January 7, 2025

MEMORANDUM

TO: **Council Members**

FROM: **Daniel Hua and Dor Hirsh Bar Gai**

SUBJECT: **Representation of Extreme Weather in Climate Change Data**

BACKGROUND:

Presenter: Daniel Hua and Dor Hirsh Bar Gai

Summary: Extreme weather events experienced in the Northwest, and elsewhere, can cause impacts on the power system. Incorporating extreme weather into the power plan analysis will help ensure more robust final Council recommendations.
At this meeting, staff will brief the Council on how extreme weather is currently captured in the climate change data being used in the plan. This includes an analysis of the magnitudes of extreme temperatures and the frequencies of multi-day extreme temperatures in the region from the climate scenarios selected for the upcoming Power Plan. Staff will also present some examples of very low wind generation during several days with extreme temperatures from one of the selected climate scenarios at a representative regional wind fleet. Staff is still considering how best to represent this risk, as well as the extreme weather impact on other resources and will report back at a future meeting.

The Council will need a final approach to modeling temperatures and other impacts in the coming months to inform load and new resource options. This will be an opportunity for members to ask questions about the existing representation of extreme weather, which will help us in

finalizing our methodologies and help shape our upcoming scenario modeling and analysis. Please come prepared with questions.

Relevance: Considering the impacts of extreme weather in the analysis for the ninth plan will enable the Council to develop 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.

Background: Extreme weather impacts the power system in multiple ways. For one, electric loads for days with extreme temperatures, either very cold or very warm, are likely to be very high. Furthermore, if extreme temperatures were to cover a large portion of the regional population and last for several consecutive days, then the very high regional loads could affect resource decisions and adequacy of the regional power system. Extreme weather can also impact resources. Demand side technologies may behave differently under different temperature regimes, impacting the potential savings to the system during periods of extreme weather. Generating resource capacity may also vary under extreme temperatures. For example, historical data has shown drop offs in wind generation during periods of extreme heat or extreme cold. Extreme temperatures also have the potential to impact the output of solar, batteries, and may impact the natural gas system as well.

More Info: The selected climate scenarios for the upcoming Power Plan are the same as those selected for the previous 2021 Power Plan. 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.

Representation of Extreme Weather in Climate Change Data

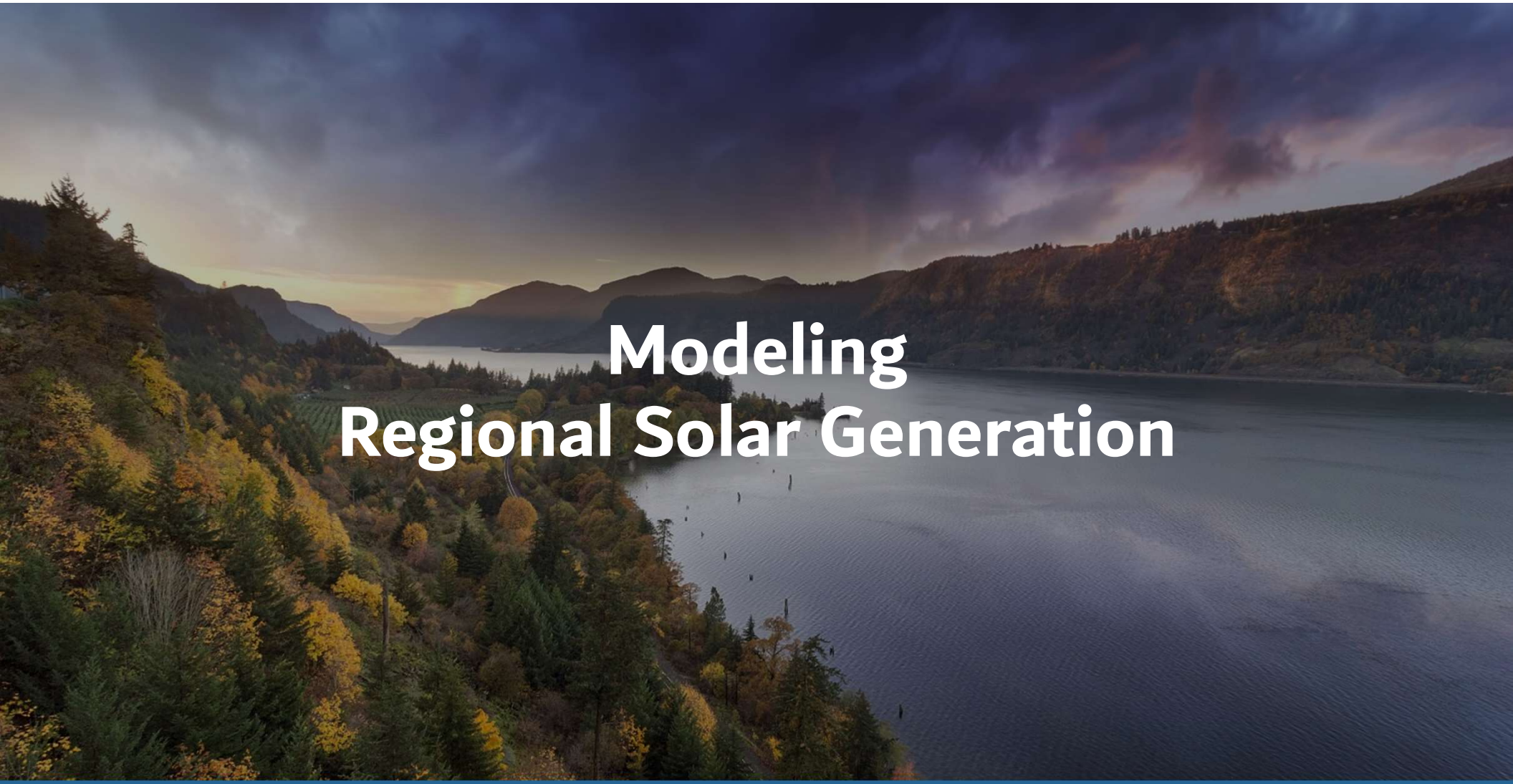
Daniel Hua and Dor Hirsh Bar Gai

1/14/2025

Northwest **Power** and **Conservation** Council

Agenda

- Modeling Regional Solar Generation
- Historical and climate-scenario extreme Temperatures (very cold or very warm) in the region:
  - Frequency of multi-day extreme temperatures: heat-waves and cold snaps
  - Magnitudes of the highest and lowest temperatures
- Very Low Regional Wind Generation



Modeling Regional Solar Generation

Modeling Regional Solar Generation

- For the upcoming Power Plan, Council staff plan to incorporate regional *climate-scenario temperatures*, *streamflows*, and *wind* data in various Council simulation
- For consistency, Council staff initially also planned to use regional *climate-scenario solar radiation* data to model regional solar generation
- However, during the Climate and Weather Advisory Committee (*CWAC*) meeting in December 2024, several climate scientists suggested that
  - the climate scenarios do not model cloud-cover well, which would affect accuracy of the simulated solar generation;
  - instead, use historical meteorological data, which include solar radiation and temperature (*which of course include historical extreme temperatures*), to simulate solar generation;
  - the solar simulation tool includes the effects of decreasing efficiency of generation from high temperatures (*and thus capture the effect of extreme high temperatures on lowering solar generation from recent heat-waves*)

