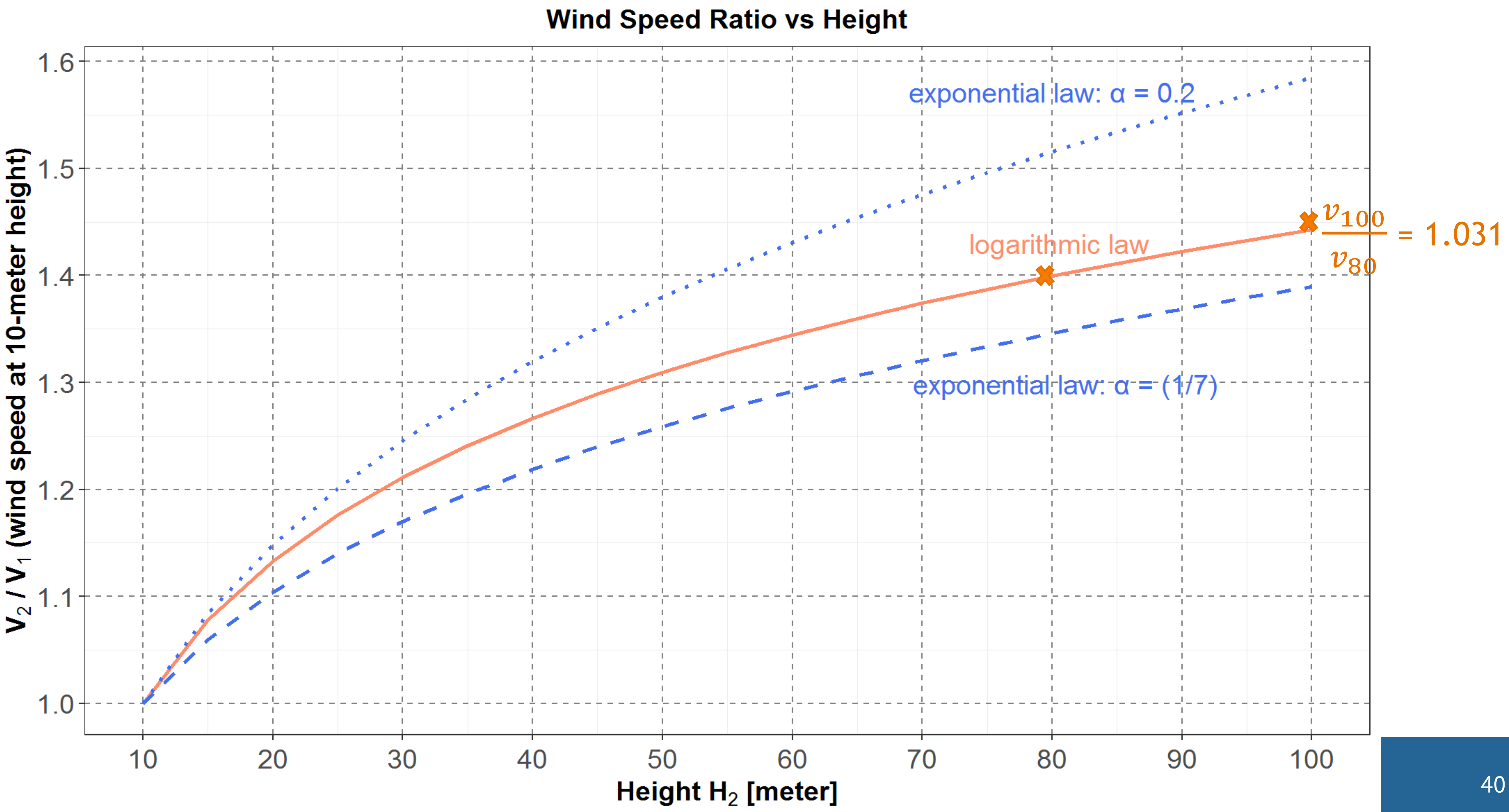
Transformation of Climate Wind Data (ii B)

- In order to model wind turbines in SAM, transform climate wind speeds at 10 m to wind speeds at 80 m and 100 m

- Log Law: $(V_2 / V_1) = \ln(H_2 / H_0) / \ln(H_1 / H_0)$
  - $H_0 =$ roughness length
  - $H_0 = 0.055,$ *for farming land dotted with some houses and 8 m tall sheltering hedgerows within a distance of 1,250 m*

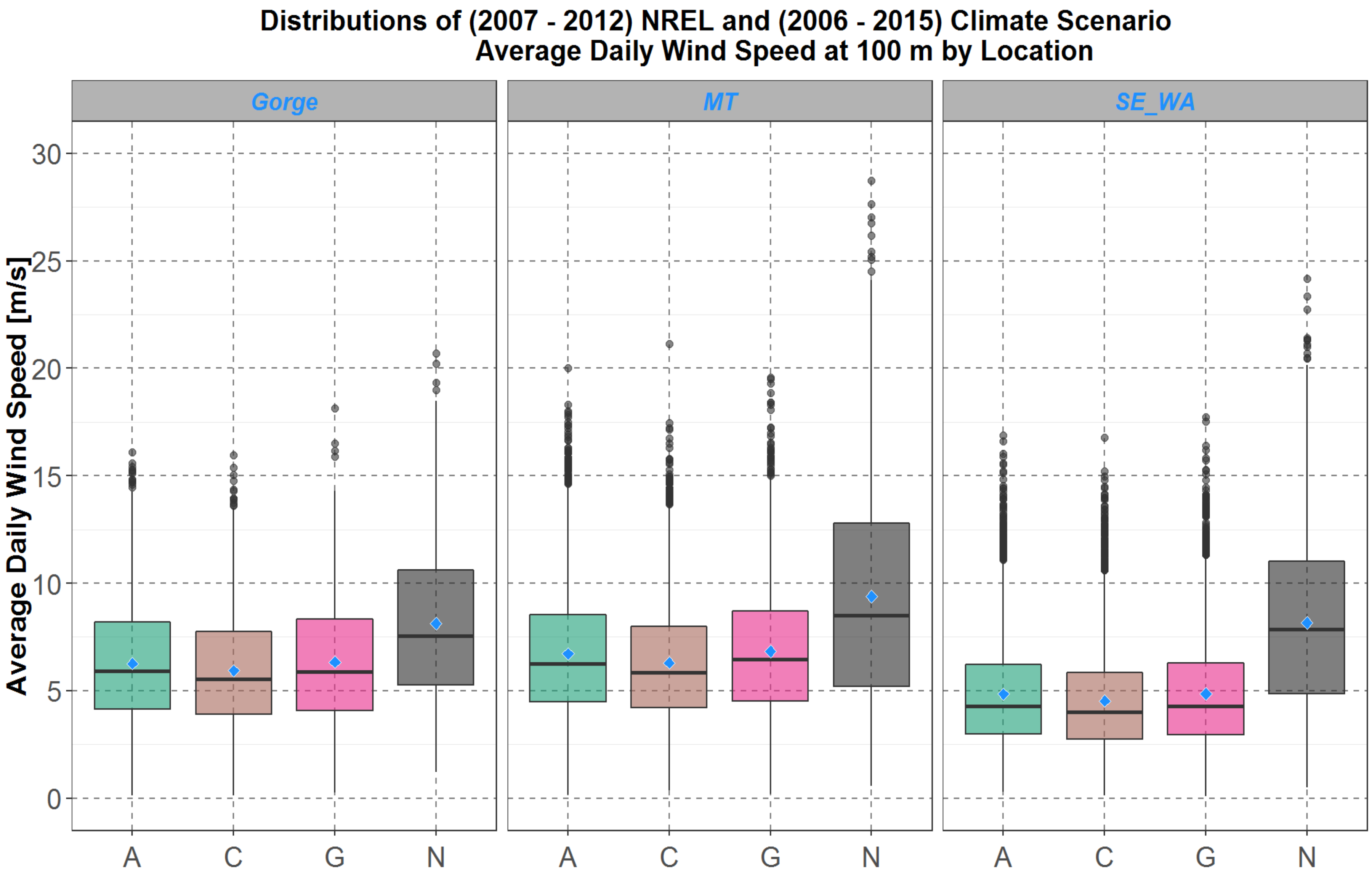
- Power Law: $(V_2 / V_1) = (H_2 / H_1)^{\alpha}$
  - $\alpha =$ the friction coefficient or Hellman exponent
  - $\alpha = (1/7) = 0.143,$ *usually*
  - $\alpha = 0.2,$ *for tall crops, hedges and shrubs*

Transformation of Climate Wind Data (ii C)



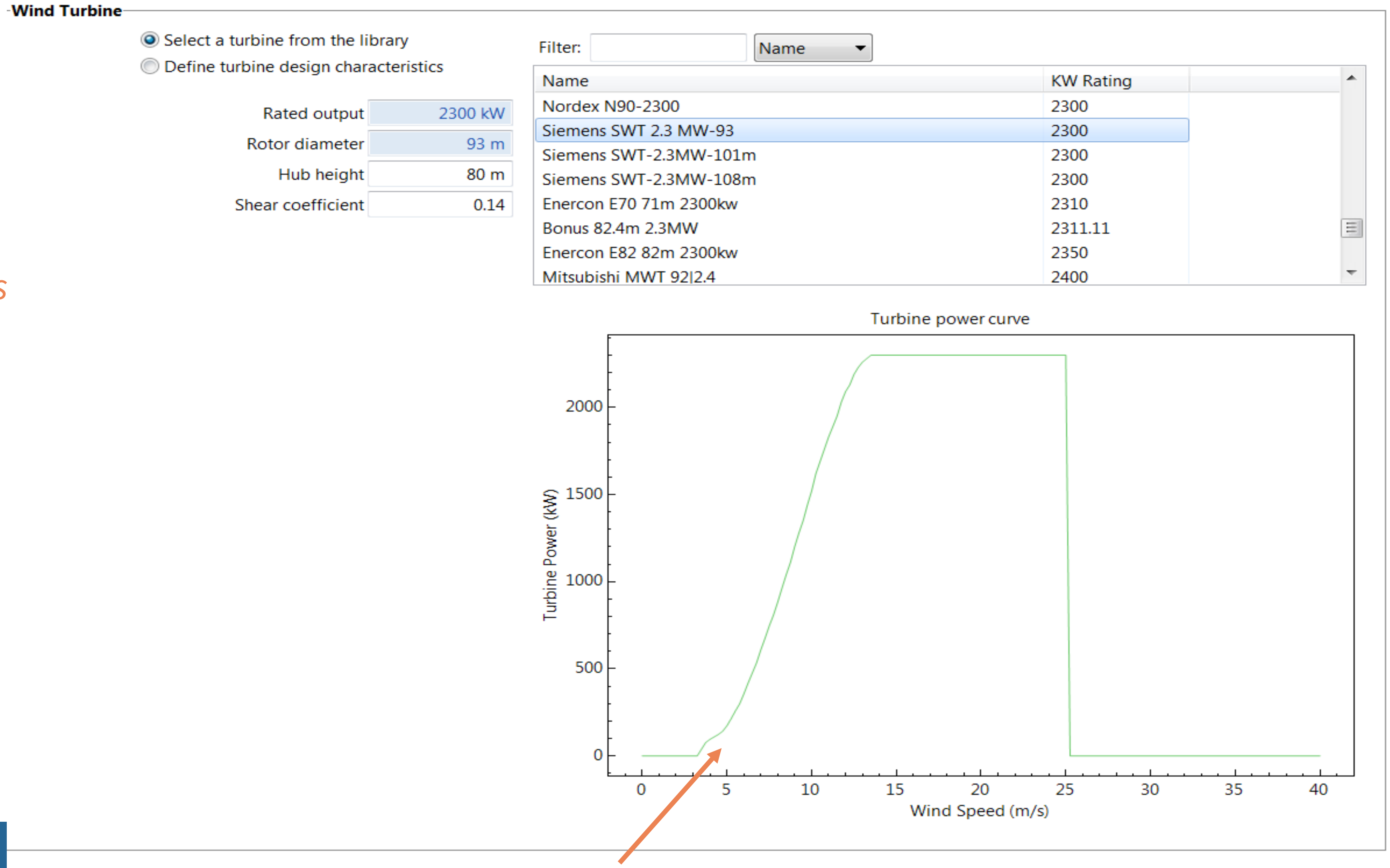
Transformation of Climate Wind Data (iii A)

