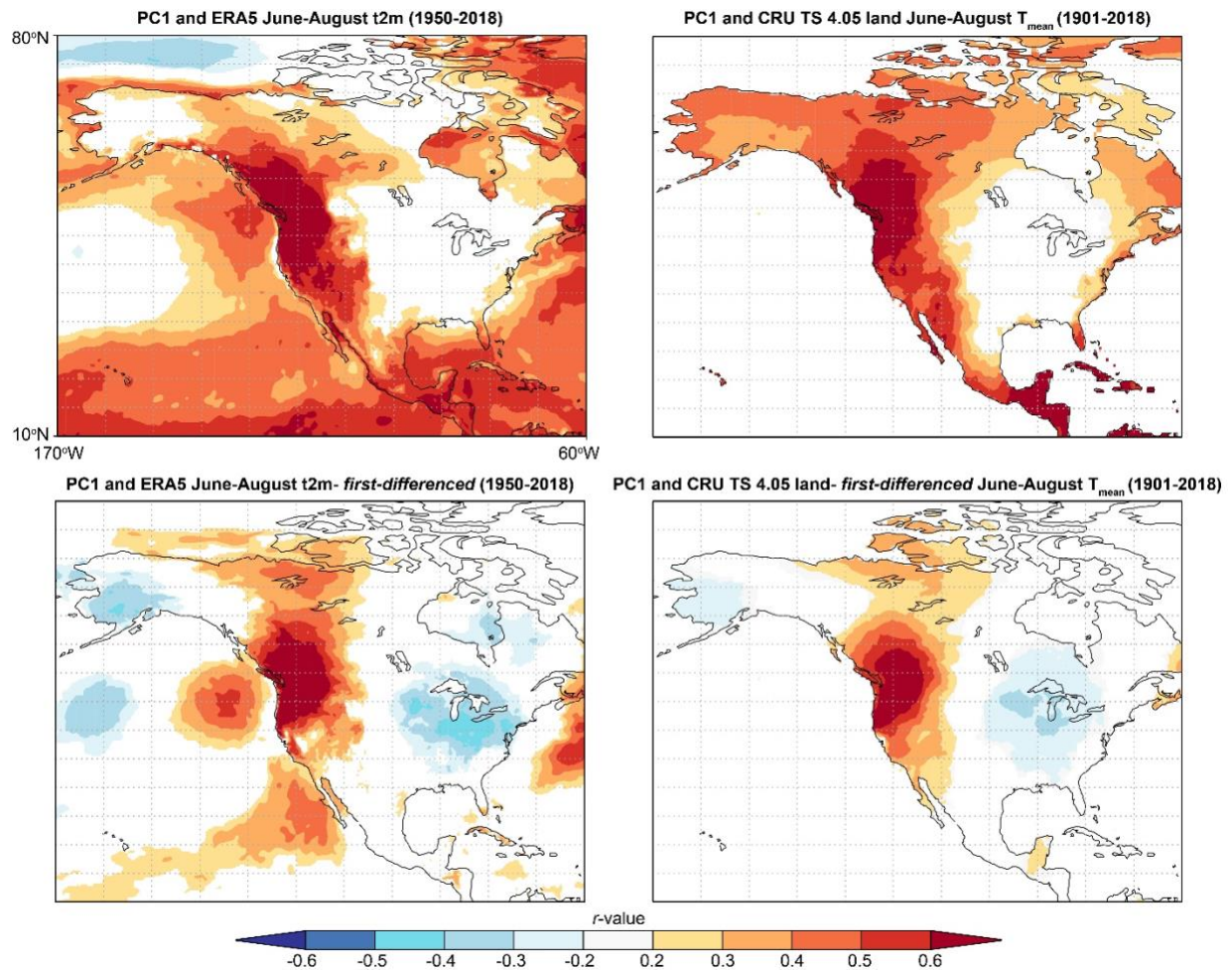


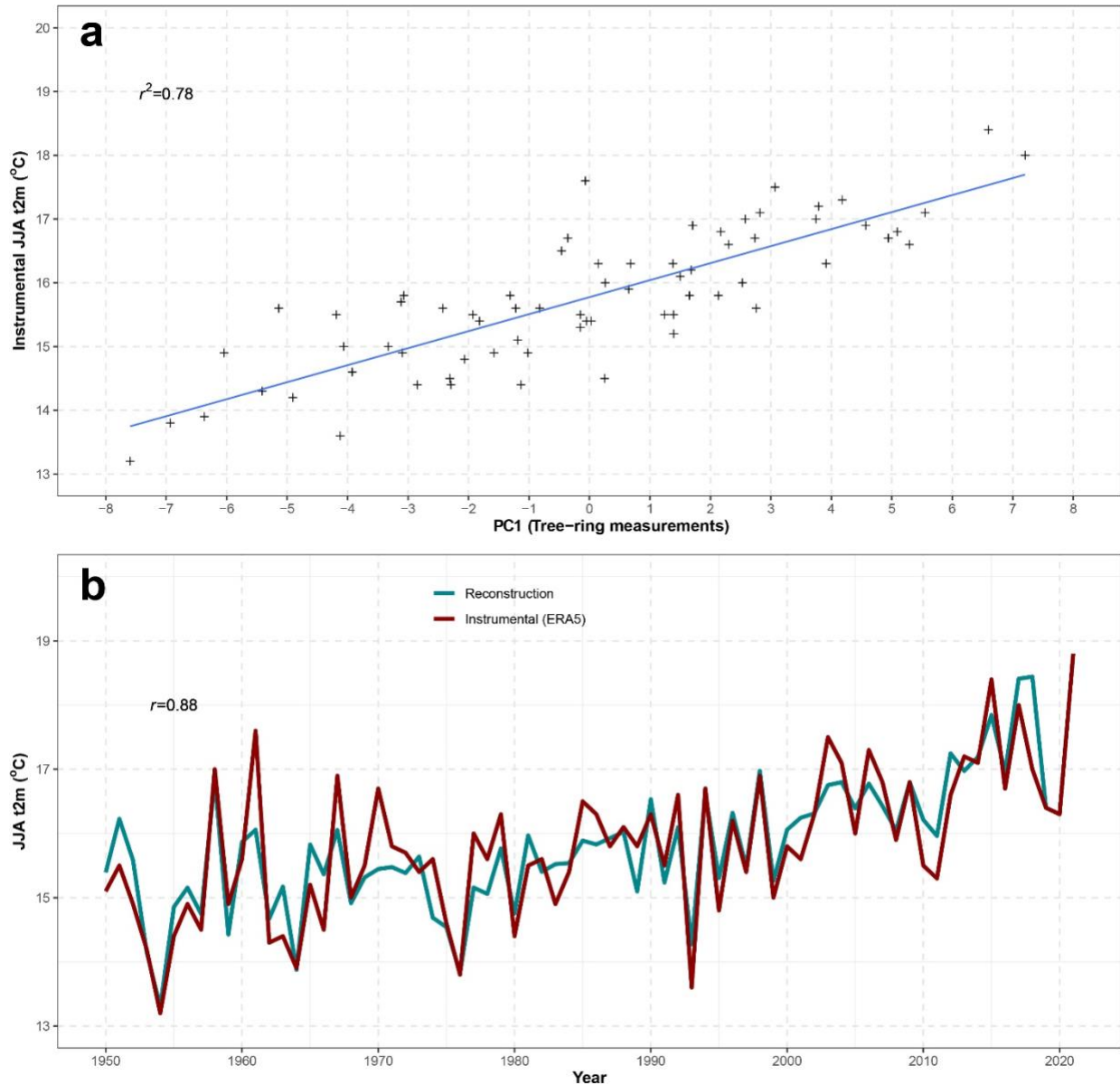
## **Supplemental Information Appendix**

