Supplementary materials

Magali Verkerk et al.

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Table S1: List of SO2 injections for which we used an eruption match. Matches are determined by geochemical identification of cryptotephra in the ice cores or the coincidence of a known eruption and an ice core signal. Isopleth heights are corrected following Aubry et al. (2023).

Volcano	Eruption date	Ice Core date	VEI	S mass (Tg of S)	Match method	Same match as eVolv2k /HolVol	Latitude (°N)	Injection height (km)	Method and reference
Okataina	1886	1886	5	0.74	Coincidence	Yes	-38.12	24	Isopleth, Carey & Sigurdsson (1989)
Krakatau	1883	1883	6	9.3	Coincidence	Yes	-6.1	35	Observations, Self & Rampino (1981)
Askja	1875	1875	5	0.67	Coincidence	Yes	65.03	23	Isopleth, Carey et al. (2010)
Kie Besi	1861	1861	4	4.5	Coincidence	Yes	0.32		
Hokkaido-Komagatake	1856	1856	4	1.3	Coincidence	Yes	42.06		
Toya	1853	1853	4	1.4	Coincidence	Yes	42.54		
Hekla	1845	1846	4	0.97	Coincidence	No	63.98	19	Isopleth, Guðnason (2017)
Cosiguina	1835	1835	5	9.5	Coincidence	Yes	12.98	24	Isopleth, Self et al. (1989)
Galunggung	1822	1822	5	2.0	Coincidence	Yes	-7.25		
Tambora	1815	1815	7	28	Coincidence	Yes	-8.25	30	Isopleth, Sigurdsson & Carey (1989)
Grimsvotn	1783	1783	4	21	Geochemical	Yes	64.4	9-18	Scaled on the observed height of phase 6, Thordarson & Self (2003)
Hekla	1766	1766	4	2.5	Coincidence	Yes	63.98	12	Isopleth, Janebo et al. (2018)
Kie Besi	1760	1762	4	4.8	Coincidence	No	0.32		
Katla	1755	1755	5	1.2	Coincidence	Yes	63.63	16	Derived from total mass, Schmith (2017)
Huaynaputina	1600	1601	6	19	Geochemical	Yes	-16.61	26	Isopleth, Prival et al. (2019)
Bardarbunga	1477	1477	6	5.1	Geochemical	Yes	64.63	14	Isopleth, Larsen (2005)
Samalas	1257	1258	7	59	Geochemical	Yes	-8.42	29	Isopleth, Vidal et al. (2015)

Changbaishan	946	946	7	1.7	Geochemical	Yes	41.98	25	Isopleth, Wei et al. (2003)
Eldgja	939 ± 1	939	4	16	Geochemical	Yes	63.63	12.5	Isopleth, Moreland (2017)
Bardarbunga	877 ± 1	879	4	3.0	Geochemical	Yes	64.63		
Churchill	853 ± 1	853	6	2.5	Geochemical	Yes	61.38	31.5	Isopleth, Lerbekmo (2008)
Katla	823	822		3.9	Geochemical	No	63.63		
Illopango	432 ± 2	433	6	14	Geochemical	No	13.67	45	Machine learning simulation of tephra deposit, Smith et al. (2020)
Taupo	232 ± 10	236	6	5.8	Geochemical	Yes	-38.82	22	Isopleth, Houghton et al. (2014)
Okmok II	-43	-43	6	48	Geochemical	No	53.43		
Aniakchak II	-1628	-1628	6	52	Geochemical	Yes	56.88		
Mazama	-5624 ± 35	-5624	7	162	Geochemical	Yes	42.93	35	Inversion of tephra deposit using tephra2, Buckland et al. (2022)
Khangar	-5922 ± 41	-5923	6	30	Geochemical	No	54.76		