- For comparable historical periods: NREL synthetic historical data (2007 – 2012), and climate models (2006 – 2015)
- For all 3 locations, the distribution of synthetic historical NREL wind speeds are higher than the distributions of climate model wind speeds
- Calibrate the climate model data to be more comparable



Wind Power Curve From SAM

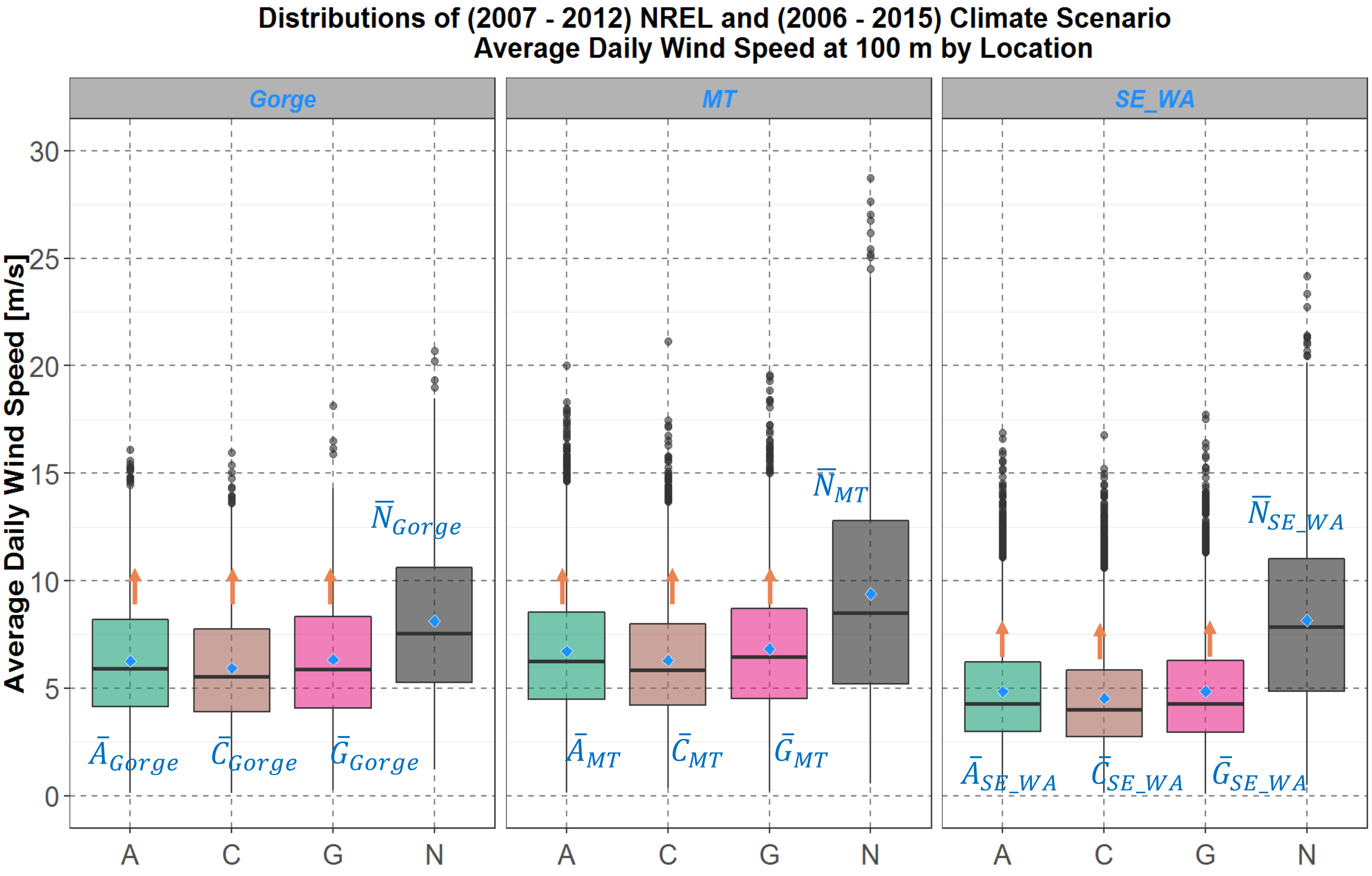
- Screen shot from SAM for a Siemens Turbine
- Turbine generation increases rapidly for wind speeds > *5 m/s*



Transformation of Climate Wind Data (iii B)

- **Method I**: use *1* parameter, α, to minimize S, the sum of square-difference between the NREL average and the climate model averages for all 3 locations:

$$
\begin{aligned}
S = & (\alpha \bar{A}_{Gorge} - \bar{N}_{Gorge})^2 + (\alpha \bar{C}_{Gorge} - \bar{N}_{Gorge})^2 + (\alpha \bar{G}_{Gorge} - \bar{N}_{Gorge})^2 \\
& + (\alpha \bar{A}_{MT} - \bar{N}_{MT})^2 + (\alpha \bar{C}_{MT} - \bar{N}_{MT})^2 + (\alpha \bar{G}_{MT} - \bar{N}_{MT})^2 \\
& + (\alpha \bar{A}_{SE\_WA} - \bar{N}_{SE\_WA})^2 + (\alpha \bar{C}_{SE\_WA} - \bar{N}_{SE\_WA})^2 + (\alpha \bar{G}_{SE\_WA} - \bar{N}_{SE\_WA})^2
\end{aligned}
$$



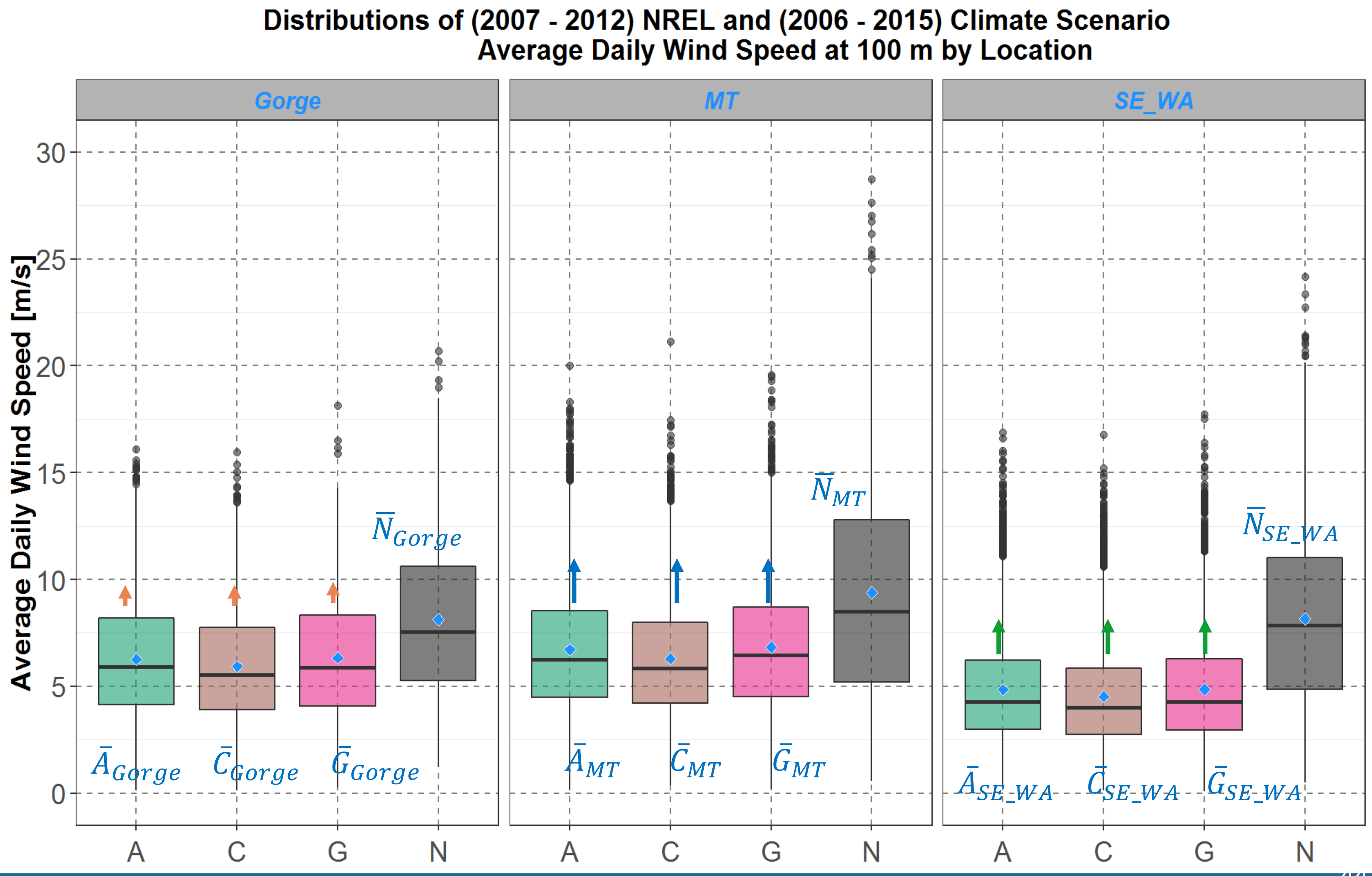
Transformation of Climate Wind Data (iii C)

- **Method II**: use 3 parameters, α_{Gorge}, α_{MT}, and α_{SE_WA}, to minimize S_{Gorge}, S_{MT}, and S_{SE_WA} respectively

$$S_{Gorge} = (\alpha_{Gorge}\bar{A}_{Gorge} - \bar{N}_{Gorge})^2 + (\alpha_{Gorge}\bar{C}_{Gorge} - \bar{N}_{Gorge})^2 + (\alpha_{Gorge}\bar{G}_{Gorge} - \bar{N}_{Gorge})^2$$

$$S_{MT} = \cdots$$

$$S_{SE\_WA} = \cdots$$



Transformation of Climate Wind Data (iii D)

