nature climate change

SUPPLEMENTARY INFORMATION

https://doi.org/10.1038/s41558-020-0863-4

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Identification of local water resource vulnerability to rapid deglaciation in Alberta

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Supplementary Information for:

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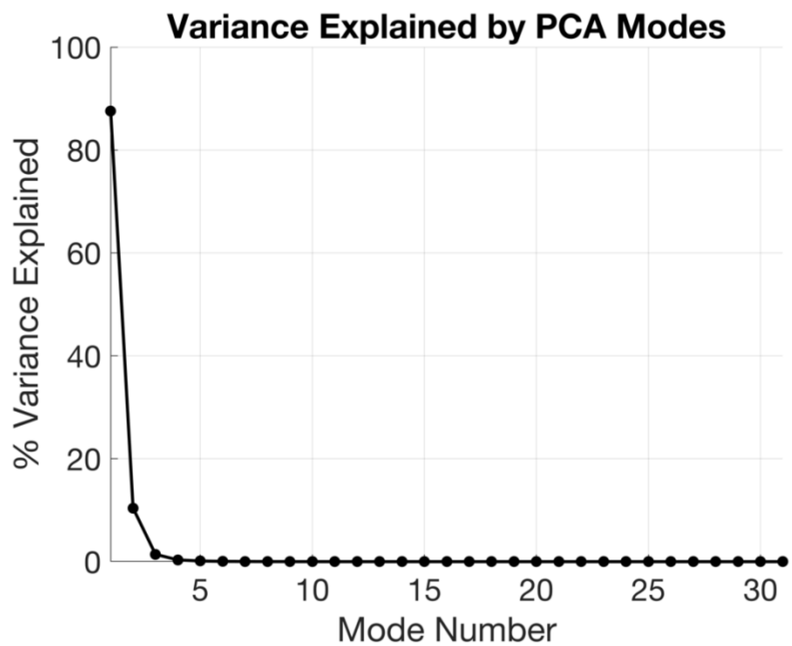
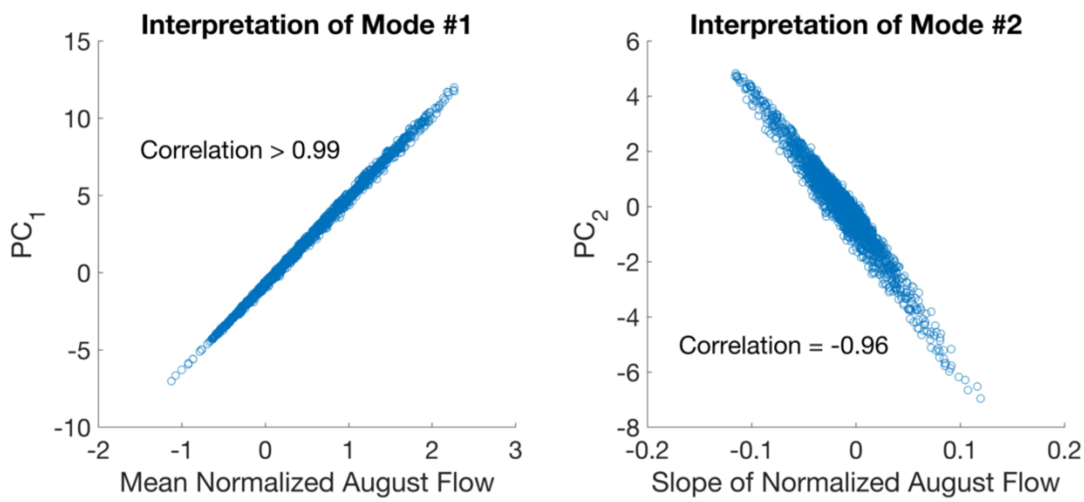
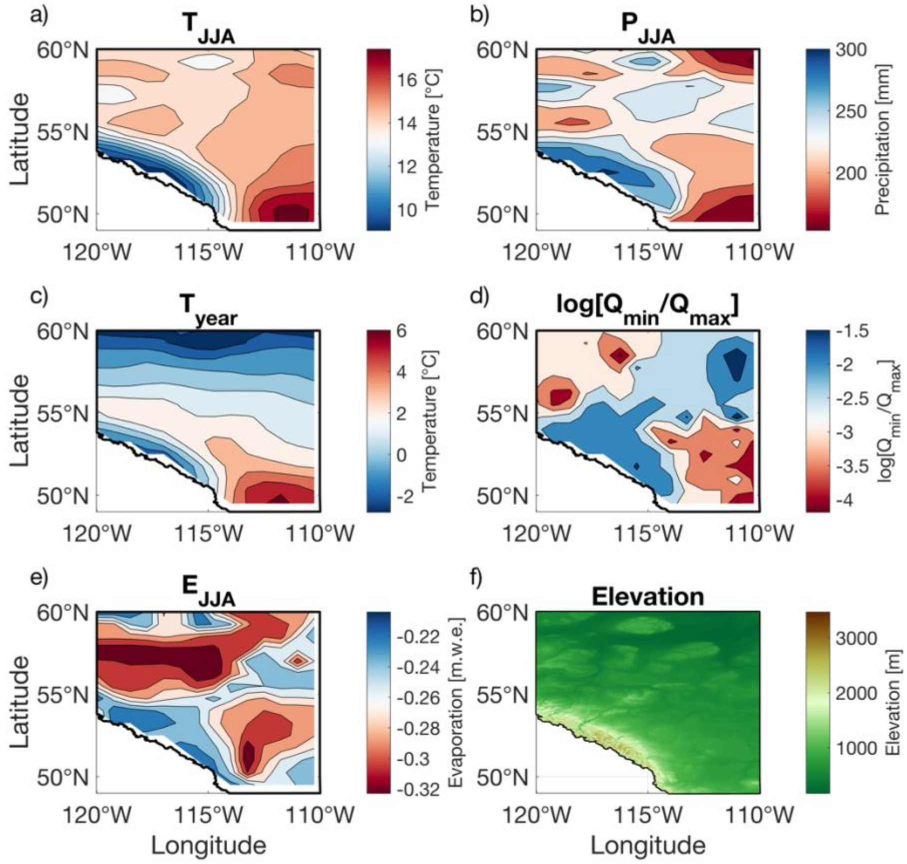


