

S1. Validation of the FA implementation

To benchmark our FA implementation, we applied it to the same 33 temperature time series from Greenland and the eastern Canadian Arctic compiled by Sundqvist et al. (2014) that Briner et al. (2016) analyzed using pPCA. Following Briner et al. (2016), the time series were averaged into 200 year bins, standardized over their common interval of overlap, and analyzed from 8 to 0 ka. The main methodological difference is the treatment of residual variance. Where pPCA assumes a single residual variance shared by all time series, our FA implementation allows residual variance to vary among time series. For this benchmark, residual variances were assigned using the time-series-specific uncertainty estimates reported by Sundqvist et al. (2014) because consistent proxy-type transfer-function errors were unavailable across all 33 time series.

Model-order selection using BIC favors a five-factor solution ($q=5$); however, the two leading factors account for the majority of shared explained variance, 59.6 and 28.1%, respectively (Fig. S1A, S1B). The leading temporal factor score (Z_1) is characterized by high values during the early to mid-Holocene followed by decreasing values toward the late Holocene. The corresponding spatial loadings (W_1) are strongest at sites north of $\sim 66^\circ\text{N}$. The second factor score (Z_2) begins increasing at 8 ka, reaches maximum values between ~ 4 and 3 ka, and decreases toward modern. This mode is most strongly expressed at sites south of $\sim 70^\circ\text{N}$.

The remaining factor solutions explain substantially less shared variance, with $Z_{3,5}$ accounting for 6.9, 5.2, and 0.2%, respectively. These higher-order factors scores display high temporal variability without clear multimillennial structure. The associated spatial loadings are also concentrated on a limited number of time series (Fig. 2). In particular, W_4 is strongly influenced by the Jake Lake pollen record from southern Baffin Island, whereas W_5 is dominated by HU84-030-021PC dinocysts time series from the Davis Strait.

The leading FA factors reproduce the first-order temporal and spatial structure identified by Briner et al. (2016). Briner et al.'s (2016) PC1, which explained 34% of variance, represented early- to middle-Holocene warmth followed by cooling and was most strongly expressed at northern sites. Their PC2 explained 16% of total variance and represented a later temperature maximum expressed more strongly at southern sites. Our Z_1 and Z_2 recover these same broad

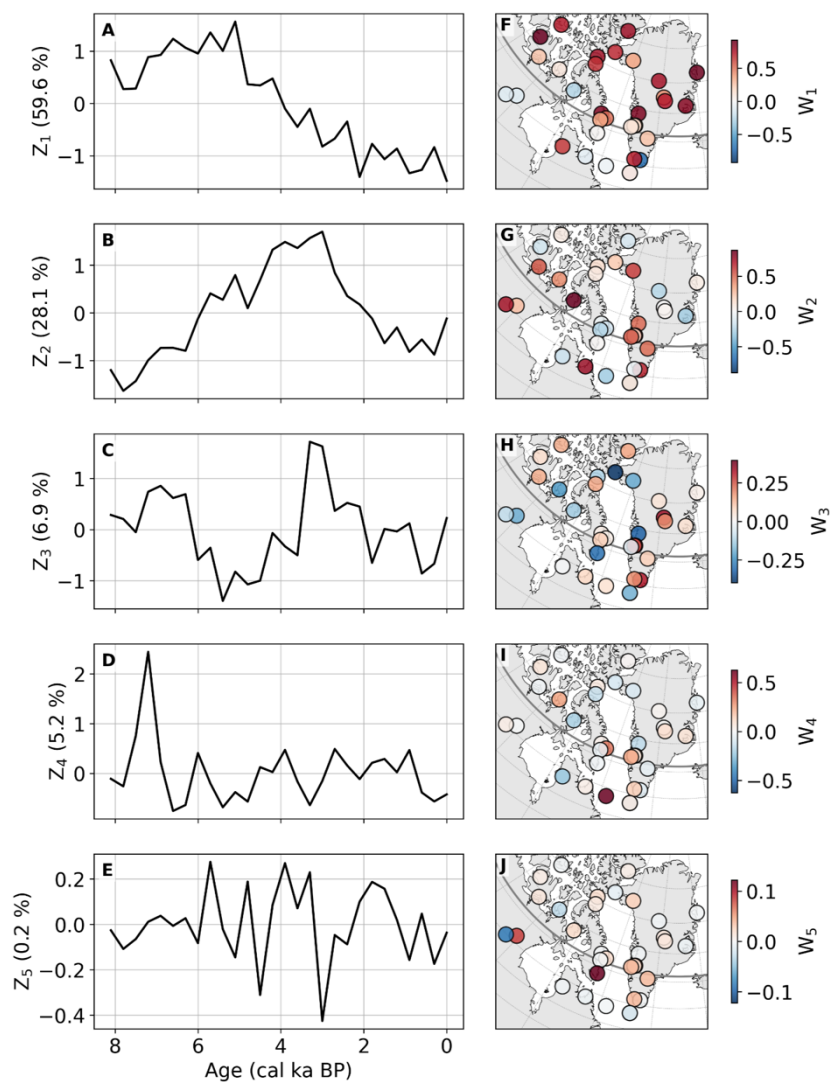
patterns, although Z_1 shows more pronounced warming between ~ 8 and 5 ka and the Z_2 maximum occurs approximately 0.7 kyr later than the corresponding pPCA maximum. These differences may reflect the different residual error and uncertainty treatments of FA and pPCA. Overall, the recovery of the two dominant spatiotemporal patterns provides a consistency check on our FA implementation prior to its application to the Greenland proxy network and climate reconstruction products.

