



Supplement of

Seasonal climate signals preserved in biochemical varves: insights from novel high-resolution sediment scanning techniques

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Table S1. Results of total carbon (TC) and nitrogen (TN) analyses with and without correction for mineralization, which was done using the formulas reported in Gálman et al. (2008).

Year	Bottom Depth (mm)	TC (%)	TN (%)	TOC (%)	TOC_corr	TN_corr	TC_corr	TOC:N_corr
2019	6.01	16.16	1.39	9.65	11.10	1.71	17.62	6.48
2018	10.4	15.96	1.30	9.72	11.40	1.65	17.64	6.92
2017	15.75	15.39	1.21	9.64	11.43	1.56	17.17	7.34
2016	21.41	15.68	1.21	9.56	11.41	1.57	17.54	7.26
2015	26.97	14.73	1.00	9.48	11.37	1.31	16.62	8.69
2014	32.18	15.35	1.22	10.35	12.46	1.60	17.47	7.77
2013	38.4	14.37	1.08	9.62	11.62	1.43	16.37	8.14
2012	43.44	14.73	1.09	9.65	11.68	1.44	16.76	8.09
2011	49.08	15.13	1.06	8.84	10.72	1.41	17.01	7.61
2010	52.29	14.82	1.11	8.92	10.83	1.48	16.73	7.33
2009	57.24	15.53	1.28	10.44	12.69	1.71	17.79	7.44
2008	64.85	14.73	0.97	8.48	10.32	1.30	16.57	7.97
2007	71.16	14.24	0.92	7.96	9.70	1.23	15.98	7.88
2006	76.65	13.98	0.95	8.38	10.22	1.27	15.81	8.03
2005	79.99	14.36	1.00	8.80	10.74	1.34	16.29	8.01
2004	85.24	14.27	1.09	9.25	11.29	1.46	16.31	7.72
2003	89	15.03	1.19	9.87	12.06	1.60	17.21	7.55
2002	94.74	14.44	1.03	8.79	10.74	1.38	16.40	7.76
2001	101.17	14.07	0.98	7.60	9.29	1.32	15.76	7.05
2000	107.67	14.85	1.00	8.87	10.85	1.35	16.83	8.07
1999	113.24	14.47	0.90	8.03	9.83	1.21	16.27	8.11
1998	119.08	13.96	1.05	9.08	11.12	1.41	16.00	7.86
1997	123.72	12.86	0.79	7.03	8.61	1.06	14.44	8.09
1996	128.42	12.42	0.90	6.75	8.27	1.21	13.94	6.82
1995	134.26	13.50	1.12	8.75	10.72	1.51	15.47	7.10
1994	140.11	12.30	0.88	7.14	8.75	1.19	13.91	7.37
1993	147.2	12.77	1.09	8.63	10.58	1.47	14.72	7.19
1992	153.66	12.65	1.10	8.71	10.68	1.48	14.62	7.19
1991	163	11.65	0.88	6.95	8.52	1.19	13.23	7.18
1990	167.93	12.90	0.94	7.53	9.24	1.27	14.61	7.28
1989	175.21	12.73	0.85	7.28	8.93	1.15	14.39	7.78
1988	181.21	12.48	0.71	5.87	7.20	0.96	13.81	7.51
1987	185.78	11.78	0.81	7.70	9.45	1.09	13.53	8.63
1986	190.93	12.50	1.00	8.83	10.84	1.35	14.51	8.02
1985	198.48	12.70	0.86	7.91	9.71	1.16	14.51	8.35

Year	Bottom Depth (mm)	TC (%)	TN (%)	TOC (%)	TOC_corr	TN_corr	TC_corr	TOC:N_corr
1984	205.56	12.17	0.90	7.51	9.22	1.22	13.89	7.58
1983	212.64	11.89	0.89	7.01	8.61	1.20	13.49	7.15
1982	221.86	11.01	0.81	6.32	7.76	1.10	12.45	7.08
1981	229.75	11.92	0.89	7.52	9.24	1.20	13.63	7.67
1980	235	11.64	0.75	7.31	8.98	1.01	13.31	8.85
1979	239.39	11.86	0.88	8.03	9.87	1.19	13.70	8.28
1978	249.31	11.25	0.94	8.74	10.74	1.27	13.25	8.44
1977	257.21	10.42	0.84	6.52	8.01	1.14	11.92	7.05
1976	264.07	9.97	0.77	6.10	7.50	1.04	11.36	7.19
1975	271.59	11.51	0.90	8.23	10.12	1.22	13.39	8.30
1974	278.52	11.23	0.81	6.98	8.58	1.10	12.83	7.82
1973	287.44	11.23	0.92	7.41	9.11	1.25	12.93	7.31
1972	294	11.50	0.85	7.27	8.94	1.15	13.16	7.76
1971	300.93	12.25	0.94	8.11	9.97	1.27	14.11	7.83
1970	304.92	12.26	1.02	9.21	11.32	1.38	14.37	8.20
1969	310.98	11.36	0.97	8.57	10.54	1.31	13.33	8.02
1968	315.99	11.42	0.78	7.93	9.75	1.06	13.24	9.23
1967	320.33	11.73	0.89	8.50	10.45	1.21	13.68	8.67
1966	325.23	11.54	0.99	8.89	10.93	1.34	13.58	8.15

Table S2. Summary of split-period validation statistics. RE = reduction of error, CE = coefficient of efficiency, RMSE = root mean square error of prediction. RE and CE were calculated according to Cook et al. (1994).