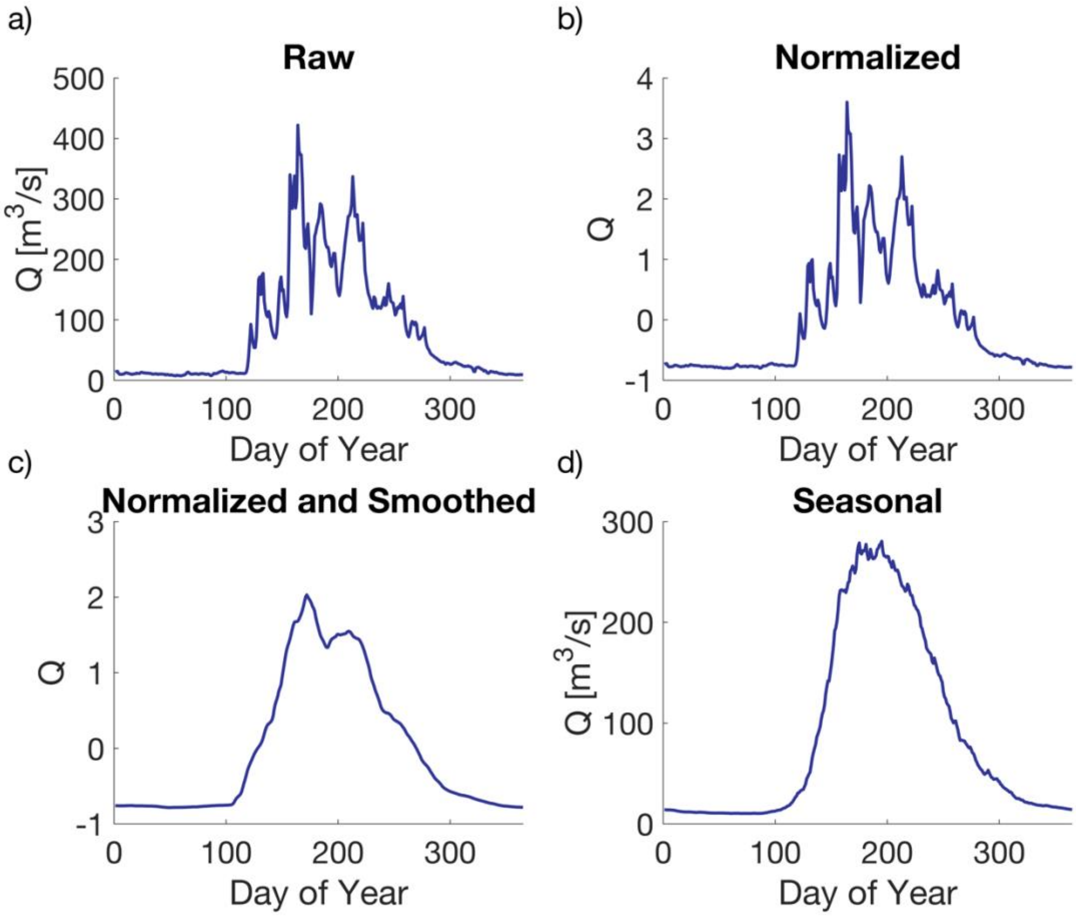
Supplementary Figure 1| The percentage variance explained in the August streamflow data by each PCA mode. The first mode explains 88% of the total variance, while the second mode explains 10% of the total variance.