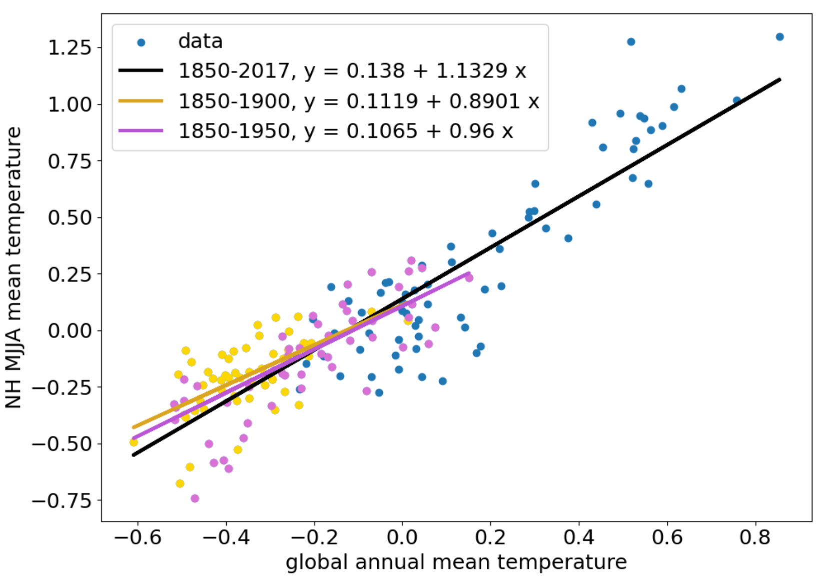

Figure S1: conversion global annual mean temperature to NH ET MJJA temperature using linear regression over the Cowtan and Way dataset; in gold 1850-1900 datapoints, pink 1900-1950 datapoints and blue 1950-2017 datapoints.

Table S2: Temperature difference between the Medieval Climate Anomaly and the Little Ice Age for different start and end dates, unless specified, the temperature is the globa mean surface temperature.

Temperature timeseries		**[950-1250] – [1450-1850]**	**[900-1200] – [1250-1850]**	**[950-1150] – [1350-1750]**
Global annual mean temperature	Simulations (LU = KK10)	0.14 ± 0.05	0.11 ± 0.04	0.12 ± 0.04
	Simulations (LU = HYDE 3.2)	0.05 ± 0.03	0.03 ± 0.03	0.05 ± 0.03
	Simulations (LU = HYDE 3.3)	0.10 ± 0.04	0.09 ± 0.04	0.10 ± 0.04
	PAGES 2k	0.16 ± 0.12	0.16 ± 0.11	0.14 ± 0.12
	LGMR	–	–	0.15 ± 0.19
	Holocene data assimilation	0.011 ± 0.007	0.015 ± 0.005	0.015 ± 0.005
	Lücke et al. simulations	0.12 ± 0.08	0.09 ± 0.06	0.09 ± 0.07
NH ET MJJA temperature	Simulations (LU = KK10)	0.18 ± 0.06	0.14 ± 0.06	0.15 ± 0.06
	Simulations (LU = HYDE 3.2)	0.07 ± 0.04	0.04 ± 0.04	0.04 ± 0.05
	Simulations (LU = HYDE 3.3)	0.13 ± 0.06	0.12 ± 0.05	0.11 ± 0.05
	King et al	0.23 ± 0.02	0.19 ± 0.04	0.15 ± 0.03
	Schneider 2015	0.04	0.00	-0.03
	Guillet 2017	0.20	0.10	0.10
	Büntgen 2021	0.15	0.15	0.14
	NTREND 2015	0.32	0.30	0.25
	Lücke et al. Land only	0.11 ± 0.08	0.07 ± 0.06	0.08 ± 0.07