## Supplementary Figures

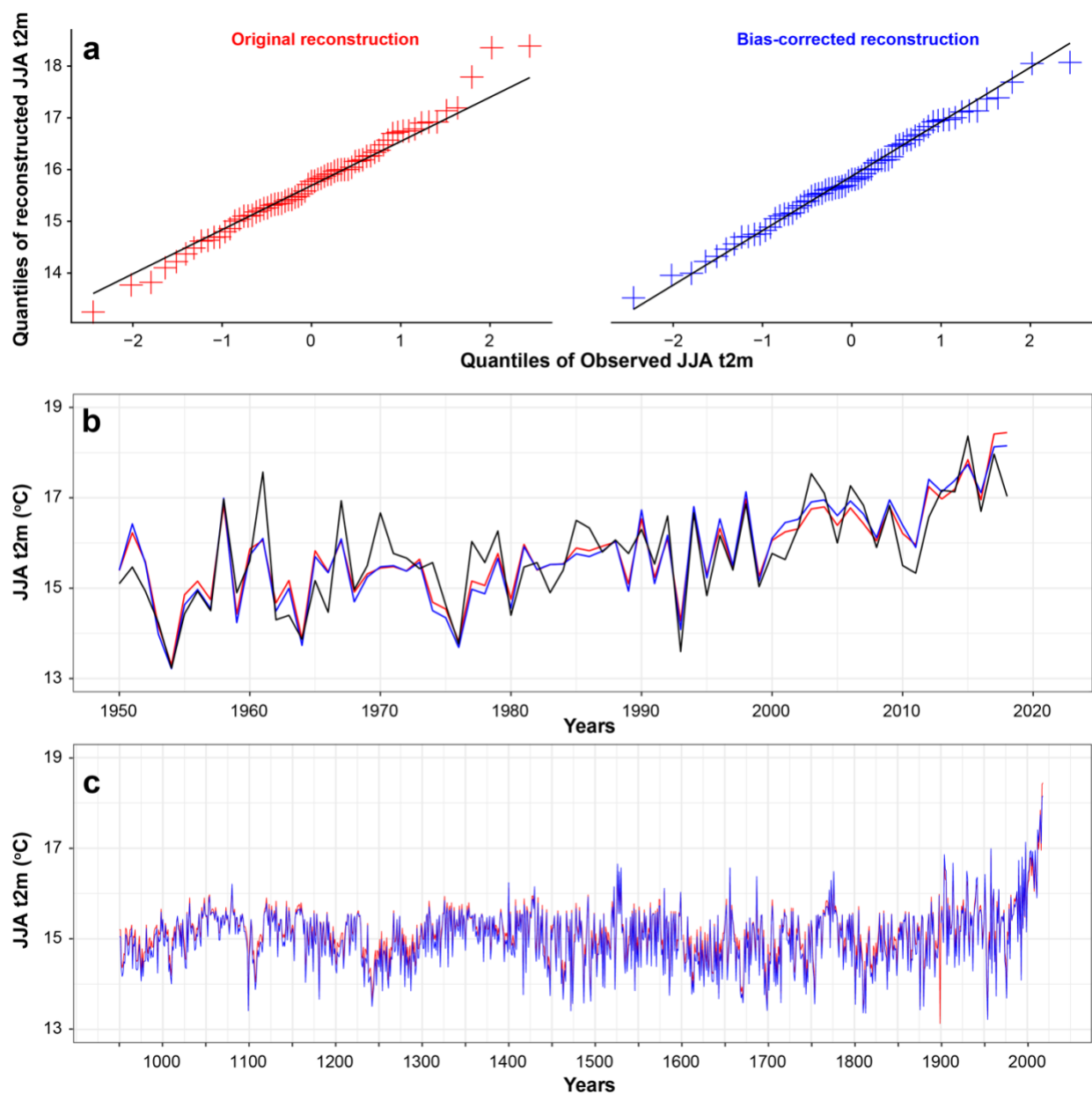


**Supplementary Figure 1. Spatial correlations between tree-ring predictors and ERA5 data.**

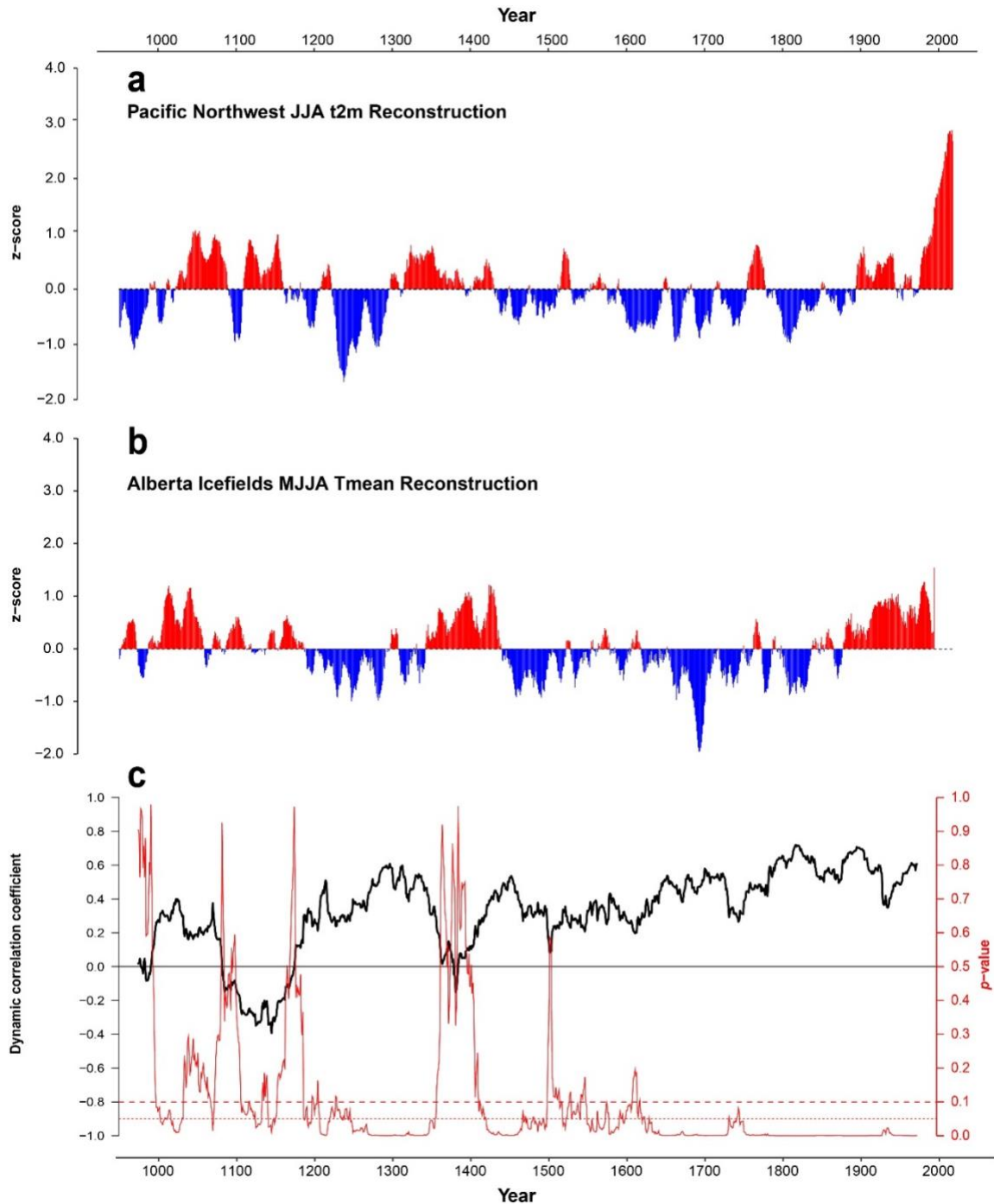
Spatial Pearson's correlations ( $r$ ) between PC1 of tree-ring predictors and ERA5 JJA t2m (left two panels) and CRU TS land v4.05 JJA mean temperatures (right two panels) over the North American region over the respective periods 1950-2018 CE and 1900-2018 CE. Correlations calculated with both non-transformed climate and tree ring data (top two panels) and transformed data using a high-pass filter based on year-to-year differencing (bottom two panels).