Tables

Table S1. Procrustes distances between proxy network and climate reconstructions factor solutions. Distances are reported for the temporal factor scores (dZ_1 and dZ_2), mean temporal distance (dZ_{mean}), spatial loading patterns (dW_1 and dW_2), mean spatial distance (dW_{mean}), and the overall mean distance across temporal and spatial solutions (Overall d_{mean}). Bolded distances indicate that the component reached the imposed lower bound during Procrustes fitting.

Climate Reconstruction	dZ_1	dZ_2	dZ_{mean}	dW_1	dW_2	dW_{mean}	Overall mean
Truax (This Study)	0.45	0.55	0.64	0.83	1.06	0.81	0.72
Badgeley et al. (2020) Preferred	0.50	0.53	0.66	0.83	1.06	0.80	0.73
Badgeley et al. (2020) Low	0.59	0.61	0.71	0.84	1.04	0.83	0.77
Buizert et al. (2018)	0.59	0.97	0.71	0.84	1.07	1.02	0.87
TraCE21k, Liu et al. (2009)	0.72	0.97	0.78	0.84	1.05	1.01	0.89
Osman et al. (2021)	0.75	1.01	0.93	1.11	0.93	0.97	0.95

44 **Figures**



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46 **Fig. S1.** Factor Analysis solutions (rows) displaying temporal factor scores (Z; A-E) and spatial
47 loadings (W; F-J) using the Sundqvist et al. proxy network of northern Canada and Greenland.