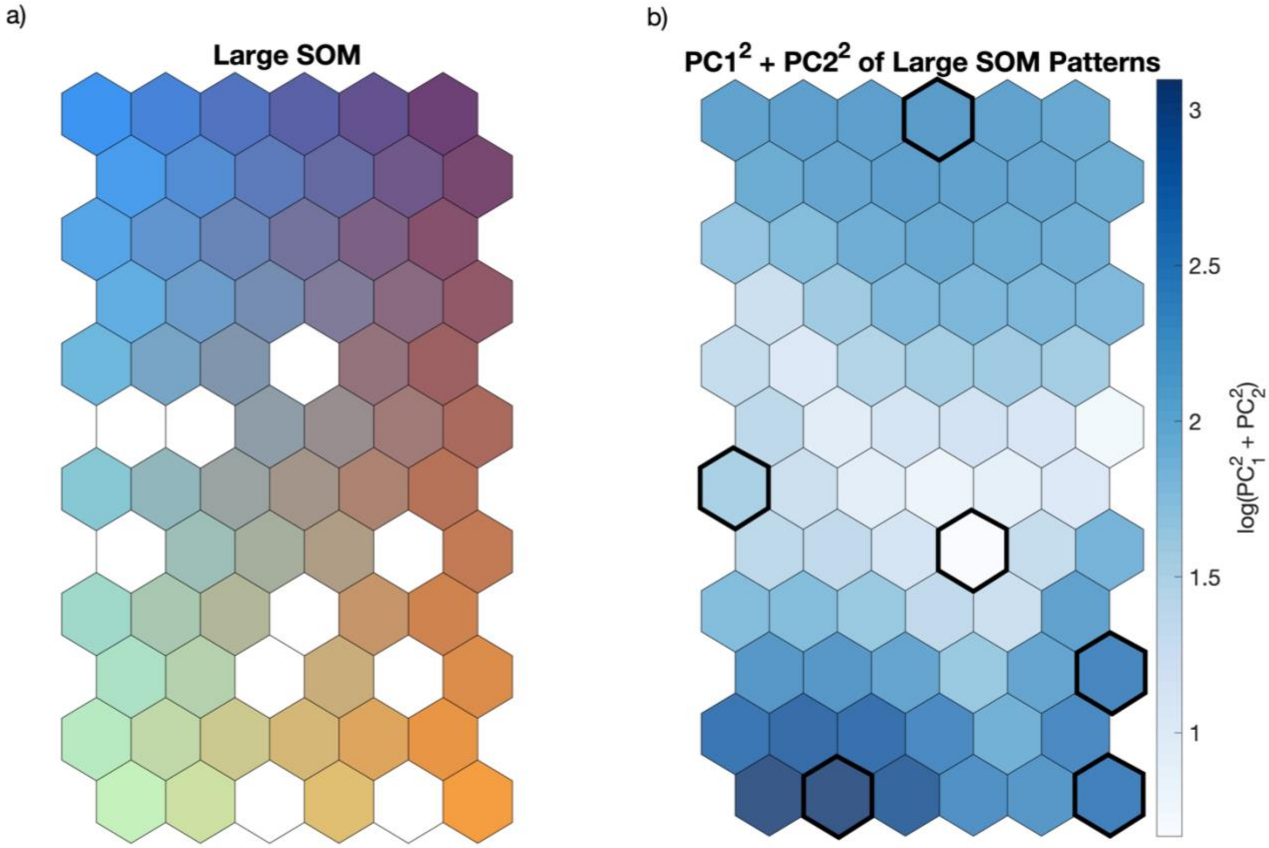
Supplementary Figure 2 | Physical interpretation of the first two modes. a) PC_1 is highly positively correlated with the mean normalized August flow for all stations and years, meaning that higher values of PC_1 indicate higher values of mean normalized August flow. In other words, higher values of PC_1 indicate that August streamflow is substantial relative to the year's mean at that station. b) The slope of the trendline of August streamflow is calculated for each year at each station. PC_2 is highly negatively correlated with the slope of the trendline of August streamflow, meaning that higher values of PC_2 indicate that normalized August streamflow is more rapidly decreasing over the month.



