Supplementary material A

Surface ocean temperatures

Age (Ma)	Longitude	Latitude	T (degC)	Site name	Reference	Paleo Latitude	Paleo longitude
0.006	175.0	-46.0	11.1	594	Herbert et al 2016	175.00	-46.00
0.006	60.0	17.0	26.8	722	Herbert et al 2016	60.00	17.00
0.006	159.0	0.0	27	806	Zhang et al 2014	159.00	0.00
0.006	-91.0	-3.0	23	846	Zhang et al 2014	-91.00	-3.00
0.006	-95.0	0.0	22.5	847	Zhang et al 2014	-95.00	0.00
0.006	-111.0	1.0	25.2	850	Herbert et al 2016	-111.00	1.00
0.006	-111.0	1.0	22	850	Zhang et al 2014	-111.00	1.00
0.006	-148.0	54.0	7.2	887	Herbert et al 2016	-148.00	54.00
0.006	-13.0	69.0	1.77	907	Herbert et al 2016	-13.00	69.00
0.006	-16.0	58.0	10.8	982	Herbert et al 2016	-16.00	58.00
0.006	-118.0	30.0	17.3	1010	Herbert et al 2016	-118.00	30.00
0.006	-128.0	39.0	14.32	1021	Herbert et al 2016	-128.00	39.00
0.006	14.0	-30.0	17.33	1085	Herbert et al 2016	14.00	-30.00
0.006	14.0	-41.0	13.8	1088	Herbert et al 2016	14.00	-41.00
0.006	-178.0	-42.0	14.45	1125	Herbert et al 2016	-178.00	-42.00
0.006	158.5	36.1	18.7	1208	Herbert et al 2016	158.50	36.10
0.006	-86.0	6.0	27.73	1241	Herbert et al 2016	-86.00	6.00
0.006	-118.0	3.0	25.6	U1338	Herbert et al 2016	-118.00	3.00
0.006	168.0	51.0	5.4	883/4	Herbert et al 2016	168.00	51.00
0.006	14.0	44.0	19.2	med	Herbert et al 2016	14.00	44.00
2.5	60.0	17.0	27.5	722	Herbert et al 2016	59.49	16.30
2.5	121.0	9.0	29	769	Zhang et al 2014	120.62	9.05
2.5	159.0	0.0	27.5	806	Zhang et al 2014	160.74	-0.94
2.5	-91.0	-3.0	25	846	Zhang et al 2014	-92.32	-3.19
2.5	-95.0	0.0	25	847	Zhang et al 2014	-96.38	-0.13
2.5	-111.0	1.0	25.5	850	Herbert et al 2016	-109.26	0.45
2.5	-111.0	1.0	24.5	850	Zhang et al 2014	-109.26	0.45
2.5	-13.0	69.0	6	907	Herbert et al 2016	-13.50	69.02
2.5	-16.0	58.0	14	982	Herbert et al 2016	-15.64	58.00
2.5	-118.0	30.0	18	1010	Herbert et al 2016	-116.74	29.30
2.5	-128.0	39.0	13	1021	Herbert et al 2016	-126.83	38.16
2.5	14.0	-30.0	19	1085	Herbert et al 2016	13.50	-30.17
2.5	14.0	-41.0	18	1088	Herbert et al 2016	13.45	-41.17

Age (Ma)	Longitude	Latitude	T (degC)	Site name	Reference	Paleo Latitude	Paleo longitude
2.5	-178.0	-42.0	18	1125	Herbert et al 2016	-176.41	-43.09
2.5	113.0	9.0	28	1143	Zhang et al 2014	112.64	9.04
2.5	158.5	36.1	21	1208	Herbert et al 2016	160.67	35.15
2.5	-86.0	6.0	27.9	1241	Herbert et al 2016	-87.19	4.38
2.5	-118.0	3.0	27	U1338	Herbert et al 2016	-116.20	1.80
2.5	-118.0	3.0	26	U1338	Zhang et al 2014	-116.20	1.80
2.5	168.0	51.0	7	883/4	Herbert et al 2016	170.26	49.98
2.5	14.0	44.0	25	med	Herbert et al 2016	13.76	43.83
4.5	175.0	-46.0	13	594	Herbert et al 2016	182.42	-47.85
4.5	60.0	17.0	27.5	722	Herbert et al 2016	59.09	15.78
4.5	121.0	9.0	29	769	Zhang et al 2014	120.36	9.04
4.5	159.0	0.0	28	806	Zhang et al 2014	162.14	-1.64
4.5	-91.0	-3.0	26.5	846	Zhang et al 2014	-93.57	-3.33
4.5	-95.0	0.0	26.5	847	Zhang et al 2014	-97.49	-0.23
4.5	-111.0	1.0	26.5	850	Herbert et al 2016	-107.86	0.01
4.5	-111.0	1.0	26.5	850	Zhang et al 2014	-107.86	0.01
4.5	-13.0	69.0	9	907	Herbert et al 2016	-13.90	69.03
4.5	-16.0	58.0	19	982	Herbert et al 2016	-15.38	58.02
4.5	-118.0	30.0	21.5	1010	Herbert et al 2016	-115.69	28.81
4.5	-128.0	39.0	17	1021	Herbert et al 2016	-125.85	37.56
4.5	14.0	-30.0	21	1085	Herbert et al 2016	13.11	-30.29
4.5	14.0	-41.0	18.5	1088	Herbert et al 2016	13.03	-41.29
4.5	-178.0	-42.0	19	1125	Herbert et al 2016	-175.10	-43.90
4.5	113.0	9.0	29	1143	Zhang et al 2014	112.36	9.06
4.5	158.5	36.1	22	1208	Herbert et al 2016	162.36	34.40
4.5	-86.0	6.0	28.2	1241	Herbert et al 2016	-88.37	3.09
4.5	-118.0	3.0	27.5	U1338	Herbert et al 2016	-114.75	1.32
4.5	-118.0	3.0	27	U1338	Zhang et al 2014	-114.75	1.32
4.5	168.0	51.0	9	883/4	Herbert et al 2016	172.00	49.22
4.5	14.0	44.0	25	med	Herbert et al 2016	13.58	43.71
7.5	175.0	-46.0	16	594	Herbert et al 2016	181.91	-48.88
7.5	60.0	17.0	28	722	Herbert et al 2016	58.45	14.99
7.5	159.0	0.0	30.5	806	Zhang et al 2014	164.22	-2.58
7.5	-91.0	-3.0	28	846	Herbert et al 2016	-95.76	-3.53
7.5	-111.0	1.0	27.6	850	Herbert et al 2016	-105.77	-0.65
7.5	-111.0	1.0	27.5	850	Zhang et al 2014	-105.77	-0.65
7.5	-148.0	54.0	16	887	Herbert et al 2016	-144.23	51.25
7.5	-13.0	69.0	11	907	Herbert et al 2016	-14.50	69.04
7.5	-16.0	58.0	23	982	Herbert et al 2016	-15.00	58.04

