

Supplementary Materials for

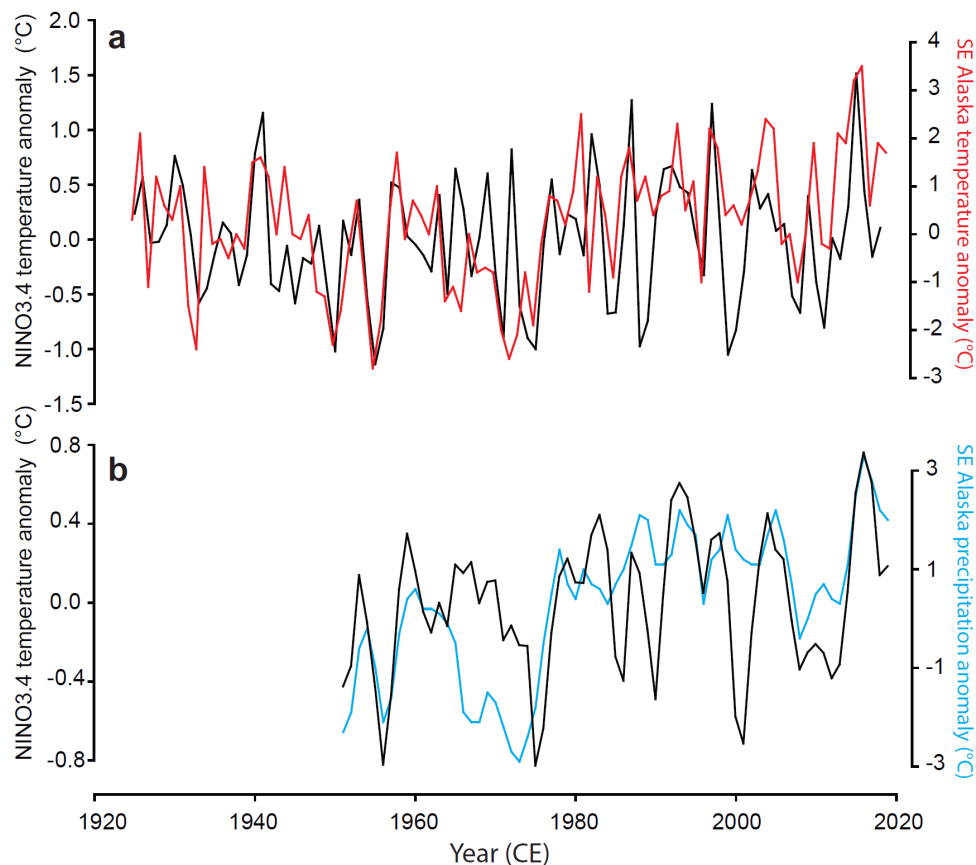
Anthropogenically forced shift in ENSO mean state after 1970 CE

Paul S. Wilcox, Manfred Mudelsee, Christoph Spötl, R. Lawrence Edwards

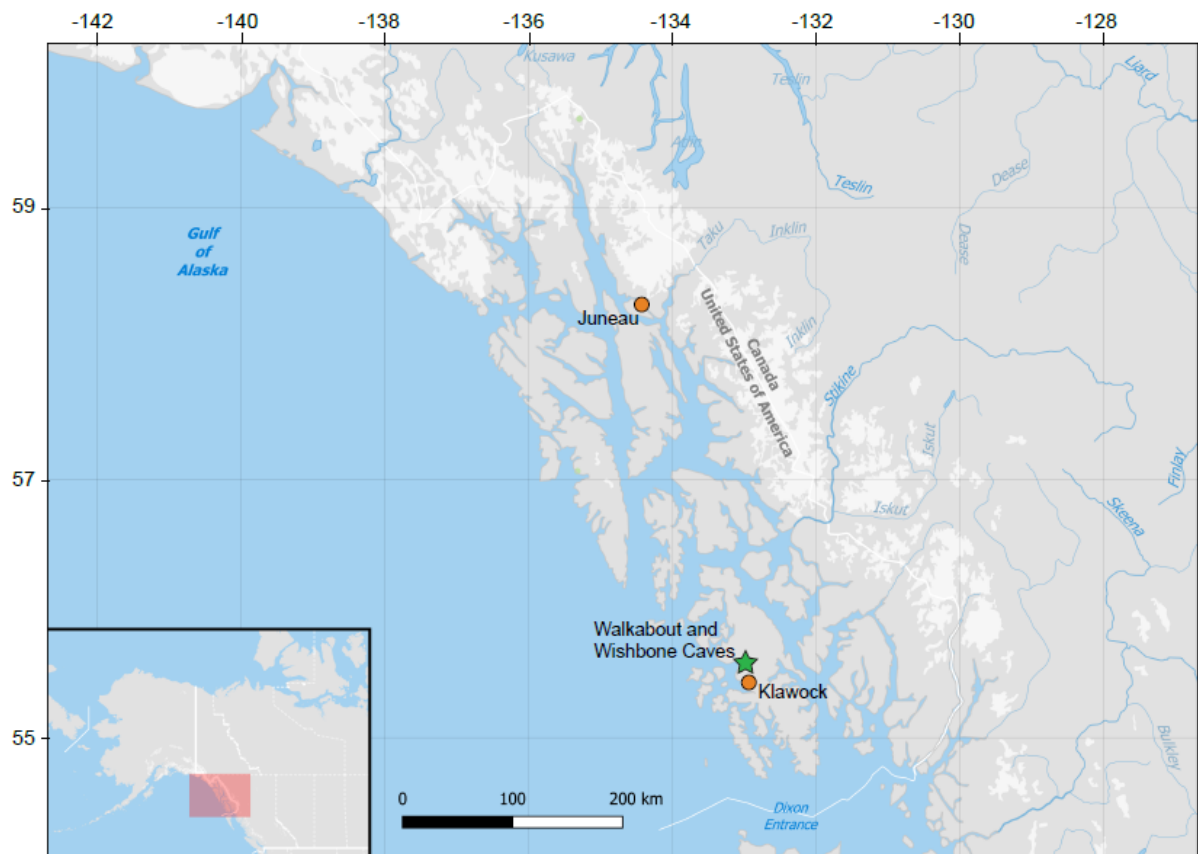
Correspondence to: paul.wilcox@uibk.ac.at

