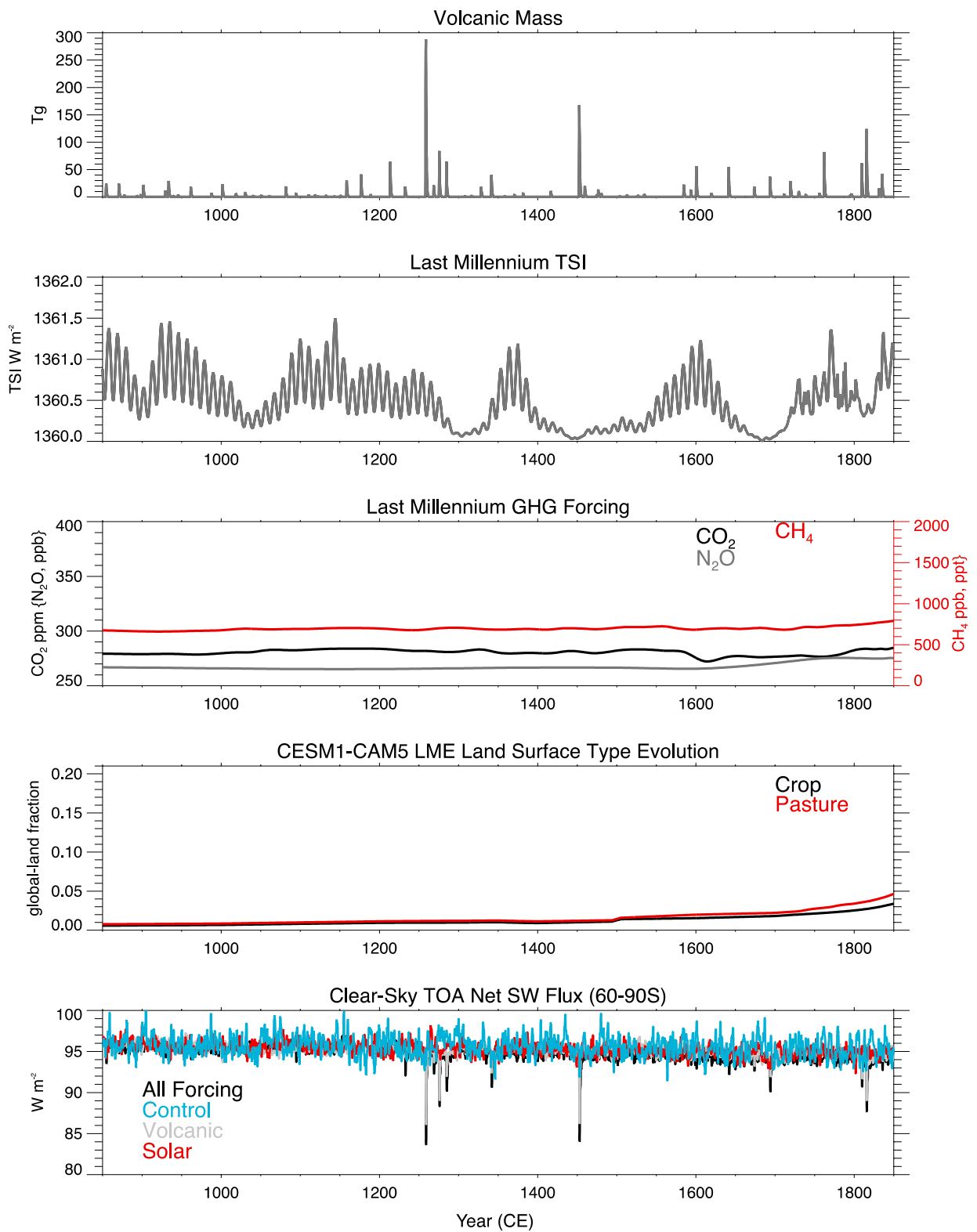


## **Supplementary Materials for**

# **Drivers of last millennium Antarctic climate evolution in an ensemble of Community Earth System Model simulations**

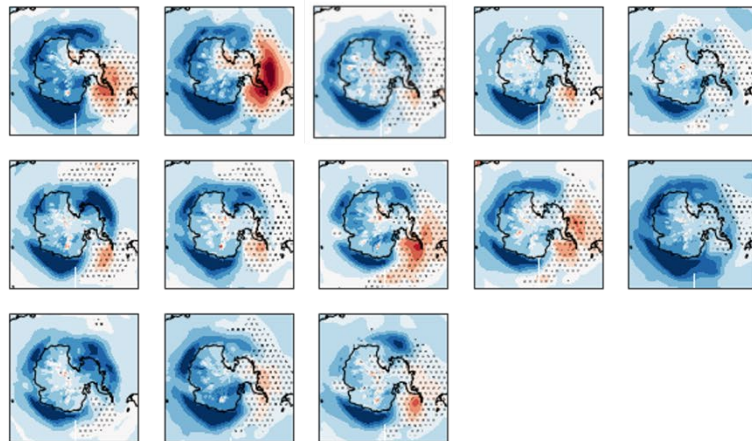
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Gary S. Wilson, Christina R. Riesselman**

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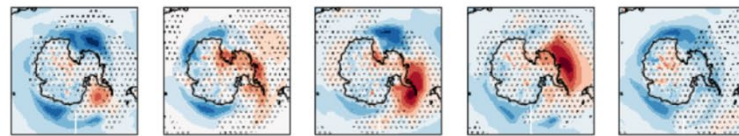


**Figure S1.