Age (Ma)	Longitude	Latitude	T (degC)	Site name	Reference	Paleo Latitude	Paleo longitude
7.5	-118.0	30.0	24	1010	Herbert et al 2016	-114.05	28.18
7.5	-128.0	39.0	17	1021	Herbert et al 2016	-124.28	36.79
7.5	14.0	-30.0	23	1085	Herbert et al 2016	12.53	-30.46
7.5	14.0	-41.0	20	1088	Herbert et al 2016	12.39	-41.46
7.5	-178.0	-42.0	23	1125	Herbert et al 2016	-173.08	-44.94
7.5	113.0	9.0	30	1143	Zhang et al 2014	111.95	9.08
7.5	158.5	36.1	24	1208	Herbert et al 2016	164.81	33.36
7.5	-86.0	6.0	27.9	1241	Herbert et al 2016	-90.53	1.20
7.5	-118.0	3.0	28	U1338	Herbert et al 2016	-112.59	0.71
7.5	-118.0	3.0	27	U1338	Zhang et al 2014	-112.59	0.71
7.5	168.0	51.0	12	883/4	Herbert et al 2016	174.49	48.21
7.5	14.0	44.0	26	med	Herbert et al 2016	13.33	43.53
10	175.0	-46.0	19.5	594	Herbert et al 2016	180.29	-49.58
10	-23.0	42.8	24	608	Super et al 2018	-24.62	42.75
10	60.0	17.0	28	722	Herbert et al 2016	57.85	14.28
10	121.0	9.0	30	769	Zhang et al 2014	119.58	9.11
10	159.0	0.0	30	806	Zhang et al 2014	165.92	-3.22
10	-91.0	-3.0	28.5	846	Herbert et al 2016	-97.89	-3.68
10	-111.0	1.0	27.8	850	Herbert et al 2016	-104.03	-1.20
10	-111.0	1.0	27.5	850	Zhang et al 2014	-104.03	-1.20
10	-13.0	69.0	17	907	Herbert et al 2016	-15.00	69.06
10	-16.0	58.0	25	982	Herbert et al 2016	-14.62	58.01
10	-118.0	30.0	26	1010	Herbert et al 2016	-112.62	27.77
10	-128.0	39.0	21	1021	Herbert et al 2016	-122.89	36.28
10	14.0	-30.0	25	1085	Herbert et al 2016	12.03	-30.65
10	14.0	-41.0	20	1088	Herbert et al 2016	11.85	-41.65
10	-178.0	-42.0	25	1125	Herbert et al 2016	-171.39	-45.64
10	113.0	9.0	30	1143	Zhang et al 2014	111.62	9.11
10	158.5	36.1	24	1208	Herbert et al 2016	166.76	32.59
10	-86.0	6.0	28.2	1241	Herbert et al 2016	-92.68	-0.35
10	-118.0	3.0	28	U1338	Herbert et al 2016	-110.79	0.31
10	-118.0	3.0	27.5	U1338	Zhang et al 2014	-110.79	0.31
10	168.0	51.0	14	883/4	Herbert et al 2016	176.47	47.51
10	14.0	44.0	28	med	Herbert et al 2016	13.13	43.33
12.5	175.0	-46.0	23.5	594	Herbert et al 2016	179.15	-50.10
12.5	-23.0	42.8	27	608	Super et al 2018	-24.91	42.61
12.5	-91.0	-3.0	28.5	846	Herbert et al 2016	-100.28	-3.82
12.5	-111.0	1.0	28.5	850	Herbert et al 2016	-102.28	-1.75
12.5	-13.0	69.0	19	907	Herbert et al 2016	-15.50	69.07

Age (Ma)	Longitude	Latitude	T (degC)	Site name	Reference	Paleo Latitude	Paleo longitude
12.5	-16.0	58.0	26	982	Herbert et al 2016	-14.14	57.90
12.5	-118.0	30.0	27	1010	Herbert et al 2016	-111.12	27.45
12.5	-128.0	39.0	22	1021	Herbert et al 2016	-121.44	35.90
12.5	14.0	-30.0	27	1085	Herbert et al 2016	11.51	-30.92
12.5	14.0	-41.0	20	1088	Herbert et al 2016	11.29	-41.92
12.5	-118.0	3.0	28.3	U1338	Herbert et al 2016	-108.98	0.00
12.5	14.0	44.0	28	med	Herbert et al 2016	12.95	43.05
15	-23.0	42.8	31	608	Super et al 2018	-25.07	42.33
15	-16.0	58.0	27	982	Herbert et al 2016	-13.51	57.66
15	-118.0	3.0	28.8	U1338	Herbert et al 2016	-107.18	-0.20
15	149.0	-48.0	17	1171	Shevenell et al 2004	149.02	-56.75
15	116.00	19.00	28	1146	Holbourn et al 2010	114.01	19.01

Table S1, Published data for surface ocean temperatures used in this study.