Target variable	Calibration period	Verification period	R ² _{adj}	RE	CE	RMSE
MAMJJA temperature	1966-1992	1993-2019	0.39	0.75	0.30	0.68 ° C (14.1%)
MAMJJA temperature	1993-2019	1966-1992	0.35	0.67	0.15	0.80 ° C (16.7%)
Mar-Dec wind days	1966-1991	1992, 1995-2019	0.30	0.61	-3.94	7.34 days (22.9%)
Mar-Dec wind days	1992, 1995-2019	1966-1991	0.15	-0.28	-3.22	15.35 days (48.0%)

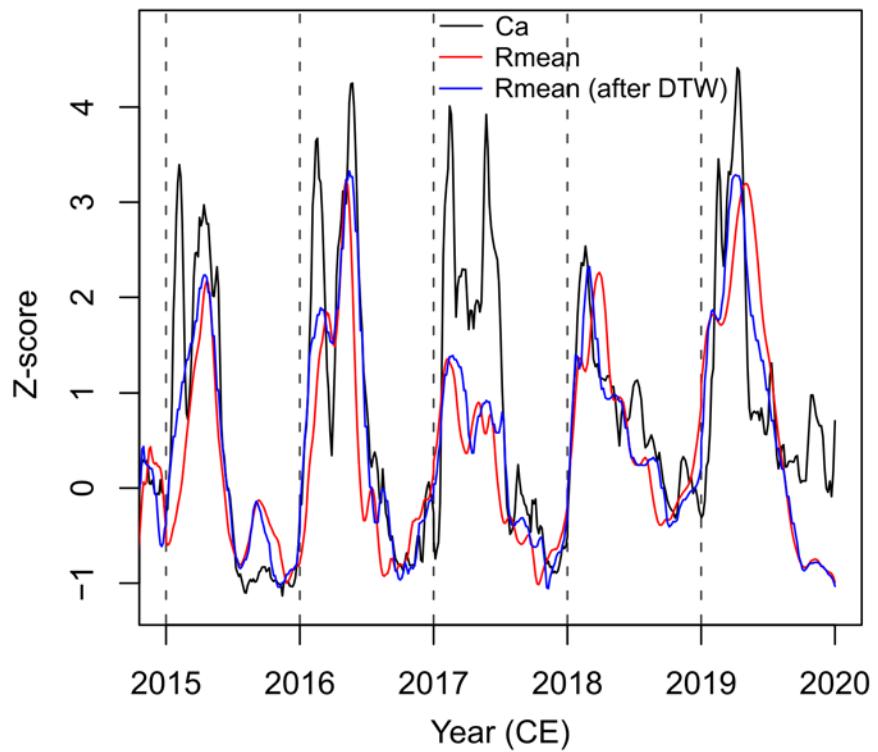


Figure S1. Example of the effect of dynamic time warping alignment used to align HSI and μ XRF data at the sub-varve scale. Red line shows Rmean plotted on varve age scale from varve counting on HSI image. Blue line shows the same data after alignment to the Ca μ XRF data. This new alignment was then applied to Bphe and TChl data from HSI before any other analyses. Dashed vertical lines depict varve boundaries.

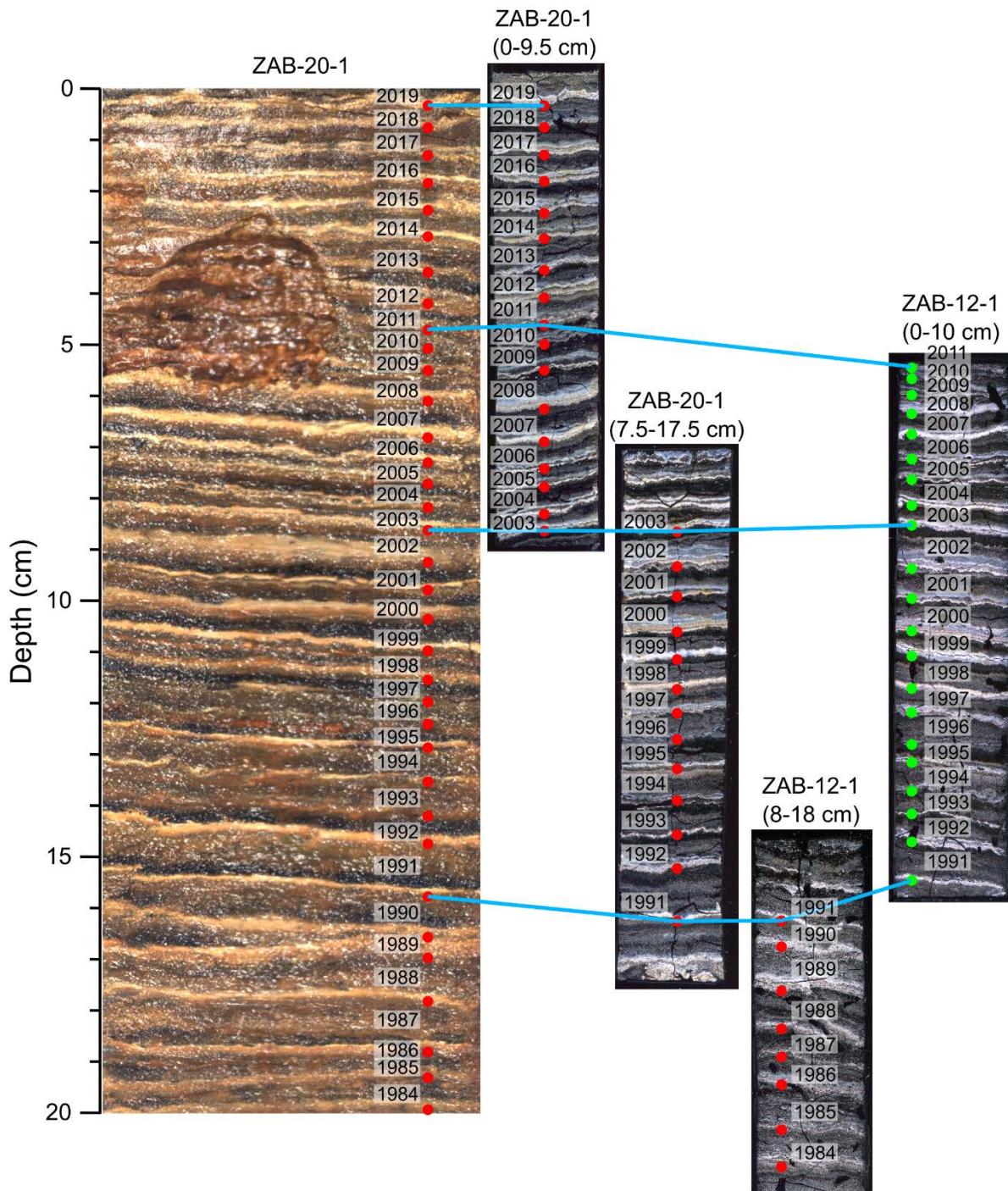


Figure S2. Varve count results shown on core images (ZAB-20-1) and resin-embedded slabs (ZAB-12-1 and ZAB-20-1) where red dots mark varve boundaries. Green dots indicate varve counts done on resin-blocks that were not used for analyses in this study, but were used to confirm the varve count.