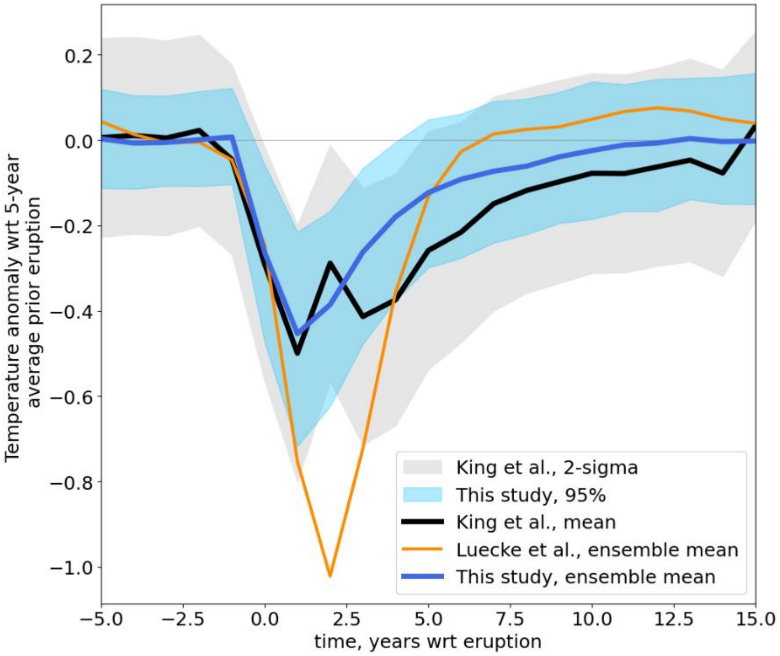

Figure S2: Superposed Epoch Analysis excluding clustered eruptions (eruptions considered: 939, 1108, 1230,1345, 1600, 1640, 1695, 1783, 1883)