References for A

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Supplementary material B

Benthic ocean $\delta^{13}C$ and $\delta^{18}O$ data points

Age slice	site tag	paleo longitude	paleo latitude	depth	$\delta^{13}C$ (‰)	$\delta^{18}O$ (‰)	Data reference	age model reference	$\delta^{18}O_{sw}$ (‰) (Cramer et al 2011)	calculated temperature (°C) (uncorrected for S) (Marchitto et al 2014 eq 8)
15	608	-25.1	42.4	3526	**1.25**	**0.95**	Miller et al 1987	Miller et al 1987	-0.75	**6.93**
15	1146	114.1	19.7	2092	**1.4**	**1.4**	Holbourn et al 2007	Nathan and Leckie 2003	-0.75	**4.93**
15	U1336	-118.3	4.5	4286	**1.44**	**1.5**	Voigt et al 2015	Voigt et al 2015	-0.75	**4.49**
15	U1335	-116.3	2.2	4330	**1.25**	**1.6**	Kochhann et al 2016	Kochhann et al 2016	-0.75	**4.04**
15	667	-24.3	4.1	3529	**1.3**	**1.95**	Woodruff and Savin 1991	Ruddimann et al 2005	-0.75	**2.49**
15	U1337	-113.1	0.9	4211	**1.35**	**1.4**	Kochhann et al 2016	Kochhann et al 2016	-0.75	**4.93**
15	U1338	-107.6	-0.2	4211	**1.3**	**1.29**	Holbourn et al 2014	Holbourn et al 2014	-0.75	**5.42**
15	806	169.5	-3.5	2520	**1.86**	**1.5**	Corfield et al 1993	Corfield et al 1993	-0.75	**4.49**
15	289	168.7	-4.3	2206	**1.45**	**1.25**	Woodruff and Savin 1991	Lazarus et al 1995	-0.75	**5.60**
15	709	57.9	-5.4	3049	**1.035**	**1.55**	Woodruff 1990	Woodruff 1990	-0.75	**4.27**
15	237	55.4	-8.4	1623	**1.6**	**1.62**	Woodruff and Savin 1991	Woodruff and Savin 1991	-0.75	**3.96**
15	525	-0.3	-30.2	2467	**1.5**	**2.1**	Woodruff and Savin 1991	Lazarus et al 1995	-0.75	**1.82**
15	1172	149.6	-52.4	2622	**1.52**	**1.75**	Ennyu et al 2004	Ennyu et al 2004	-0.75	**3.38**
15	1170	145.3	-55.9	2705	**1.45**	**1.4**	Ennyu et al 2004	Ennyu et al 2004	-0.75	**4.93**
15	744	77.6	-61.4	2317	**1.5**	**1.8**	Majewski 2002	Majewski 2002	-0.75	**3.16**
12.5	555	-22.9	56.4	1582	**1**	**1.9**	Wright Miller Fairbanks 1992	Cramer et al 2018	-0.2	**5.16**
12.5	553	-25.4	55.9	2233	**1**	**1.8**	Miller Aubry et al 1985	Cramer et al 2018	-0.2	**5.60**
12.5	608	-25.0	42.7	3379	**0.95**	**1.8**	Wright Miller 1996, Miller Fairbanks Thomas 1987	Cramer et al 2018	-0.2	**5.60**
12.5	563	-41.9	33.4	3518	**1.1**	**2.03**	Woodruff and Savin 1991, Wright Millar Fairbanks 1991, Wright Millar Fairbanks 1992, Miller Fairbanks 1985	Cramer et al 2018	-0.2	**4.56**
12.5	1146	114.5	19.6	2092	**0.65**	**2.1**	Holbourn et al 2013	Holbourn et al 2013	-0.2	**4.27**
12.5	667	-23.8	4.3	3400	**1**	**1.7**	Woodruff and Savin 1991	Cramer et al 2018	-0.2	**6.04**
12.5	574	-124.7	0.9	4268	**0.9**	**2.4**	Pisias Shackelton Hall 1985	Cramer et al 2018	-0.2	**2.93**
12.5	926	-41.3	3.8	3626	**1.2**	**1.75**	Shackelton Hall 1997	Cramer et al 2018	-0.2	**5.82**
12.5	806	167.8	-3.2	2520	**1**	**2.1**	Corfield et al 1993	Corfield et al 1993	-0.2	**4.27**
12.5	289	167.0	-4.0	2453	**0.9**	**2.25**	Savin Douglas et al 1981, Woodruff et al 1981, Woodruff and Savin 1991	Cramer et al 2018	-0.2	**3.60**
12.5	709	58.4	-5.0	3049	**0.92**	**2.56**	Woodruff 1990	Woodruff 1990	-0.2	**2.22**
12.5	237	56.0	-8.0	1623	**0.93**	**2.28**	Woodruff and Savin 1991	Woodruff and Savin 1991	-0.2	**3.47**
12.5	317	-153.5	-15.2	2638	**0.85**	**2.35**	Woodruff and Savin 1989	Cramer et al 2018	-0.2	**3.16**
12.5	1237	-86.2	-17.8	3212	**0.9**	**2.4**	Holbourn et al 2007	Holbourn 2005	-0.2	**2.93**
12.5	527	-0.8	-28.8	4357	**1**	**2.25**	"ref 2" (Cramer et al 2018)	Cramer et al 2018	-0.2	**3.60**
12.5	525	0.3	-29.8	2470	**1.5**	**2.2**	Shackelton Hall and Boersma 1984	Cramer et al 2018	-0.2	**3.82**
12.5	357	-33.4	-29.8	2037	**1.1**	**2.4**	Savin	Cramer et al 2018	-0.2	**2.93**

Age slice	site tag	paleo longitude	paleo latitude	depth	$\delta^{13}C$ (‰)	$\delta^{18}O$ (‰)	Data reference	age model reference	$\delta^{18}O_{sw}$ (‰) (Cramer et al 2011)	calculated temperature (°C) (uncorrected for S) (Marchitto et al 2014 eq 8)
12.5	360	15.4	-36.8	3108	**0.85**	**2.1**	Wright Miller Fairbanks 1992	Cramer et al 2018	-0.2	**4.27**
12.5	1172	149.2	-51.0	2622	**1.2**	**2.6**	Ennyu et al 2004	Ennyu et al 2004	-0.2	**2.04**
12.5	1170	145.0	-54.7	2705	**1.437**	**2.74**	Ennyu et al 2004	Ennyu et al 2004	-0.2	**1.42**
12.5	1171	148.7	-56.1	1903	**1.1**	**2.2**	Shevenell Kennett et al 2004	Cramer et al 2018	-0.2	**3.82**
12.5	1120	130.3	-54.0	544	**1**	**1.6**	Ando et al 2011	Carter et al 1999	-0.2	**6.49**
12.5	747	74.1	-54.4	1685	**1.035**	**2.45**	Majewski and Bohaty 2010, Billups and Schrag 2002, Wright and Miller 1992	NeptuneSB (Renaudie et al 2019, Lazarus 1994), Cramer et al 2018	-0.2	**2.71**
12.5	744	77.8	-61.3	2311	**1.2**	**2.3**	Woodruff and Chambers 1991	Cramer et al 2018	-0.2	**3.38**
10	982	-17.5	57.5	1134	**1.25**	**1.9**	Andersson and Jansen 2003	Andersson and Jansen 2003	-0.1	**5.60**
10	555	-22.6	56.5	1581	**1.1**	**2.1**	Wright Miller Fairbanks 1992	Cramer et al 2018	-0.1	**4.71**
10	554	-25.3	56.3	2463	**1.3**	**2.3**	BF (Cramer et al 2018)	Cramer et al 2018	-0.1	**3.82**
10	553	-25.1	56.0	2275	**1**	**2**	Miller Aubry et al 1985	Cramer et al 2018	-0.1	**5.16**
10	552	-25.0	56.0	2233	**1**	**2.2**	Keigwin Aubry Kent 1987	Cramer et al 2018	-0.1	**4.27**
10	410	-27.9	45.2	2396	**1.35**	**2**	Keigwin Aubry Kent 1987	Cramer et al 2018	-0.1	**5.16**
10	608	-24.7	42.8	3526	**1**	**1.8**	Miller Fairbanks Thomas 1987, Wright Miller 1996	Cramer et al 2018	-0.1	**6.04**
10	334	-33.0	36.7	2012	**1.5**	**1.6**	Keigwin Aubry Kent 1987	Cramer et al 2018	-0.1	**6.93**
10	310	-175.6	33.3	3529	**0.5**	**2.2**	Keigwin 1979	Cramer et al 2018	-0.1	**4.27**
10	563	-42.4	33.5	3786	**1.2**	**1.8**	Wright Miller Fairbanks 1991, Wright Miller Fairbanks 1992	Cramer et al 2018	-0.1	**6.04**
10	1146	114.9	19.6	2092	**0.5**	**2.2**	Holbourn et al 2013	Holbourn et al 2013	-0.1	**4.27**
10	926	-41.6	3.8	3638	**1.1**	**1.95**	Lear et al 2003, Shackelton Hall 1997	Cramer et al 2018	-0.1	**5.38**
10	289	165.4	-3.6	2383	**0.7**	**2.2**	Savin, Douglas et al 1981	Cramer et al 2018	-0.1	**4.27**
10	709	58.9	-4.7	3049	**0.6**	**2.7**	Woodruff 1990	Woodruff 1990	-0.1	**2.04**
10	525	0.9	-29.6	2470	**1.4**	**2.3**	Shackelton Hall Boersma 1984	Cramer et al 2018	-0.1	**3.82**
10	357	-33.9	-29.8	2046	**1.2**	**2.2**	Cramer et al 2018	Cramer et al 2018	-0.1	**4.27**
10	360	16.0	-36.5	2949	**0.8**	**1.8**	Wright et al 1991, Wright Miller Fairbanks 1992	Mudelsee et al 2014, Wright et al 1991, Cramer et al 2018	-0.1	**6.04**
10	1088	11.3	-41.8	2082	**0.8**	**2.5**	Billups 2002	Billups 2002	-0.1	**2.93**
10	1172	149.1	-49.7	2622	**0.9**	**2.7**	Ennyu et al 2004	Ennyu et al 2004	-0.1	**2.04**
10	704	5.1	-47.4	2541	**0.85**	**2**	Wright et al 1991, Katz Miller 1991, Muller Hodell et al 1991	Wright et al 1991, Cramer et al 2018	-0.1	**5.16**
10	1120	174.2	-53.5	544	**1.6**	**1.8**	Ando et al 2011	Carter et al 1999	-0.1	**6.04**
10	747	74.5	-54.5	1684	**1**	**2.4**	Wright Miller 1992	Cramer et al 2018	-0.1	**3.38**
7.5	555	-22.1	56.6	2487	**1**	**2.3**	Wright Miller Fairbanks 1992	Cramer et al 2018	-0.1	**3.82**
7.5	552	-24.6	56.1	2266	**0.87**	**2.275**	BF (Cramer et al 2018), Keigwin Aubry Kent 1987, Wue 2 (Cramer et al 2018), Mudelsee et al 2014	Cramer et al 2018, Mudelsee et al 2014	-0.1	**3.93**
7.5	410	-28.3	45.3	2642	**1.2**	**2.15**	Keigwin Aubry Kent 1987, Mudelsee et al 2014	Cramer et al 2018, Mudelsee et al 2014	-0.1	**4.49**
7.5	608	-24.3	42.8	3526	**1.1**	**2.05**	Wright Miller 1996, Wright et al 1991, Mudelsee et al 2014	Cramer et al 2018, Wright et al 1991, Mudelsee et al 2014	-0.1	**4.93**
7.5	334	-33.3	36.8	2259	**1.2**	**2.15**	Keigwin Aubry Kent 1987, Drury et al 2017	Cramer et al 2018, Drury et al 2017	-0.1	**4.49**