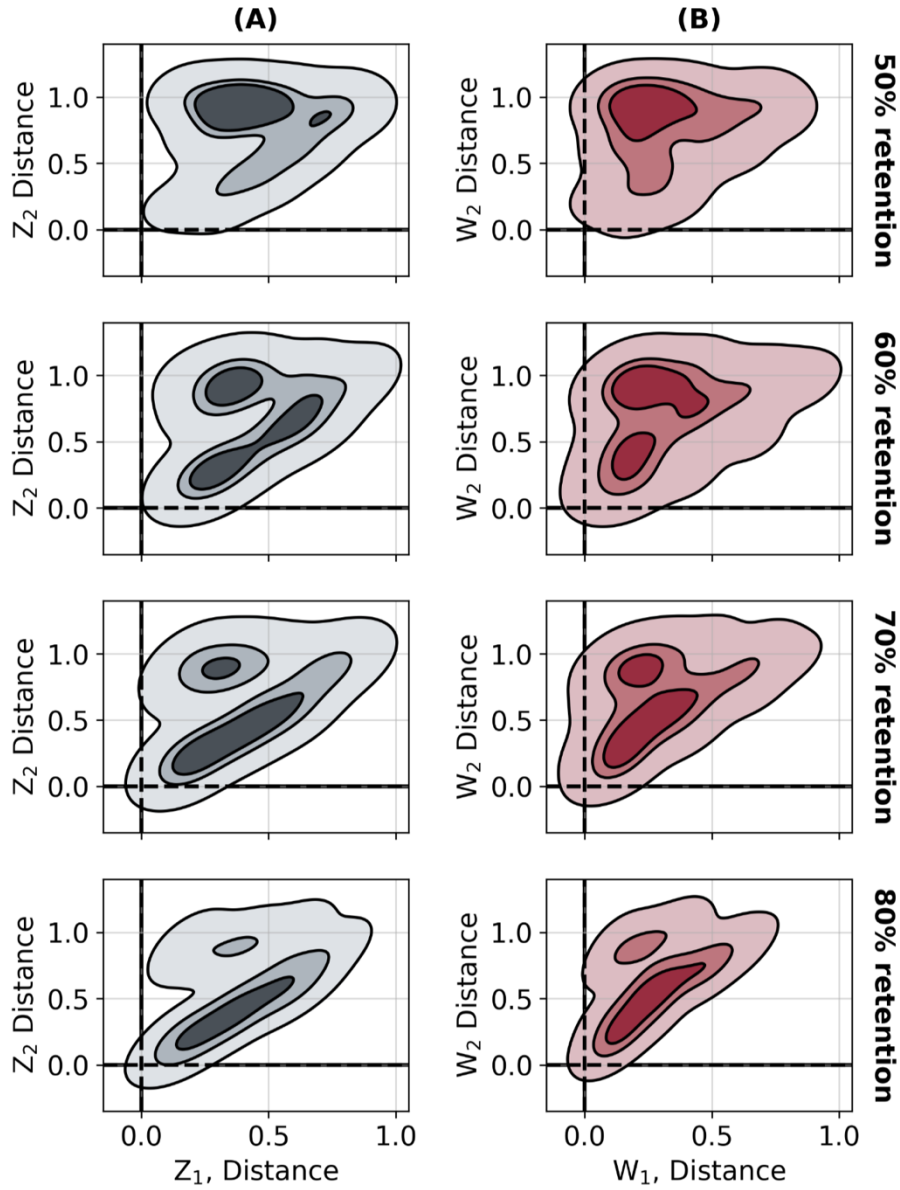


Fig. S2. Monte Carlo resampling reveals stability in FA solutions. Empirical variance distributions of proxy Procrustes distances for temporal factor scores (column A) and loading patterns (column B) via Monte Carlo resampling of the full proxy network using variable resampling proportions (rows). Variance distributions of the 100 randomly drawn proxy sites without replacement are illustrated by shaded regions with light, mid, and dark regions indicating the 95th, 68th, and 34th percentiles, respectively.