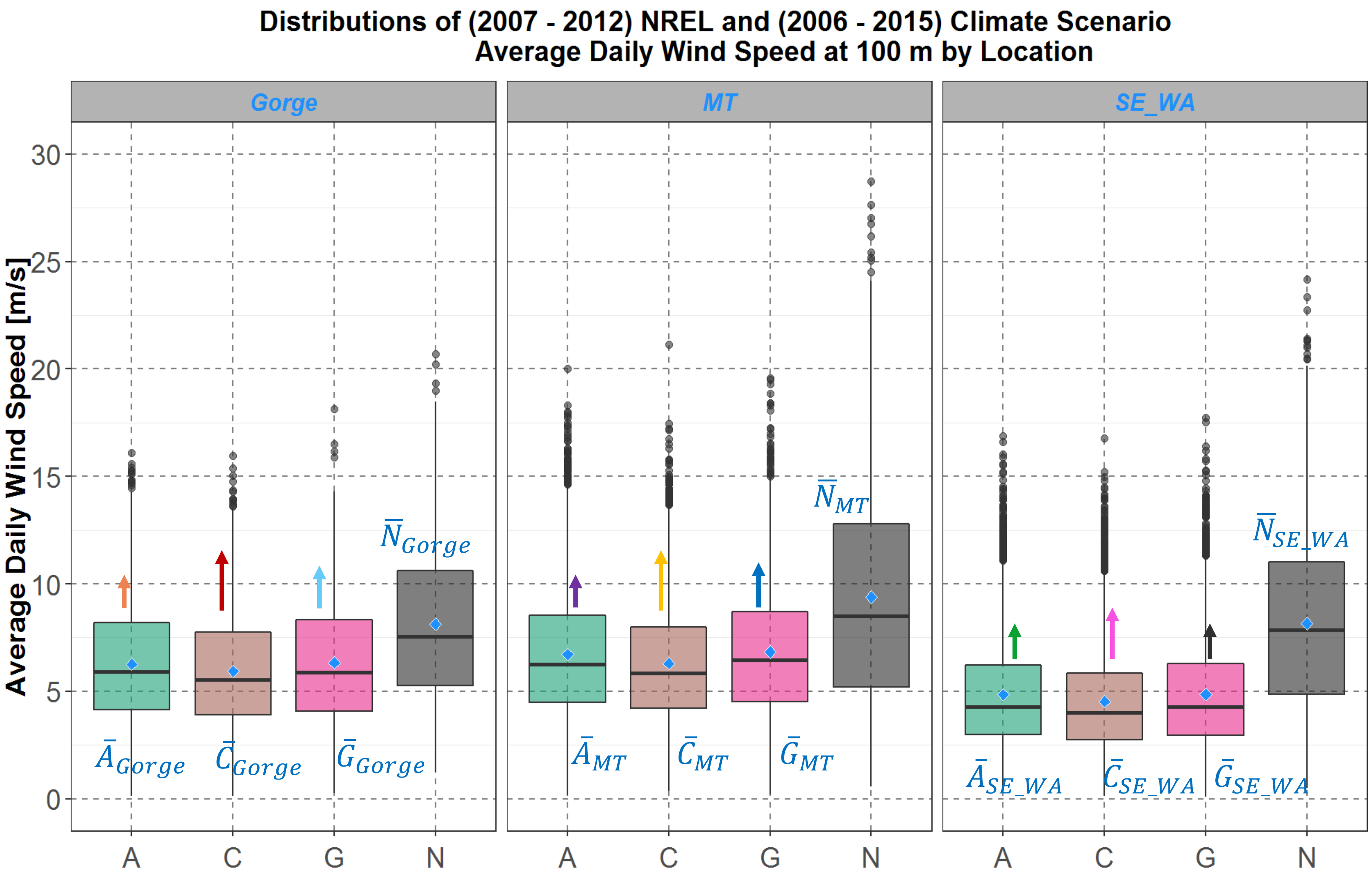
- **Method III**: use 9 parameters, α^A_{Gorge}, α^C_{Gorge}, α^G_{Gorge}, α^A_{MT}, α^C_{MT}, α^G_{MT}, $\alpha^A_{SE\_WA}$, $\alpha^C_{SE\_WA}$, and $\alpha^G_{SE\_WA}$, to minimize S^A_{Gorge}, S^C_{Gorge}, S^G_{Gorge}, S^A_{MT}, S^C_{MT}, S^G_{MT}, $S^A_{SE\_WA}$, $S^C_{SE\_WA}$, and $S^G_{SE\_WA}$ respectively

$$S^A_{Gorge} = (\alpha^A_{Gorge}\,\bar{A}_{Gorge} - \bar{N}_{Gorge})^2$$

$$S^C_{Gorge} = (\alpha^C_{Gorge}\,\bar{C}_{Gorge} - \bar{N}_{Gorge})^2$$

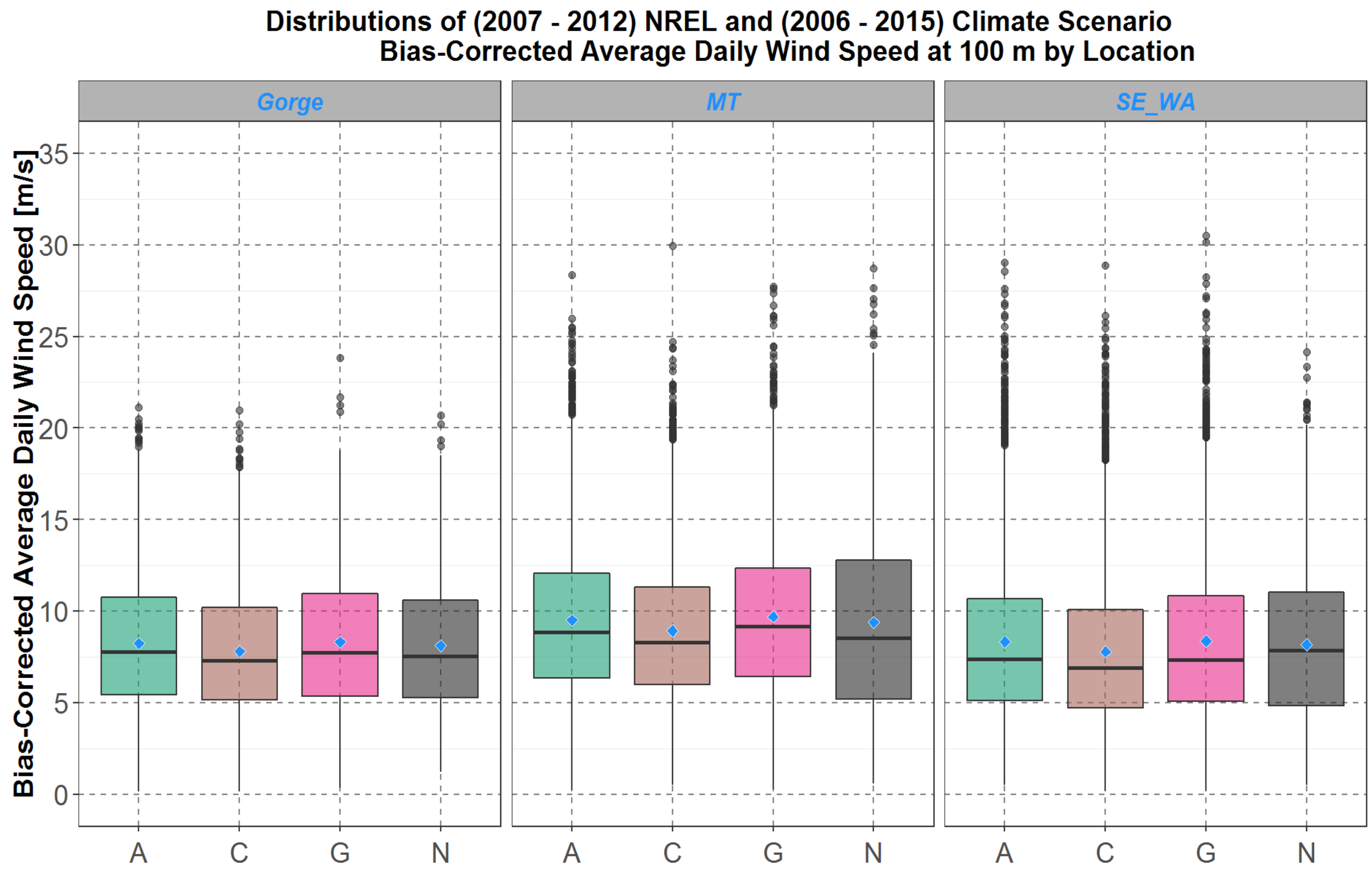
$$S^G_{Gorge} = (\alpha^G_{Gorge}\,\bar{G}_{Gorge} - \bar{N}_{Gorge})^2$$

$etc., \cdots$

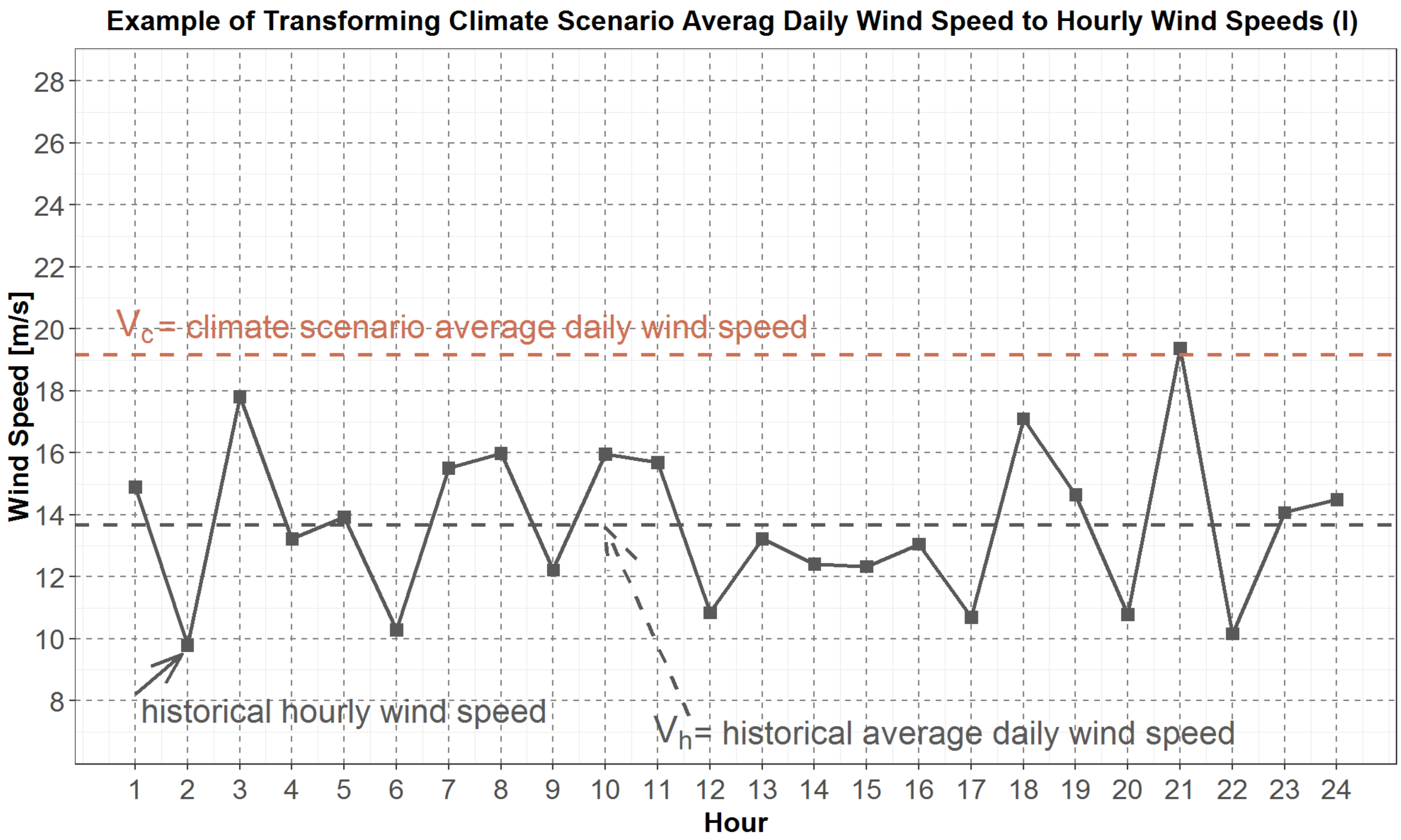


Transformation of Climate Wind Data (iii E)