Age slice	site tag	paleo longitude	paleo latitude	depth	$\delta^{13}C$ (‰)	$\delta^{18}O$ (‰)	Data reference	age model reference	$\delta^{18}O_{sw}$ (‰) (Cramer et al 2011)	calculated temperature (°C) (uncorrected for S) (Marchitto et al 2014 eq 8)
7.5	310	-177.4	34.0	3534	**0.3**	**2.3**	Keigwin 1979	Cramer et al 2018	-0.1	**3.82**
7.5	397	-16.0	26.7	3192	**0.45**	**1.97**	Mudelsee et al 2014, Shackelton 1979, Keigwin Aubry Kent 1987	Mudelsee et al 2014, Cramer et al 2018	-0.1	**5.30**
7.5	1146	115.2	19.5	2091	**0.8**	-	Diester-Haas et al 2006	Diester-Haas et al 2006	-0.1	-
7.5	721	58.1	14.5	1948	**0.3**	-	Diester-Haas et al 2006	Diester-Haas et al 2006	-0.1	-
7.5	999	-78.7	12.7	2828	**0.94**	**1.58**	Bickert et al 2004	Bickert et al 2004	-0.1	**7.04**
7.5	667	-23.0	4.5	3490	**1.1**	**2.45**	REF (Cramer et al 2018)	Cramer et al 2018,	-0.1	**3.16**
7.5	U1337	-118.1	1.8	4476	**0.4**	**2.4**	Drury et al 2017	Drury et al 2017	-0.1	**3.38**
7.5	926	-42.0	3.8	3610	**1.402**	**2.1**	Drury et al 2017, Shackelton Hall 1997	Drury et al 2017, Cramer et al 2018	-0.1	**4.71**
7.5	289	163.7	-3.1	2329	**0.2**	**2.3**	Savin Douglas et al 1981	Cramer et al 2018	-0.1	**3.82**
7.5	846	-95.6	-3.6	3296	**0.6**	**2.2**	Diester-Haas et al 2006, Shackelton Hall et al 1995	Diester-Haas et al 2006, Cramer et al 2018	-0.1	-
7.5	525	1.5	-29.4	2470	**0.75**	**2.65**	Mudelsee et al 2014, Shackelton Hall Boersma 1984	Mudelsee et al 2014, Cramer et al 2018	-0.1	**2.27**
7.5	360	16.5	-36.3	2949	**0.82**	**2.165**	Mudelsee et al 2014, Wright Miller Fairbanks 1992	Mudelsee et al 2014, Cramer et al 2018	-0.1	**4.42**
7.5	1088	11.9	-41.6	2082	**0.556**	**2.68**	Billups 2002, Mudelsee et al 2014	Cramer et al 2018, Mudelsee et al 2014	-0.1	**2.13**
7.5	1172	149.1	-48.3	2622	**1**	-	Diester-Haas et al 2006	Diester-Haas et al 2006	-0.1	-
7.5	704	5.8	-47.3	2541	**1.25**	**2.55**	Wright et al 1991, Muller et al 1991, Katz Miller 1991	Wright et al 1991, Muller et al 1991, Cramer et al 2018	-0.1	**2.71**
7.5	1120	185.0	-52.9	544	**1.1**	**1.65**	Ando et al 2011	Carter et al 1999	-0.1	**6.71**
4.5	397	-15.7	26.7	3104	**0.4**	**2.1**	Shackelton 1979	Cramer et al 2018	-0.2	**4.27**
4.5	516	-34.5	-30.2	1306	**0.75**	**2.067**	"Plio", Leonard et al 1983, Mudelsee et al 2014	Cramer et al 2018, Mudelsee et al 2014, Leonard et al 1983	-0.2	**4.41**
4.5	518	-37.4	-29.9	3949	**1.1**	**2.15**	"Plio" (Cramer et al 2018)	Cramer et al 2018	-0.2	**4.04**
4.5	552	-24.0	56.0	2280	**1.2**	**2.3**	"BF" (Cramer et al 2018), Mudelsee et al 2014	Cramer et al 2018, Mudelsee et al 2014	-0.2	**3.38**
4.5	586	161.6	-2.1	2207	**0.0**	**2.5**	Whitman and Berger 1993	Whitman and Berger 1993	-0.2	**2.49**
4.5	590	162.9	-33.8	1299	**0.7**	**1.8**	Elstrom et al 1986	Richter et al 1988	-0.2	**5.60**
4.5	659	-21.6	18.0	3149	**0.65**	**2.3**	Tiedemann et al 1994	Cramer et al 2018	-0.2	**3.38**
4.5	704	6.5	-47.1	2542	**0.4**	**2.367**	Hodell et al 1991, Mudelsee et al 2014, Muller et al 1991	Froelich et al 1991, Mudelsee et al 2014, Muller et al 1991	-0.2	**3.08**
4.5	846	-93.4	-3.4	3239	**-0.15**	**2.5**	Diester-Haas et al 2006, Shackelton Hall et al 1995	Diester-Haas et al 2006, Shackelton Hall et al 1995	-0.2	**2.49**
4.5	925	-42.9	4.3	3094	**1**	**2.3**	Billups Ravelo Zachos 1998	Cramer et al 2018	-0.2	**3.38**
4.5	959	-3.4	3.4	2120	**0.4**	**2.3**	Norris 1999 (Cramer et al 2018)	Cramer et al 2018	-0.2	**3.38**
4.5	999	-78.7	12.7	2828	**0.3**	**1.6**	Bickert et al 2004	Bickert et al 2004	-0.2	**6.49**
4.5	1088	12.6	-41.4	2086	**0.45**	**2.6**	Billups 2002	Cramer et al 2018	-0.2	**2.04**
4.5	1092	6.1	-46.6	1993	**0.4**	**2.6**	Andersson, Warnke et al 2002	Cramer et al 2018	-0.2	**2.04**
4.5	1146	115.7	19.5	2091	**0.2**	-	Diester-Haas et al 2006	Diester-Haas et al 2006	-0.2	-
4.5	1172	149.4	-46.7	2622	**0.15**	-	Diester-Haas et al 2006	Diester-Haas et al 2006	-0.2	-
4.5	1236	-84.5	-21.9	1324	**0.65**	**3.1**	Tiedermann et al 2007	Tiedermann et al 2007	-0.2	**-0.18**
4.5	1237	-79.2	-16.7	3212	**0.2**	**2.7**	Tiedermann et al 2007	Tiedermann et al 2007	-0.2	**1.60**
4.5	1239	-84.6	-1.2	1415	**-0.2**	**2.2**	Tiedermann et al 2007	Tiedermann et al 2007	-0.2	**3.82**