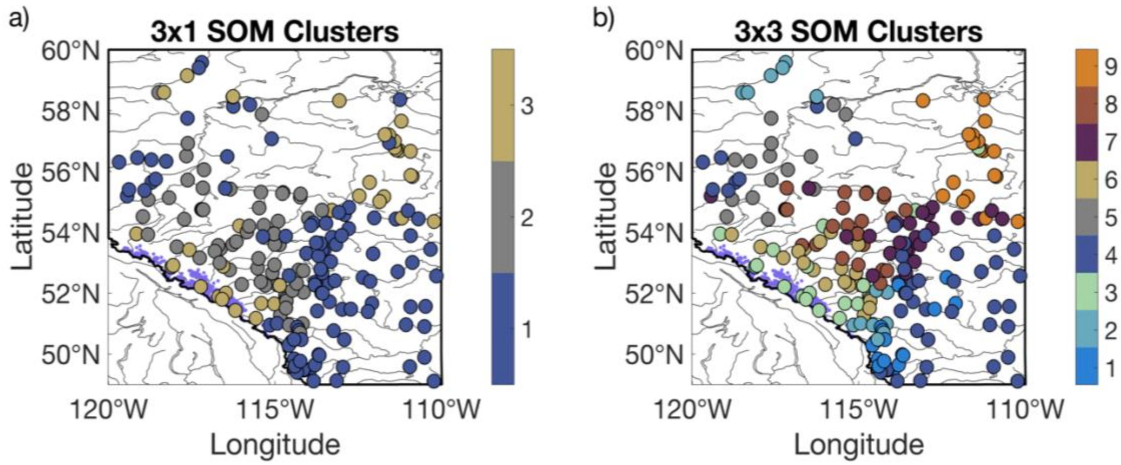
Supplementary Figure 3| Spatial distribution of predictors used in the MLR models. a) Mean June, July, and August (JJA) temperature (T_{JJA}) in Alberta from ERA-Interim Reanalysis. b) Mean JJA total precipitation (P_{JJA}) in Alberta from ERA-Interim Reanalysis. c) Mean yearly temperature (T_{year}) in Alberta, from ERA-Interim Reanalysis. d) The logarithm of the ratio of minimum seasonal flow (Q_{min} [m^3/s]) to maximum seasonal flow (Q_{max} [m^3/s]), interpolated from stream gauges using inverse distance weighting with a power of two. Q_{min} and Q_{max} are calculated for each stream gauge as the minimum and maximum discharge values on the seasonal hydrograph (further shown in Supplementary Figure 7). For stations with a baseflow of zero (i.e. the stream is consistently dry for at least one day of the year), log(Q_{min}/Q_{max}) approaches negative infinity. In these cases, Q_{min}/Q_{max} is set to be the minimum non-zero ratio of all other stream gauges. c) Mean JJA total evaporation (E_{JJA}) in Alberta, from ERA-Interim Reanalysis. This value includes a simplified representation of transpiration. Negative evaporation indicates a flux of water into the atmosphere. Note that all ERA-Interim data has approximately 80 x 80 km spatial resolution and is interpolated here for the contour plots. f) Elevation (h) in Alberta, from the Shuttle Radar Topography Mission (SRTM) at 90 m resolution.