- Calibration results using Method II.
- where $\alpha_{Gorge} = 1.314$, $\alpha_{MT} = 1.417$ and $\alpha_{SE\_WA} = 1.721$
- Then at respective locations, multiply corresponding parameters to climate model wind speeds for years 2020 to 2049

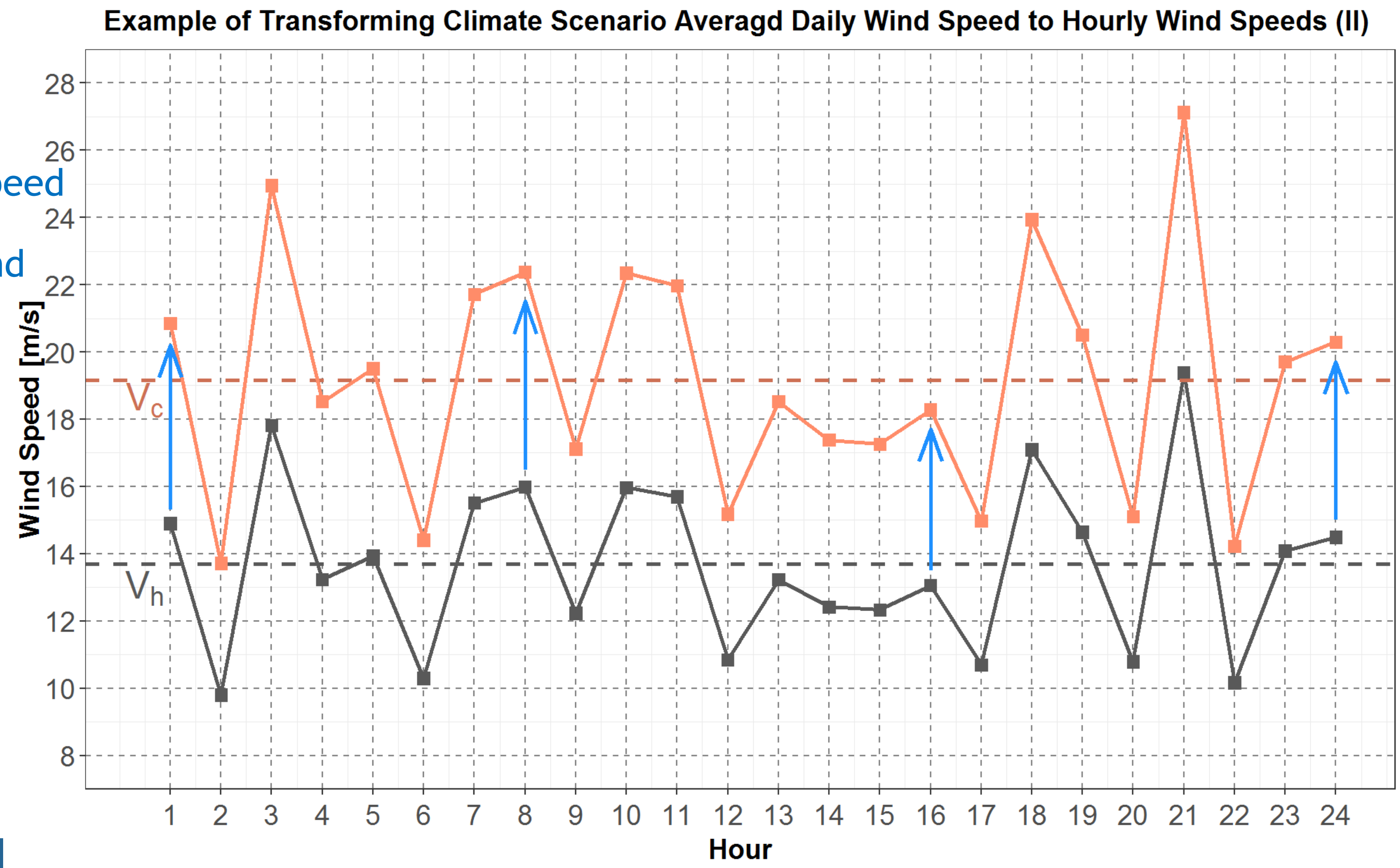


Transformation of Climate Wind Data (iv A)



Transformation of Climate Wind Data (iv B)

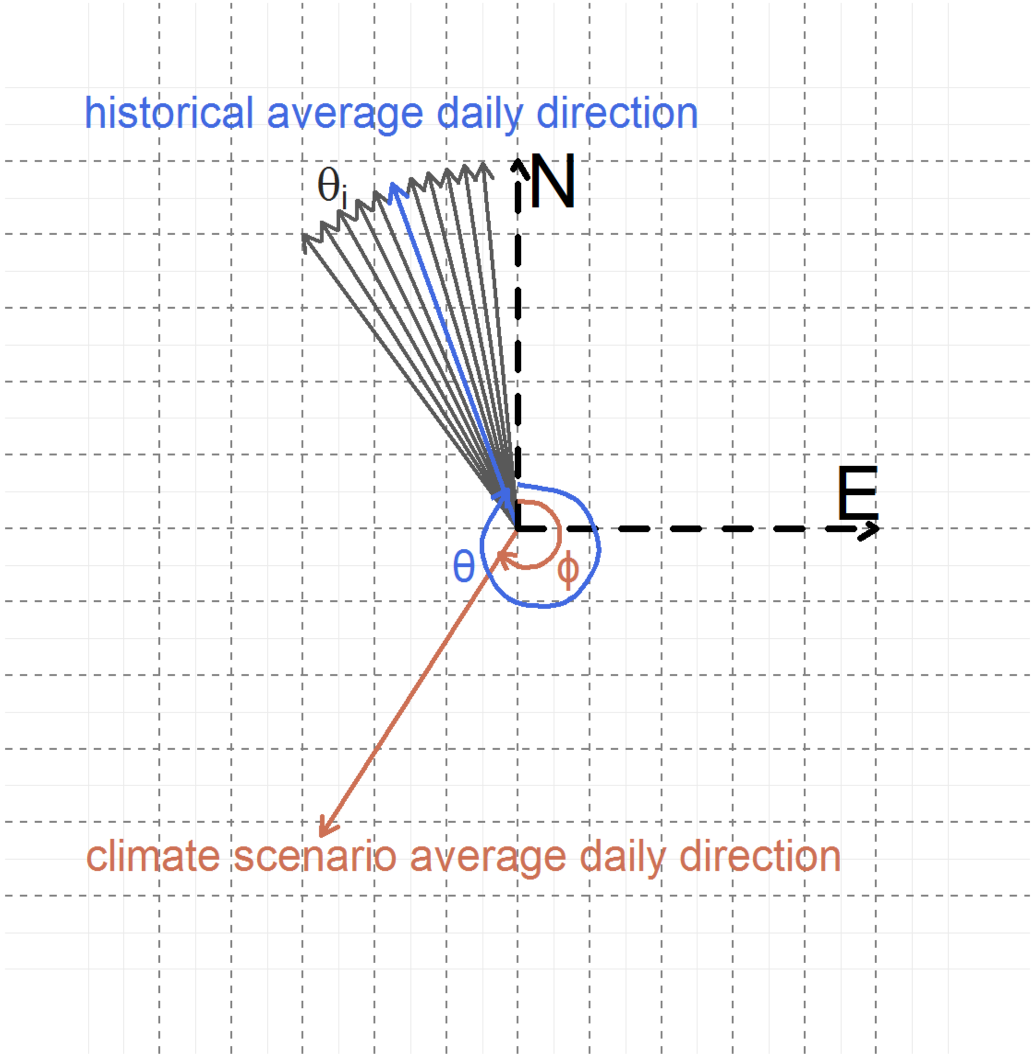
- Climate model hourly wind speed $= \left(\frac{V_c}{V_h}\right) \times$ historical hourly wind speed



Transformation of Climate Wind Data (v A)

- climate model daily averaged direction: ϕ
- historical hourly directions: $(\theta_1, \theta_2, \cdots, \theta_{24})$
- calculate historical daily averaged direction: θ

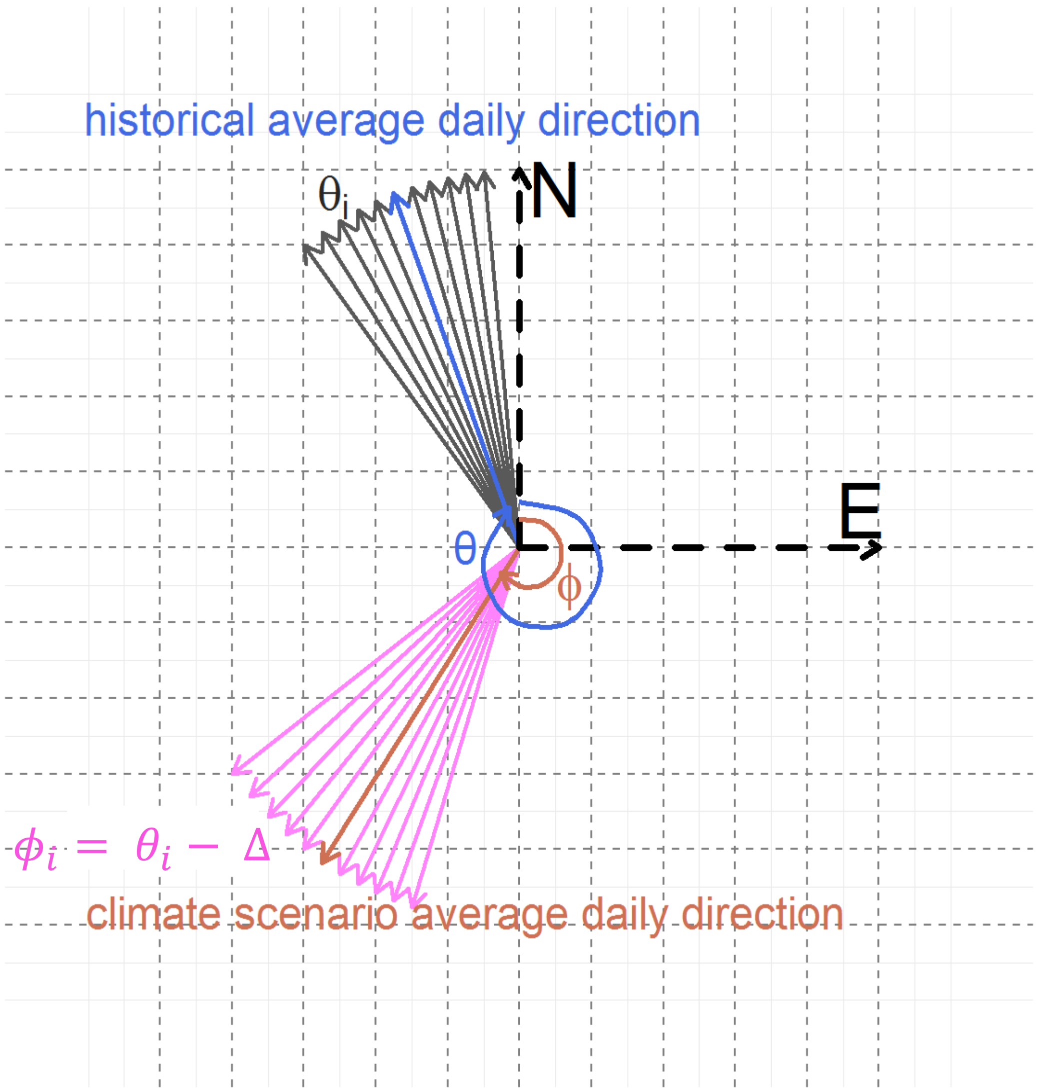
Example of Transforming Climate Scenario Averagd Daily Wind Direction to Hourly Wind Directions (I)