**Supplementary Figure 2. Reconstruction model of mean summer temperatures over the Pacific Northwest. (a)** Linearity and strength of relationship between PC1 of tree-ring predictors and regionalized ERA5 JJA t2m predictand data, with fitted linear regression line (blue line) and regression coefficient ( $r^2$ ). **(b)** Relationship of observational (red line) and reconstructed (teal line) JJA t2m anomalies over the model's common calibration period (1950-2017 CE), with Pearson's  $r$ .

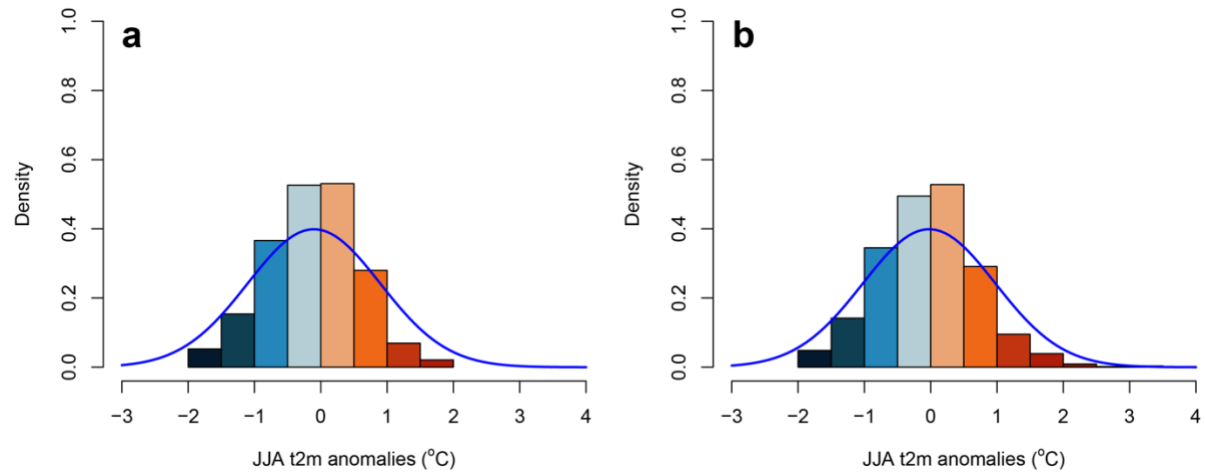


**Supplementary Figure 3. Bias correction of temperature reconstruction.** (a) Quantile-quantile plots of original (red) and bias-corrected (blue) reconstruction values. (b) Time series of ERA-5 JJA t2m (black line) plotted with original JJA t2m reconstruction (red line) and the bias-corrected JJA t2m reconstruction (blue line) over the common period (1950-2018 CE). (c) Full time series of original JJA t2m reconstruction (red) and the bias-corrected JJA t2m reconstruction (blue line) over the period 950-2018 CE.