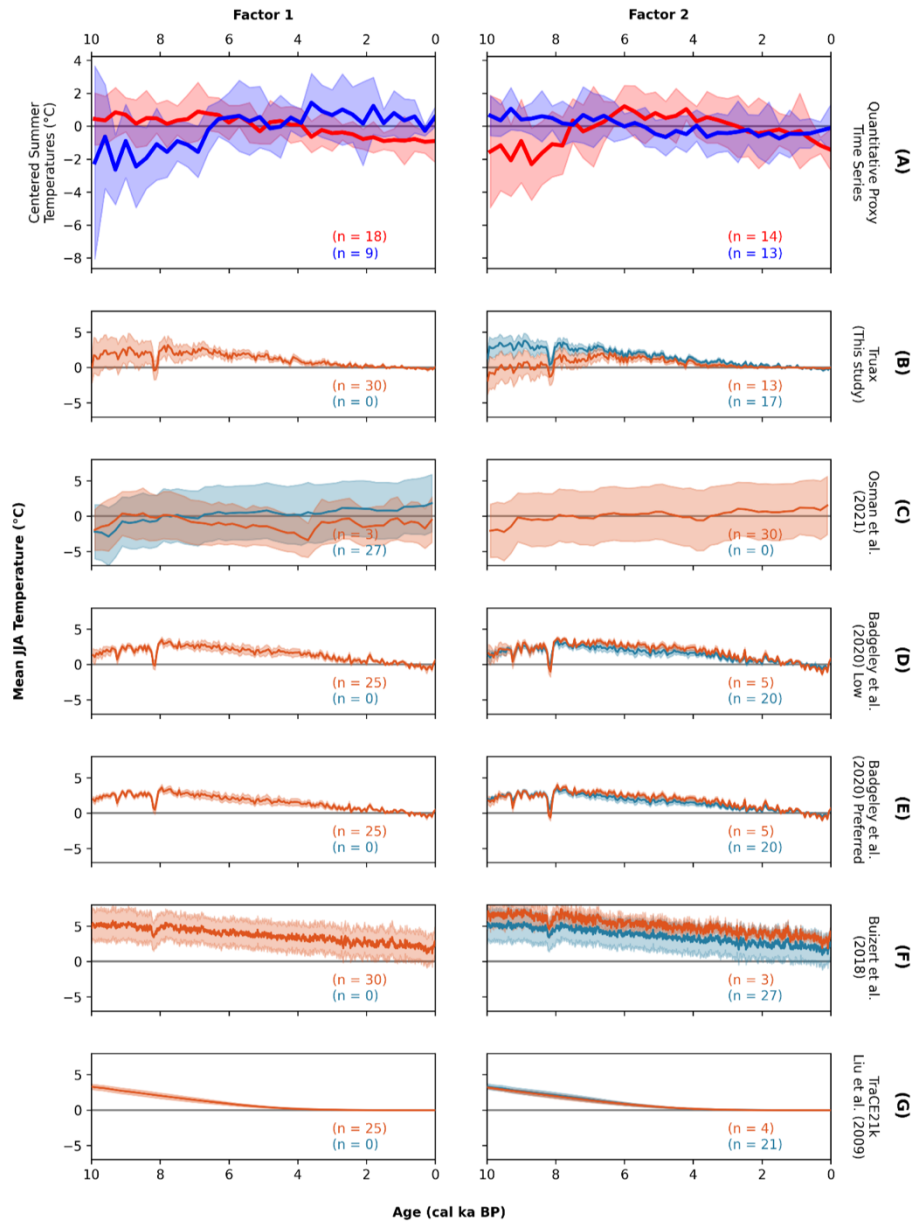
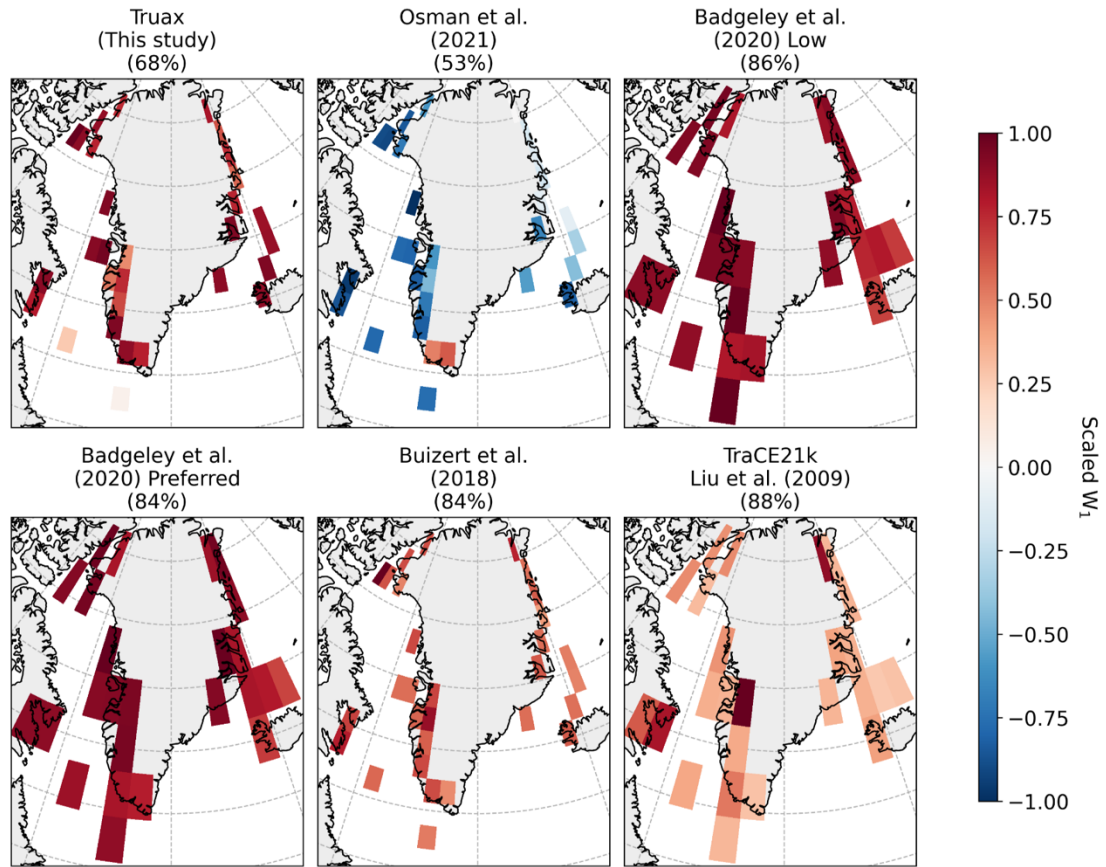