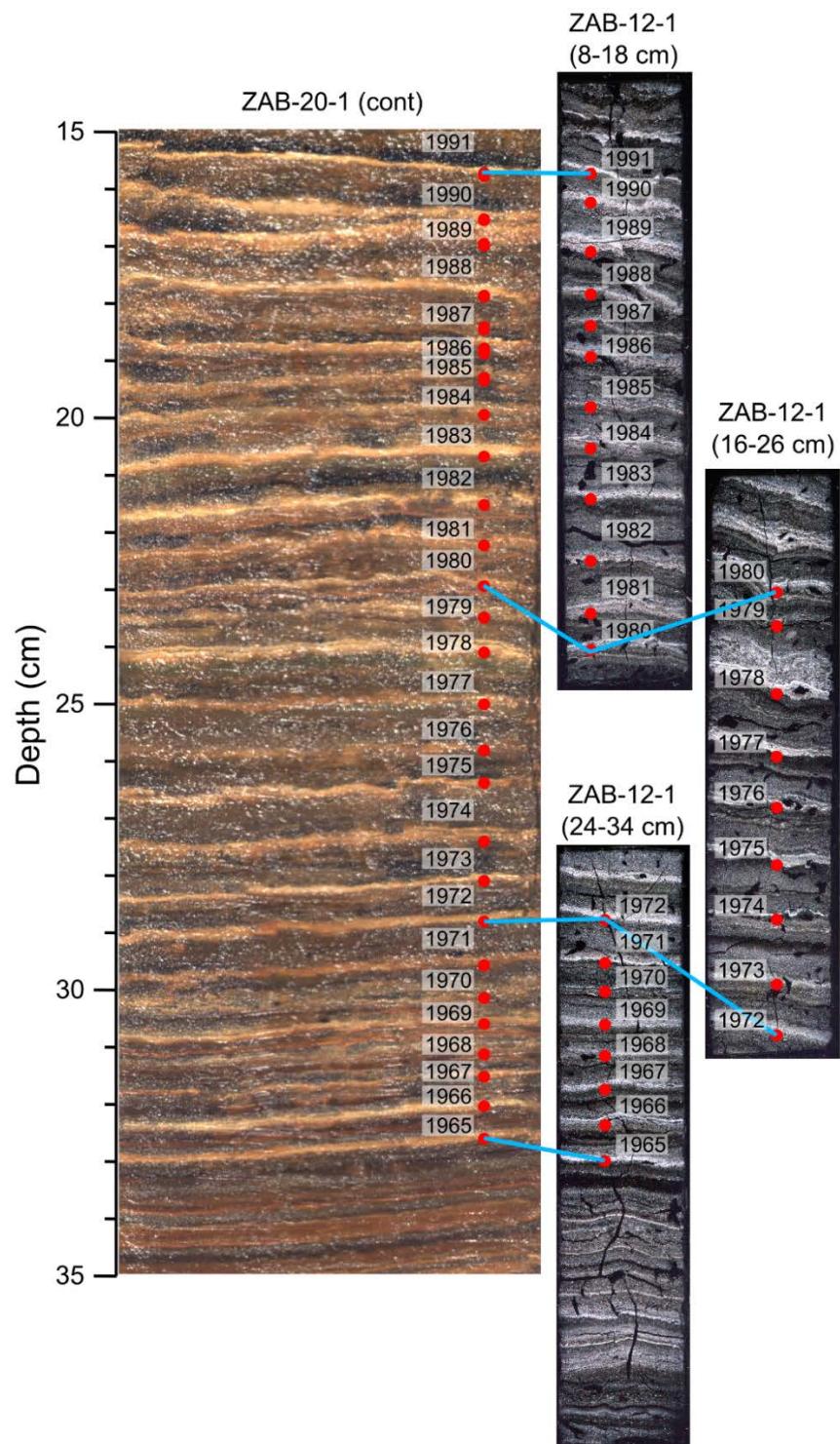


Figure S2 (cont). Varve count results shown on core images (ZAB-20-1) and resin-embedded slabs (ZAB-12-1 and ZAB-20-1).

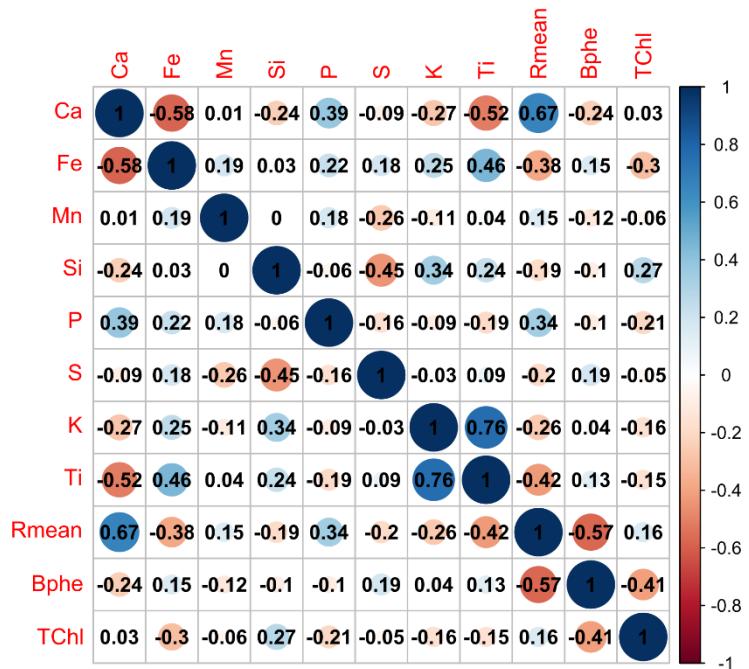


Figure S3. Correlation plot of high-resolution spectroscopy imaging data at original resolution (60 μm , n = 5631).