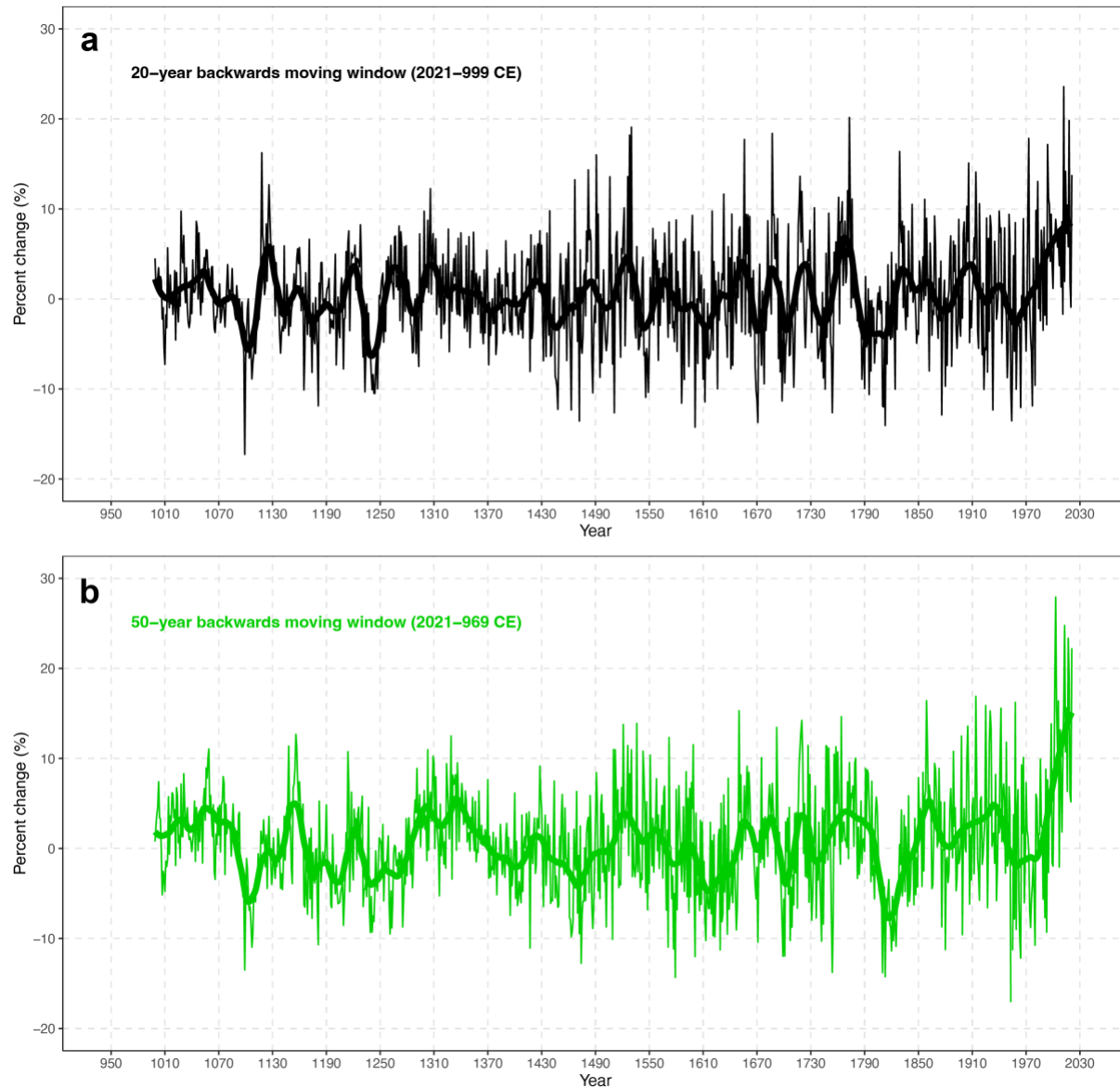


**Supplementary Figure 4. Comparison of the Pacific Northwest and Alberta Icefields temperature reconstructions.** (a) The Pacific Northwest June-August t2m reconstruction from this study and (b) the May-August mean temperature reconstruction for the Alberta Icefields. Reconstructed anomalies are transformed to z-scores, using the mean and standard deviation over the period 1950-1980. Z-scores are smoothed with an 11-year average. Warm anomalies are depicted in red, and cool anomalies are depicted in blue. (c) The relationship between the two