Extreme Temperatures in the Region

Regional Load and Extreme Temperatures

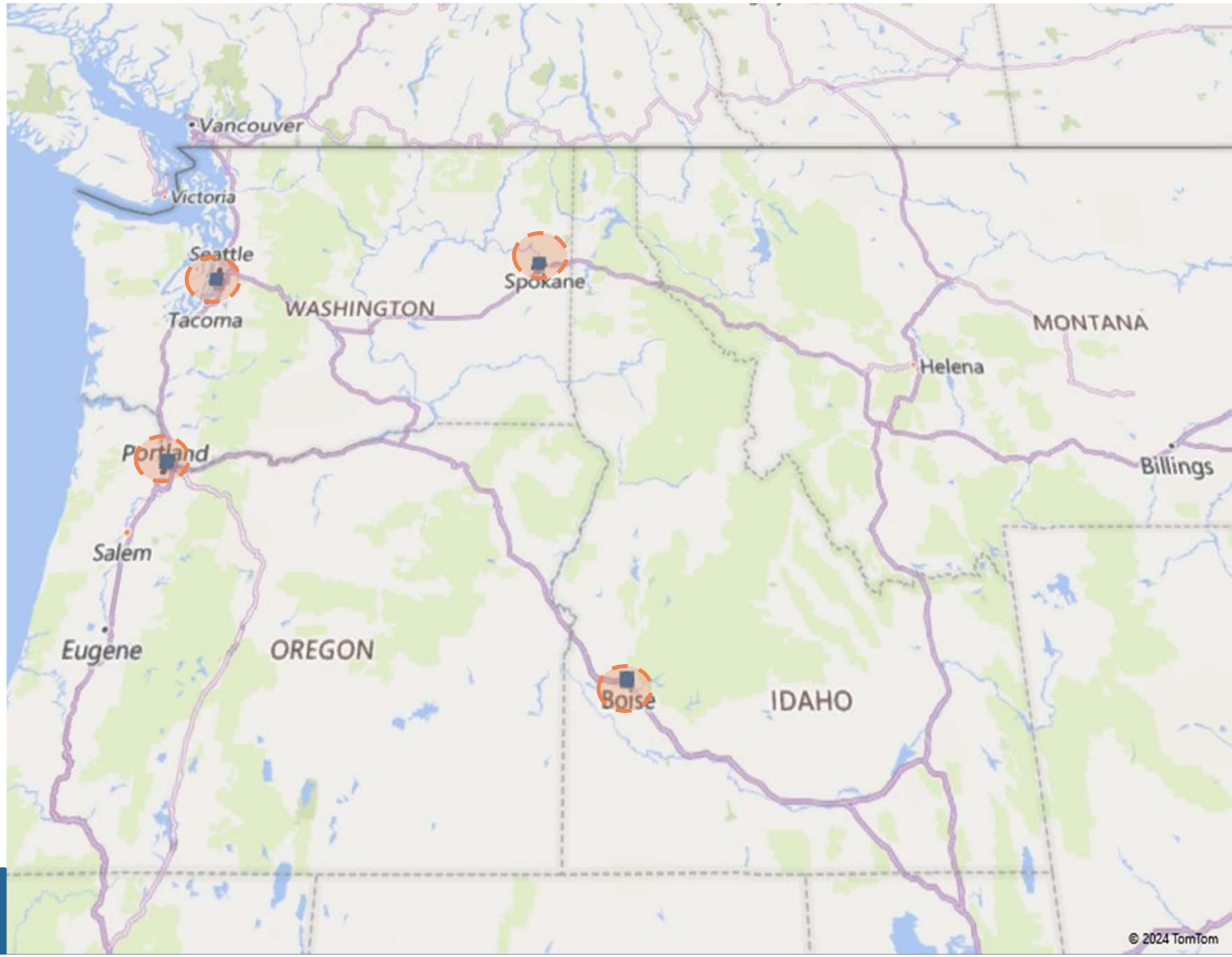
- The regional load becomes very high when extreme temperatures, i.e.,
  - very *low winter* temperatures
  - very *high summer* temperatures

cover *many* high-population areas in the region – e.g., the metropolitan area of 4 cities: Boise, Portland, Seattle and Spokane

- If regional extreme temperatures last for *3 or more consecutive* days, then it become very important to examine adequacy of the power system

Regional Population Centers

- Four regional metropolitan areas
  - Boise
  - Portland
  - Seattle
  - Spokane



The Historical Temperature Data

- Temperature data: *daily minimum* and *daily maximum* temperatures

- Historical data (downloaded from ***NOAA***: *https://www.ncei.noaa.gov/cdo-web/search*):
  - Boise 1940-01-01 to 2024-12-11
  - Portland 1940-10-14 to 2024-12-11
  - Seattle 1949-01-01 to 2024-12-11
  - Spokane 1947-12-08 to 2024-12-11

  - Therefore, historical time-period is 1949 to 2024 (*76 years*)

The Climate Scenario Temperature Data

- Temperature data: *daily minimum* and *daily maximum* temperatures

- The three climate scenarios selected for the Power Plan:
  - **A**: CanESM2_RCP85_BCSD_VIC_P1
  - **C**: CCSM4_RCP85_BCSD_VIC_P1
  - **G**: CNRM-CM5_RCP85_MACA_VIC_P3

  - "*XYZ*" – the Global Climate Model (GCM) & RCP8.5 emission level (***high***)
  - "*XYZ*" – the downscaling method, ***BCSD*** or ***MACA***
  - "*XYZ*" – the hydrological model, **3** versions of ***V****ariable* ***I****nfiltration* ***C****apacity*, ***VIC_P1***, ***VIC_P2***, ***VIC_P3***, or ***P****recipitation* ***R****unoff* ***M****odeling* ***S****ystem*, ***PRMS***

  - Climate scenario time-period is 2020 to 2024 (30 *years* × 3 climate scenarios = 90 *years*)

Multi-Days with Extremely Warm Temperatures: Heat-Wave

Example of a Regional Heat Wave

- Many would consider the *2021 Heat-Dome* to be a heat-wave event
- *3-day* event: from 6/26/2021 to 6/28/2021
- The *daily maximum* temperatures (at the airport) of the 4 cities are:

Dates / Cities	Boise	Portland	Seattle	Spokane
6/26/2021	95	108	102	98
6/27/2021	99	112	104	102
6/28/2021	103	116*	108*	105

*highest recorded historical daily maximum temperature

Defining a Regional Heat-Wave

- Regional heat-wave:
  - define a threshold temperatures T_{max}
  - and 3 *out of the* 4 cities have daily maximum temperatures $T_i \geq T_{max}$
  - for 3 *or more* consecutive days

- Let $T_{max} = 98$

Dates / Cities	Boise	Portland	Seattle	Spokane
6/26/2021	95	108	102	98
6/27/2021	99	112	104	102
6/28/2021	103	116	108	105

  - On $6/26/2021$, 3 out of 4 cities have daily maximum temperatures ≥ 98

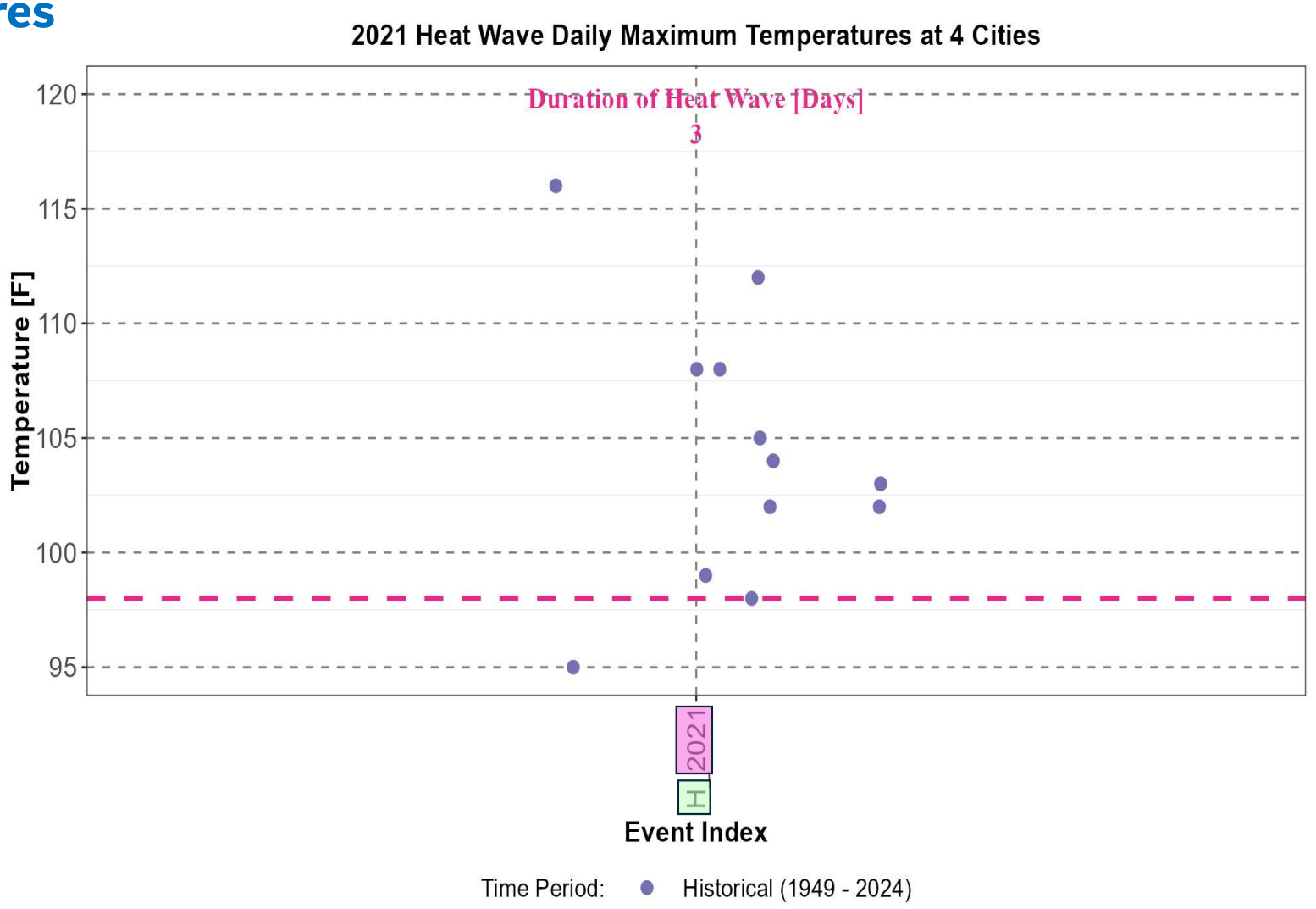
A Regional Heat-Wave

- *Regional* heat-wave event:
  - lasts for *3 or more consecutive days* where
  - for at least *3 out the 4* cities: Boise, Portland, Seattle and Spokane
  - their daily maximum temperatures $\geq 98\ F$