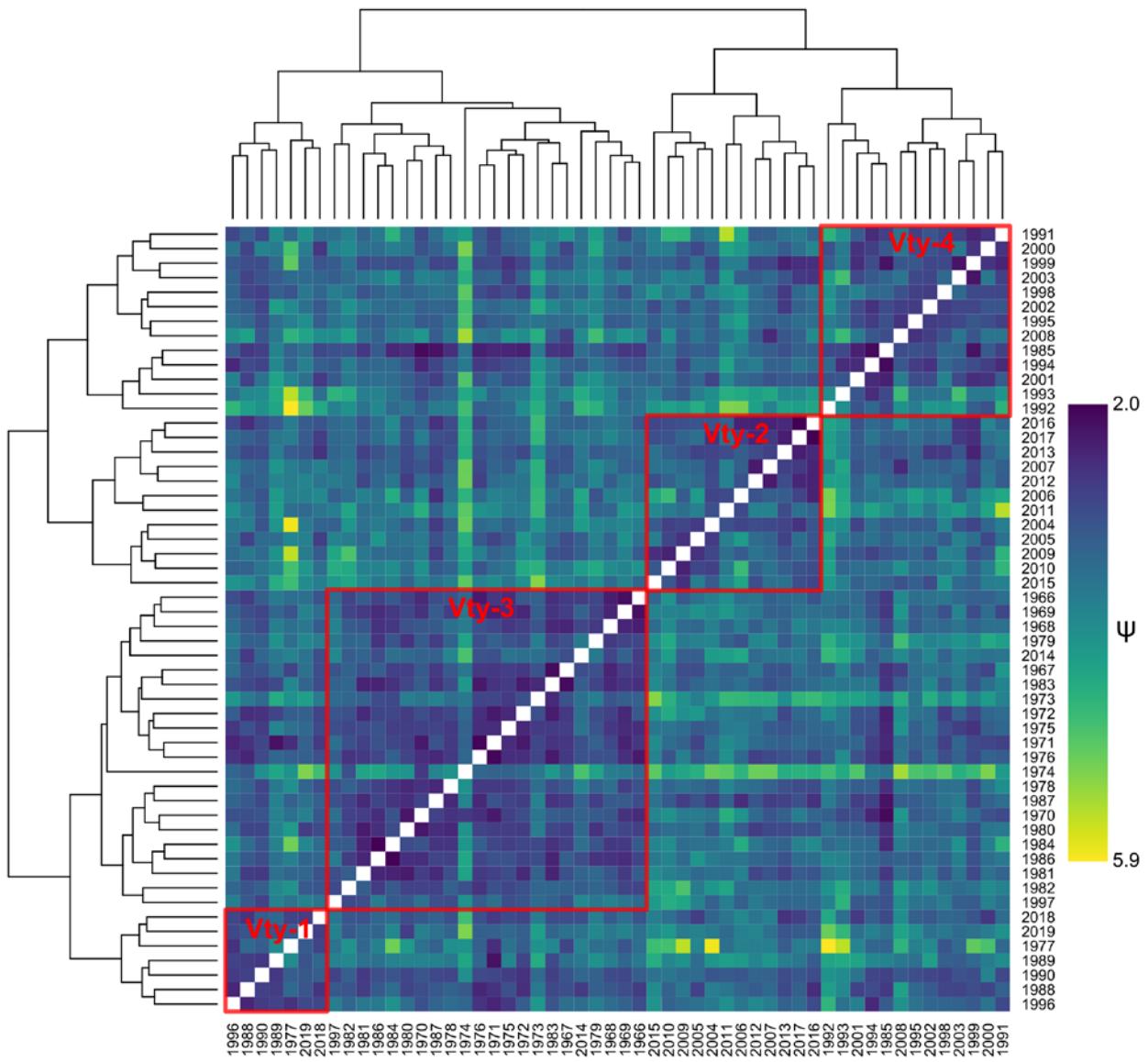


Figure S4. Matrix of dissimilarity values ψ (psi) and dendrogram resulting from hierarchical clustering. Red boxes identify varve type (Vty) clusters.

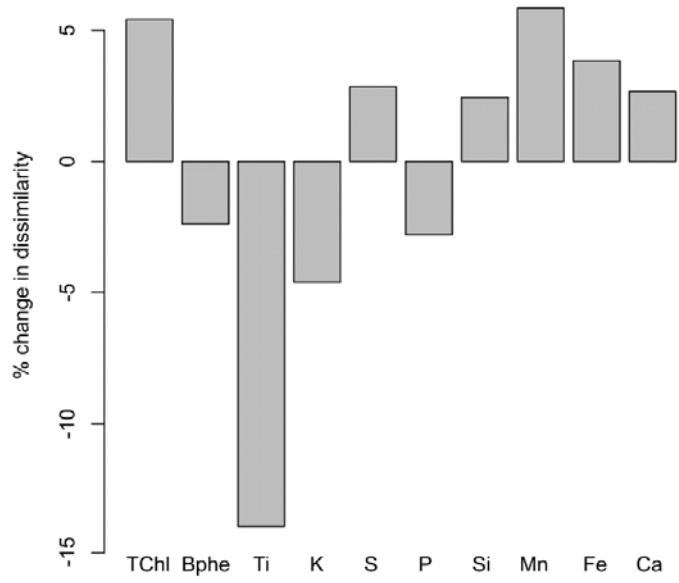


Figure S5. Percent change in dissimilarity (ψ) attributed to each variable. Positive values indicate the variable contributes to year-to-year dissimilarity in annual time series. Negative values indicate that the variable contributes to year-to-year similarity in annual time series.