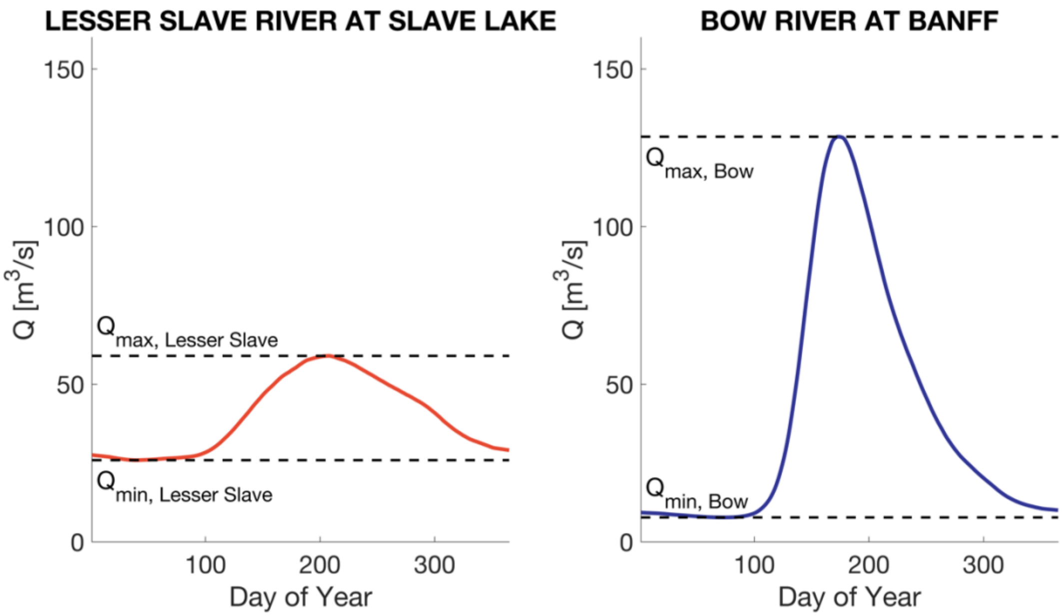
Supplementary Figure 4 | The streamflow data at various stages of processing, shown for the Athabasca River near Jasper. a) Raw daily streamflow in 1987 (in m^3/s). b) Normalized timeseries of 1987 streamflow (unitless). This data has zero mean and unity variance. Positive (negative) values indicate streamflow which is above (below) 1987's mean flow. Normalized streamflow values indicate how many standard deviations that day of streamflow is from the annual (1987) mean flow; in other words, values of normalized streamflow indicate how substantially different each day of streamflow is from the year's average. c) Normalized 1987 streamflow that has been smoothed using a 30-day running mean (unitless). Note that the high-frequency fluctuations from a) and b) are no longer present. Values of smoothed normalized streamflow indicate how substantially different each 30-day window of streamflow is from the year's average. "Day of year" here refers to the 16th day of the moving window (e.g. August 1 in the smoothed dataset is the average over July 17 through August 15). In cases without enough elements to fill the window (i.e. in the first and last 15 days of the year), the average is computed with the number of elements that are inside of the window. This choice does not impact our results since our analysis is focused on August. d) The seasonal hydrograph for 1987 - 2010, where the streamflow for each day of the year is averaged across the 24 years of available data. Seasonal hydrographs are used to calculate the minimum seasonal streamflow and maximum seasonal streamflow.