This PDF file includes:

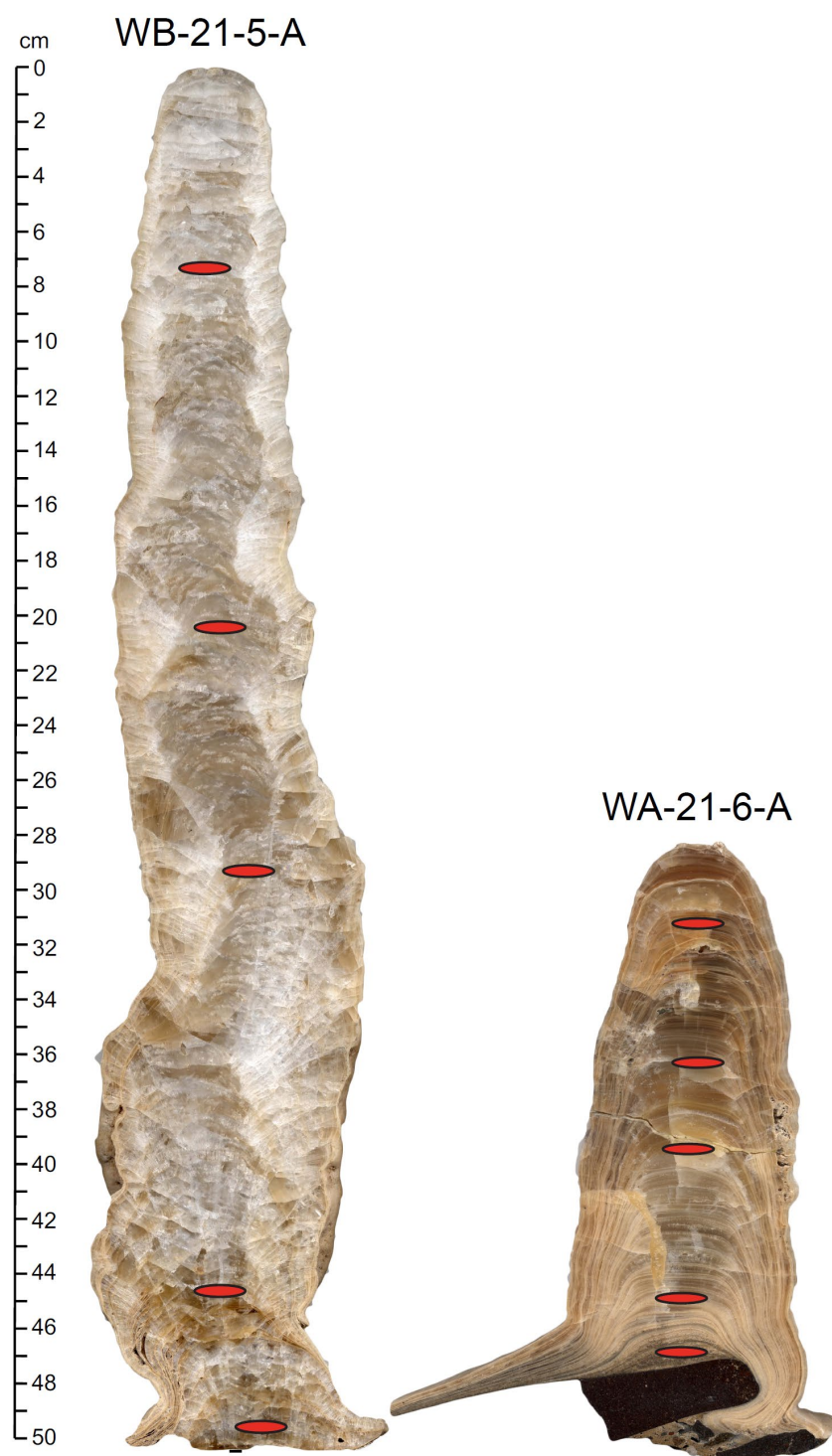
Supplementary Figs. S1 – 12



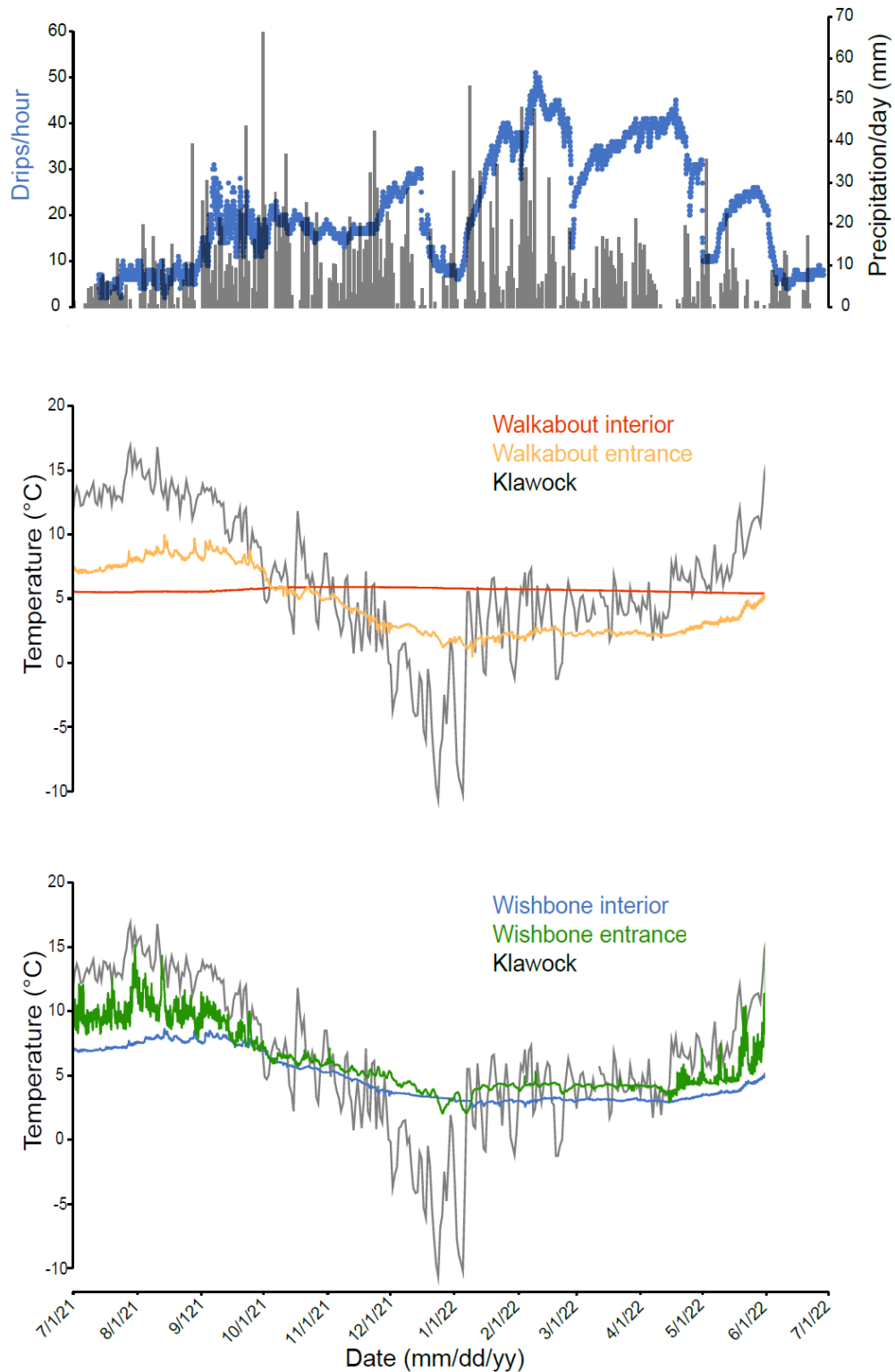
Supplementary Fig. S1: (a) Comparison of annual instrumental NINO3.4 and southeastern Alaska regional temperature anomalies, showing significant correlation at $r = .46$ ($P < .001$). (b) Comparison of 36-month instrumental NINO3.4 and regional precipitation at Juneau, Alaska, showing significant correlation at $r = .51$ ($P < .001$). NINO3.4 data was acquired at (https://psl.noaa.gov/gcos_wgsp/Timeseries/Nino34/) and Alaska instrumental data was acquired at (www.ncdc.noaa.gov/).