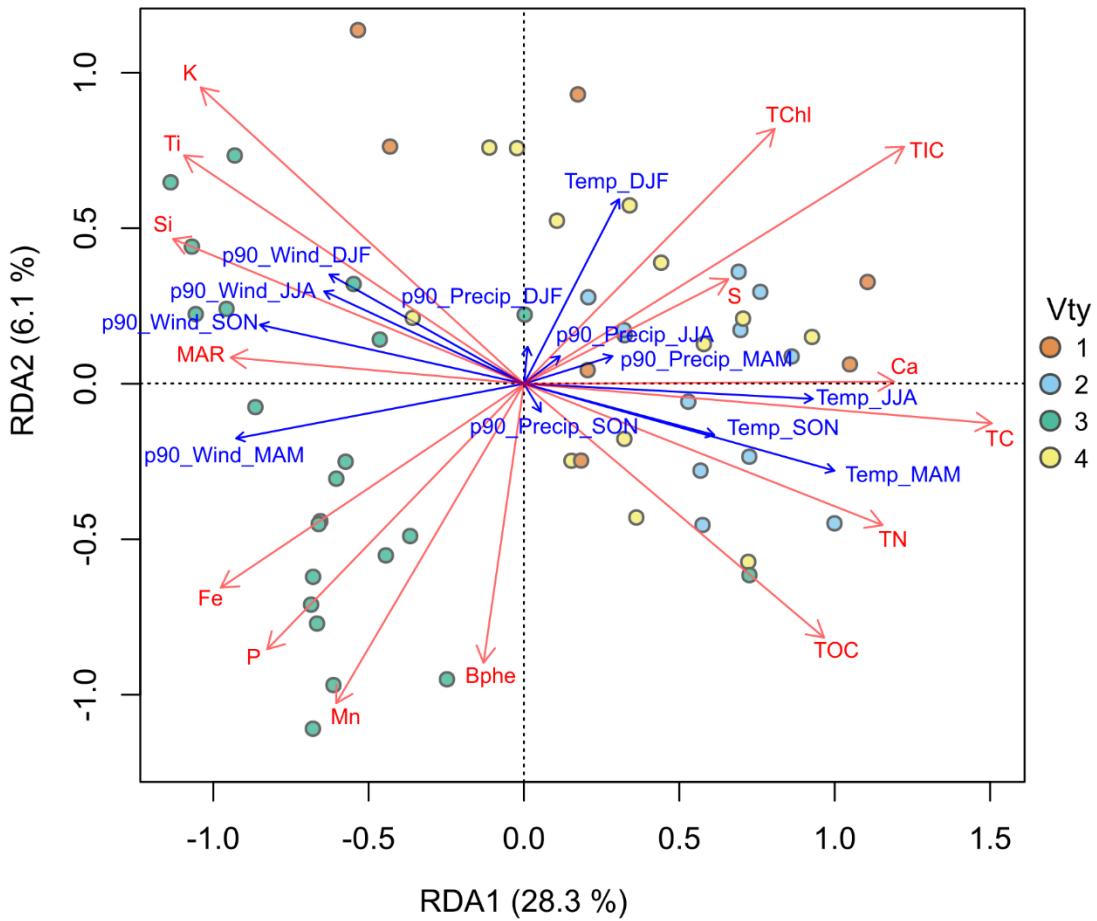


Figure S6. Results of a Redundancy Analysis (RDA) with mean annual proxy data as response variables and seasonal meteorological data as explanatory variables.

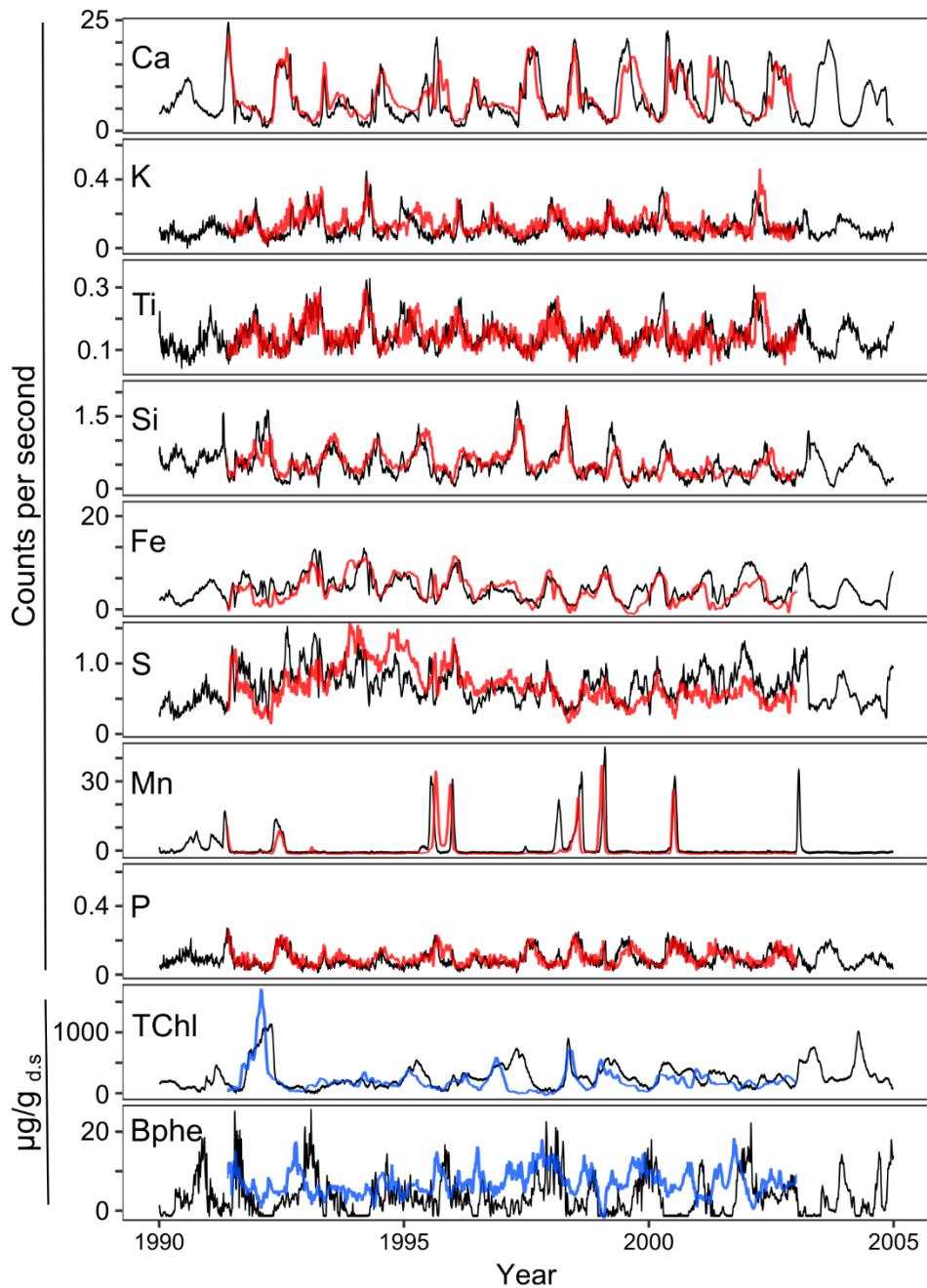


Figure S7. Plot demonstrating reproducibility of high-resolution scanning data by measurement of overlapping sections from different cores. Black lines represent data used in this study. Red lines represent an overlapping segment of the ZAB-12-1 core that was not used in the composite data for this study. Blue lines represent HSI data from an additional core (ZAB-19-1) not used for other analyses in this study.