Transformation of Climate Wind Data (v B)

- calculate difference between θ and ϕ:
  $\Delta = \theta - \phi$
- then climate model hourly directions:
  $\phi_i = \theta_i - \Delta$

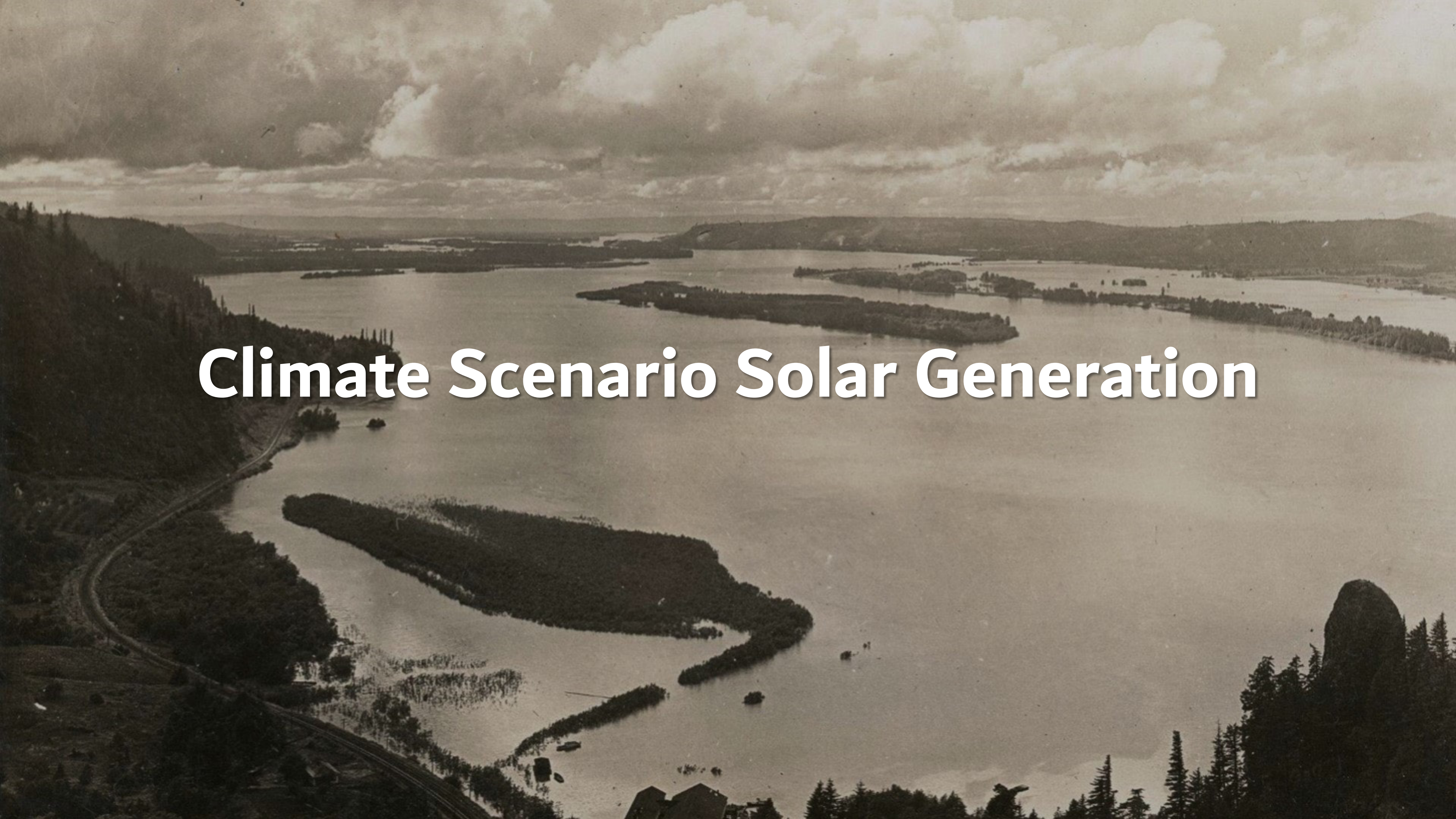
Example of Transforming Climate Scenario Averagd Daily Wind Direction to Hourly Wind Directions (II)



Upcoming Power Plan

- Add Additional Wind Fleet Locations
- Work in progess

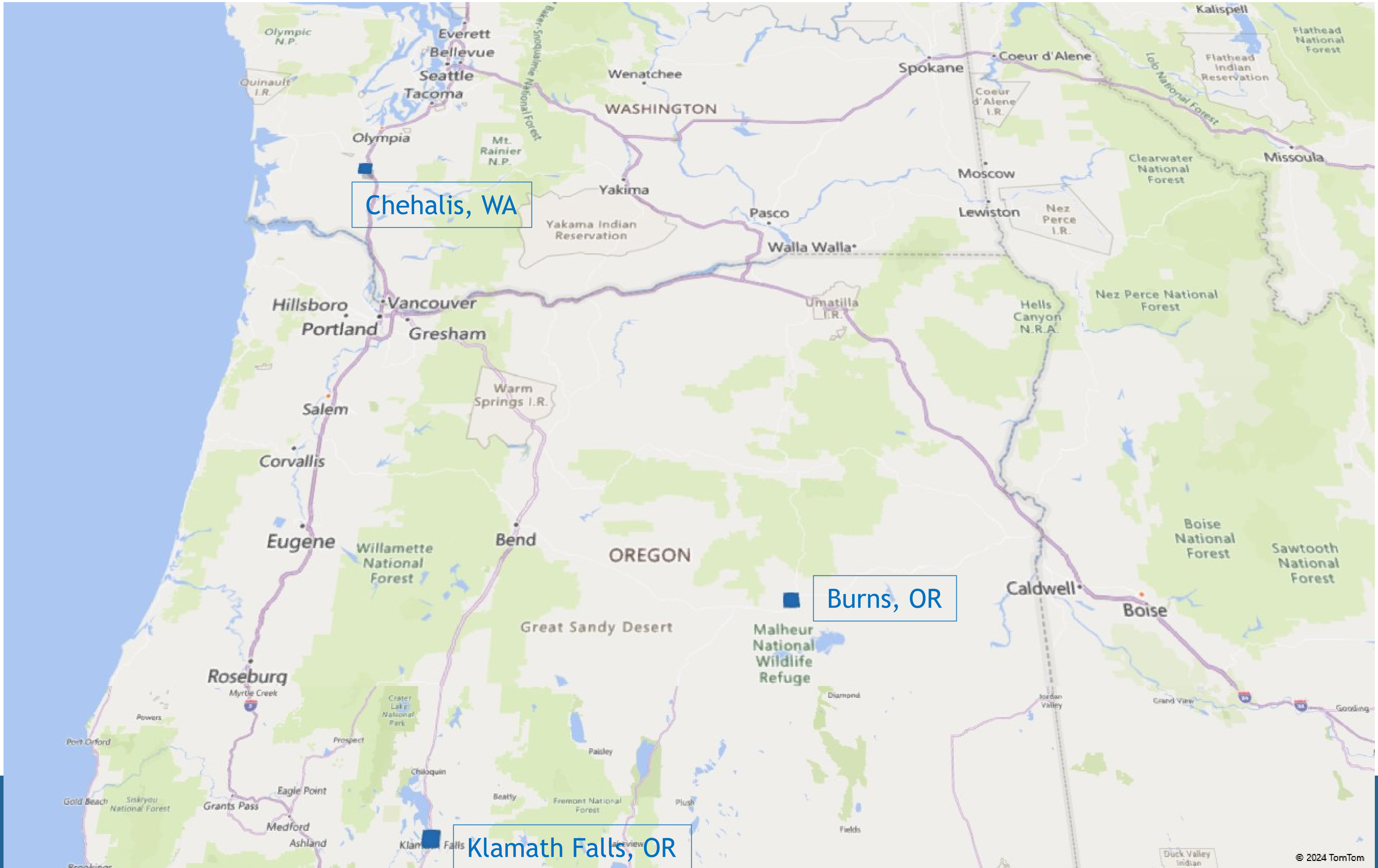
Climate Scenario Solar Generation



Previous Power Plan

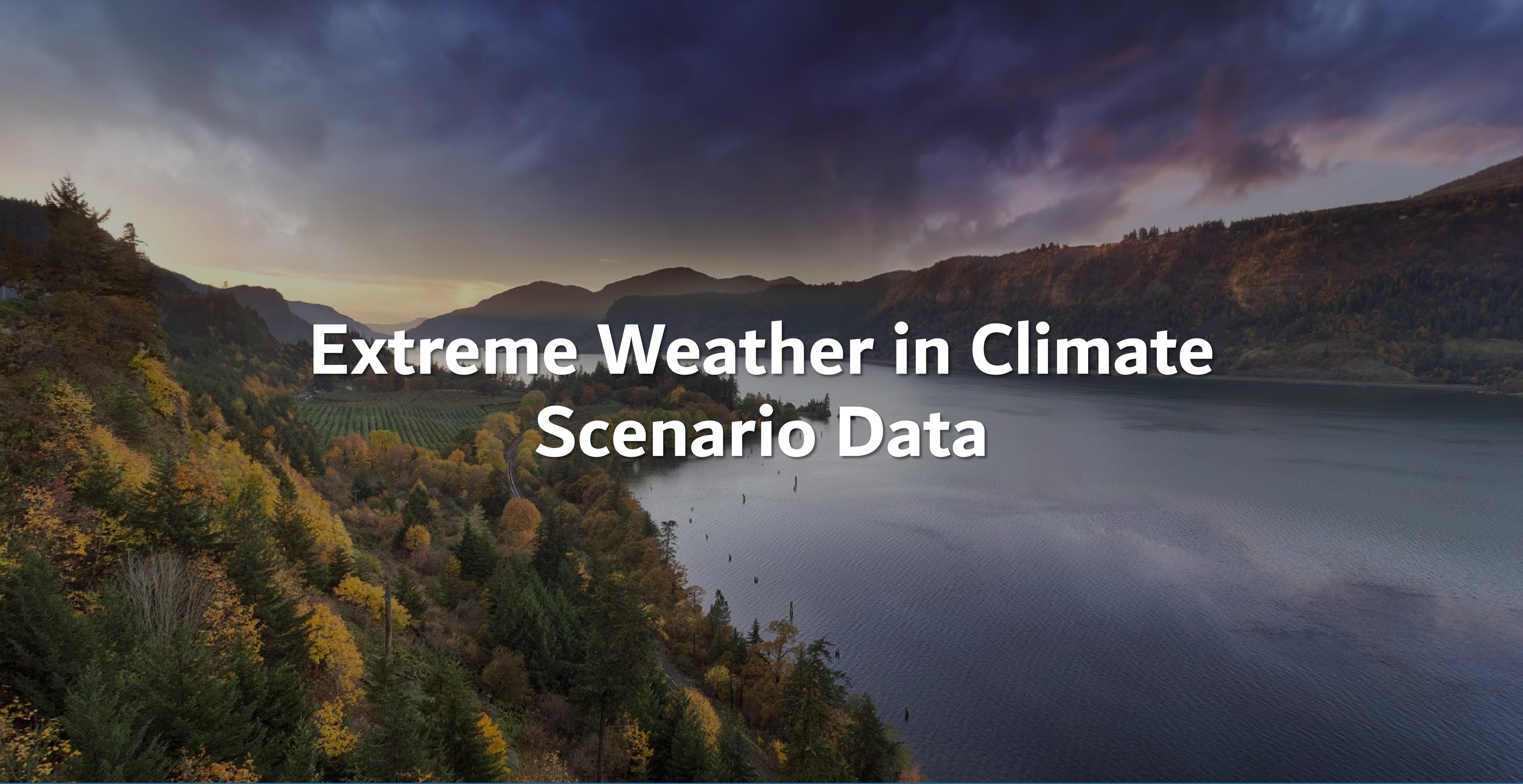
Solar Generation

- Historical hourly solar data at Chehalis, WA
- And the average of the historical hourly solar data at Burns and Klamath Falls in OR