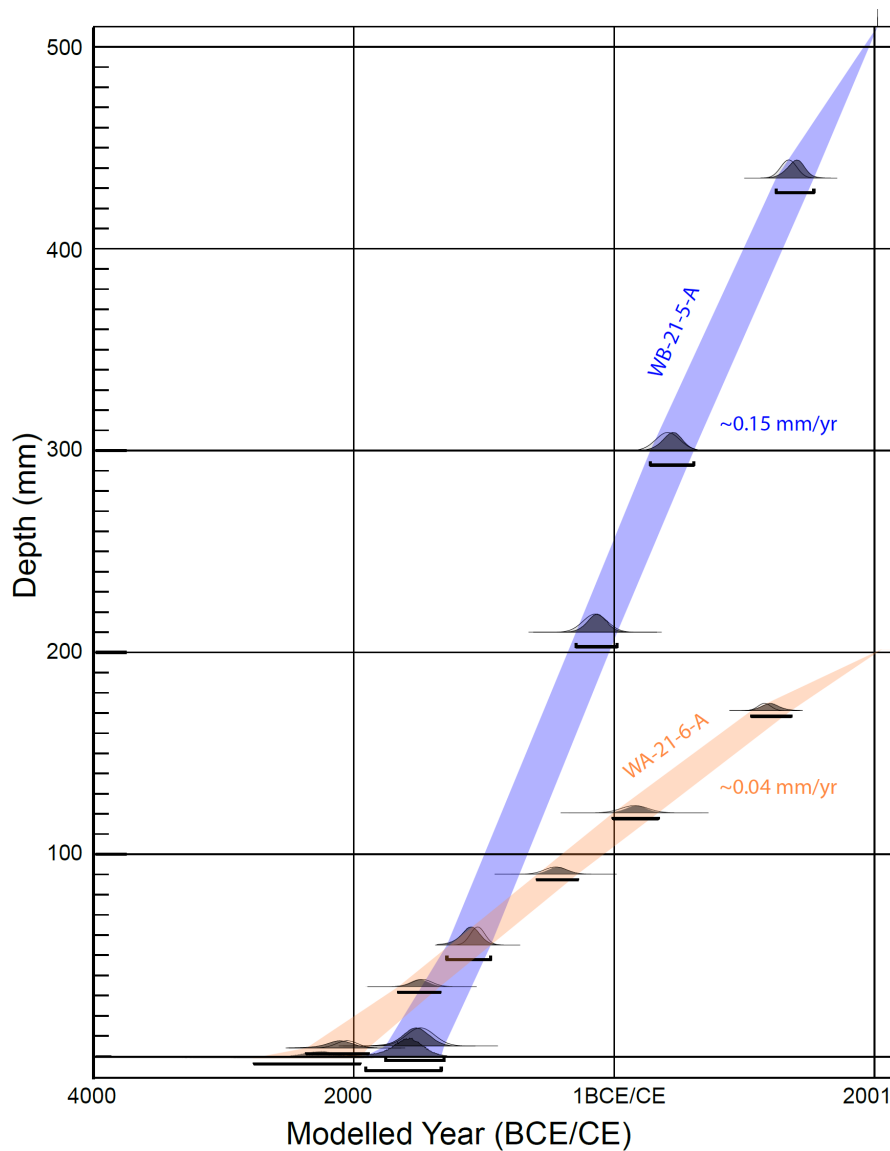
Supplementary Fig. S2: Map of study area, with location of Walkabout and Wishbone Caves (green star) and cities with NOAA meteorological data (orange circles). The caves are ~400 m apart.



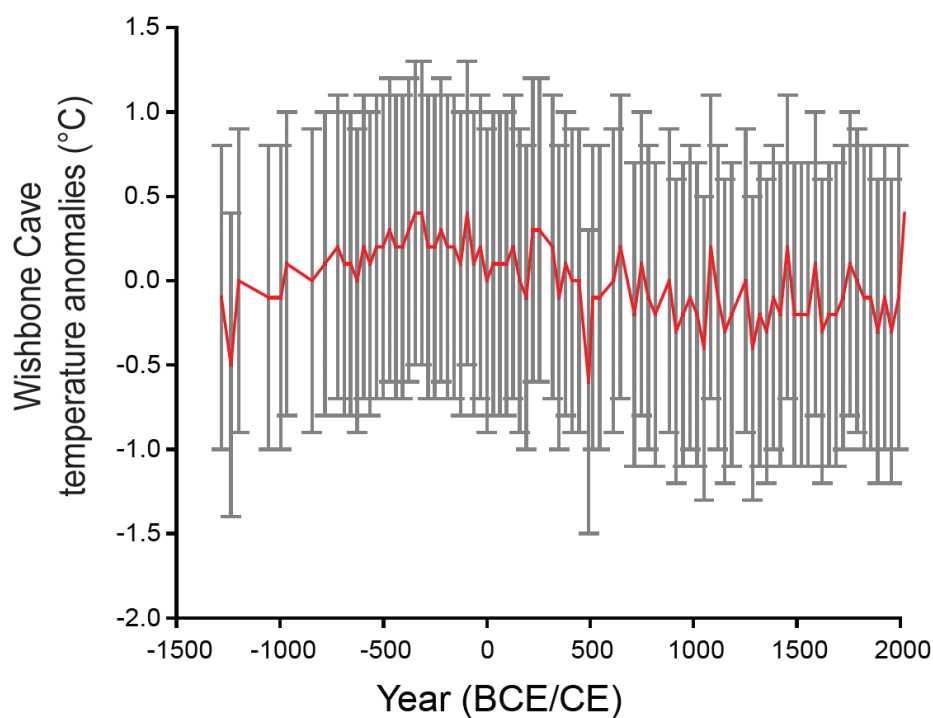
Supplementary Fig. S3: Images of cut and polished speleothems WB-21-5-A and WA-21-6-A. Red ellipses represent U-Th sampling locations.