Extreme Temperatures during the "2021 Heat Dome" (I)

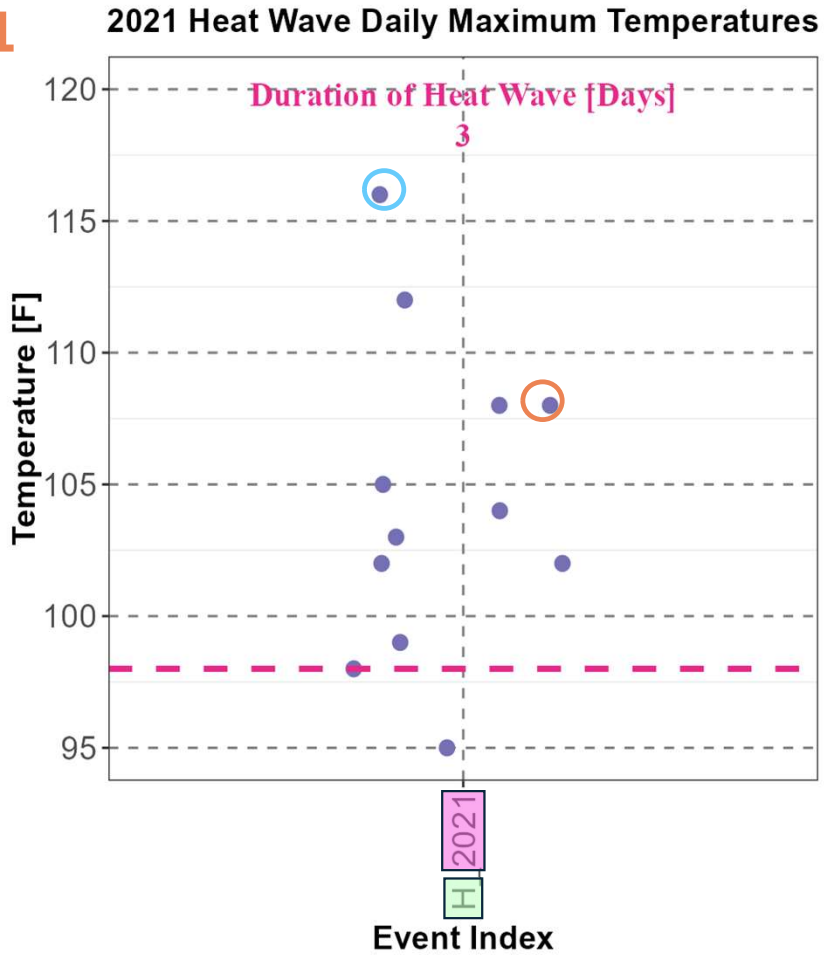
- Each data point is the daily maximum temperature at the airport of
  - Boise
  - Portland
  - Seattle
  - Spokane

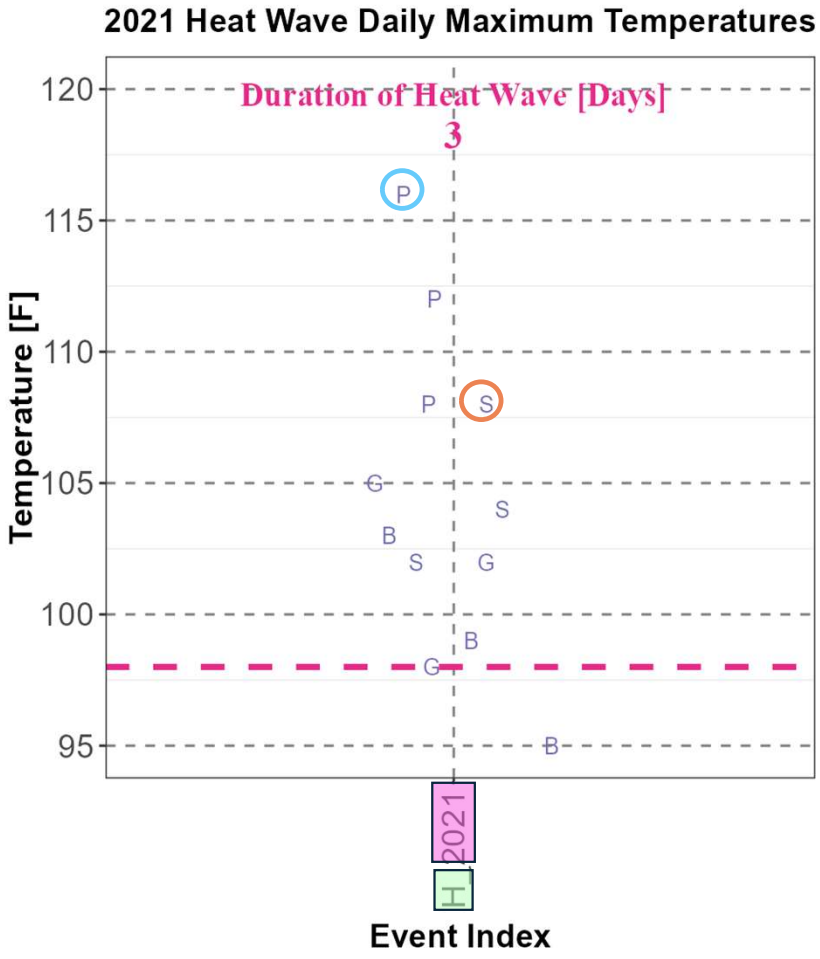
- (4 daily maximum temperatures) × (3 consecutive days) = 12 data points



Extreme Temperatures during the "2021 Heat Dome" (II)

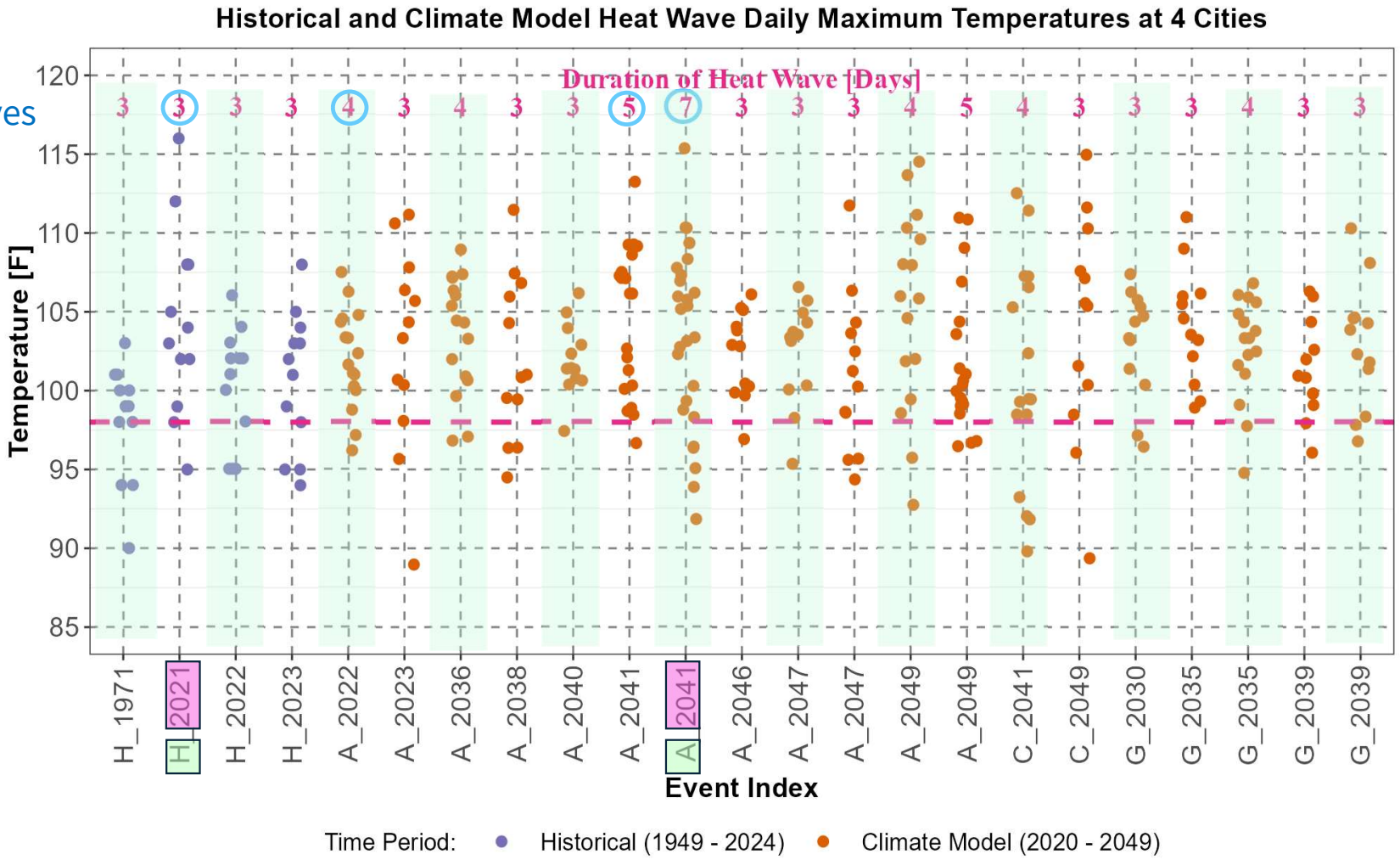
- The right figure has the 4 cities explicitly labelled
  - Boise : ***B***
  - Portland: ***P***
  - Seattle: ***S***
  - Spokane: ***G***