Age slice	site tag	paleo longitude	paleo latitude	depth	$\delta^{13}C$ (‰)	$\delta^{18}O$ (‰)	Data reference	age model reference	$\delta^{18}O_{sw}$ (‰) (Cramer et al 2011)	calculated temperature (°C) (uncorrected for S) (Marchitto et al 2014 eq 8)
4.5	1241	-88.8	3.0	2027	**0.1**	**2.4**	Tiedermann et al 2007	Tiedermann et al 2007	-0.2	**2.93**
2.5	659	-21.4	18.0	3115	**0.35**	**3**	Tiedemann et al 1994	Cramer et al 2018	0.05	**1.38**
2.5	677	-22.3	4.6	3352	**-0.5**	**3**	Shackelton Hall 1989	Cramer et al 2018	0.05	**1.38**
2.5	704	6.9	-47.0	2543	**0.2**	**3.2**	Mudelsee et al 2014, Hodell et al 1991	Mudelsee et al 2014, Froelich et al 1991	0.05	**0.49**
2.5	747	76.2	-54.7	1701	-	**3.5**	Billups Schrag 2002	Cramer et al 2018	0.05	**-0.84**
2.5	806	161.1	-0.7	2556	-	**2.7**	Lear Rosenthal Wright 2003	Cramer et al 2018	0.05	**2.71**
2.5	846	-92.1	-3.3	3237	**-0.5**	**3**	Le Mix Shackleton 1995	Cramer et al 2018	0.05	**1.38**
2.5	1088	13.0	-41.3	2081	**0.5**	**3**	Diester-Hass et al 2006, Billups 2002	Diester-Hass et al 2006, Billups 2002	0.05	**1.38**
2.5	1090	8.9	-42.9	3720	**0.1**	**3.1**	Mudelsee et al 2014, Hodell Charles et al 2003	Mudelsee et al 2014, Cramer et al 2018	0.05	**0.93**
2.5	1236	-83.0	-21.7	1323	**0.3**	**3.5**	Tiedermann et al 2007	Tiedermann et al 2007	0.05	**-0.84**
2.5	1239	-83.4	-1.0	3212	**-0.2**	**2.7**	Tiedermann et al 2007	Tiedermann et al 2007	0.05	**2.71**
2.5	1241	-87.6	4.2	2027	**-0.3**	**3**	Tiedermann et al 2007	Tiedermann et al 2007	0.05	**1.38**
2.5	1313	-33.0	41.0	3426	**0.4**	-	Lang et al 2014	Lang et al 2014	0.05	-
2.5	397	-15.5	26.8	2900	**0.0**	**2.55**	Mudelsee et al 2014, Shackleton 1979, Stein 1985	Mudelsee et al 2014, Cramer et al 2018	0.05	**3.38**
2.5	516	-34.9	-30.2	1313	**0.7**	**2.5**	Leonard et al 1983	Leonard et al 1983	0.05	**3.60**
2.5	518	-37.7	-29.9	3951	**0.5**	**2.9**	"Plio" Cramer et al 2018	Cramer et al 2018	0.05	**1.82**
2.5	552	-23.7	56.0	2287	**0.7**	**3**	Mudelsee et al 2014, "BF" (Cramer et al 2018)	Mudelsee et al 2014, Cramer et al 2018	0.05	**1.38**
2.5	586	160.3	-1.4	2207	**-0.2**	**3**	Whitman and Berger 1993	Whitman and Berger 1993	0.05	**1.38**
2.5	590	163.1	-32.6	1299	**0.7**	**2.6**	Elstrom et al 1986	Richter et al 1988	0.05	**3.16**
2.5	607	-33.0	41.0	3407	**0.8**	**2.8**	Raymo Ruddiman et al 1989	Cramer et al 2018	0.05	**2.27**

Table S2, Published benthic $\delta^{13}C$ and $\delta^{18}O$ data used in this study, together with calculated benthic temperature derived from $\delta^{18}O$, Cramer et al. (2011) global ice volume, and the Marchitto et al. (2014) paleotemperature calculation (see main text) so is uncorrected for salinity in this table.