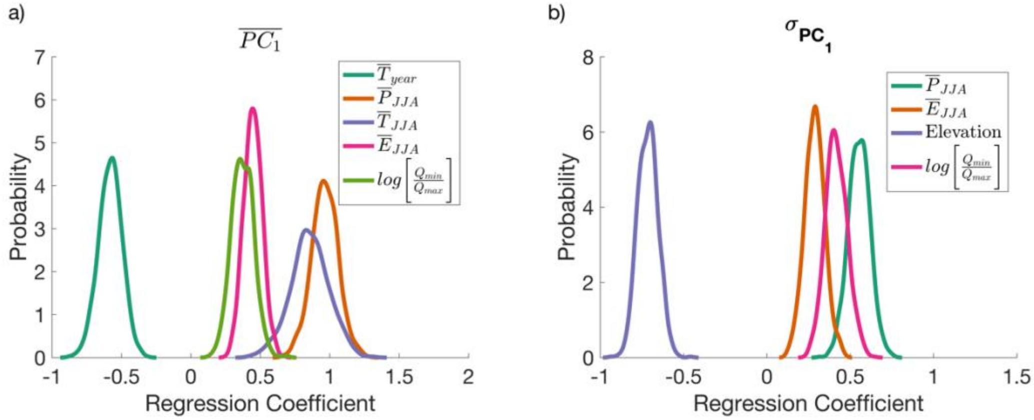
Supplementary Figure 5 | Using a large SOM to determine the optimal number of clusters. a) The large 12 x 6 SOM generated from the 194 $\overline{v_k}$ vectors. The hexagons are clusters on the SOM. White hexagons are clusters which have no members in the dataset. The color coding is for visual reference only. b) We perform PCA on patterns of the large SOM clusters, i.e. on the 72 vectors, and create a topology defined as the sum of the squares of the first two PCs. The color of a hexagon corresponds to the value of $PC_1^2 + PC_2^2$ of that cluster. The local maxima and global minima on this topology are outlined by a thick black border. The analysis reveals 6 optimal clusters, i.e. 3x2 SOM as the optimal sized SOM (Figure 2c).