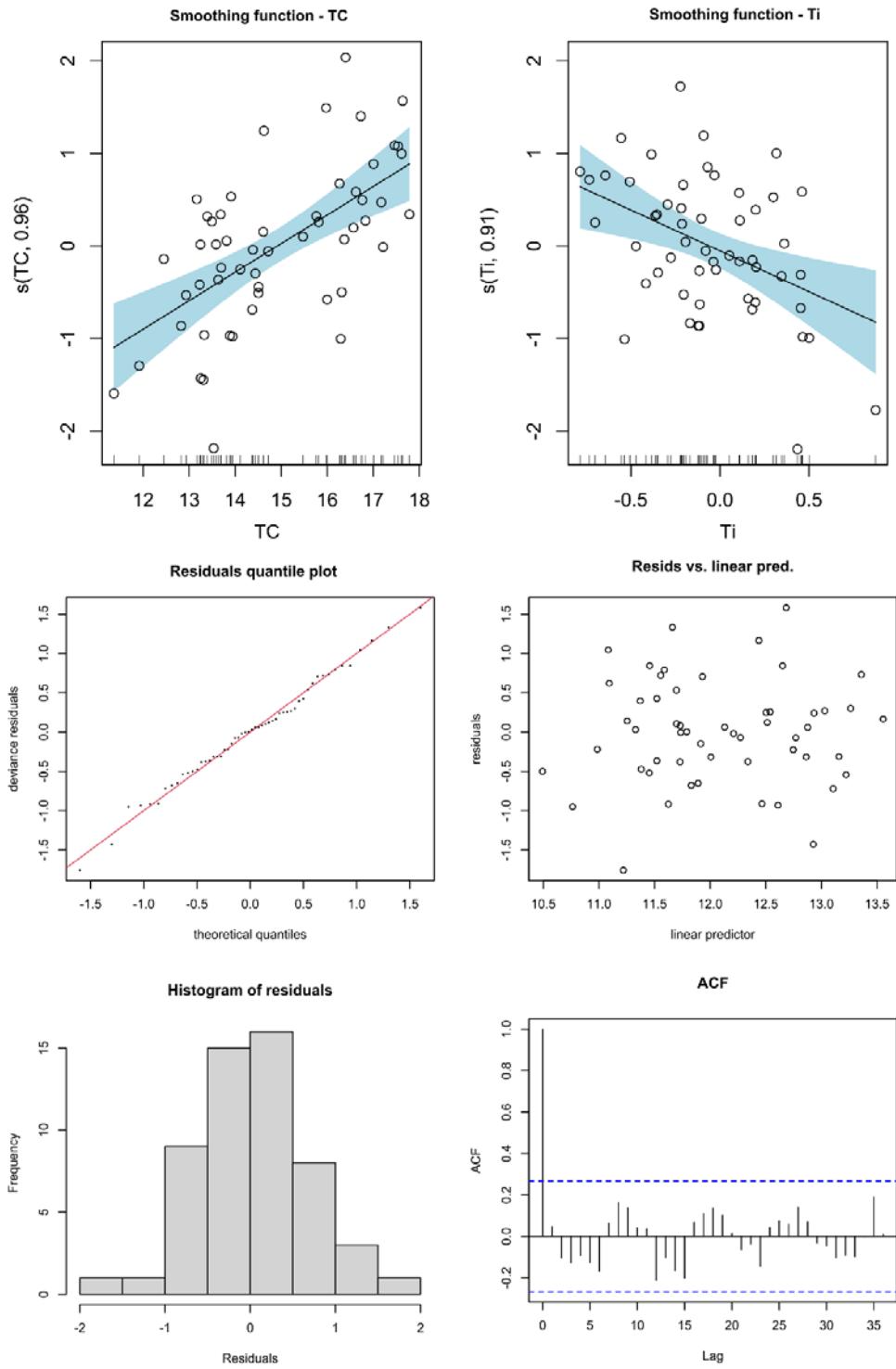


Figure S8. Partial effect plots and diagnostic plots for spring and summer temperature GAM reconstruction fit with TC and Ti.