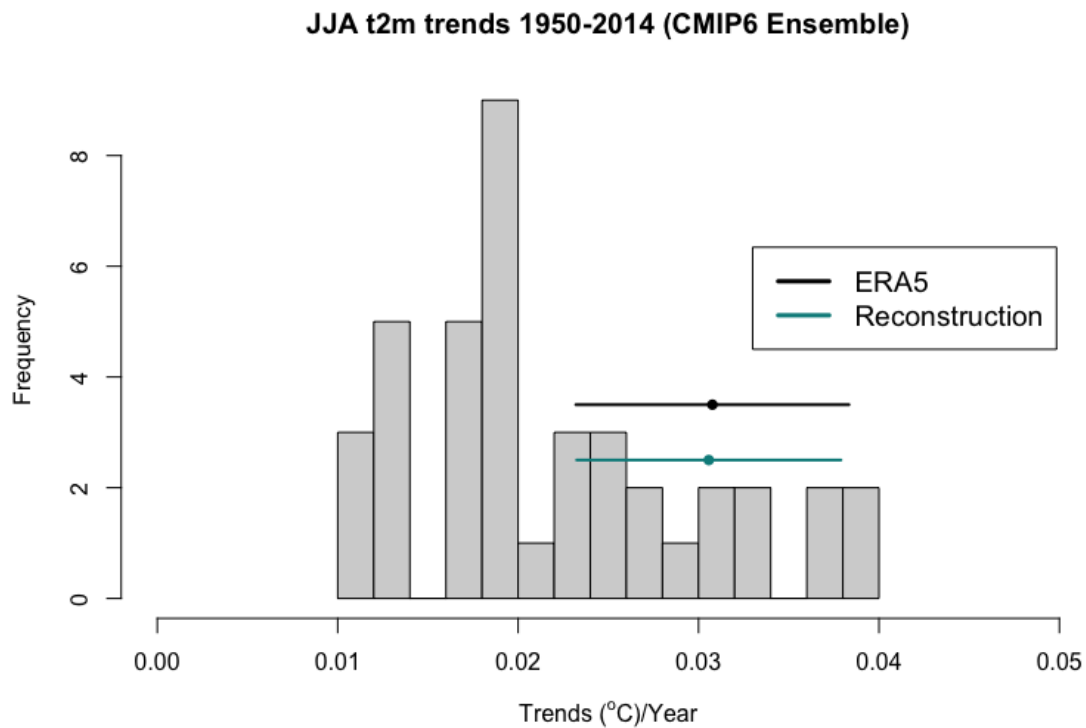
reconstructions is quantified over time using a rolling Pearson's correlation ( $r$ ) over the shared period 950-1994 CE, using a 51-year moving window (panel c), with the associated  $p$ -value (red line). The dashed and dotted red lines signify the  $p < 0.10$  and  $0.05$  levels, respectively.



**Supplementary Figure 5. Distribution of reconstructed mean temperature values over differing periods.** Histograms and probability density distributions (blue lines) of reconstructed summer (June-August) t2m values over the periods **(a)** 950-1899 CE, with a mean of -0.10 and a skew of -0.10, and **(b)** 950-2021 CE, with a mean of -0.02 and a skew of +0.04.



**Supplementary Figure 6. Comparison of percent change in reconstructed JJA t2m values through time. (a)** Percent change using a 20 year (black line) and **(b)** a 50 year (green line) backward-moving windows, each overlaid with a 50-year LOESS smoothed version of the percent change timeseries.



**Supplementary Figure 7. Comparison of summer (JJA) warming trends across the Pacific Northwest.** Trends are calculated as °C warming per year, across the CMIP6 historical runs from all 40 ensemble members, smoothed with a 30-year average (*histogram*), with the warming trend in the ERA5 t2m data, and reconstructed t2m values (black and teal lines, respectively). Trends for ERA5 and reconstructed values are calculated from annual (non-smoothed) values, are plotted with the 95% confidence interval, and are independent from the left side y-axis. Warming trends are calculated for each time series using anomalies relative to the period 1951-1980 CE.