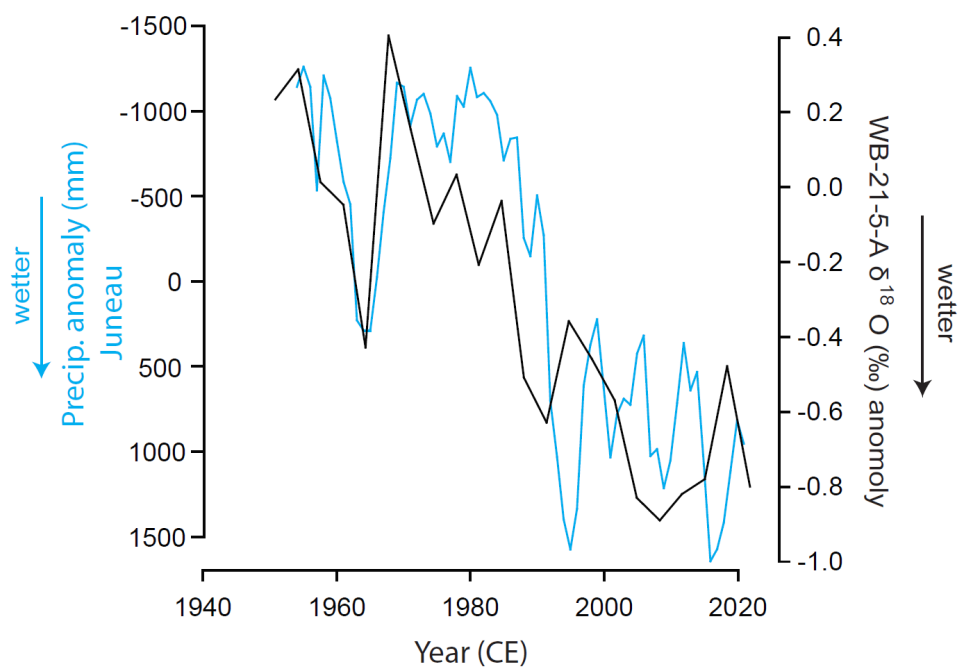
Supplementary Fig. S4: Cave monitoring data. Drip rates were collected from Walkabout Cave. Local precipitation and temperature data collected from Klawock (55.555° N, 133.096° W; 24 m a.s.l. - Supplementary Fig. S2) (Western Regional Climate Center). Drip rate fluctuations after March, and especially in mid-April, are likely influenced by snowmelt, with local temperatures consistently above 0 °C. However, precipitation trends still dominate the drip rate fluctuations.



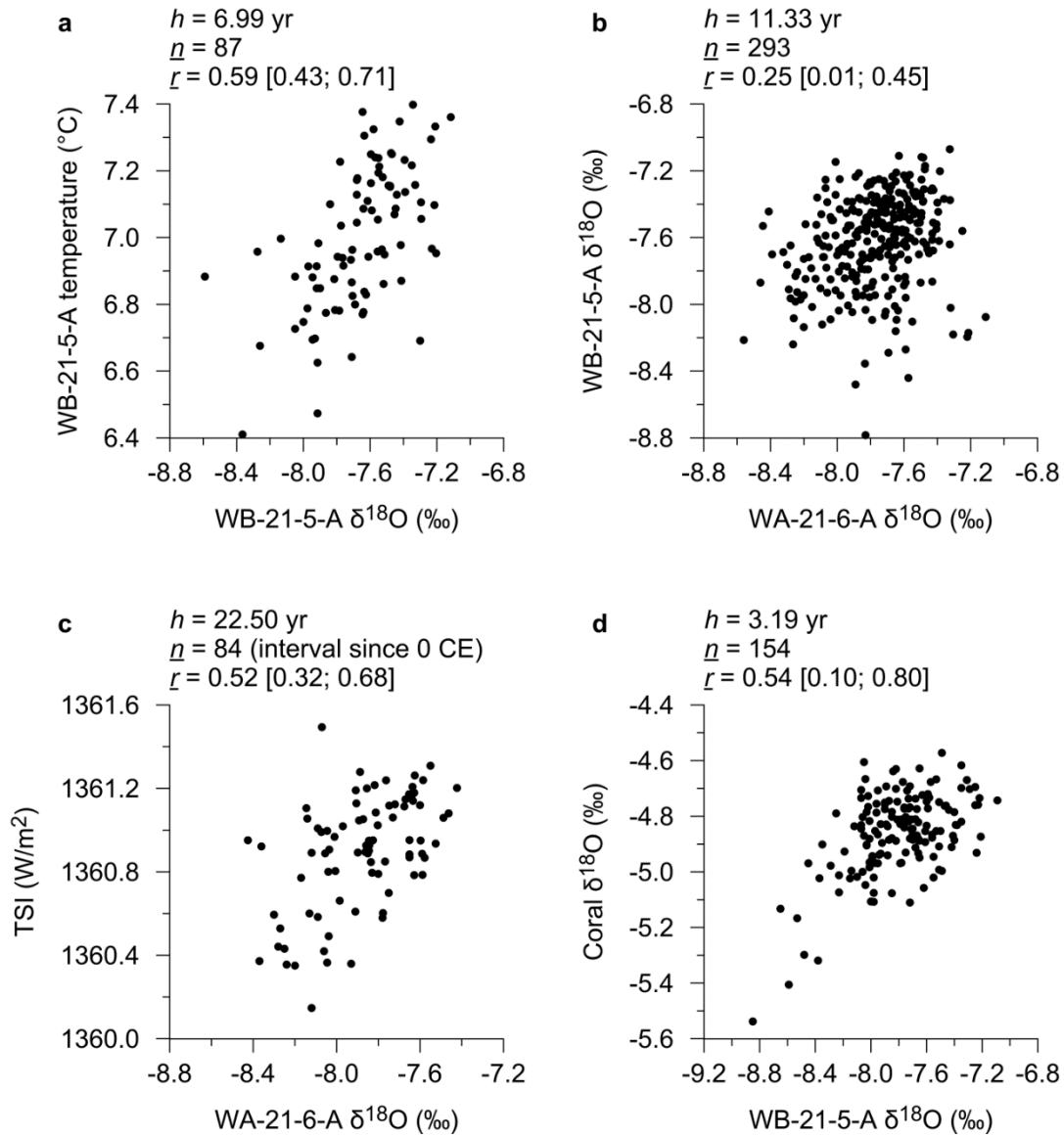
Supplementary Fig. S5: Age-depth model of speleothems WB-21-5-A (blue) and WA-21-6-A (orange), produced in OxCal 4.4 using a “k” parameter of 0.2 mm^{-1} (Bronk Ramsey, 2008; Bronk Ramsey, 2009; Bronk Ramsey & Lee, 2013). There is a notable difference in growth rates between the two speleothems, with speleothem WB-21-5-A growing $\sim 3\times$ faster than speleothem WA-21-5-A.