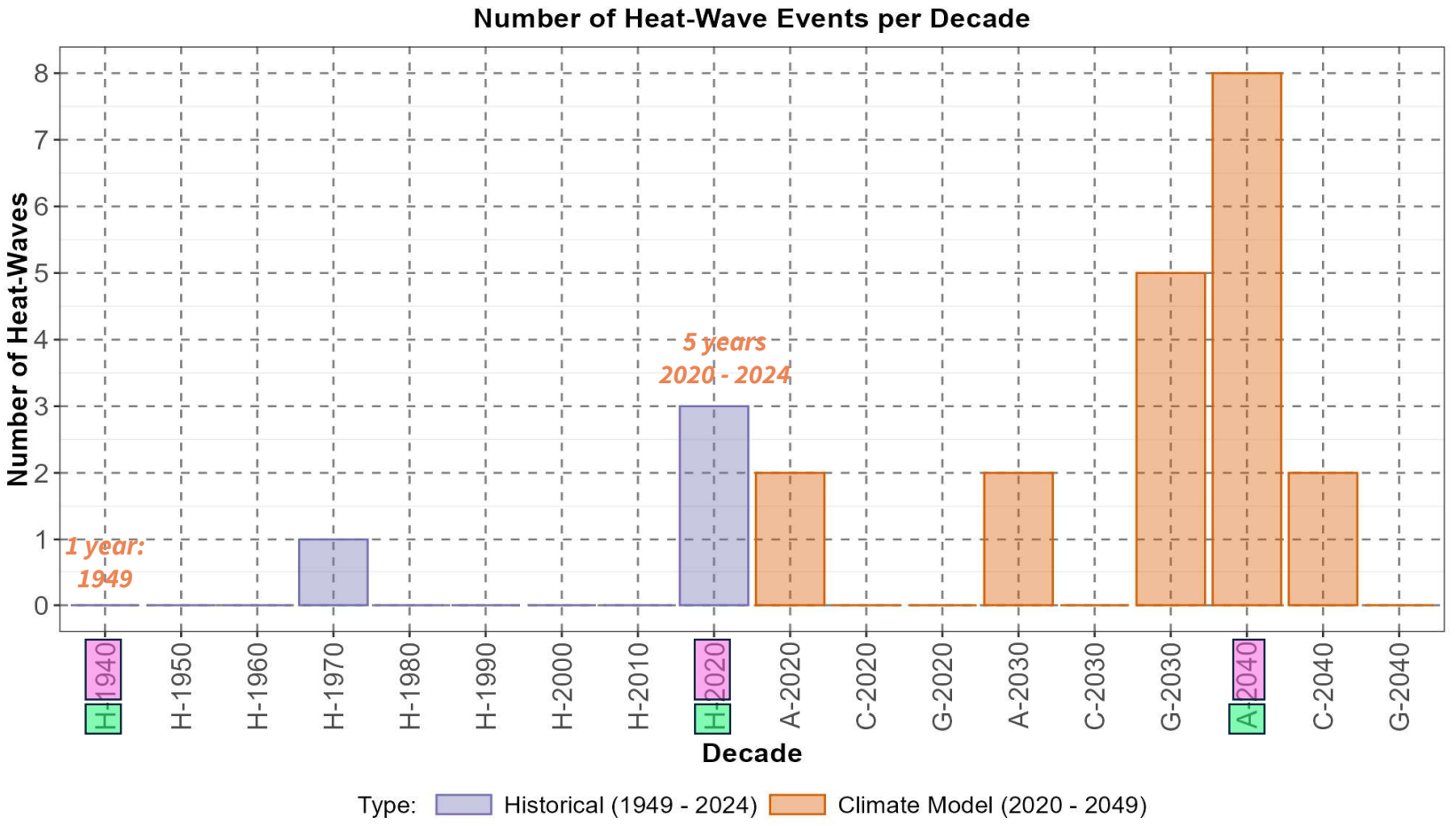
Heat-Wave Event Daily Maximum Temperatures

- 4 historical heat-waves
- 19 climate scenario heat-waves
  - 12 from A
  - 2 from C
  - 5 from G



Frequency of Heat-Wave Events Per Decade

- Increasing frequency of heat-wave events is consistent with the *warming climate trend*



Highest Temperatures

Maximum Temperature	BOI	GEG	PDX	SEA
Historical (1949 – 2024)	111	109	116	108
Climate Scenario (2020 – 2049)	117	113	115	109

Dates	BOI	GEG	PDX	SEA
Historical (1949 – 2024)	1960	2021	2021	2021
Climate Scenario (2020 – 2049)	**A:** 2038	**A:** 2041	**A:** 2041	**G:** 2035

- For BOI, GEG and SEA, their highest temperatures have increased
- Climate scientists in the CWAC agree with the increasing highest temperatures from the climate scenarios

(Many other climate-scenario temperatures) BOI: 112 - 116 GEG: 110 - 112

Multi-Days with Extremely Cold Temperatures: Cold-Snap

A Regional Cold Snap

- *Regional* cold snap event:
  - lasts for *3 or more consecutive days* where
  - for at least *3 out the 4* cities: Boise, Portland, Seattle and Spokane
  - their daily minimum temperatures $\leq 15\ F^*$

* If daily minimum temperatures $\leq 20\ F$, then too many data points to be plotted on 1 slide