## Supplementary Tables

**Supplementary Table 1.** Tree-ring data used for the PNW JJA temperature reconstruction. We use the following abbreviations for chronology type: latewood blue intensity (LWB), total ring-width (TRW). The species are abbreviated as: *Picea engelmannii* (PIEN), *Tsuga mertensiana* (TSME), *Pseudotsuga menziesii* (PSME), *Abies amabilis* (ABAM), and *Abies magnifica* (ABMA). The **r** column reports the correlations between the ERA5 temperature data and the tree ring predictors used in the reconstruction. The **Beta** column reports the backtransformed regression coefficients (beta weights) for the initial reconstruction model based on all predictors.

| Name               | Type | Species | Span<br>(CE) | Lat<br>°N | Long<br>°E | r    | Beta  |
|--------------------|------|---------|--------------|-----------|------------|------|-------|
| Cultus Creek       | BI   | PIEN    | 1930-2018    | 46.04     | -121.75    | 0.32 | 0.03  |
| Cultus Creek       | TRW  | PIEN    | 1920-2018    | 46.04     | -121.75    | 0.34 | 0.02  |
| Little Cultus Lake | BI   | PIEN    | 1930-2018    | 43.80     | -121.87    | 0.26 | 0.03  |
| Little Cultus Lake | TRW  | PIEN    | 1920-2018    | 43.80     | -121.87    | 0.19 | 0.002 |
| Lightning Springs  | BI   | TSME    | 1740-2018    | 42.93     | -122.16    | 0.44 | 0.13  |
| Lightning Springs  | TRW  | TSME    | 1740-2018    | 42.93     | -122.16    | 0.18 | 0.01  |
| Paradise           | BI   | TSME    | 1700-2018    | 46.79     | -121.75    | 0.79 | 0.24  |
| Paradise           | TRW  | TSME    | 1699-2018    | 46.79     | -121.75    | 0.53 | 0.05  |
| Mount Hood         | BI   | TSME    | 1850-2018    | 45.33     | -121.72    | 0.75 | 0.26  |
| Mount Hood         | TRW  | TSME    | 1788-2018    | 45.33     | -121.72    | 0.41 | 0.03  |
| Tahoma/MacBlo      | BI   | PMSE    | 950-2018     | 46.81     | -121.85    | 0.64 | 0.07  |
| Tahoma             | TRW  | PMSE    | 1400-2018    | 46.81     | -121.85    | 0.54 | 0.01  |
| Mount Baker        | BI   | TSME    | 1796-2018    | 48.76     | -121.89    | 0.75 | 0.15  |
| Joffrey Lake       | BI   | PIEN    | 1818-2017    | 50.35     | -122.48    | 0.70 | 0.11  |
| Joffrey Lake       | TRW  | PIEN    | 1775-2017    | 50.35     | -122.48    | 0.20 | 0.01  |
| Mount Gurr         | BI   | PIEN    | 1830-2017    | 52.28     | -126.89    | 0.54 | 0.02  |
| Peyto Lake         | BI   | PIEN    | 1856-2017    | 51.72     | -116.51    | 0.68 | 0.06  |
| Revelstoke         | BI   | PIEN    | 1785-2017    | 51.04     | -118.13    | 0.73 | 0.03  |
| Revelstoke         | TRW  | PIEN    | 1718-2017    | 51.04     | -118.13    | 0.31 | 0.01  |
| Sicamous           | BI   | PIEN    | 1769-2017    | 50.86     | -118.99    | 0.75 | 0.06  |
| Sicamous           | TRW  | PIEN    | 1760-2017    | 50.86     | -118.99    | 0.17 | 0.004 |
| Train Trailhead    | BI   | ABAM    | 1776-2017    | 50.13     | -123.10    | 0.73 | 0.11  |
| Train Trailhead    | BI   | TSME    | 1780-2017    | 50.13     | -123.10    | 0.76 | 0.16  |
| Train Trailhead    | TRW  | TSME    | 1728-2017    | 50.13     | -123.10    | 0.27 | 0.004 |
| Wilson             | BI   | PIEN    | 1795-2017    | 49.75     | -124.17    | 0.70 | 0.07  |
| Wilson             | TRW  | PIEN    | 1754-2017    | 49.75     | -124.17    | 0.25 | 0.01  |
| Big Fisher Lake    | BI   | PIEN    | 1721-2018    | 48.84     | -116.56    | 0.43 | 0.03  |
| Big Fisher Lake    | TRW  | PIEN    | 1710-2018    | 48.84     | -116.56    | 0.36 | 0.03  |
| Lady of the Woods  | TRW  | ABMA    | 1740-2018    | 42.90     | -122.14    | 0.29 | 0.001 |

**Supplementary Table 2.** Calibration/verification statistics for JJA t2m reconstruction, including all forward and backward nests. **CP** indicates common period. **EV>1** indicates eigenvalues greater than 1.0 for each model nest.