Upcoming Power Plan

- Add Additional Solar Farm Locations
- Work in progress



Extreme Weather in Climate Scenario Data

Extreme Temperatures in Northwest Region

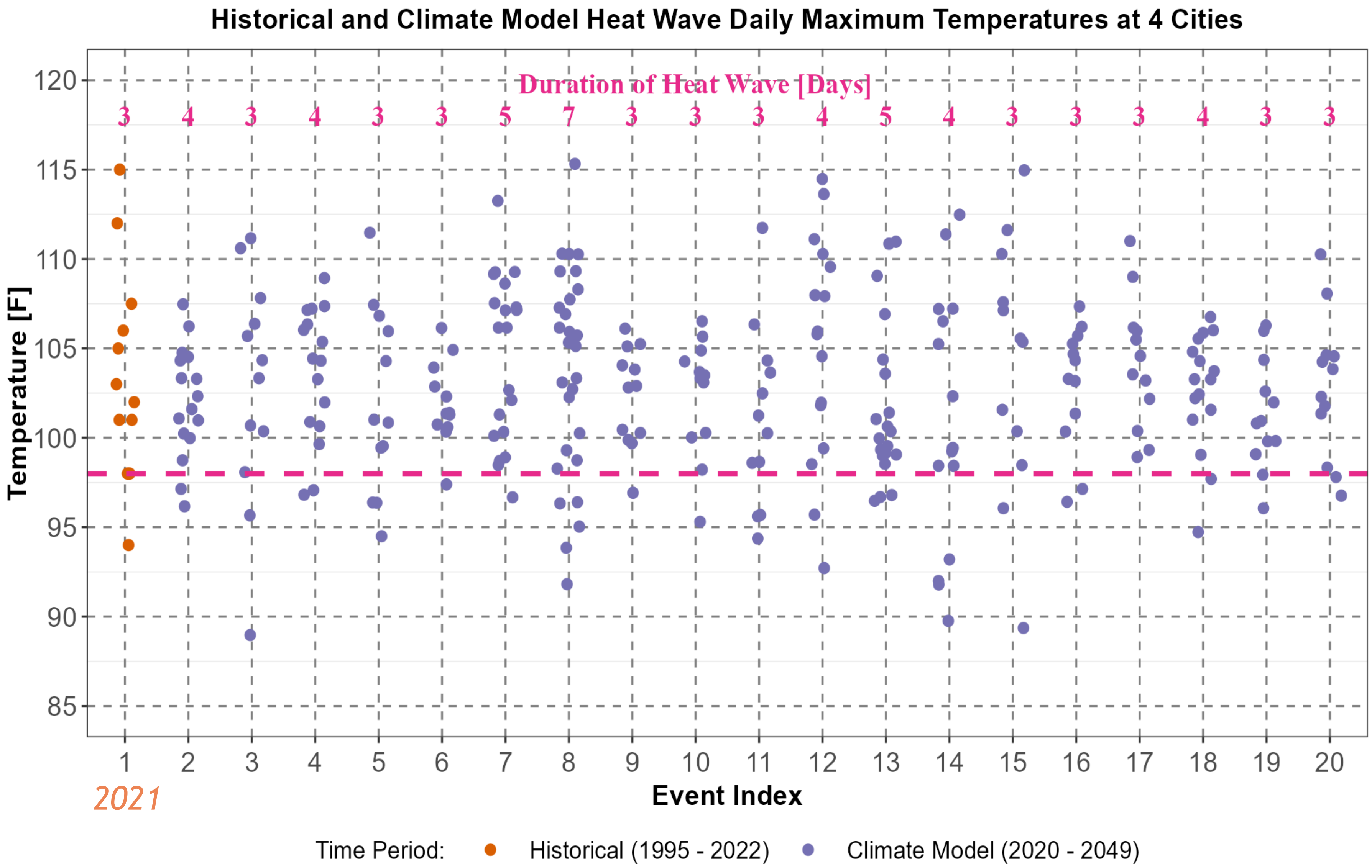
- Temperatures at Boise, Portland, Seattle and Spokane

- Regional heat wave:
  - at least 3-day duration,
  - at least 3 cities where the maximum daily temperatures $\geq 98F$

- Regional cold snap
  - at least 3-day duration,
  - at least 3 cities where the maximum daily temperatures $\leq 30F$

Regional Heat Waves

- historical time-period: 1995 to 2022, 28 years
- climate model time periods: 2020 to 2049, 30 years
- **1** historical heat wave (*2021 heat dome*)
- **19** climate model heat waves
- equal population comparison: about *3 vs 19*



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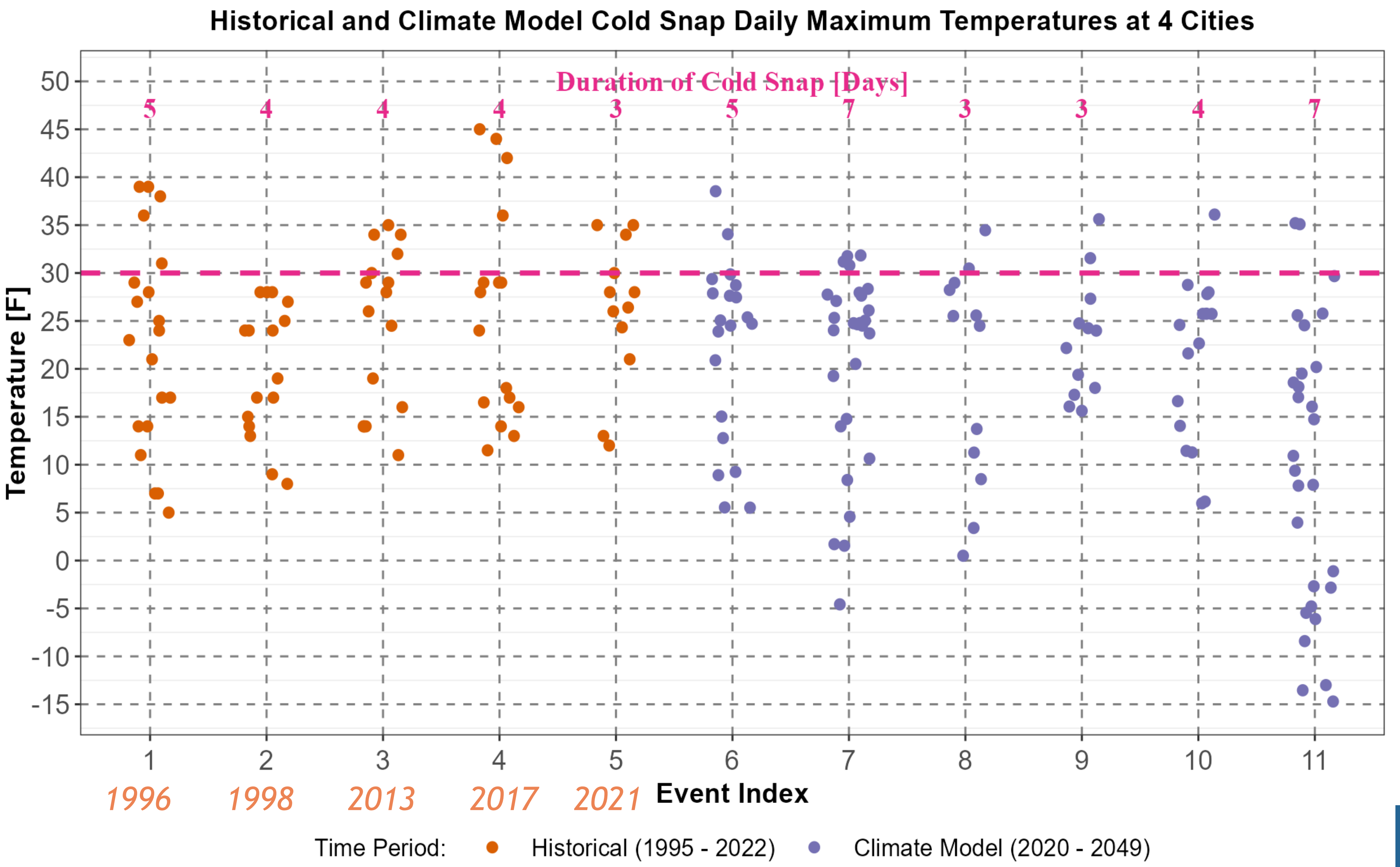
Regional Cold Snaps

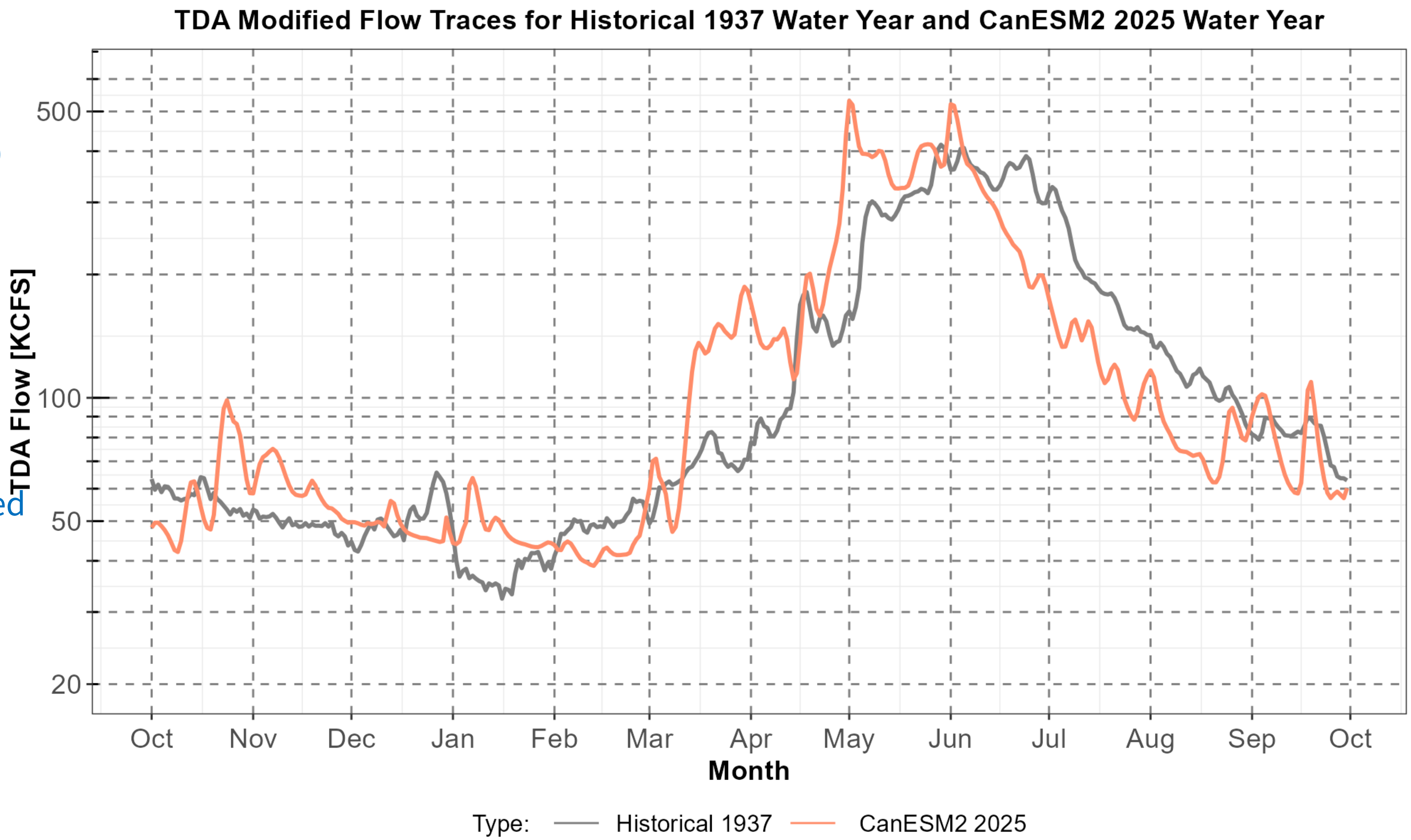
- historical time-period: 1995 to 2022, 28 years
- climate model time periods: 2020 to 2049, 30 years
- **5** historical cold snaps
- **6** climate model cold snaps
- equal population comparison: about *15 vs 6*