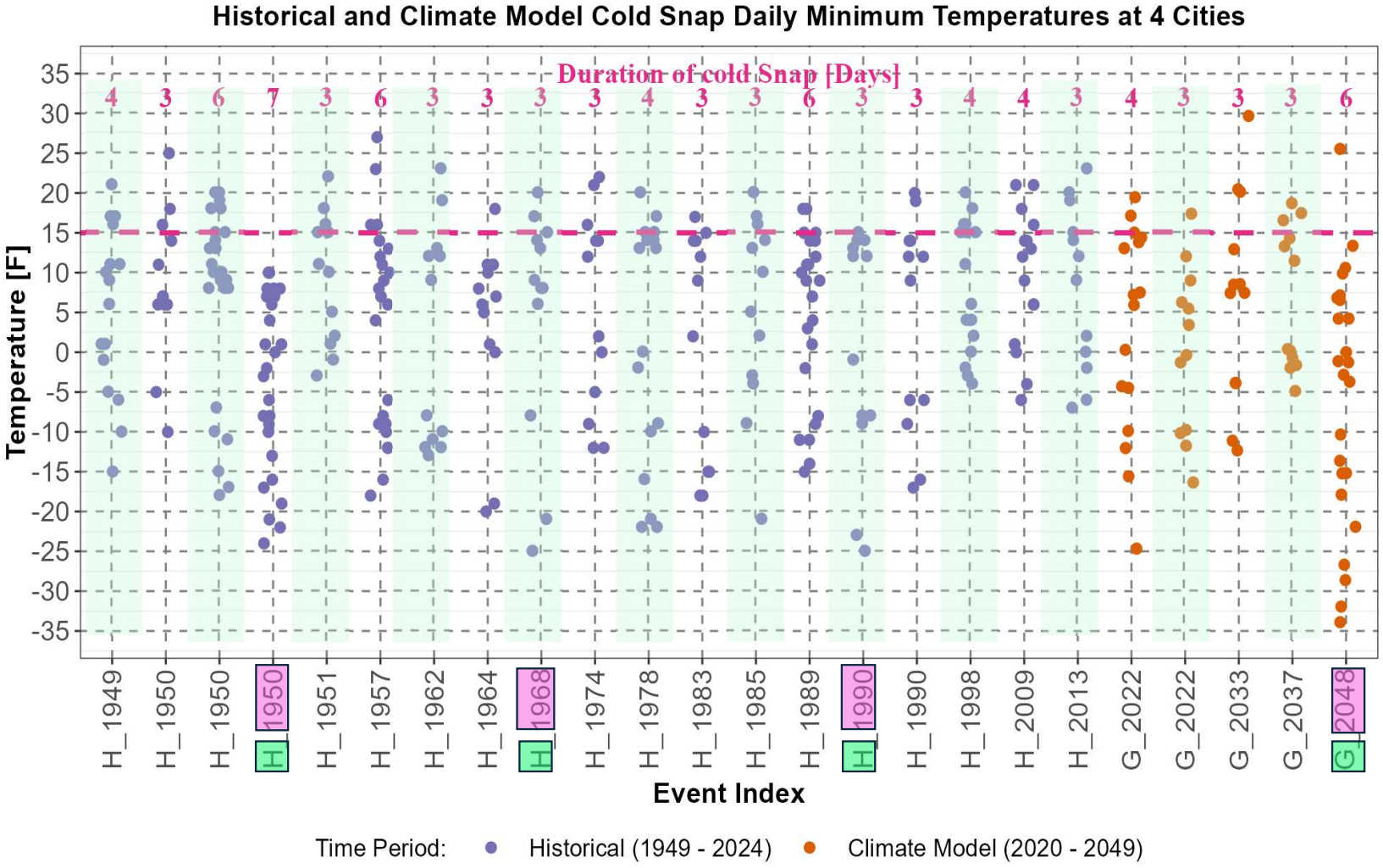
Coldest Days in 2024

Date / Minimum Temperature	BOI	GEG	PDX	SEA
1/12/2024	18	−7	21	15
1/13/2024	7	−10	15	15
1/14/2024	11	−4	17	19
1/15/2024	3	−2	22	21
1/16/2024	3	5	20	22
1/17/2024	9	9	25	30

- Only 1 day where at least 3 *out of* 4 cities have daily minimum temperature ≤ 15
- By definition: not a cold-snap in January 2024

Cold Snap Daily Minimum Temperatures (A)

- 19 historical cold snaps
- 5 climate scenario cold snaps
  - 0 from A
  - 0 from C
  - 5 from G



Lowest Temperatures

Minimum Temperature	BOI	GEG	PDX	SEA
Historical (1949 – 2023)	−25	−25	−3	0
Climate Scenario (2020 – 2049)	−29	−34	−15	−4

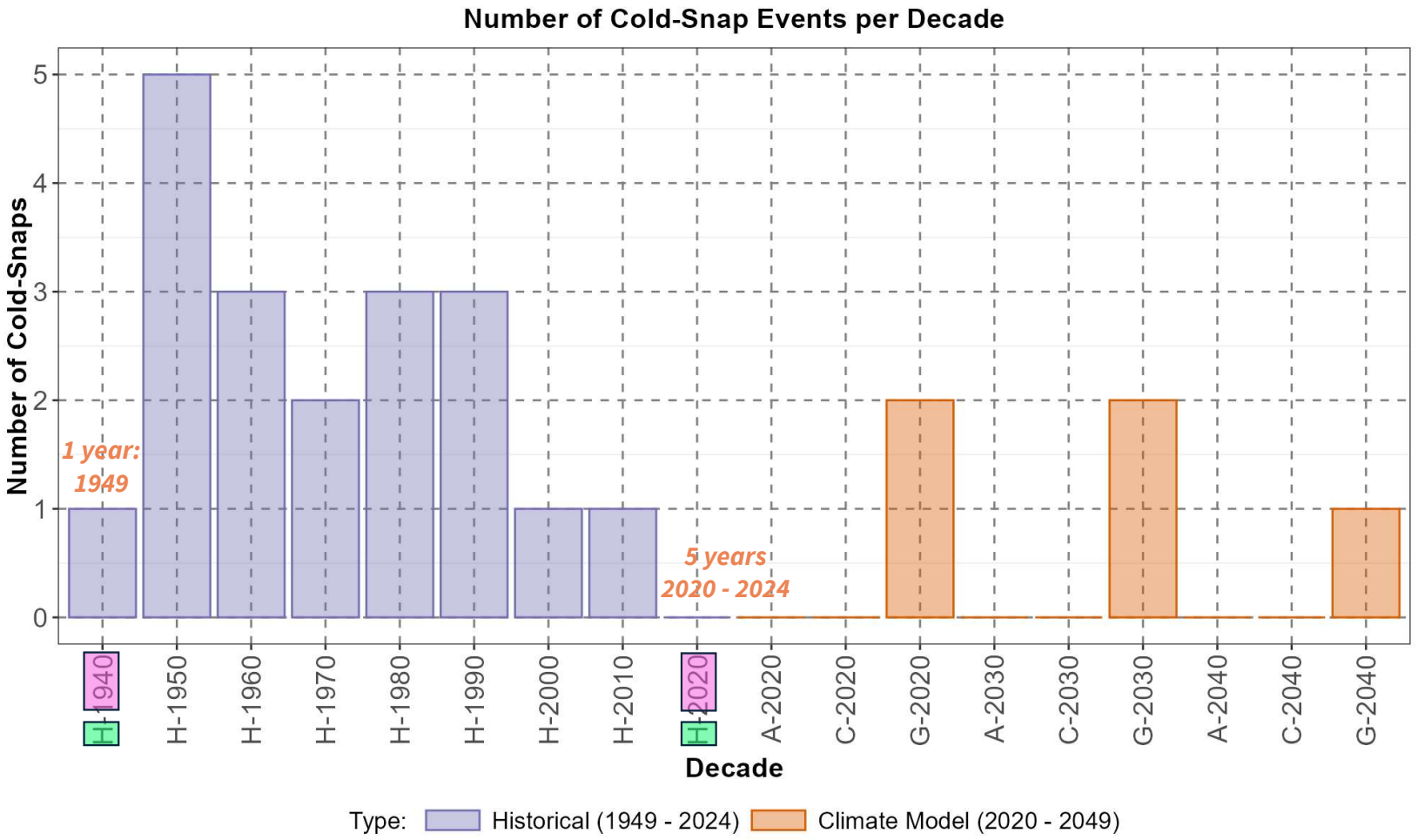
Dates	BOI	GEG	PDX	SEA
Historical (1949 – 2023)	1990	1968	1950	1950
Climate Scenario (2020 – 2049)	**G:** 2048	**G:** 2048	**G:** 2048	**G:** 2048

- Several climate scientists from the CWAC suggested that −15 at PDX and −34 at GEG could be too low

(Other climate scenario temperatures) BOI: −28 GEG: −32, −27 PDX: −3 SEA: −1

Frequency of Cold-Snap Events Per Decade

- Decreasing frequency of cold-snap events is consistent with the *warming climate trend*