** Evolution of the major forcings used for the CESM-LME including (from top to bottom): volcanic mass, TSI, GHG concentrations, crop and pasture extent, and top of atmosphere net clear-sky shortwave flux over the Antarctic (60-90°S).

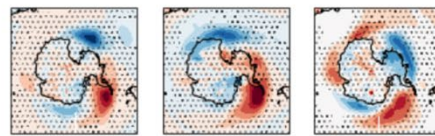
Full forcing ensemble (n=13)



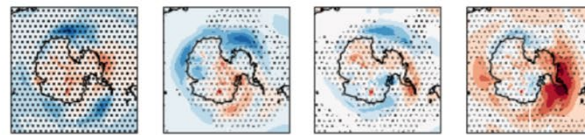
Volcanic forcing ensemble (n=5)



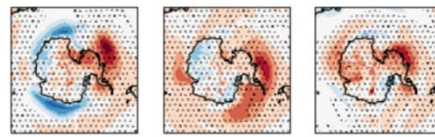
Orbital forcing ensemble (n=3)



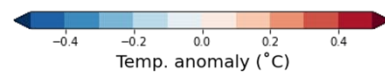
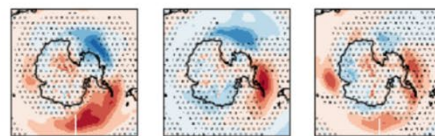
Solar forcing ensemble (n=4)