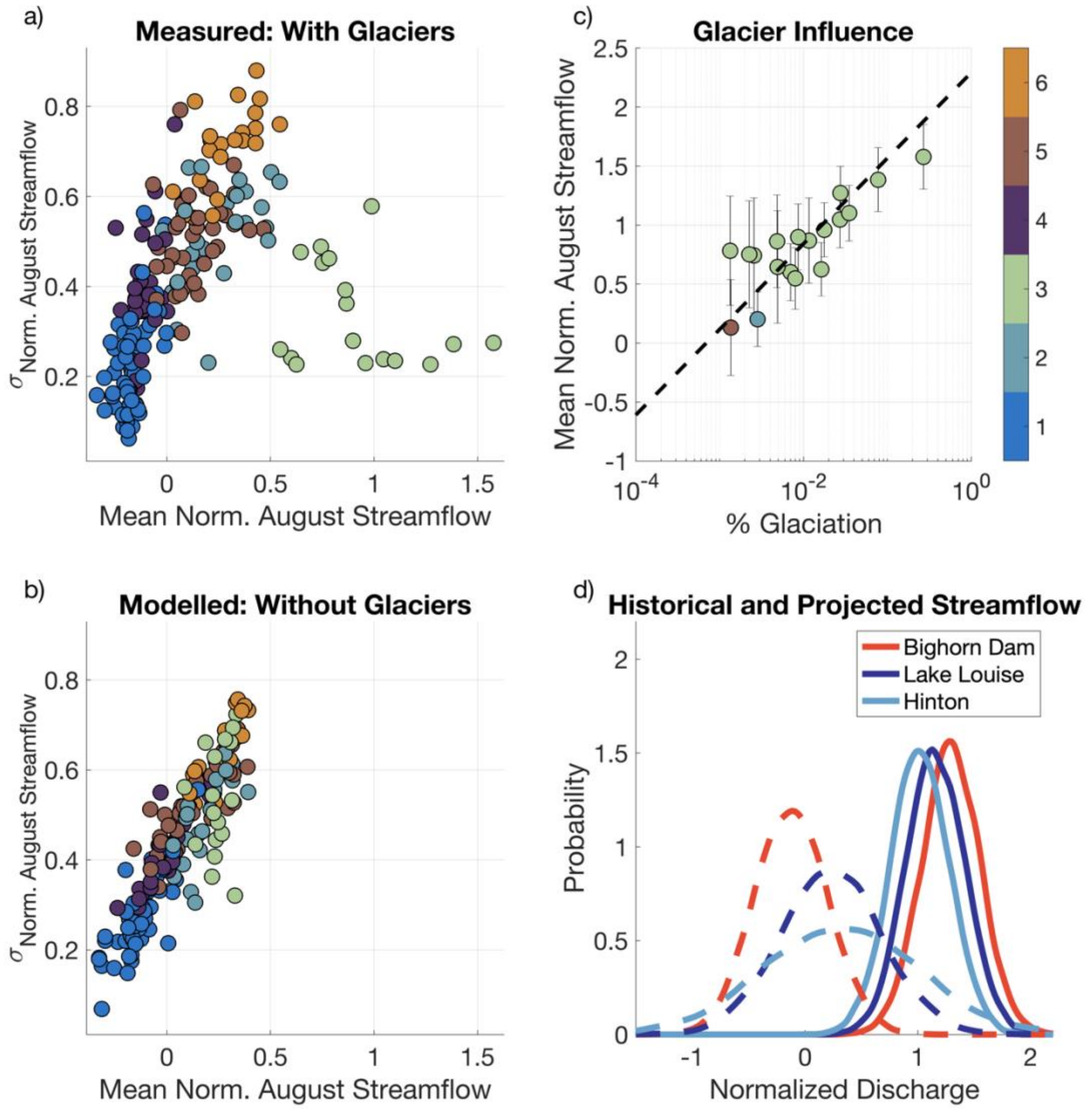
Supplementary Figure 6| The spatial patterns revealed by clustering on a) a 3x1 SOM (3 clusters) and b) a 3x3 SOM (9 clusters). Both a) and b) demonstrate what we also learned from using a 3x2 SOM (6 clusters) in Figure 2: non-glacier-fed stream gauges cluster spatially, with stream gauges that are nearby having similar August streamflow patterns, while glacier-fed stream gauges behave similarly to other glacier-fed stream gauges. For example, in the 3x1 SOM, cluster #1 exists in the grassland and parkland natural regions in the southeast and northwest, while in the 3x3 SOM, clusters #4 and #7 exist in this region. Additionally, glacier-fed rivers are clustered together in cluster #3 in both SOMs. Note, however, that the two cases of clustering do not need to share the cluster index in order to reveal the same patterns. It is a coincidence that glacier-fed rivers share the same cluster index (#3).



Supplementary Figure 7 | Two different seasonal hydrographs smoothed with a 30-day running mean. The minimum seasonal streamflow and maximum seasonal streamflow is identified on each. The river in a) has a greater minimum seasonal flow and a lesser maximum seasonal flow as compared to the river in b). Therefore, the logarithm of the ratio of minimum seasonal flow to maximum seasonal flow is larger for the river in a) than the river in b). This measure is a proxy for how important the processes are which dominate in the low-flow season (such as groundwater or lake contributions, which may also contribute during the summer) as compared to the processes which dominate the high-flow season (such as snowmelt).



Supplementary Figure 8| The distributions of regression coefficients in the MLR models (Equations 2 and 3 from the main text) calculated via bootstrapping for both a) $\overline{PC_1}$, and b) σ_{PC1}. All predictors have mean regression coefficients that are of similar magnitude, indicating that no individual predictor dominates the observed August streamflow behaviour. All curves are normalized to have unity area.



Supplementary Figure 9| Key results when regressing onto mean normalized August discharge instead of $\overline{PC_1}$. a) Increasing mean normalized August streamflow is accompanied by an increase in variability, except in cluster #3. b) The modelled mean and standard deviation of normalized August streamflow if glacier runoff was negligible. c) Mean normalized August streamflow increases nonlinearly with percentage glaciation for glacier-fed rivers. Error bars are one standard deviation (n = 24). d) Normalized discharge for the Bighorn Dam, Lake Louise, and Hinton. Curves are normalized to have unity area. Solid curves are modelled historical probability densities, and dashed curves are modelled estimates of probability densities if glacier runoff was negligible and other factors remain constant.