Summary

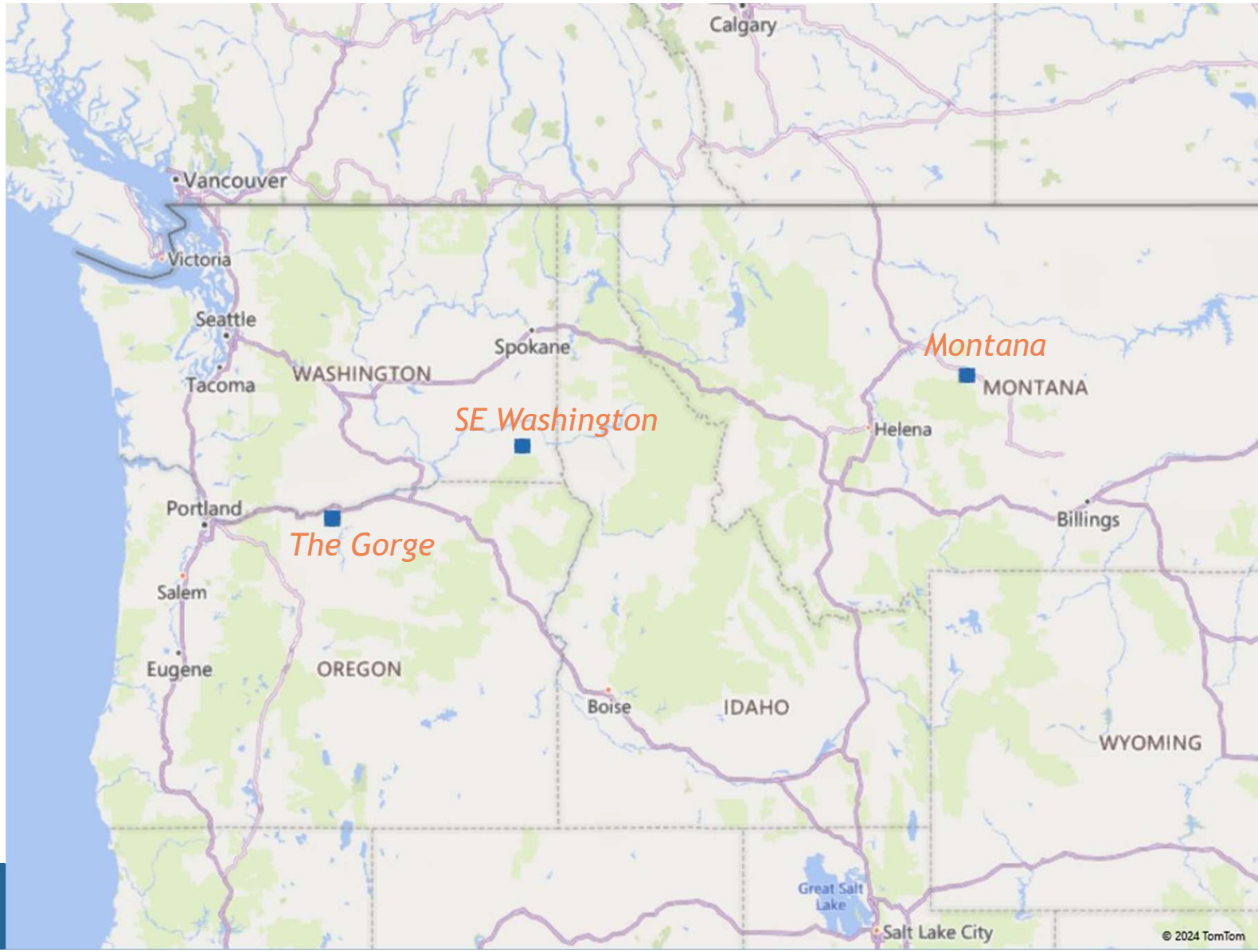
- Compared to the 1949 to 2024 historical data, the 2020 to 2024 climate scenarios data show that:
  - the frequency of heat wave is increasing;
  - the frequency of cold snap is decreasing;
  - there are *many* higher temperatures than the highest historical temperatures (*except for PDX*);
  - *a few* lower temperatures than the lowest historical temperatures;

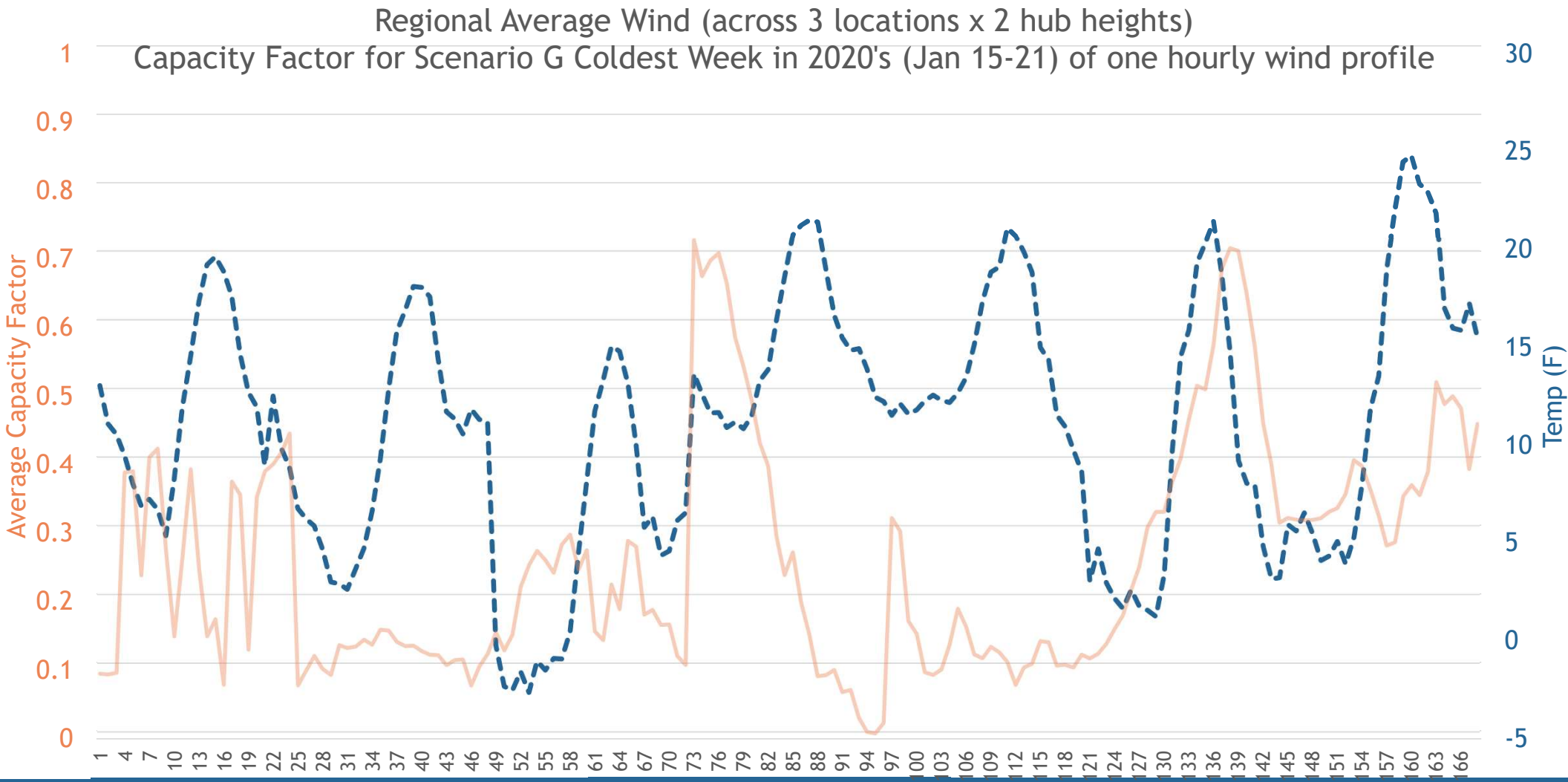
- Consensus from the CWAC on the 3 climate scenarios selected for the Power Plan:
  - agrees with the trends, magnitudes and frequencies of extreme temperatures embedded in the climate scenarios;
  - the climate scenarios contain sufficient extreme temperatures over the years covered by the Power Plan;