Fig. S3. Ensemble summer-temperature time series of quantitative proxies (top row) and grid cells in the climate reconstruction products, differentiated by grid cells that load positively (red/orange) or negatively (blue) on Factor 1 (left column) or Factor 2 (right column). Solid lines indicate median temperatures, and shaded regions indicate 1 σ . Climate reconstruction ensembles include only the grid cells that overlap with the proxy sites.



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64 **Fig. S4.** Leading spatial loading solutions (W_1) of each climate reconstruction product. Loading
 65 values are all scaled using the maximum absolute value to aid visual comparison.

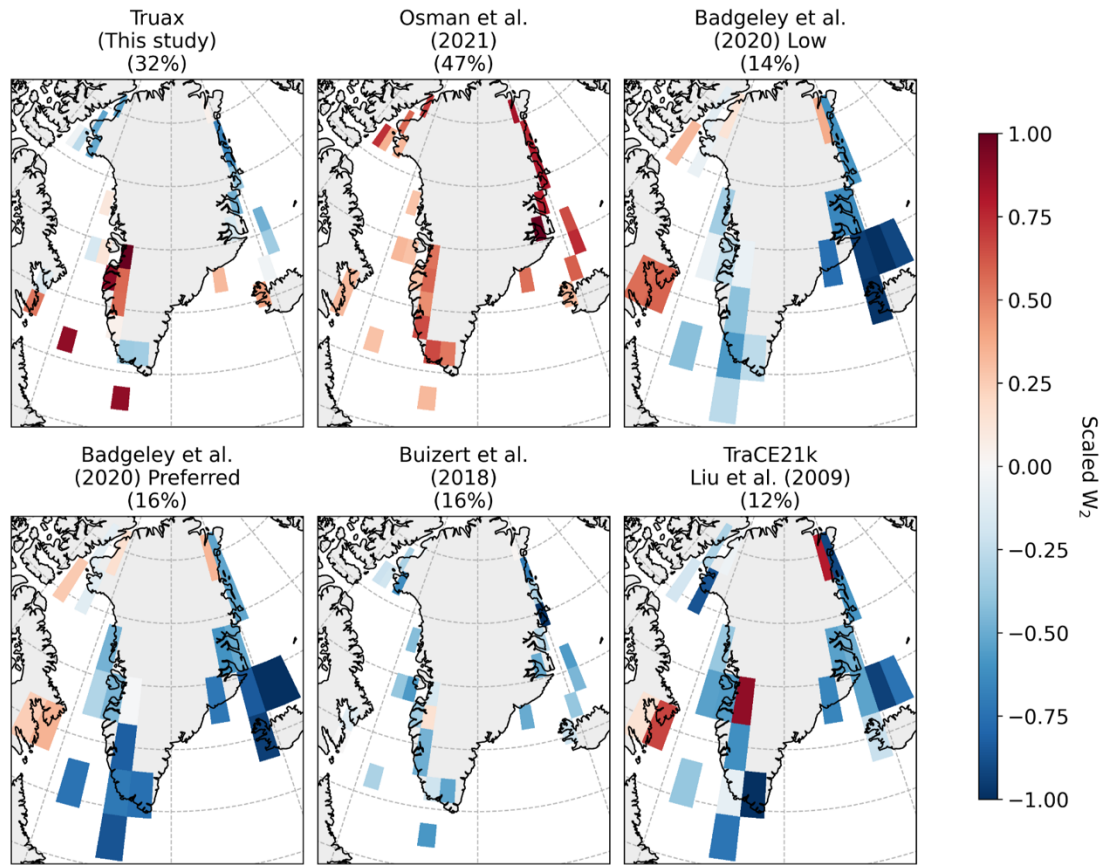


Fig. S5. Second spatial loading solutions (W_2) of each climate reconstruction product. Loading values are all scaled using the maximum absolute value to aid visual comparison.