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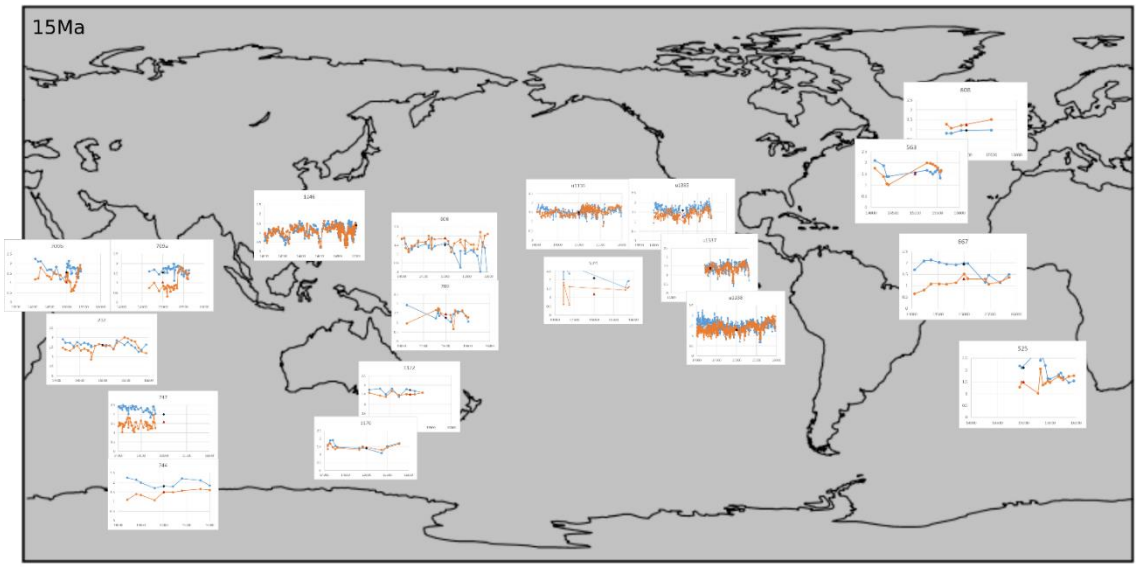
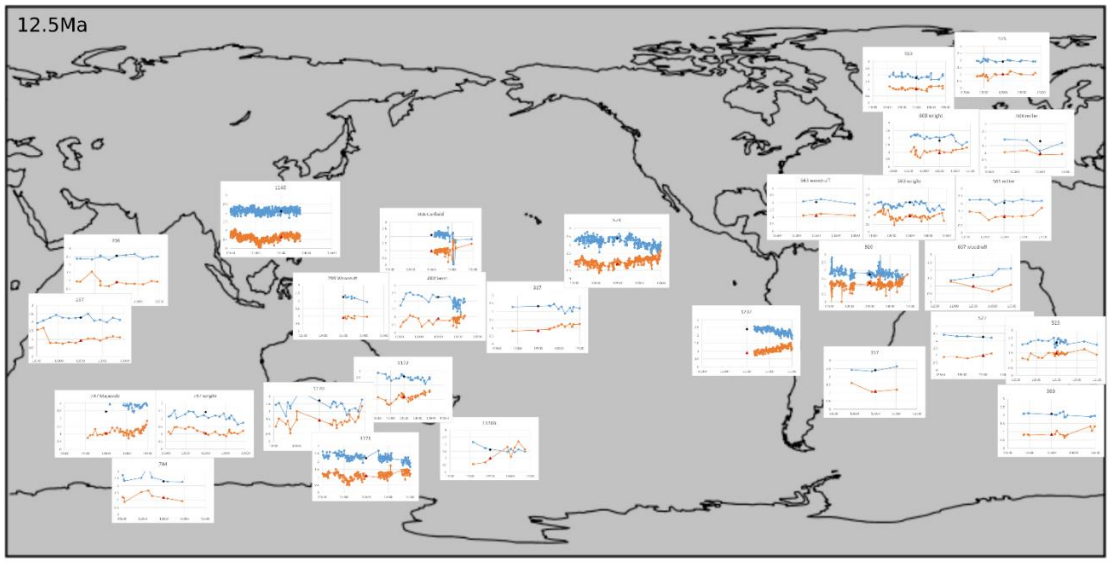
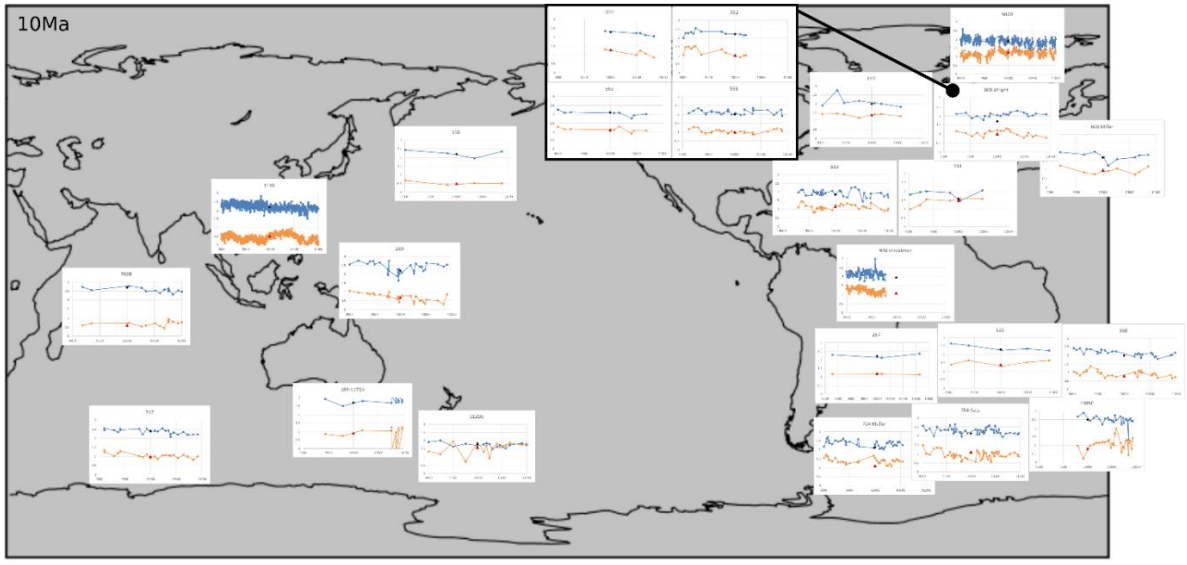
Supplementary material C