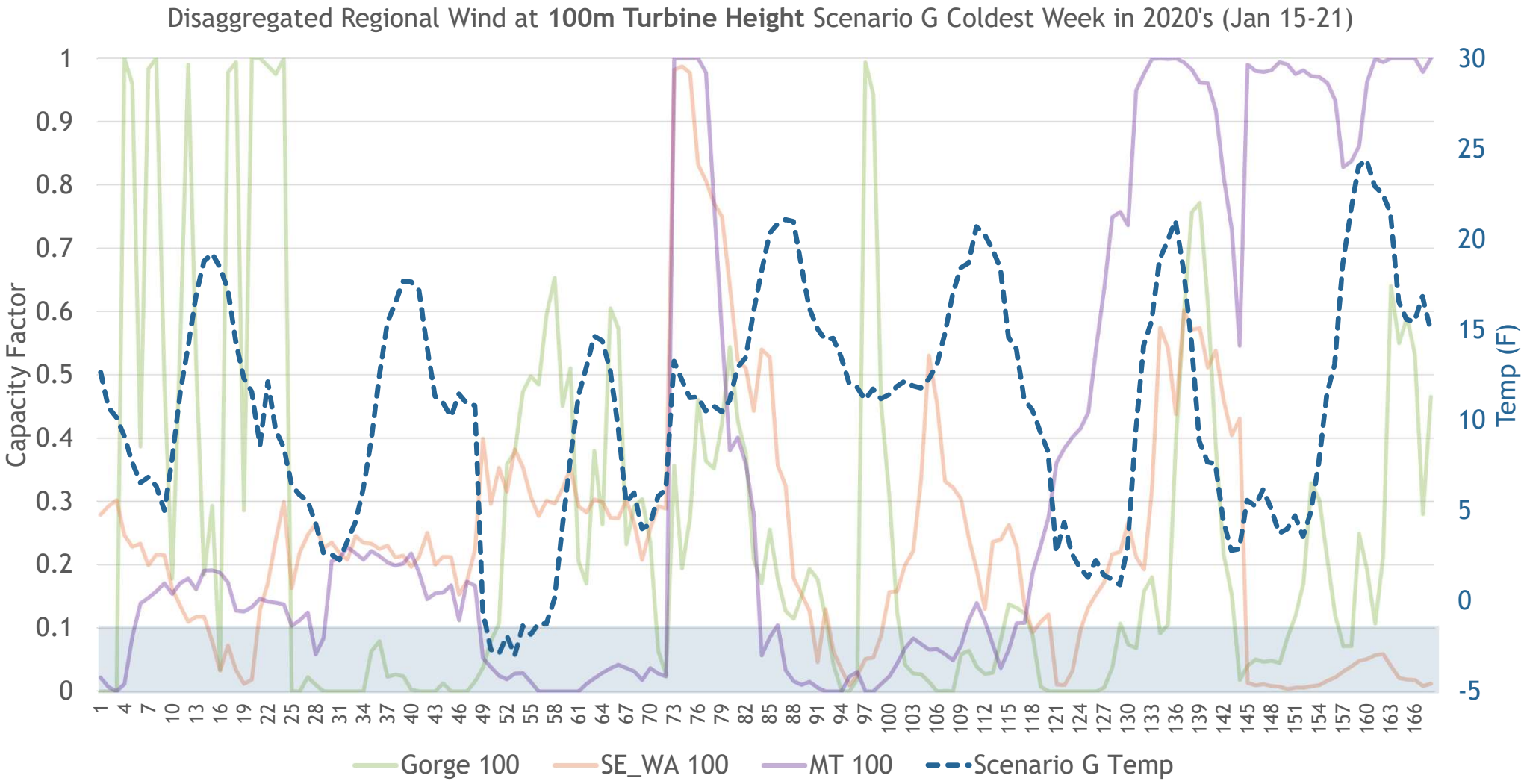
Extreme Temperatures and Very Low Wind Generation

Climate Wind Generation Modeled in 2021 Power Plan

- Climate scenario wind generation modeled with 2 hub-heights (80 m and 100 m) at 3 representative sites
  - The Gorge
  - SE Washington
  - Montana

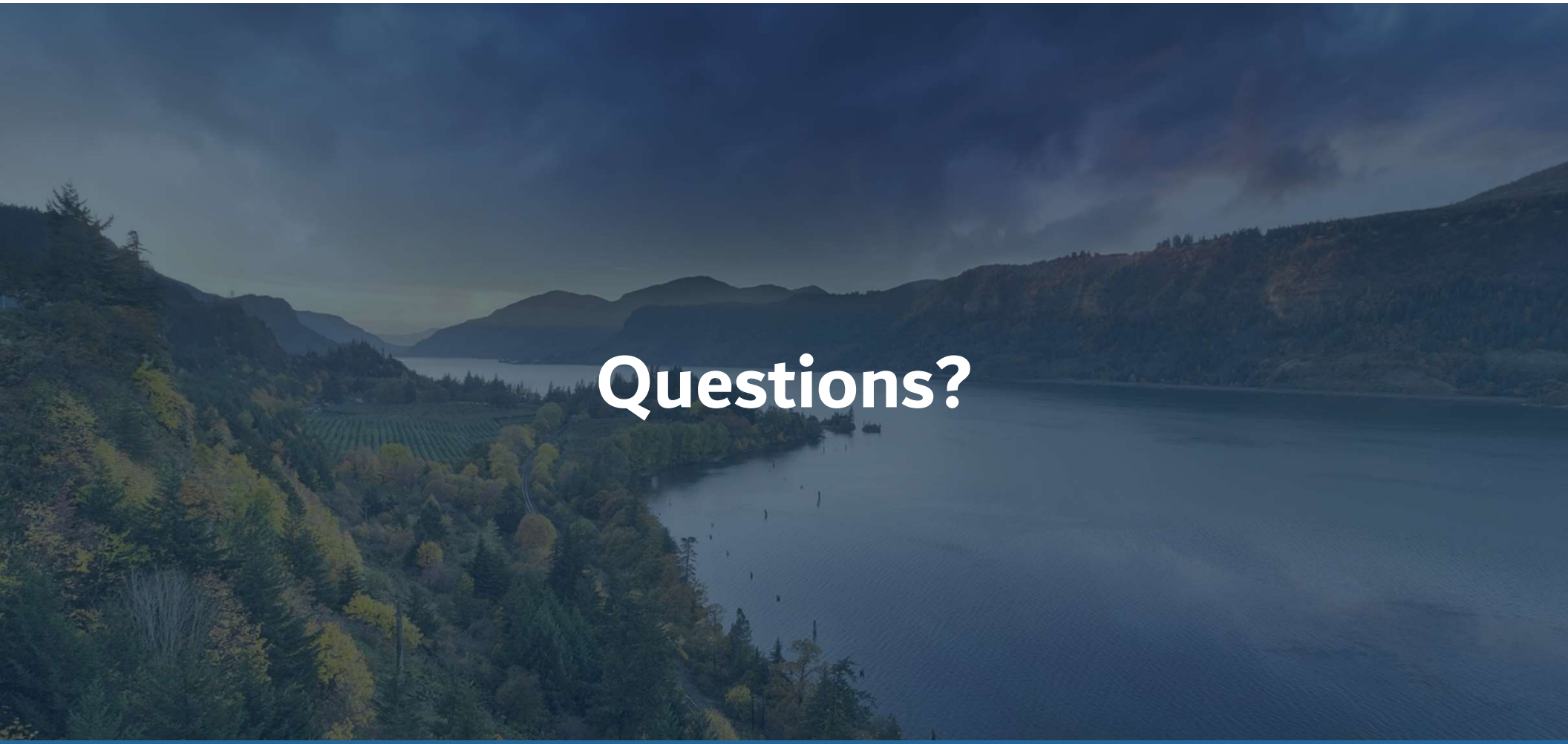



Regional Average Wind (across 3 locations x 2 hub heights)
Capacity Factor for Scenario G Coldest Week in 2020's (Jan 15-21) of one hourly wind profile
Average Capacity Factor
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Temp (F)
30
25
20
15
10
5
0
-5
1 4 7 10 13 16 19 22 25 28 31 34 37 40 43 46 49 52 55 58 61 64 67 70 73 76 79 82 85 88 91 94 97 100 103 106 109 112 115 118 121 124 127 130 133 136 139 142 145 148 151 154 157 160 163 166
Hours of the Week (1-168)


Disaggregated Regional Wind at **100m Turbine Height** Scenario G Coldest Week in 2020's (Jan 15-21)
Capacity Factor
Temp (F)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
30
25
20
15
10
5
0
-5
1 4 7 10 13 16 19 22 25 28 31 34 37 40 43 46 49 52 55 58 61 64 67 70 73 76 79 82 85 88 91 94 97 100 103 106 109 112 115 118 121 124 127 130 133 136 139 142 145 148 151 154 157 160 163 166
Gorge 100
SE_WA 100
MT 100
Scenario G Temp

Summary

- The climate change wind generation includes zero and very low capacity factors that may occur during extreme cold temperatures
- Wind diversity across the region is represented at 3 locations (at 2 hub heights)
- Staff will continue engaging with the Climate and Weather Advisory Committee on fine-tuning wind generation assumptions and profiles to capture appropriate correlation of capacity factors across the range of temperatures