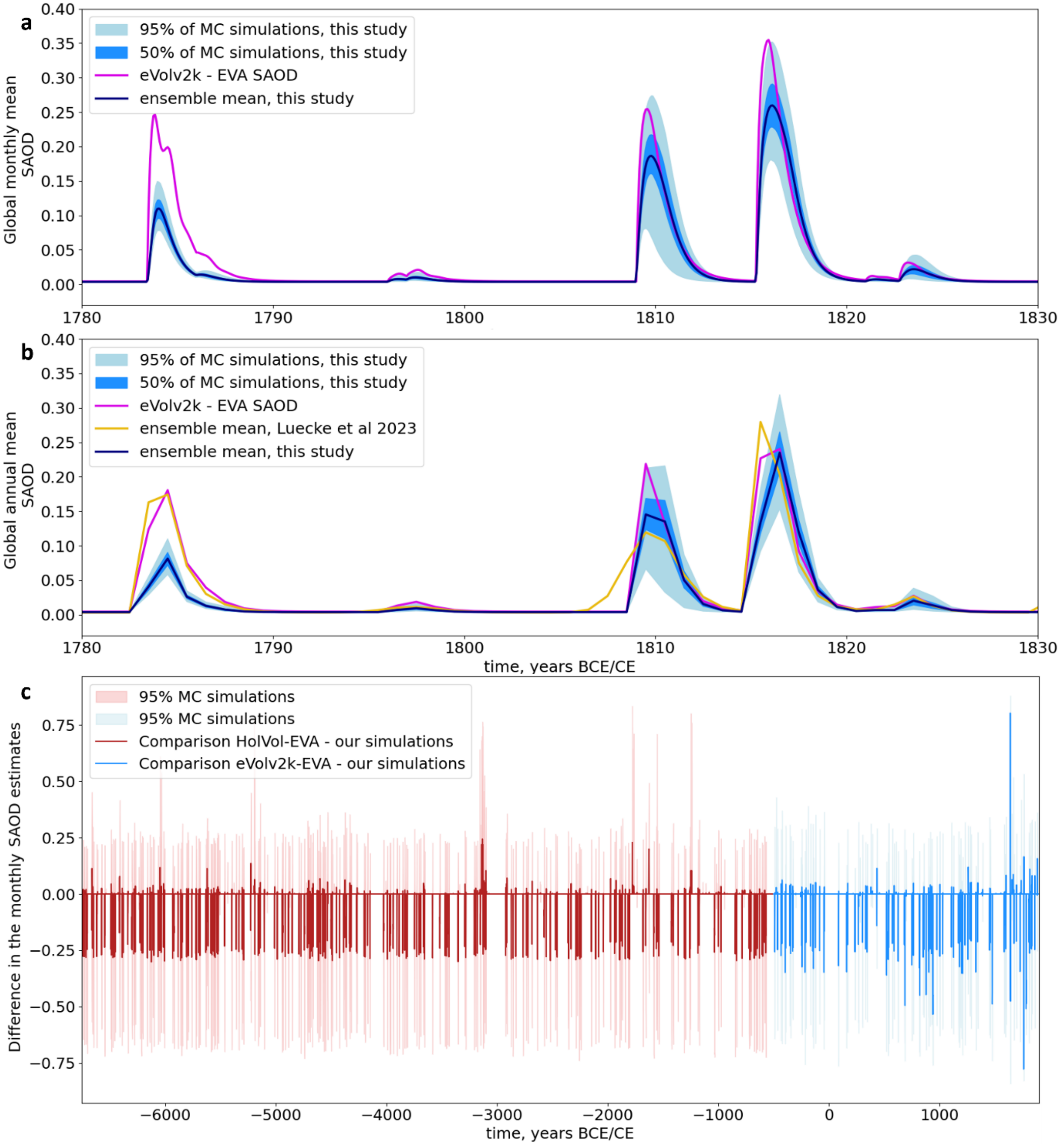

Figure S3: a. Global monthly mean SAOD for the period 1780 – 1830 CE modelled using eVolv2k and EVA (Toohey and Sigl (2017) in purple, or eVolv2k and EVA_H (this study, in blue); b. Global annual mean SAOD modelled using eVolv2k and EVA (Toohey and Sigl (2017) in purple and Lücke et al. (2023) in yellow) or eVolv2k and EVA_H (this study, in blue); c. Relative difference between our simulations using EVA_H and other simulations using EVA (Sigl et al. (2022) in red, Toohey and Sigl (2017) in blue)