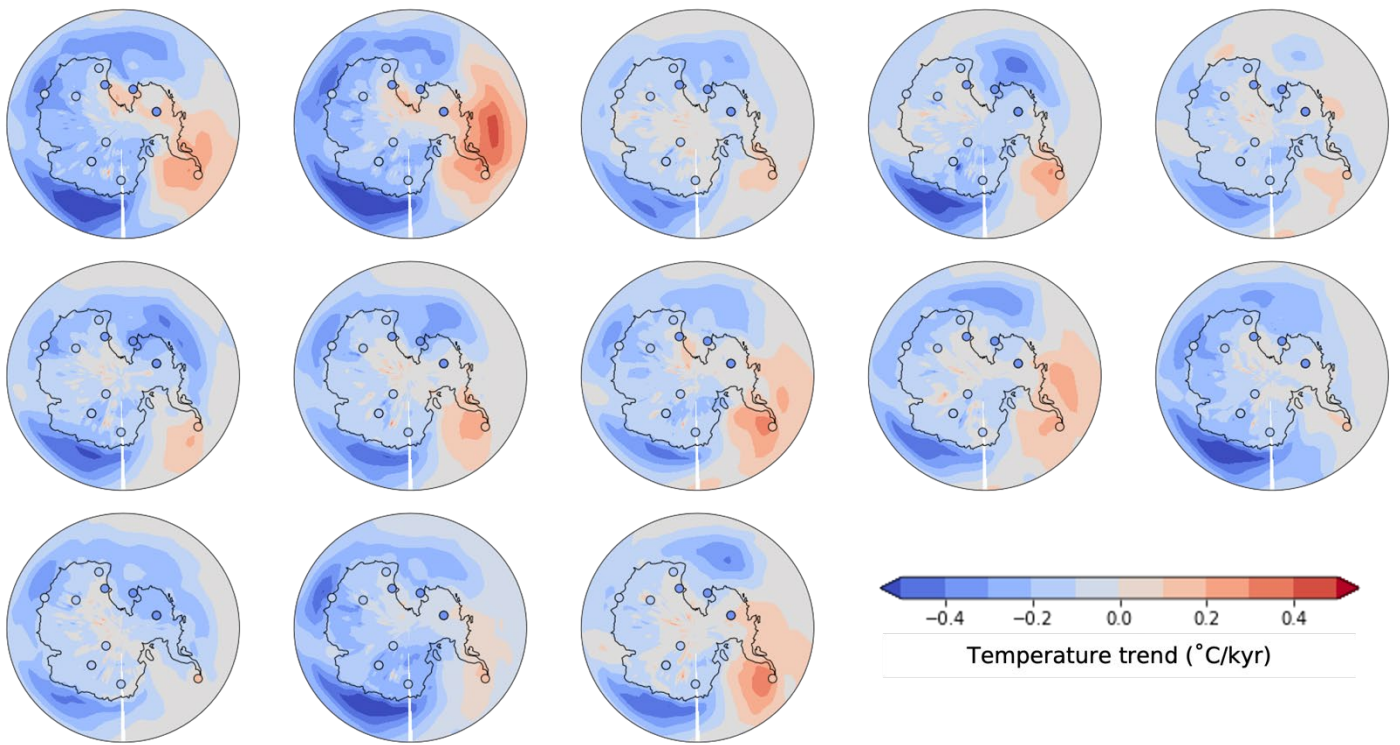
LULC forcing ensemble (n=3)



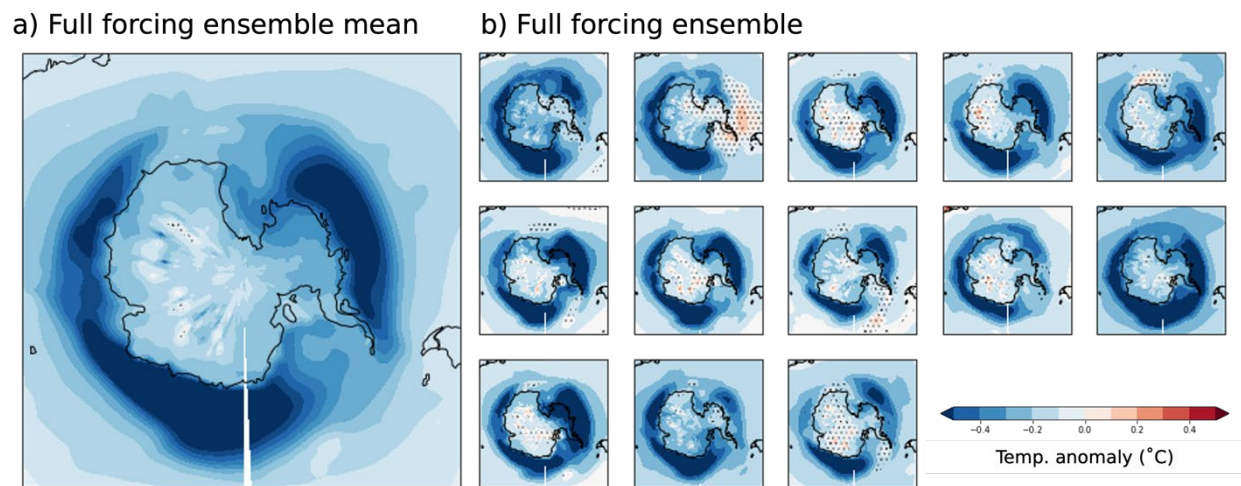
GHG forcing ensemble (n=3)