| <b>Nest</b> | <b>Years</b> | <b># predictors</b> | <b># EV&gt;1</b> | <b>CRSQ</b> | <b>VRE</b> | <b>VCE</b> | <b>RMSE</b> |
|-------------|--------------|---------------------|------------------|-------------|------------|------------|-------------|
| -18         | 950-1399     | 1                   | 1                | 0.45        | 0.29       | 0.11       | 0.81        |
| -17         | 1400-1679    | 2                   | 1                | 0.46        | 0.33       | 0.16       | 0.80        |
| -16         | 1680-1699    | 3                   | 1                | 0.46        | 0.33       | 0.16       | 0.80        |
| -15         | 1700-1709    | 5                   | 1                | 0.66        | 0.56       | 0.44       | 0.64        |
| -14         | 1710-1719    | 6                   | 1                | 0.67        | 0.56       | 0.45       | 0.63        |
| -13         | 1720-1729    | 7                   | 1                | 0.66        | 0.56       | 0.44       | 0.63        |
| -12         | 1730-1739    | 9                   | 2                | 0.67        | 0.57       | 0.46       | 0.63        |
| -11         | 1740-1759    | 11                  | 2                | 0.67        | 0.57       | 0.45       | 0.63        |
| -10         | 1760-1769    | 13                  | 3                | 0.69        | 0.57       | 0.46       | 0.62        |
| -9          | 1770-1779    | 14                  | 3                | 0.72        | 0.62       | 0.52       | 0.58        |
| -8          | 1780-1789    | 17                  | 3                | 0.74        | 0.67       | 0.59       | 0.57        |
| -7          | 1790-1799    | 19                  | 3                | 0.72        | 0.66       | 0.57       | 0.58        |
| -6          | 1800-1819    | 21                  | 3                | 0.73        | 0.67       | 0.59       | 0.56        |
| -5          | 1820-1829    | 22                  | 3                | 0.74        | 0.66       | 0.57       | 0.57        |
| -4          | 1830-1849    | 23                  | 4                | 0.74        | 0.66       | 0.57       | 0.56        |
| -3          | 1850-1859    | 24                  | 4                | 0.77        | 0.69       | 0.61       | 0.53        |
| -2          | 1860-1919    | 25                  | 3                | 0.77        | 0.69       | 0.61       | 0.53        |
| -1          | 1920-1929    | 27                  | 4                | 0.76        | 0.69       | 0.60       | 0.54        |
| <b>CP</b>   | 1930-2017    | 29                  | 5                | 0.78        | 0.71       | 0.63       | 0.56        |
| +1          | 2017-2018    | 15                  | 3                | 0.74        | 0.68       | 0.59       | 0.56        |

**Supplementary Table 3.** Changes to mean and variance in differing time series of temperature estimates through time.

| <b>Period (CE)</b> | <b>Data source</b>                                                | <b>Mean</b> | <b>Variance</b> |
|--------------------|-------------------------------------------------------------------|-------------|-----------------|
| 950-1850           | Reconstruction                                                    | -0.35       | 0.35            |
| 1851-1949          | Reconstruction                                                    | 0.01        | 0.45            |
| 1950-2021          | ERA5-t2m Reanalysis                                               | 0.46        | 1.34            |
| 2022-2100          | CMIP6 SSP-2.45 multi-model ensemble (median)                      | 3.37        | 0.58            |
| 2022-2100          | CMIP6 SSP-2.45 multi-model ensemble (5 <sup>th</sup> percentile)  | 1.84        | 0.39            |
| 2022-2100          | CMIP6 SSP-2.45 multi-model ensemble (95 <sup>th</sup> percentile) | 5.71        | 1.20            |

**Supplementary Table 4.** Modeled annual risk (% likelihood of occurrence) of 3.6 °C summer (June- August) average temperatures with associated error ( $p<0.05$ ). Risk estimates are based on CMIP6 SSP2-4.5 and SSP3-7.0 multi-model ensemble estimates for the Pacific Northwest.

| <b>Year</b> | <b>SSP 245 (%)</b> | <b>SSP 370 (%)</b> |
|-------------|--------------------|--------------------|
| 1950        | 0 (0-0)            | 0 (0-0)            |
| 1960        | 0 (0-0)            | 0 (0-0)            |
| 1970        | 0 (0-0)            | 0 (0-0.)           |
| 1980        | 0 (0-0)            | 0 (0-0)            |
| 1990        | 0 (0-0)            | 0 (0-0)            |
| 2000        | 0 (0-0)            | 0 (0-0)            |
| 2010        | 0 (0-1)            | 1 (0-1)            |
| 2020        | 5 (3-8)            | 5 (3-9)            |
| 2030        | 15 (9-23)          | 15 (9-25)          |
| 2040        | 29 (20-39)         | 35 (23-47)         |
| 2050        | 42 (32-54)         | 51 (38-64)         |
| 2060        | 53 (41-65)         | 67 (54-78)         |
| 2070        | 61 (49-72)         | 79 (68-88)         |
| 2080        | 68 (58-78)         | 88 (79-93)         |
| 2090        | 74 (64-83)         | 92 (86-96)         |
| 2100        | 77 (67-86)         | 94 (90-97)         |