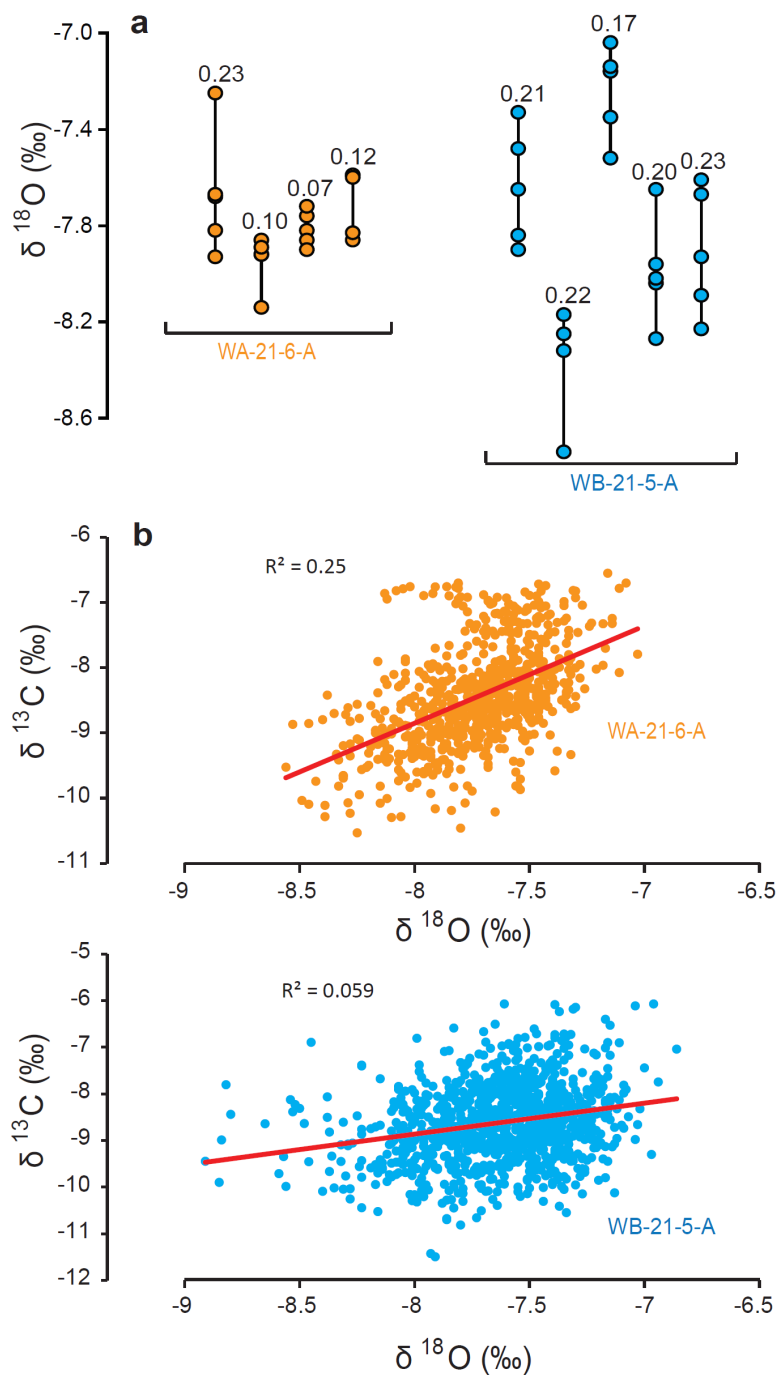
Supplementary Fig. S6: Fluid inclusion temperature reconstruction from speleothem WB-21-5-A. The transfer function of 0.31 ‰/°C was used for the temperature reconstruction (red line).