**Figure S2.** LIA (1600-1850) – MCA (850-1200) temperature anomaly in LME full and single forcing simulations. Stippling indicates differences that are not statistically significant at the 95% level using a Students *t*-test.

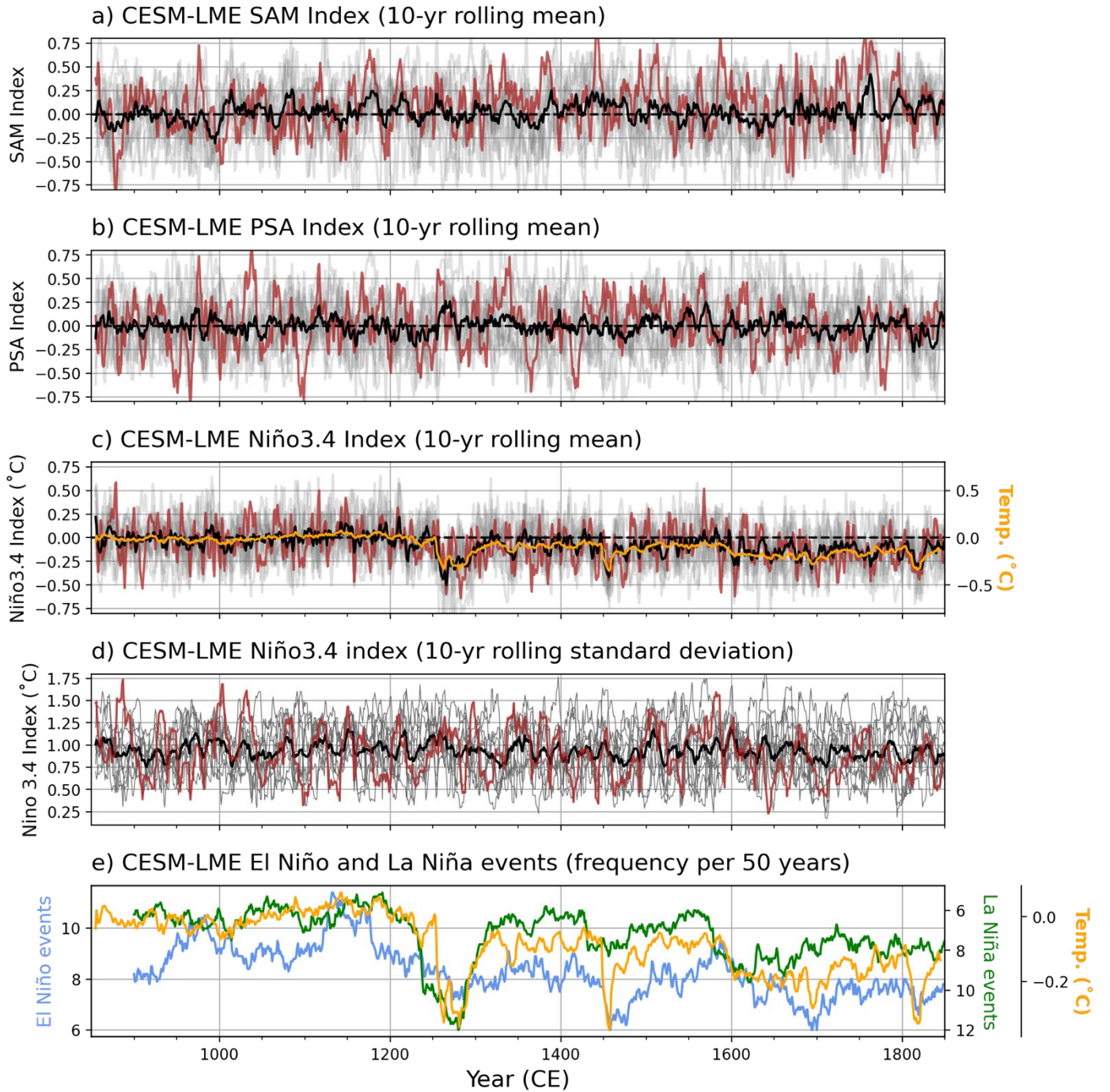


**Figure S3.** Temperature trend (°C/kyr years) for all LME full forcing ensemble members compared to ice core records. The location of records spanning the full LM (850-1850CE) shown on the map; ice core reconstructions are regional