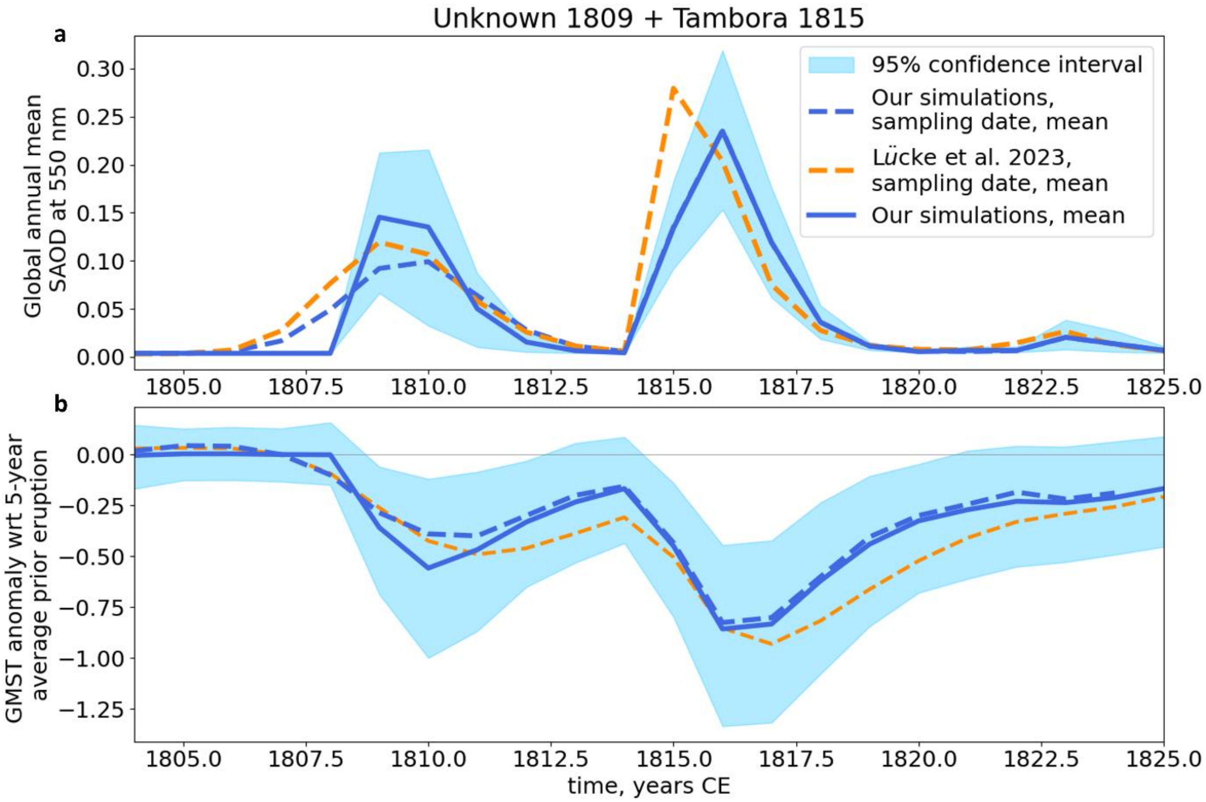

Figure S4: a. Comparison of our simulated global annual mean SAOD for 1809 and Tambora 1815 eruptions when sampling the eruption date for unknown eruptions (dashed line) or not (solid line) and simulations from Lücke et al. 2023; b. corresponding GMST responses.