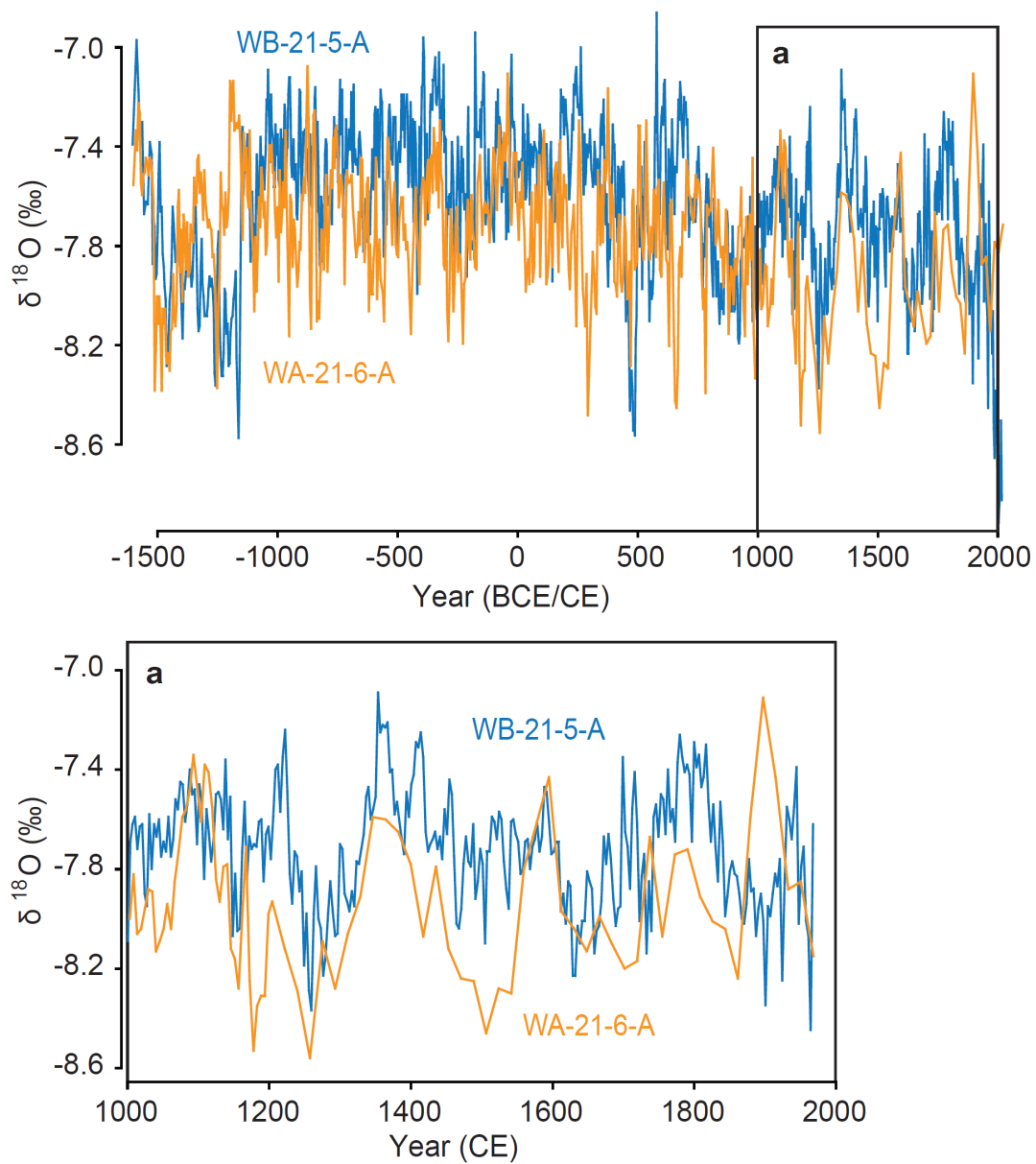
Supplementary Fig. S7: Comparison of $\delta^{18}\text{O}$ from speleothem WB-21-5-A and 60-month regional precipitation data from Juneau, Alaska (www.ncdc.noaa.gov/).