composites of all records included in the Stenni et al. [23] data-based. The locations of all records included in the composite are shown in Figure 1.

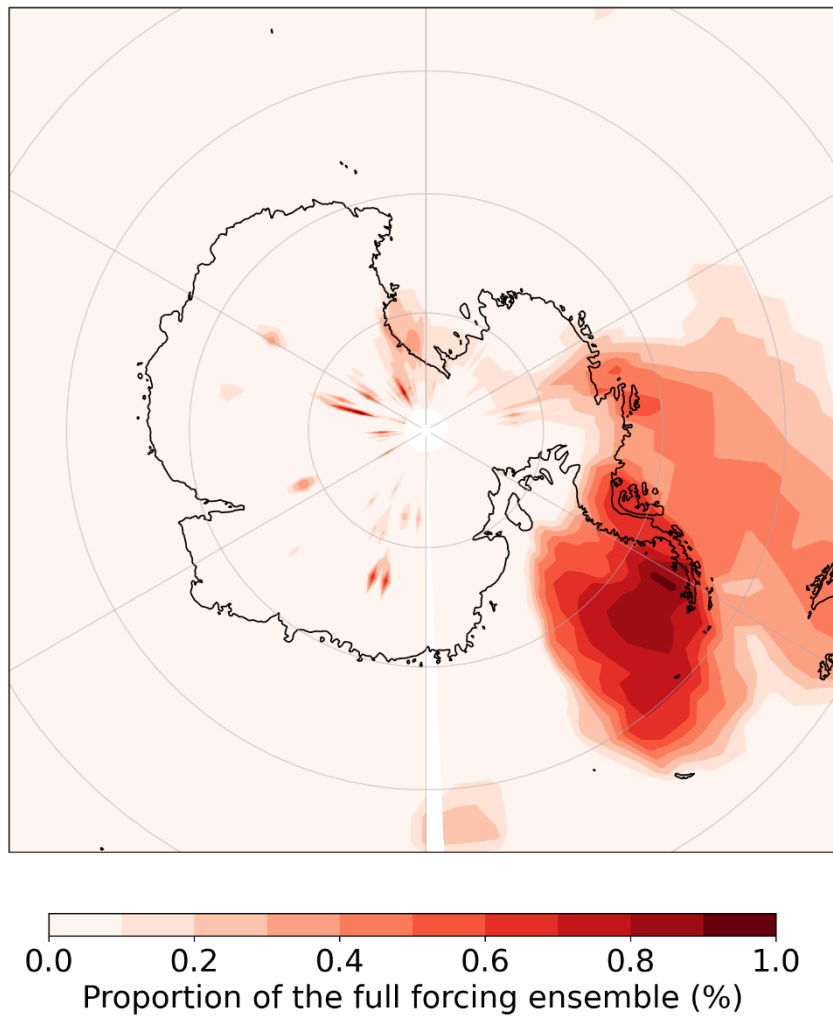


**Figure S4.** LIA (1600-1850) – MCA (850-1200) temperature anomaly in LME full forcing ensemble mean (a) and individual ensemble members (b) that were not detrended using the control simulation. Stippling indicates differences that are not statistically significant at the 95% level using a Student's *t* test.