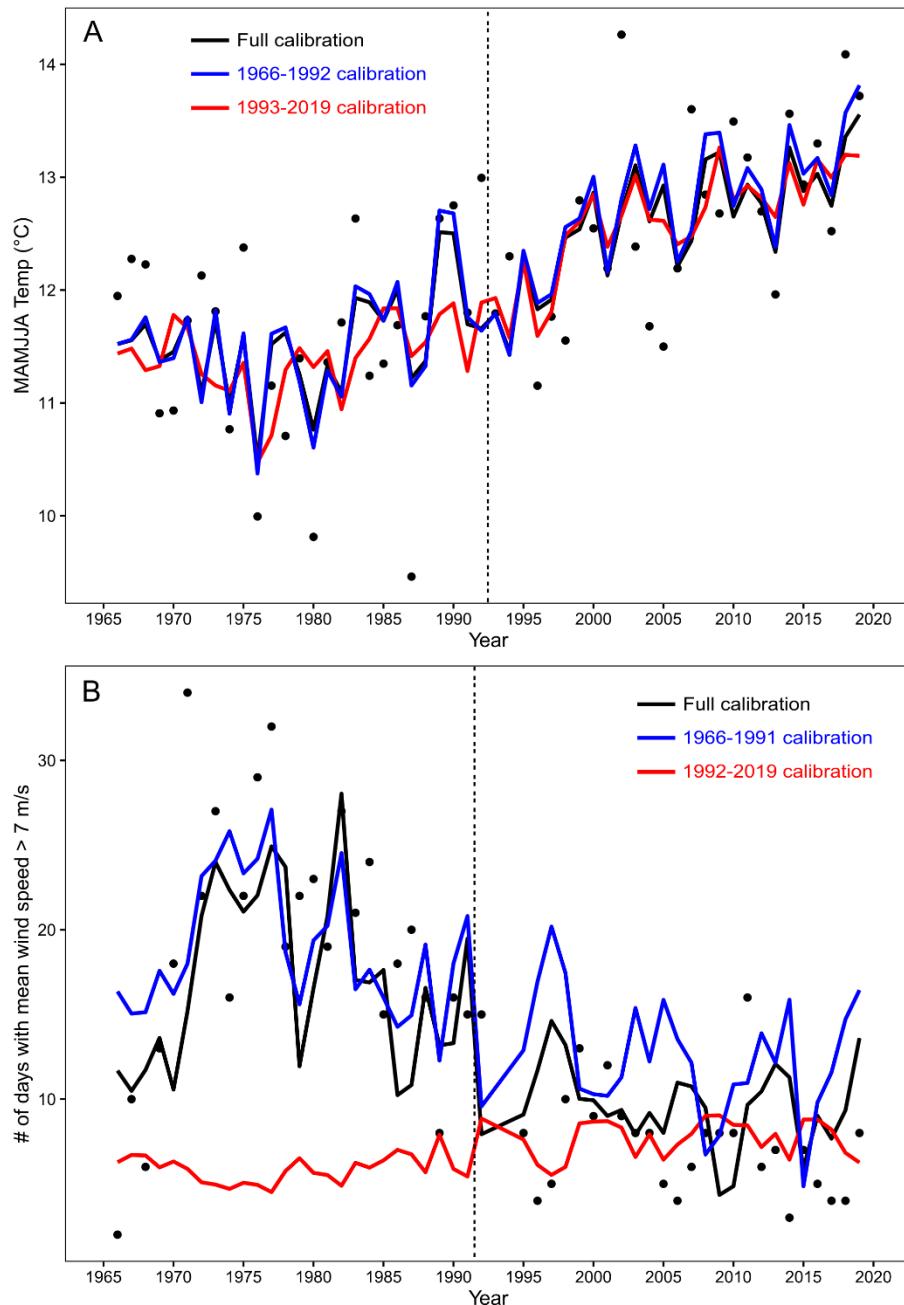


Figure S9: Comparison of GAM model outputs using full calibration period (black line) or half the dataset (blue and red lines) used for the split-period validation. Black dots show instrumental data. A) MAMJJA temperature models; B) Mar-Dec wind days models.

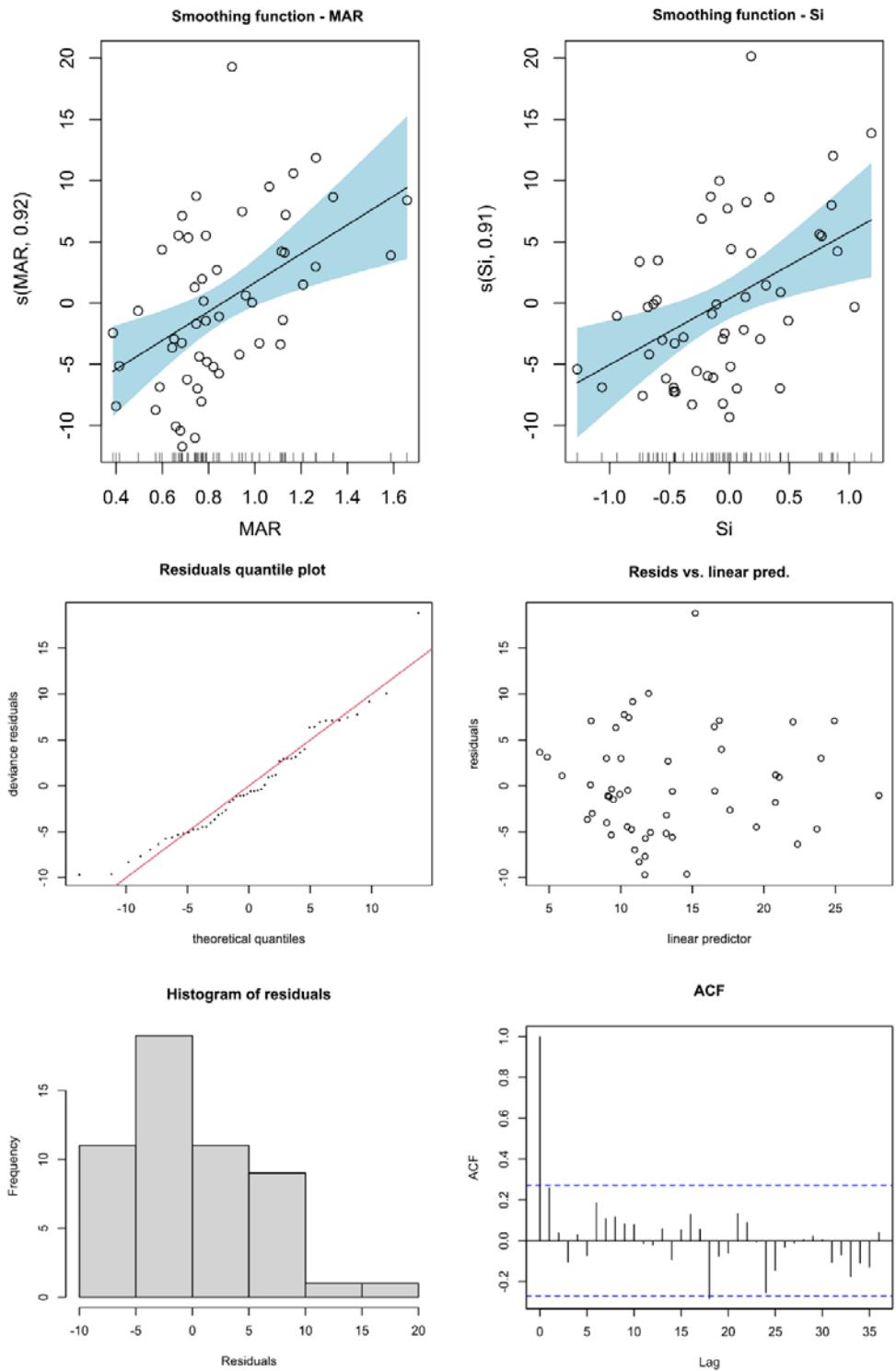


Figure S10. Partial effect plots and diagnostic plots of Mar-Dec wind days GAM reconstruction fit with MAR and Si.