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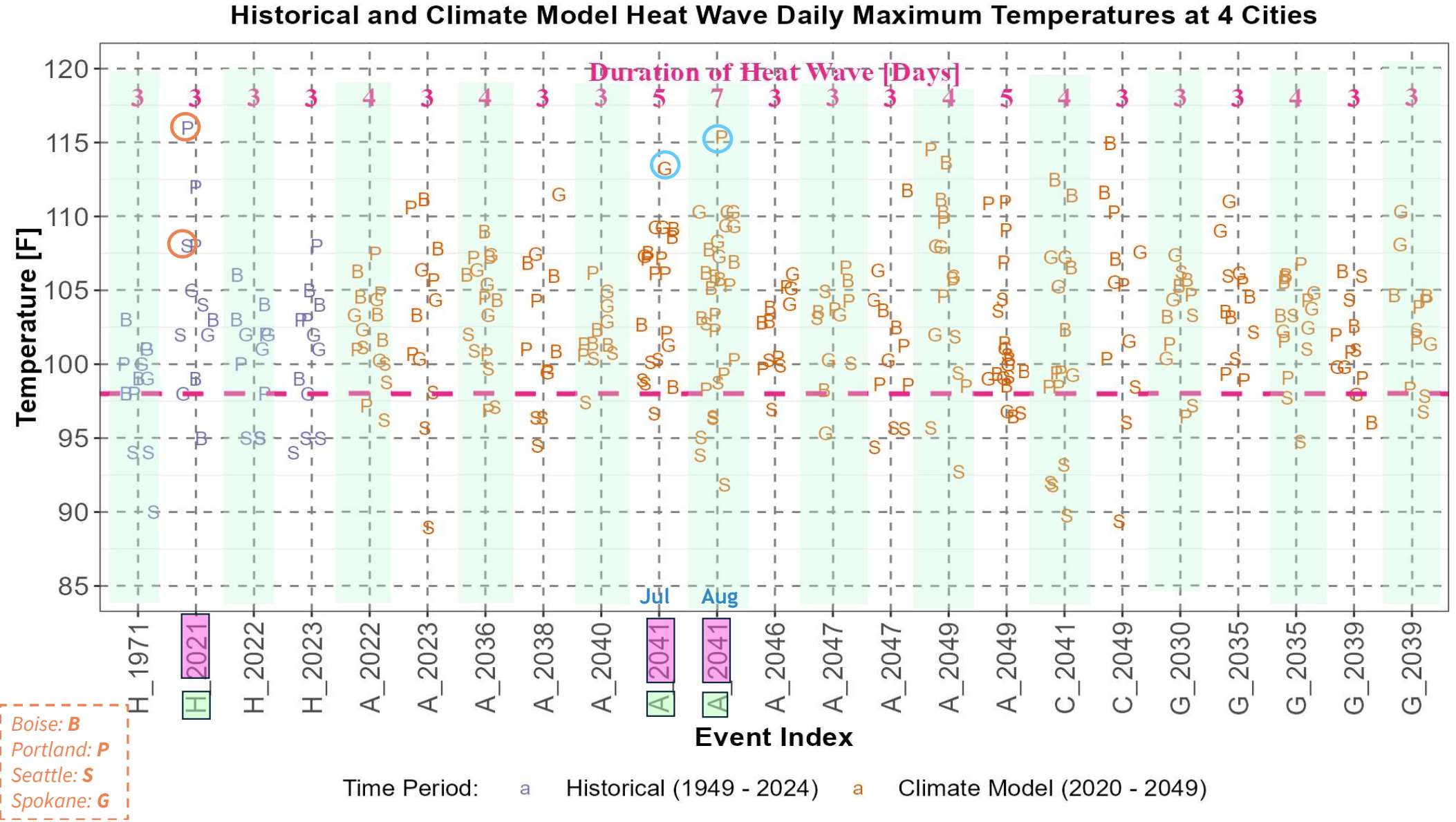
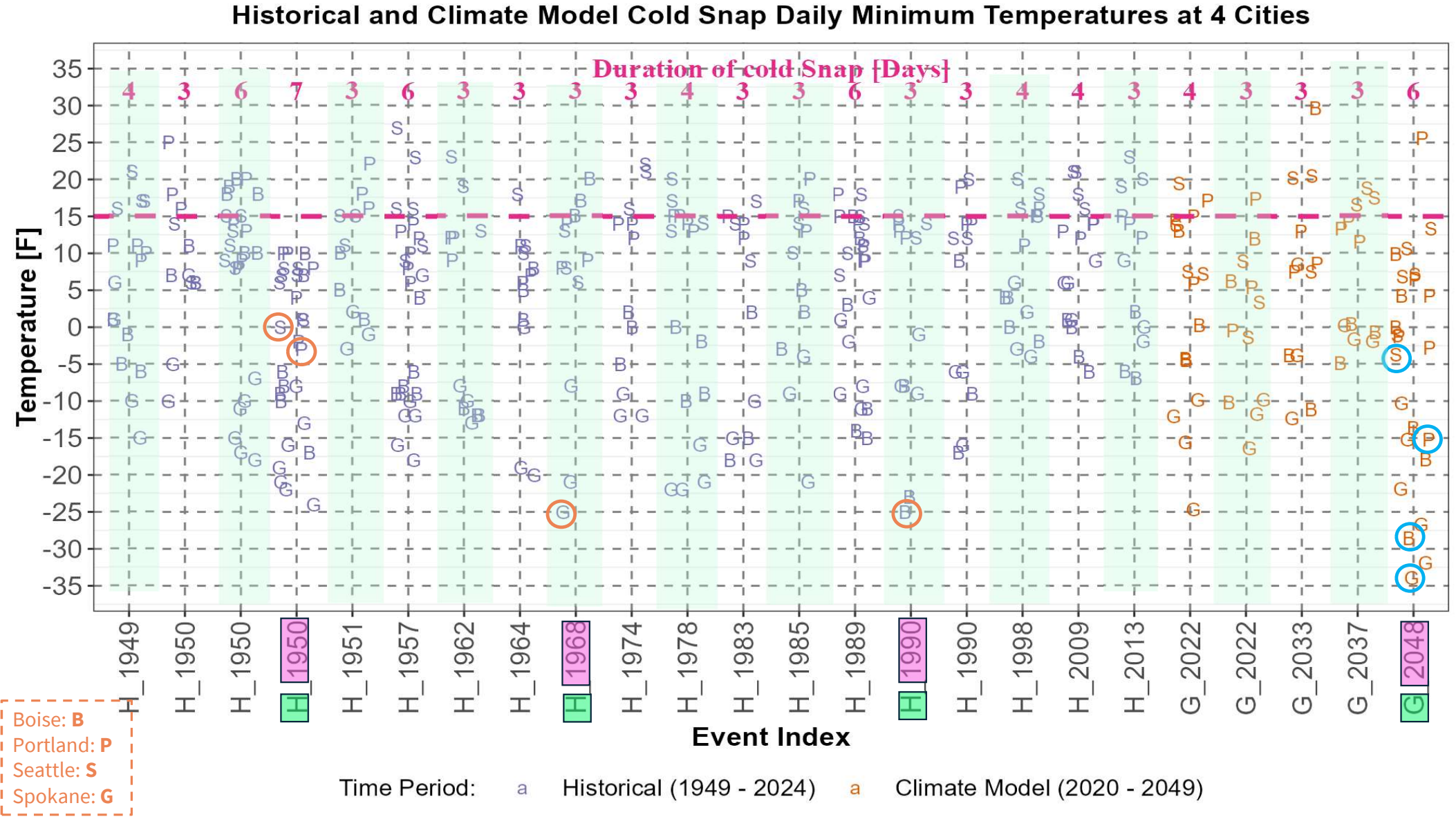
Extras


Historical and Climate Model Heat Wave Daily Maximum Temperatures at 4 Cities
Duration of Heat Wave [Days]
3 3 3 3 4 3 4 3 3 5 7 3 3 3 4 5 4 3 3 3 4 3 3
Temperature [F]
120
115
110
105
100
95
90
85
Jul
Aug
H_1971
H_2021
H_2022
H_2023
A_2022
A_2023
A_2036
A_2038
A_2040
A_2041
A_2041
A_2046
A_2047
A_2047
A_2049
A_2049
C_2041
C_2049
G_2030
G_2035
G_2035
G_2039
G_2039
H
A
A
Event Index
Boise: B
Portland: P
Seattle: S
Spokane: G
Time Period: a Historical (1949 - 2024) a Climate Model (2020 - 2049)


Historical and Climate Model Cold Snap Daily Minimum Temperatures at 4 Cities
Duration of cold Snap [Days]
4 3 6 7 3 6 3 3 3 3 4 3 3 6 3 3 4 4 3 4 3 3 3 6
Temperature [F]
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
H_1949
H_1950
H_1950
H_1950
H_1951
H_1957
H_1962
H_1964
H_1968
H_1974
H_1978
H_1983
H_1985
H_1989
H_1990
H_1990
H_1998
H_2009
H_2013
G_2022
G_2022
G_2033
G_2037
G_2048
Event Index
Boise: B
Portland: P
Seattle: S
Spokane: G
Time Period: a Historical (1949 - 2024) a Climate Model (2020 - 2049)

Wind Generation Droughts

- Define wind drought as having daily-averaged $\mathrm{CF} \leq 0.05$ representing 5% wind-fleet nameplate capacity
  - For example, for 2024, BPA BA wind fleet nameplate capacity is 2,927 MW
  - 5% of the nameplate is 146 MW

Consecutive Days with Drought	# of Drought Events in 30 years	Percentage of Total Days
0	10,177	0.8994
1	900	0.0795
2	201	0.0178
3	32	0.0028
4	5	0.0004

The Regional Temperature

- Define a representative *regional* temperature as:

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

(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)