Additional figures







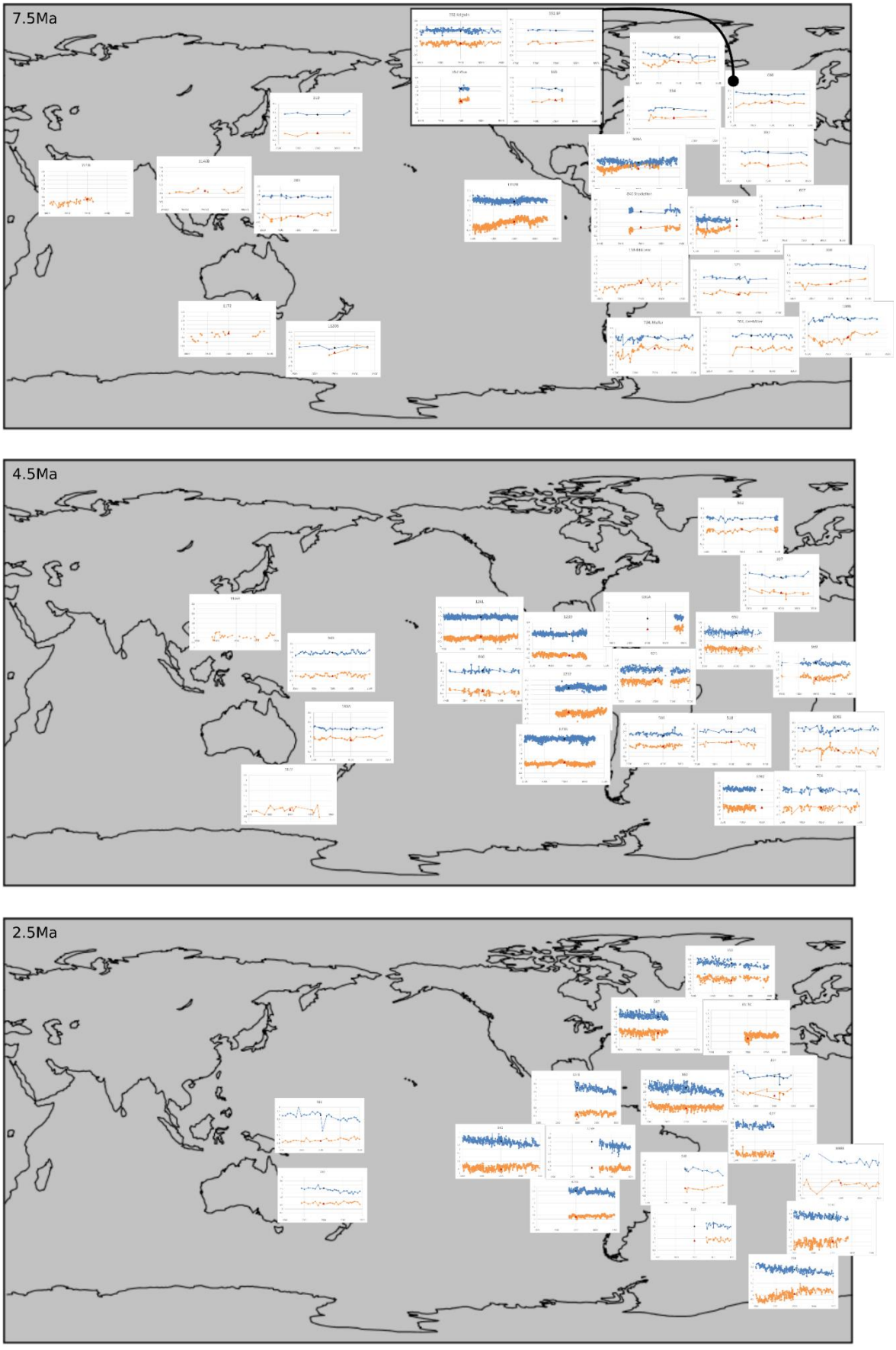


Figure S1, Datamaps for each time slice indicating the (rough) location of the sediment core in the present day, and ±1Ma window around the target age for $\delta^{13}C$ and $\delta^{18}O$. Target age is marked top-left on each map. Data points corresponds to that in Table S2 (black filled circle for $\delta^{18}O$, red filled triangle for $\delta^{13}C$). Where more than one record is available for a core site, the higher resolution set or that from Cramer et al. (2011) is plotted here. All data is plotted permil (‰), $\delta^{18}O$ timeseries coloured blue, $\delta^{13}C$ is orange.

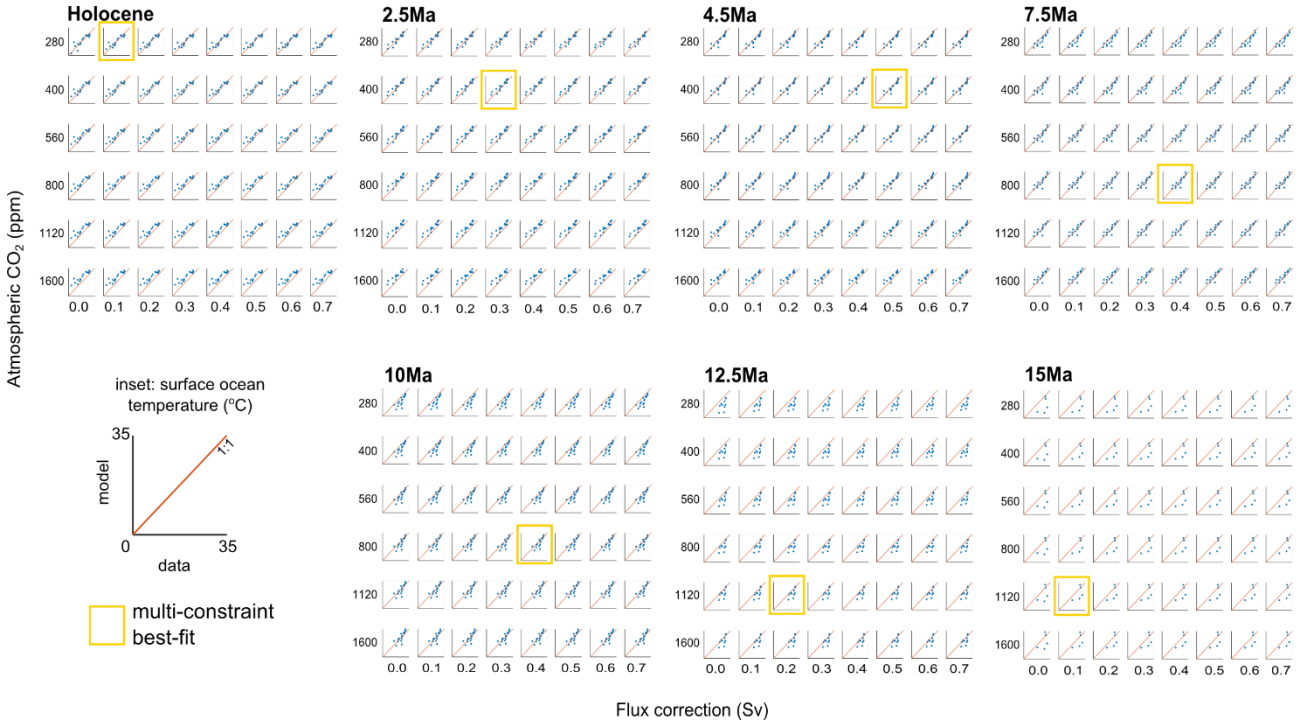


Figure S2, Surface ocean temperature cross plots showing all data and corresponding model (0m to 80m) surface ocean temperature. The overall best-fit for each timeslice is outlined in yellow.