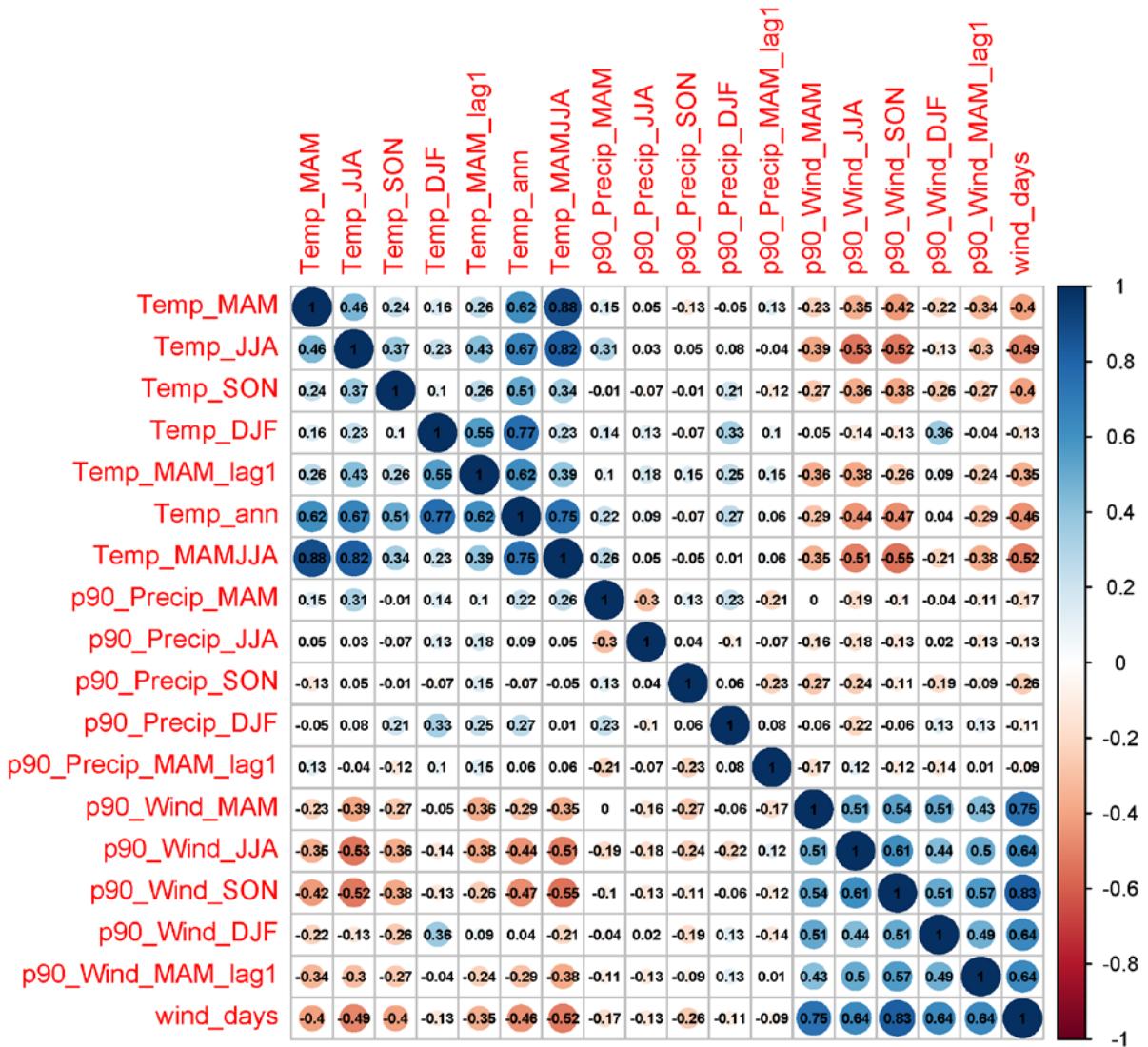


Figure S11. Correlation plot of selected meteorological variables.

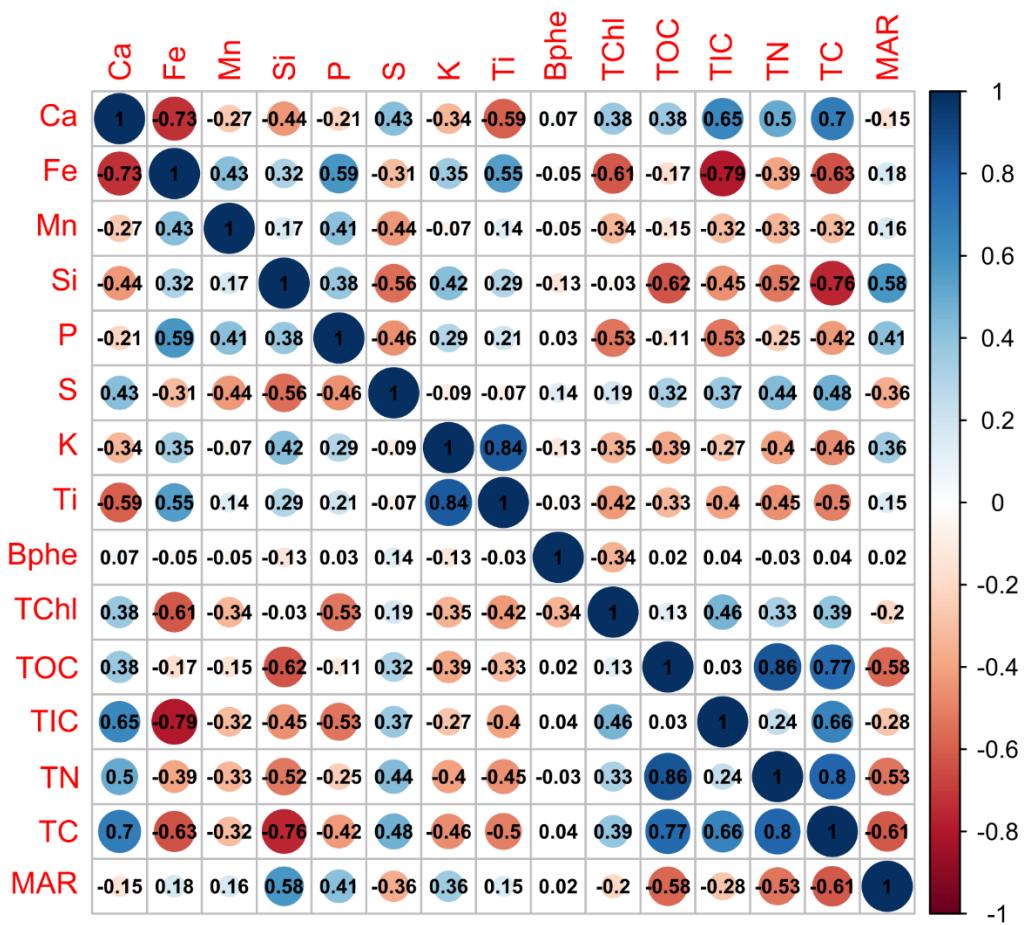


Figure S12. Correlation plot of proxy data at annual resolution (mean annual values, n = 54).