**Figure S5.** Simulated low frequency (multi-decadal) anomalies from the 850 to 1200 CE mean in modes of large-scale Southern Hemisphere climate variability in the LME. Ensemble mean shown in black, ensemble member 3 is highlighted in red to illustrate modeled SAM variability in individual ensemble members (shown collectively in grey). Orange line on c) and e) shows the global equatorial temperature anomaly (5°S to 5°N). Anomalies are computed relative to the 850-1200 CE mean. El Niño and La Niña events in e) are defined as departures exceeding  $\pm 1\sigma$  of Niño3.4 sea surface temperature anomalies; note the flipped axis for La Niña events.



**Figure S6.** Regions of Antarctica with a LM warming trend (linear temperature trend  $>0^{\circ}\text{C/kyr}$  between 850 and 1850 CE) in the 13 full forcing ensemble simulations.

**Table S1.** List of sites in the Antarctic region and qualitative paleotemperature inference from Lünig et al. [13]. For further discussion of the paleoclimate records, the methodology used to determine a qualitative paleotemperature reconstruction, and full citations for each reconstruction see Lünig et al. [13].

No	Locality	Region	Latitude	Longitude	# of age constraints	Proxies	Reference	Inferred Last Millennium Temperature Trend
1	Kerguelen Islands	Antarctic Islands	-49.44	69.19	9	Moraine dating	Jomelli et al. (2017)	Cooling
2	Ile de la Possession	Antarctic Islands	-46.39	51.81	4	Diatoms	Ooms et al. (2011)	Warming
3	TN057-17	Antarctic Islands	-50.00	6.00	1	Diatoms	Nielsen et al. (2004), Divine et al. (2010)	Neutral
4	PS1652-2	Antarctic Islands	-53.66	5.10	2	Diatoms	Xiao et al. (2016)	Neutral
5	PS2102-2	Antarctic Islands	-53.35	-4.99	4	Diatoms	Xiao et al. (2016)	Cooling
6	Hamberg Lakes	Antarctic Islands	-54.35	-36.33	7	Ti as glacial activity proxy	Clapperton et al. (1989), van der Bilt et al. (2017)	Cooling
7	Fan Lake	Antarctic Islands	-54.50	-37.05	16	Palynology, GDGT	Strother et al. (2015), Foster et al. (2016)	Cooling
8	Signy Island	Antarctic Islands	-60.72	-45.63	5	$\delta^{18}\text{O}$ of authigenic lake carbonate, mites	Noon et al. (2003), Hodgson and Convey (2005)	Cooling
9	A9-EB2, eastern Bransfield Basin	Antarctic Peninsula	-61.97	-55.96	9	Magnetic susceptibility	Khim et al. (2002)	Cooling
10	JPC24	Antarctic Peninsula	-62.28	-57.63	5	TOC	Barnard et al. (2014)	Cooling
11	GEBRA-1	Antarctic Peninsula	-62.59	-58.54	3	Diatoms	Bárcena et al. (1998)	Cooling
12	PS69/335	Antarctic Peninsula	-62.26	-58.77	5	Elemental ratios, TOC, opal, grain size	Hass et al. (2010), Monien et al. (2011)	Neutral
13	Collins Ice Cap	Antarctic Peninsula	-62.18	-58.90	12	Dating mosses	Hall (2007)	Cooling
14	Ardley Island	Antarctic Peninsula	-62.21	-58.94	?	P <sub>2</sub> O <sub>5</sub>	Sun et al. (2000), Huang et al. (2011), Liu et al. (2005)	Cooling
15	Yanou Lake	Antarctic Peninsula	-62.22	-58.96	3	GDGT-MSAT	Roberts et al. (2017)	Neutral*