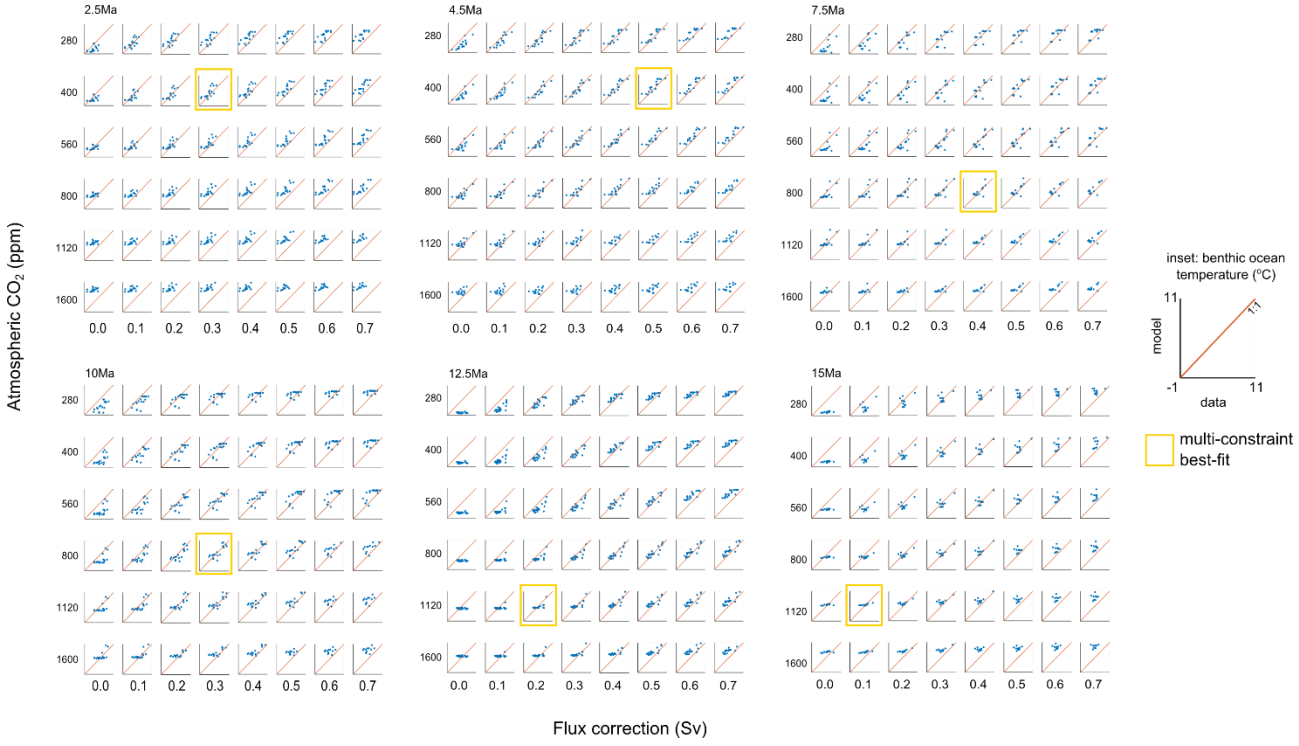


Figure S3, Benthic temperature cross plot showing all calculated and corresponding model (deepest ocean grid cell) benthic temperatures. The overall best-fit for each timeslice is outlined in yellow.

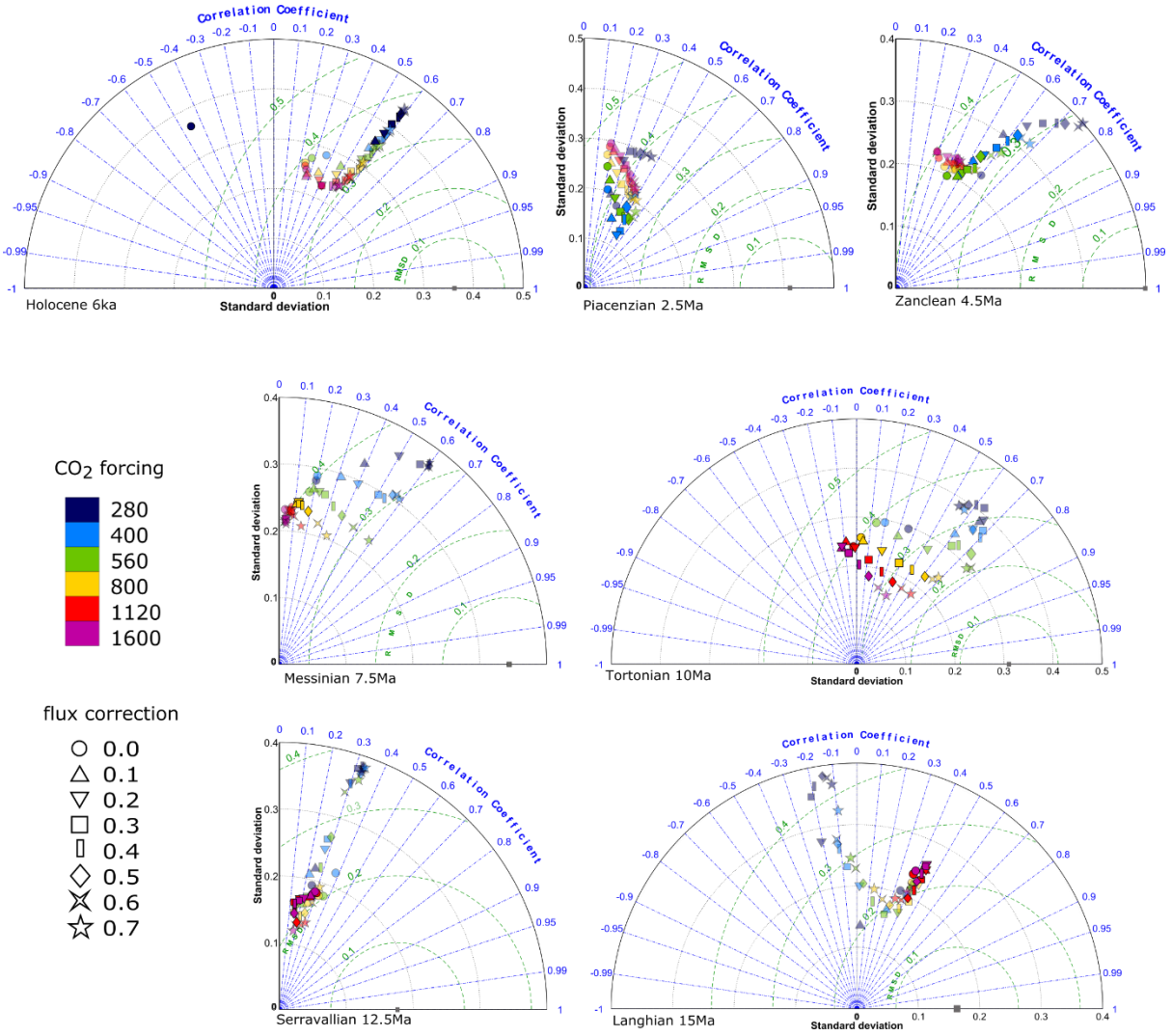


Figure S4, Taylor plots for fit of benthic δ13C model to benthic data. Taylor plots shows standard deviation, correlation and root mean square difference simultaneously. Generally, the closer the model point is to data (shown as a grey square on the horizontal axis) the better the model fits the data $\delta^{13}C$ pattern. Ghosted model points represent CO_2 that does not agree with surface temperature data (see main text), and FwF higher than 0.5Sv.