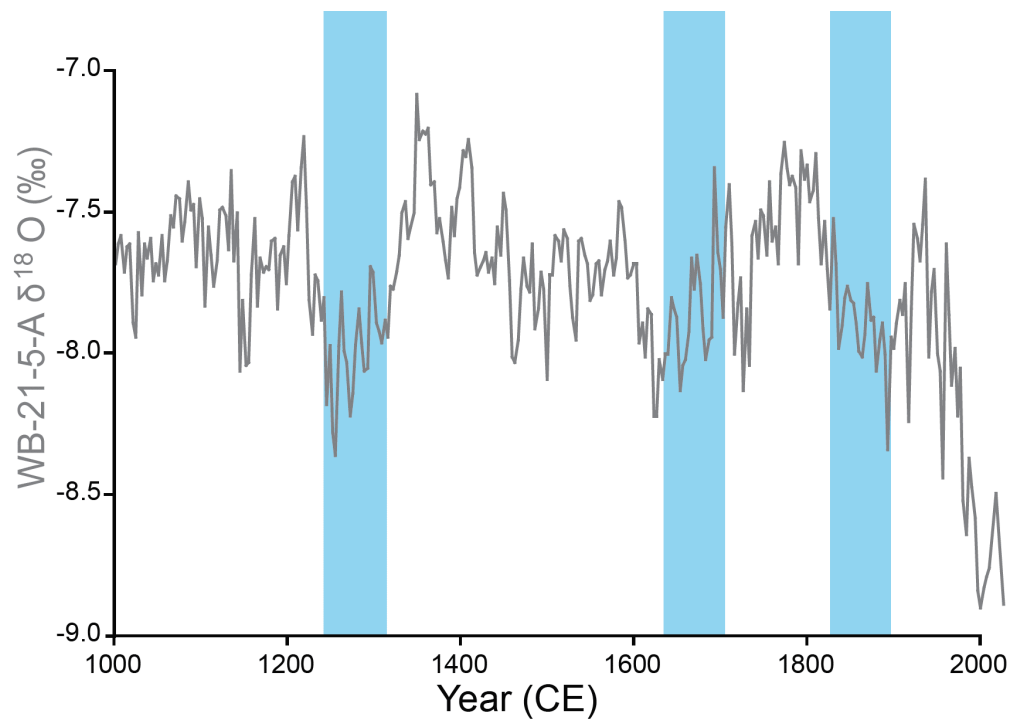
Supplementary Fig. S8: Scatterplots for selected pairs of proxy climate variables and stalagmites with results of binned correlation analysis (Mudelsee, 2014). h , binwidth; \underline{n} , number of filled bins; \underline{r} , binned correlation coefficient with calibrated 90% Student's t confidence interval.



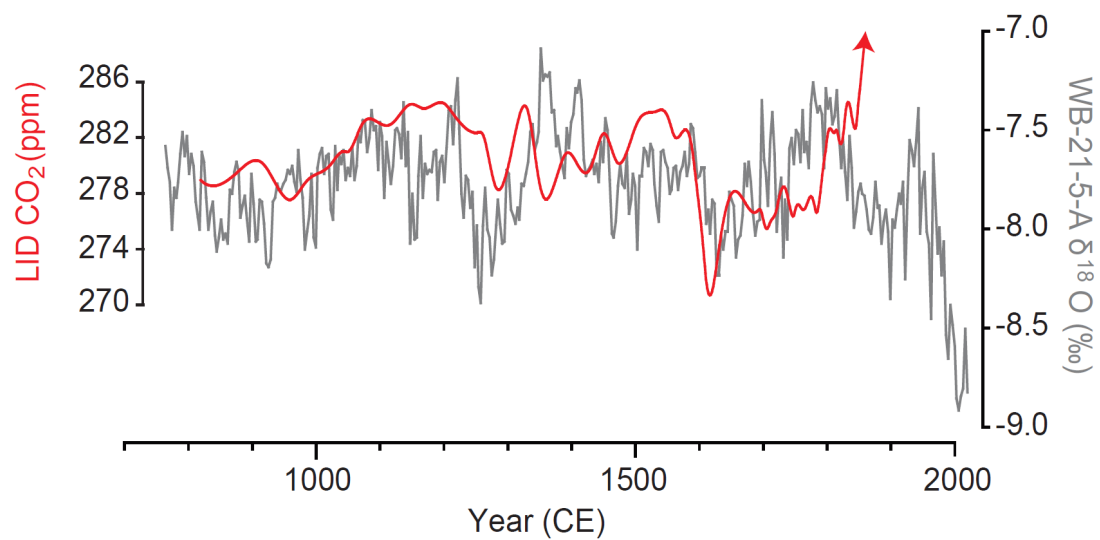
Supplementary Fig. S9: **(a)** Hendy tests for speleothem WA-21-6-A and WB-21-5-A, with a standard deviation of 0.07–0.23 for speleothem WA-21-6-A and 0.12–0.23 for speleothem WB-21-5-A, suggesting no substantial isotopic enrichment along individual growth layers. **(b)** $\delta^{18}\text{O}$ versus $\delta^{13}\text{C}$ for speleothem WA-21-6-A and WB-21-5-A. Correlations between $\delta^{18}\text{O}$ versus $\delta^{13}\text{C}$ are statistically insignificant, suggesting equilibrium fractionation.



Supplementary Fig. S10: Comparison of $\delta^{18}\text{O}$ records of speleothems WB-21-5-A and WA-21-6-A showing strong covariation. Insert **a** shows comparison between 1970 and 1000 CE that highlights the frequency difference between the two speleothems.



Supplementary Fig. S11: Speleothem WB-21-5-A $\delta^{18}\text{O}$ record for the last millennium compared to periods of glacial advances in southern Alaska (Wiles et al., 2008) marked by blue bars. Inferred periods of glacial advances before 1000 CE are excluded due to lack of chronological constraints.



Supplementary Fig. S12: Speleothem WB-21-5-A $\delta^{18}\text{O}$ vs Law Ice Dome (LID) CO_2 concentration (Rubino et al., 2019). Atmospheric CO_2 disconnects with the natural variability of the speleothem record at ~ 1850 CE.