16	Midge Lake	Antarctic Peninsula	-62.63	-61.09	2	LOI	Björck et al. (1991)	Neutral
17	JPC2	Antarctic Peninsula	-63.36	-55.84	12	TOC, Ikaite crystallization	Lu et al. (2012)	Neutral
18	JPC38	Antarctic Peninsula	-63.72	-57.41	2	Diatoms	Barbara et al. (2016)	Cooling
19	Hidden Lake	Antarctic Peninsula	-63.40	-57.00	3	LOI	Zale (1994)	Cooling
20	Herbert Sound	Antarctic Peninsula	-63.96	-57.73	9	Diatoms, petrography	Minzoni et al. (2015)	Warming
21	JRI ice core	Antarctic Peninsula	-64.20	-57.68	16	$\delta D$	Mulvaney et al. (2012), Abram et al. (2013)	Warming
22	Anvers Island	Antarctic Peninsula	-64.49	-63.87	6	Dating mosses and shells	Hall et al. (2010)	Cooling
23	U.S. Palmer Station	Antarctic Peninsula	-64.78	-64.04	24	Dating mosses	Yu et al. (2016)	Cooling
24	Litchfield Island	Antarctic Peninsula	-64.77	-64.09	8	Peat accumulation rate	Stelling et al. (2018)	Neutral*
25	ODP 1098	Antarctic Peninsula	-64.86	-64.20	2	Magnetic susceptibility, Tex <sub>86</sub> , benthic foraminifera isotopes	Domack and Mayewski (1999), Shevenell and Kennett (2002), Shevenell et al. (2011)	Cooling
26	Bigo Bay	Antarctic Peninsula	-65.61	-64.76	5	Total organic carbon, biogenic opal	Kim et al. (2018)	Cooling
27	KC-55	Antarctic Peninsula	-65.66	-64.92	4	Total organic carbon	Christ et al. (2015)	Cooling
28	Müller Ice Shelf	Antarctic Peninsula	-67.20	-66.88	2	Sedimentology, geochemistry, foraminifera	Domack et al. (1995)	Cooling
29	Rothera Point	Antarctic Peninsula	-67.57	-68.10	5	Dating mosses	Guglielmin et al. (2016)	Cooling
30	JPC43	Antarctic Peninsula	-68.26	-66.96	1	Magnetic susceptibility	Allen et al. (2010)	Neutral
31	Berkner Island Ice Core	Ronne & Filchner Ice Shelf	-79.57	-45.78	-	$\delta D$ , $\delta^{18}O$	Mulvaney et al. (2002), Graf et al. (2006)	Warming
32	Dronning Maud Land Traverse	East Antarctica	-75.36	-4.22	-	$\delta^{18}O$	Graf et al. (2002)	Cooling