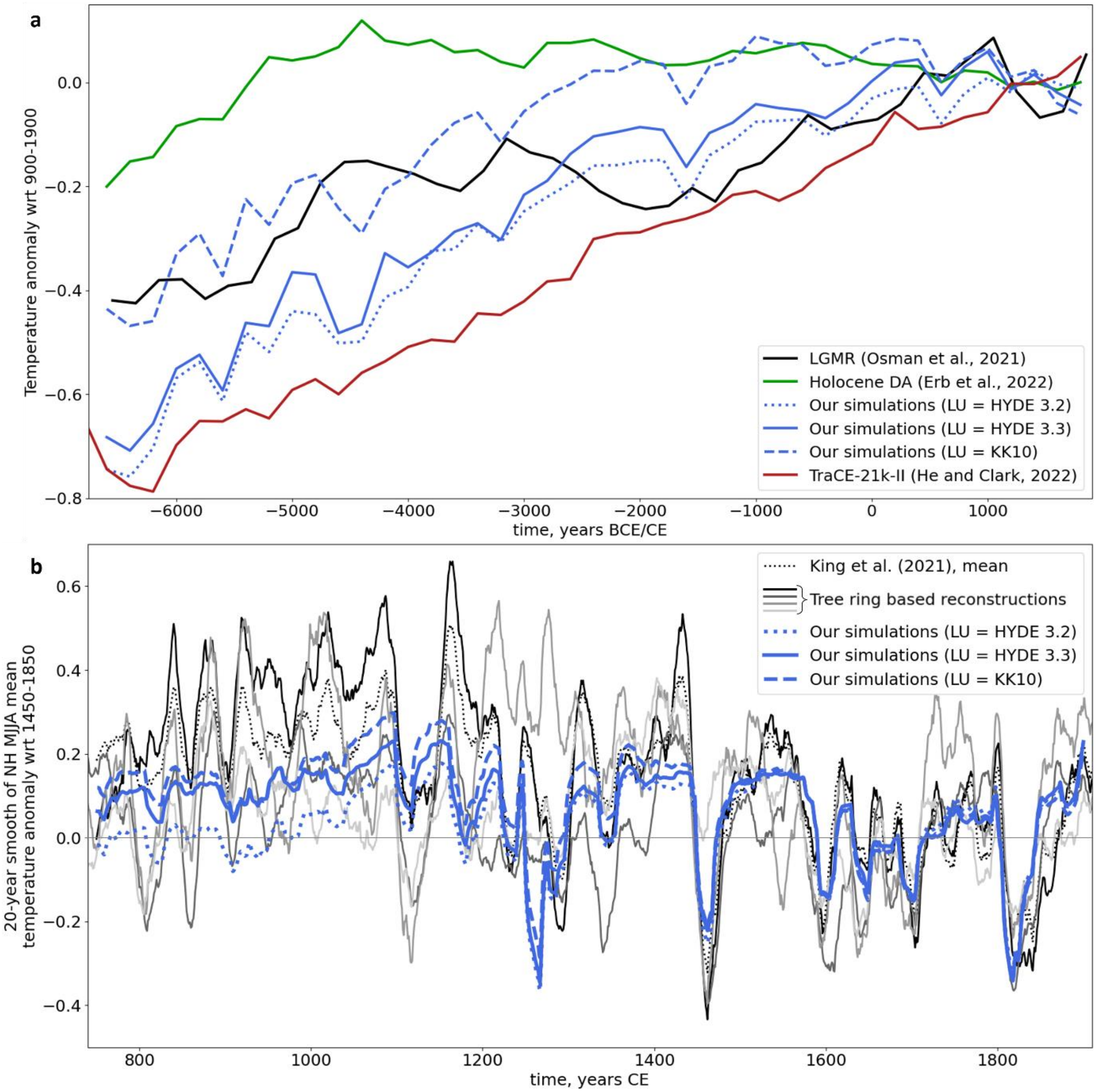

Figure S5: a. Comparison of the Last Glacial Maximum Reanalysis with our simulations for different land-use forcing; b. Comparison of the tree ring-based reconstruction with our simulations for three different land-use forcing, with a 20-year smoothing.