Very Low Seasonal Streamflows

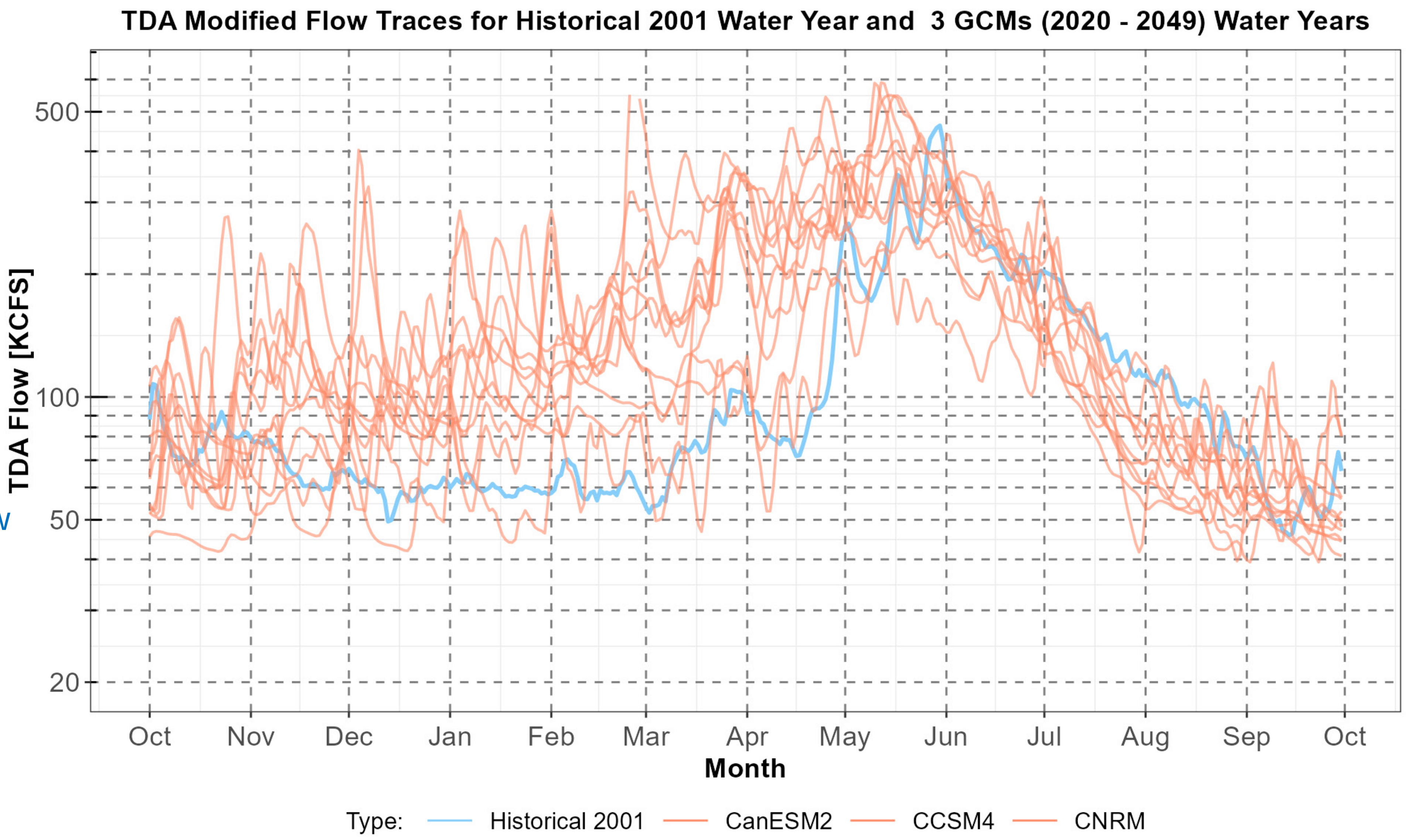
1937 Historical and Climate Scenario Water Years

- For convenience, compare Oct to Feb streamflow volumes at The Dalles (TDA)
- 1937 Historical Water Year has the lowest streamflow volume
- CanESM2 2025 Water Year has the lowest streamflow volume among the 3 selected climate scenarios
- Climate scenarios do not have Oct to Feb streamflow volumes as low as that in historical 1937 Water year



2001 Historical and Climate Scenario Water Years

- For convenience, compare Jun to Sep streamflow volumes at The Dalles (TDA)
- 2001 Historical Water Year has the lowest streamflow volume
- 11 Climate Scenario Water Years have lower streamflow volumes than 2001 Historical Water year



Discussions and Inputs

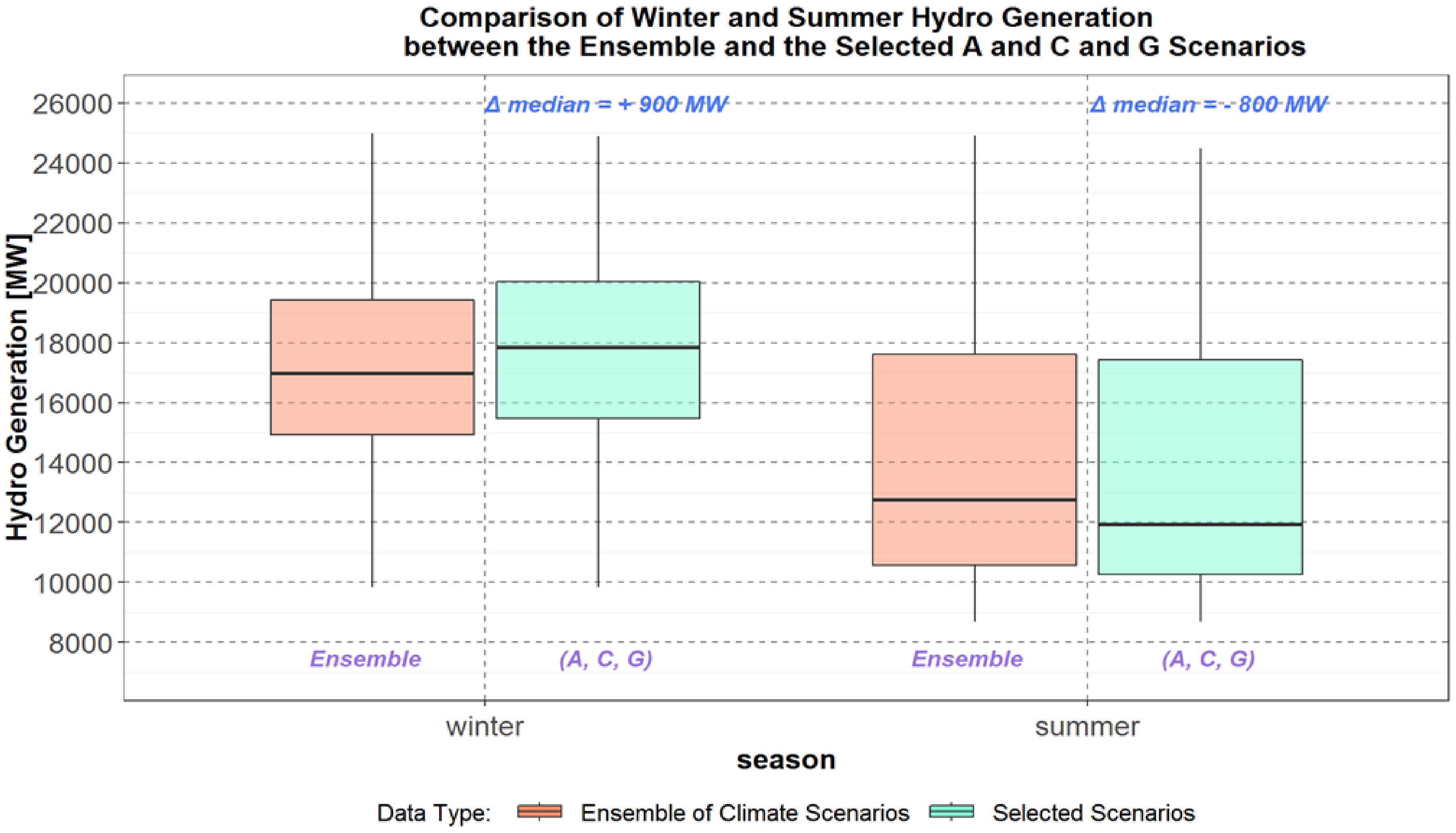
Climate Scenario Selection

Selected Scenarios

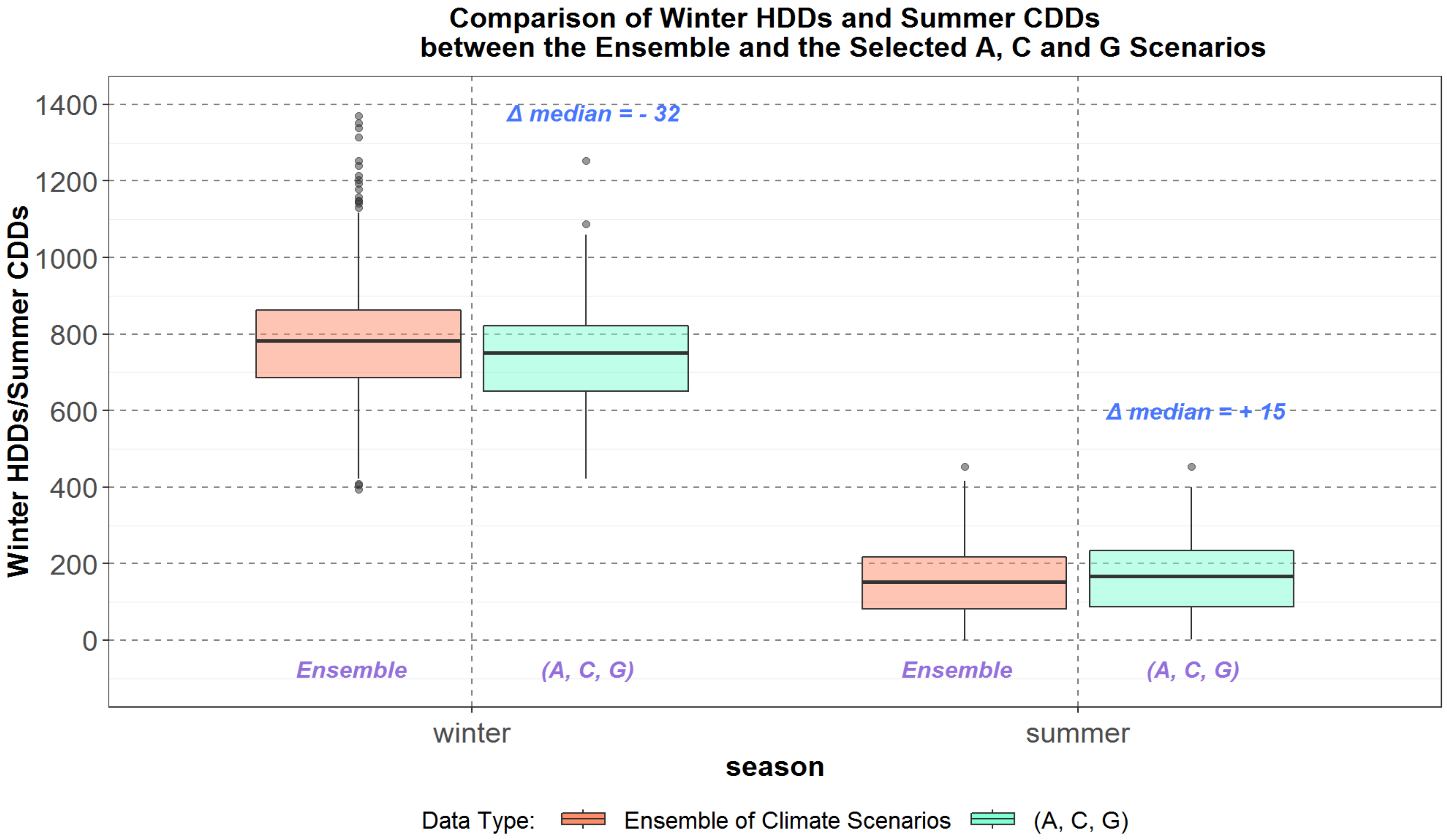
Scenario\Metric	Winter Generation	Summer Generation	Winter HDD	Summer CDD
A			low	high
C	high	low	-	-
G	low	high	high	low