33	Schirmacher Oasis	East Antarctica	-70.76	11.59	3	TOC, BSi, grain size, elemental geochemistry	Govil et al. (2016)	Warming
34	Lützow Holm Bay	East Antarctica	-69.50	39.70	18	Diatoms, sedimentology, geochemistry	Tavernier et al. (2014)	Neutral*
35	Dome Fuji Ice Core	East Antarctica	-77.32	39.70	-	$\delta^{18}\text{O}$	Horiuchi et al. (2008)	Cooling
36	Plateau Remote Ice Core	East Antarctica	-84.00	43.00	-	$\delta^{18}\text{O}$	Mosley-Thompson (1996)	Cooling
37	Lake Terrasovoje AM02 core	East Antarctica	-70.55	68.00	4	Diatoms, geochemistry	Wagner et al. (2004)	Neutral*
38	Amery Ice Shelf	East Antarctica	-69.71	72.64	1	Diatoms	Hemer and Harris (2003)	Cooling
39	Kirisjes Pond	East Antarctica	-69.37	76.13	3	Diatoms	Verleyen et al. (2004)	Cooling
40	Co1010	East Antarctica	-68.80	77.95	2	TOC	Berg et al. (2010)	Neutral
41	Zolotov Island	East Antarctica	-68.65	77.87	4	$\text{P}_2\text{O}_5$	Huang et al. (2011)	Neutral*
42	Long Peninsula	East Antarctica	-68.50	78.10	6	P/Al	Gao et al. (2019)	Cooling
43	Dome B Ice Core	East Antarctica	-77.90	94.92	-	$\delta\text{D}$	Masson et al. (2000), Vimeux et al. (2001)	Cooling
44	Vostok Ice Core EPICA	East Antarctica	-78.47	106.80	-	$\delta\text{D}$	Masson et al. (2000), Vimeux et al. (2001)	Neutral
45	Dome Concordia ("Dome C") Ice Core	East Antarctica	-75.10	123.35	-	$\delta\text{D}$	Masson et al. (2000), Masson-Delmotte et al. (2004)	Cooling
46	Dome Summit South (DSS) - Law Dome Ice Core	East Antarctica	-66.77	112.81	-	$\delta\text{D}$ , $\delta^{18}\text{O}$	Morgan and Ommen (1997), Dahl-Jensen et al. (1999), Roberts et al. (2001), Plummer et al. (2012), Goosse et al. (2004)	Neutral
47	TALDICE Ice Core	East Antarctica	-72.82	159.18	-	$\delta^{18}\text{O}$ , $\delta\text{D}$ , deuterium excess	PAGES 2k Consortium (2017), Mezgec et al. (2017)	Cooling
48	WRS_CH	Ross Sea	-72.30	170.00	3	Diatoms	Mezgec et al. (2017)	Cooling
49	WRS_WB	Ross Sea	-74.18	166.00	3	Diatoms	Mezgec et al. (2017)	Cooling

50	Edmonson Point Glacier	Victoria Land coast	-74.32	165.07	10	Moraine dating	Baroni and Orombelli (1994b)	Cooling
51	Prior Island	Victoria Land coast	-75.68	162.87	6	Penguin remains ages	Baroni and Orombelli (1994a)	Cooling
52	Western Ross Sea Offshore	Victoria Land coast	-76.00	162.00	51	Dating elephant seal skin	Hall et al. (2006)	Cooling
53	core KC208.09	Ross Sea	-77.00	162.85	3	Diatoms	Leventer et al. (1993)	Cooling
54	Lower Glacier Ice Core	Victoria Land coast	-77.33	162.53	4	$\delta D$	Bertler et al. (2011)	Cooling
55	Wilson Piedmont Glacier	Victoria Land coast	-77.37	163.50	27	Glacial topo- graphy dating	Hall and Denton (2002)	Cooling
56	Taylor Dome Ice Core	East Ant- arctica	-77.80	158.72	-	$\delta D, \delta^{18}O$	Steig et al. (1998)	Cooling
57	RICE Ice Core	Eastern Ross Sea	-79.39	-161.46	-	$\delta D$	Bertler et al. (2018)	Cooling
58	Siple Dome Ice Core	West Ant- arctica	-81.67	-148.83	-	$\delta D, \delta^{18}O$	Mayewski et al. (2013)	Cooling
59	Dominion Range Ice Core	East Ant- arctica	-79.47	-112.09	-	$\delta D$	Masson et al. (2000)	
60	WAIS Di- vide Ice Core	West Ant- arctica	-75.36	-4.22	-	$\delta^{18}O$ , air bubble density	Steig et al. (2013), Fegyveresi et al. (2016), Fudge et al. (2016)	Warming

\*Record without reliable resolution or age control