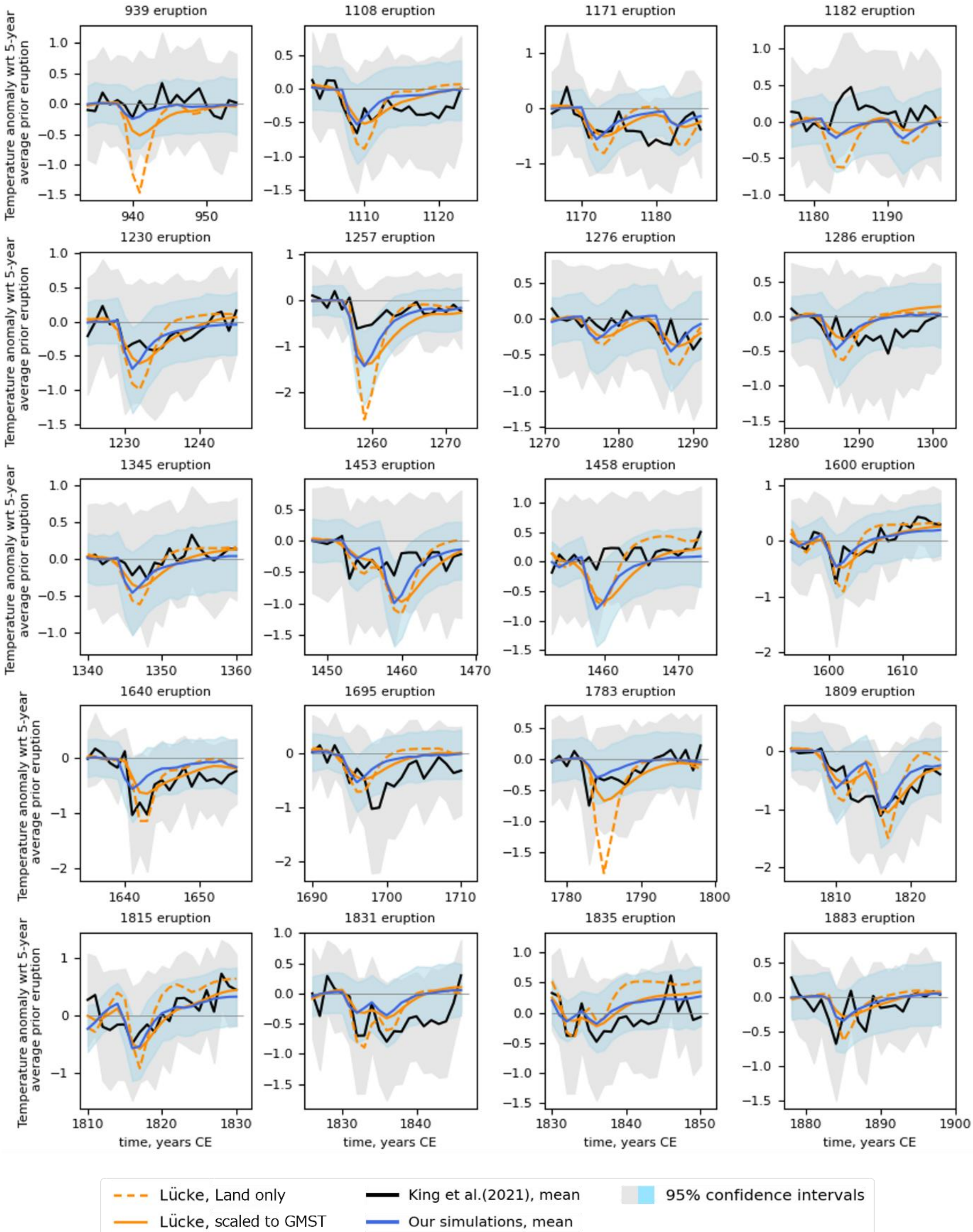
939 eruption
1108 eruption
1171 eruption
1182 eruption
1230 eruption
1257 eruption
1276 eruption
1286 eruption
1345 eruption
1453 eruption
1458 eruption
1600 eruption
1640 eruption
1695 eruption
1783 eruption
1809 eruption
1815 eruption
1831 eruption
1835 eruption
1883 eruption
Temperature anomaly wrt 5-year average prior eruption
time, years CE
Lücke, Land only
Lücke, scaled to GMST
King et al.(2021), mean
Our simulations, mean
95% confidence intervals

Figure S6: Comparison NH MJJA temperature simulated in this study, in Lücke et al. for land only temperature (dashed) and scaled from GMST (solid line), and reconstructed in King et al., for the 20 largest eruptions between 885 and 1900 CE.