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

How Well do the Selected Scenarios represent the Ensemble Hydrogeneration?



How Well do the Selected Scenarios represent the Ensemble HDDs and CDDs?



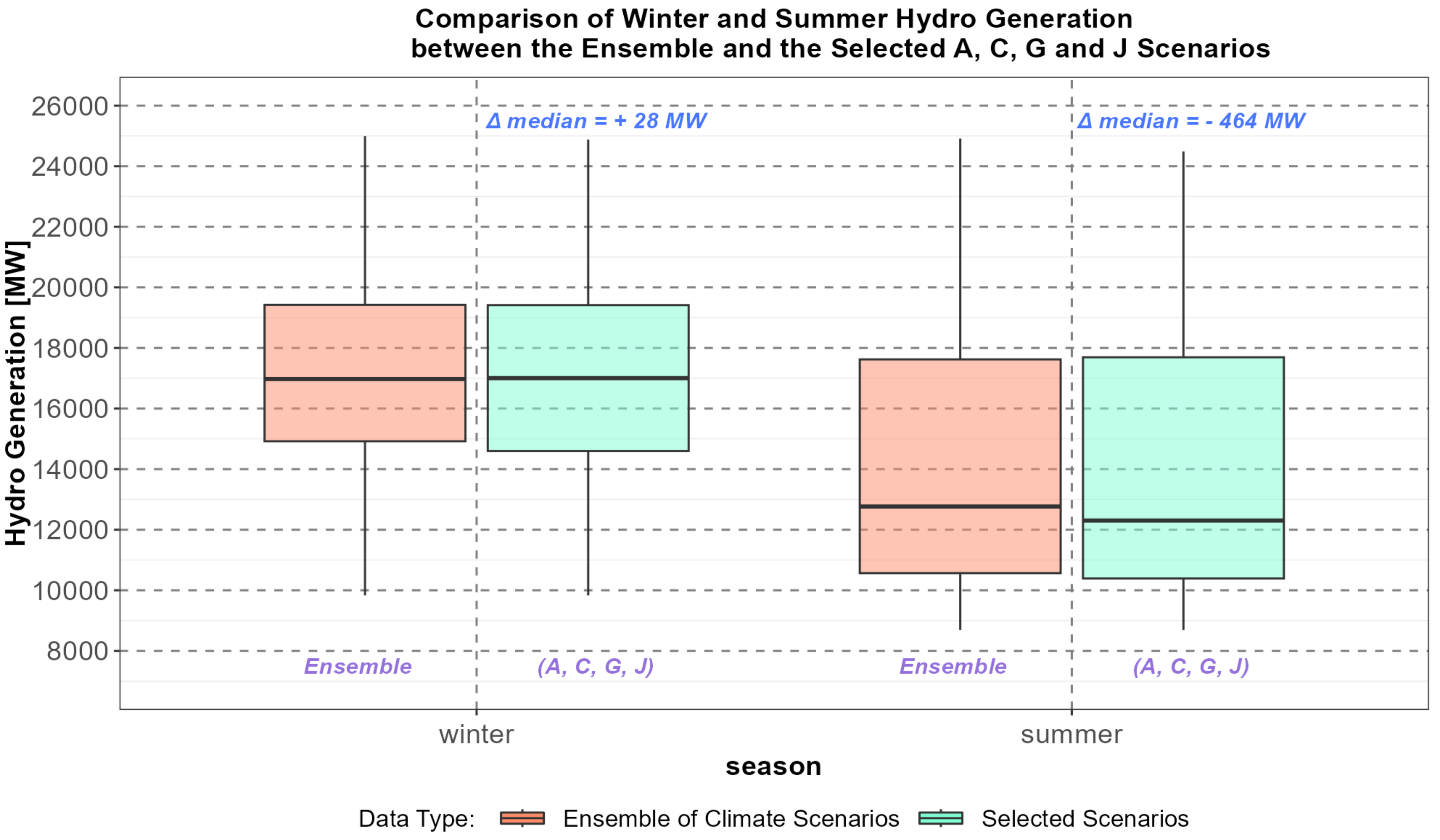
Adding back the
“J” (GFDL) Climate Scenario

Selected Scenarios

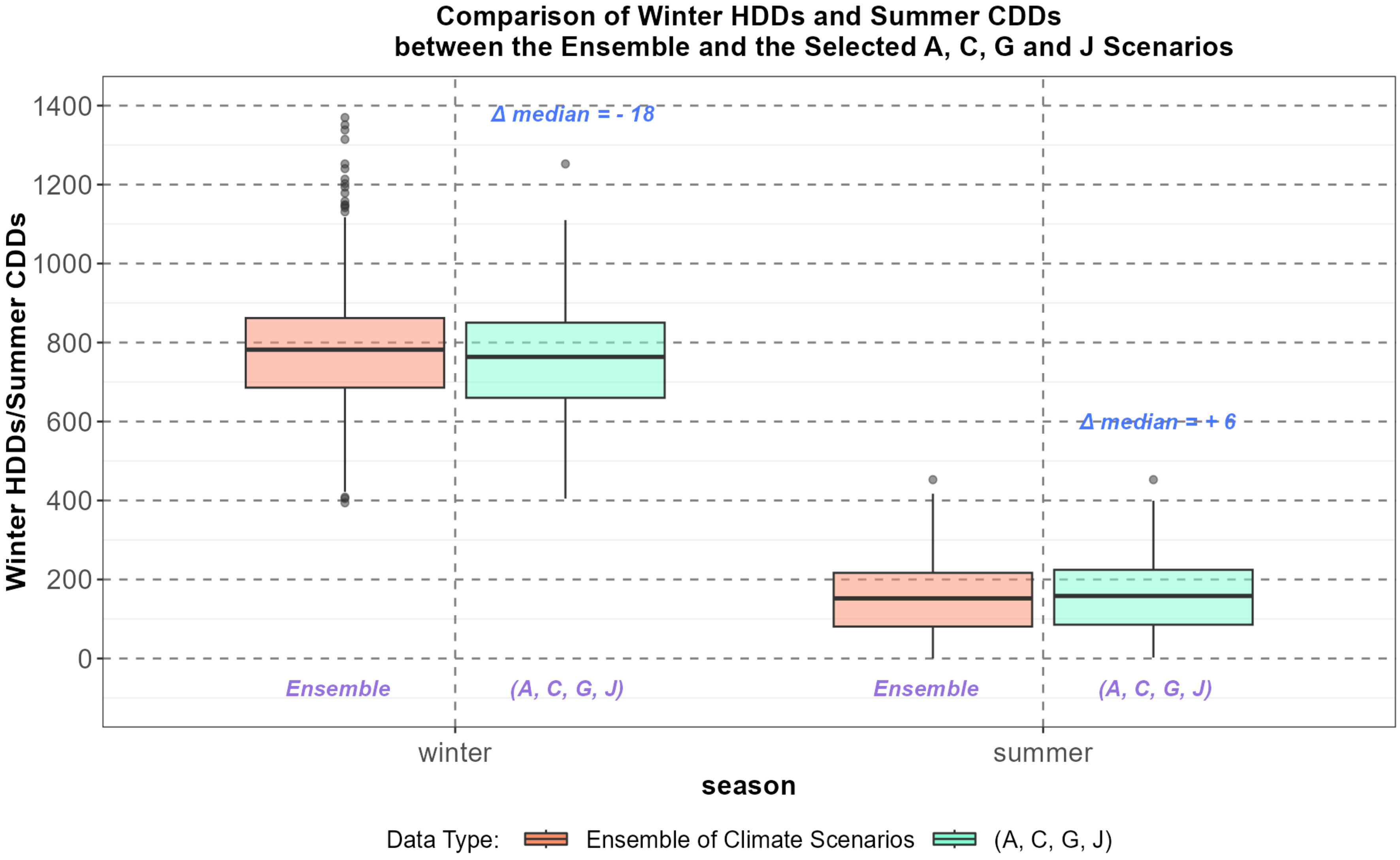
Scenario\Metric	Winter Generation	Summer Generation	Winter HDD	Summer CDD
A			low	high
C	high	low		
G		high		
J	*low*		high	*low*

A: *CanESM2_RCP85_BCSD_VIC_P1*
C: *CCSM4_RCP85_BCSD_VIC_P1*
G: *CNRM-CM5_RCP85_MACA_VIC_P3*
J: *GFDL_ESM2M_RCP85_MACA_VIC_P1*

How Well do the Selected Scenarios represent the Ensemble Hydrogeneration?



How Well do the Selected Scenarios represent the Ensemble HDDs and CDDs?



Climate Scenarios Selection

- Stay with the same 3 climate scenarios?
  - A: *CanESM2_RCP85_BCSD_VIC_P1*
  - C: *CCSM4_RCP85_BCSD_VIC_P1*
  - G: *CNRM-CM5_RCP85_MACA_VIC_P3*

- Add a 4th scenario?
  - A: *CanESM2_RCP85_BCSD_VIC_P1*
  - C: *CCSM4_RCP85_BCSD_VIC_P1*
  - G: *CNRM-CM5_RCP85_MACA_VIC_P3*
  - J: *GFDL_ESM2M_RCP85_MACA_VIC_P1*

Climate Scenario Years

Power Plan Years and Climate Scenarios Years

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

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

Topics for the Next Climate and Weather Advisory Committee

Combined CWAC/CRAC Meeting

- **CRAC: C**onservation **R**esources **A**dvisory **C**ommittee
- Scheduled for Wednesday, August 21st from 2-4 PM Pacific
- Register for meeting here: https://www.nwcouncil.org/meeting/climate-and-weather-and-conservation-resources-adv-comm-combined-meeting-2024-08-21/
- Meeting topic: *Modeling Energy Efficiency with Future Climate Data for the 9th Plan*
  - Review methodology and data used for the 8th (2021) Plan
  - Propose methodology and data for the 9th Plan