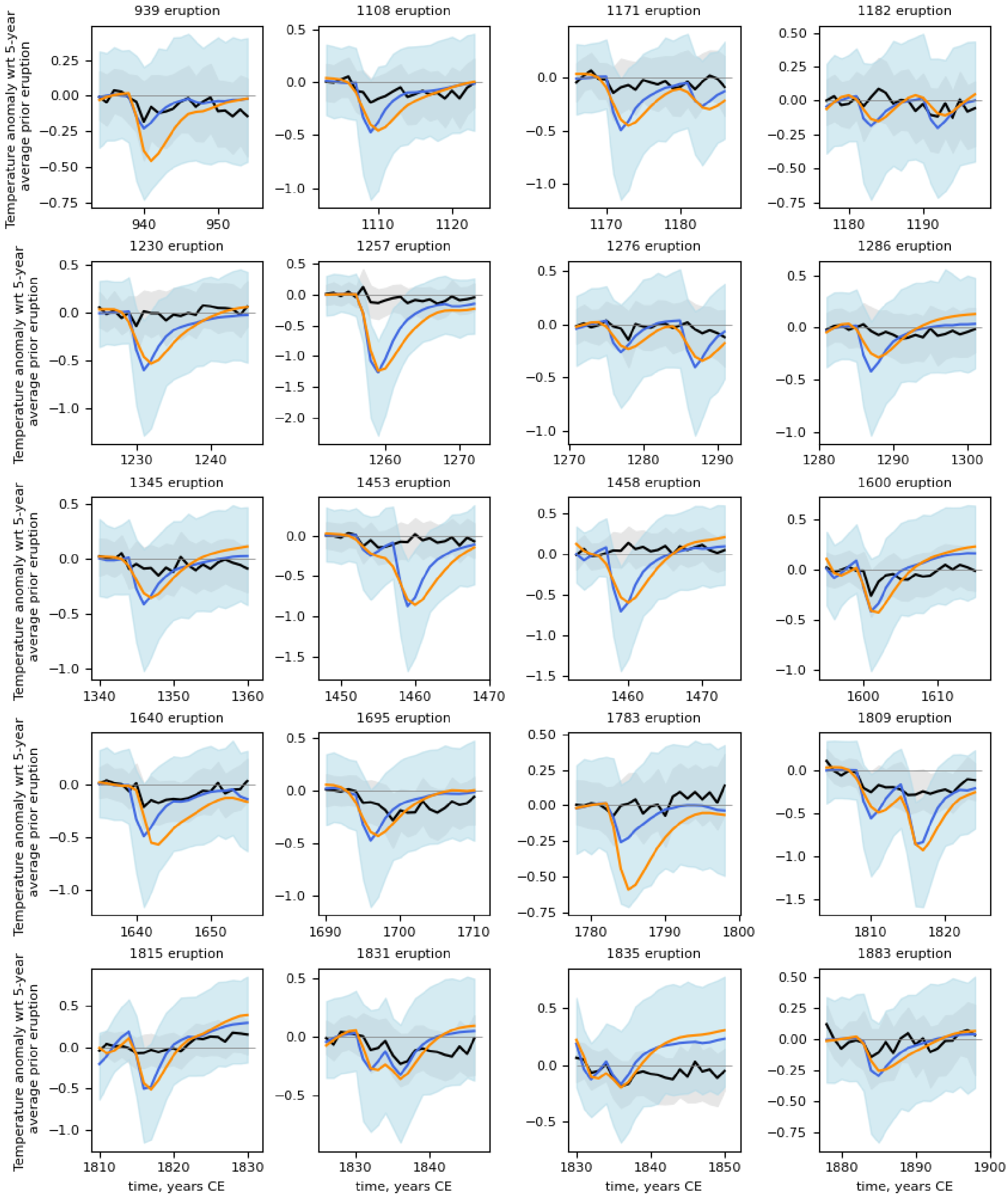

Figure S7: Comparison GMST simulated in this study, in Lücke et al., and reconstructed in PAGES 2k, for the 20 largest eruptions between 885 and 1900 CE.

Table S3: Integrated response of the superposed epoch analysis (Error! Reference source not found.**d)**

Temperature timeseries	**Interval after eruption**			
	0-3 years	0-5 years	0-10 years	0-15 years
NTREND 2015	-0.26 K	-0.32 K	-0.32 K	-0.27 K
Schneider 2015	-0.18 K	-0.18 K	-0.12 K	-0.06 K
Guillet 2017	-0.31 K	-0.33 K	-0.28 K	-0.20 K
Büntgen 2021	-0.15 K	-0.20 K	-0.23 K	-0.20 K
King 2021 *	-0.23 K	-0.21 K	-0.26 K	-0.21 K
Our simulations	-0.34 ± 0.08 K	-0.35 ± 0.08 K	-0.27 ± 0.07 K	0.20 ± 0.06 K
Marshall et al., 2024 AOP driven	-0.49 K	-0.43 K	-0.32 K	-0.23 K
Marshall et al., 2024 SO2 emission driven	-0.55 K	-0.49 K	-0.31 K	-0.20 K
Lücke et al., 2023	-0.40 ± 0.04 K	-0.49 ± 0.03 K	-0.29 ± 0.03 K	0.17 ± 0.02 K