Supplementary Materials

Figure 1: Wettest month of the year for the control simulation (a) and the GPCP observations. Regions receiving less than 1mm/day are kept blank.

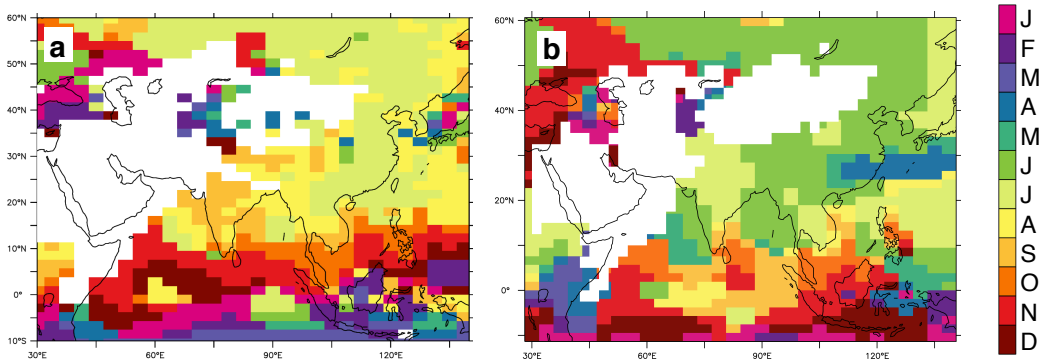


Figure 2: a) paleotopography and paleobathymetry and b) idealized vegetation map prescribed.
For b), color coding is: Boreal Needleleaf Summergreen (red), Boreal Broadleaf Summergreen (cyan), Temperate Broadleaf Evergreen + Temperate Broadleaf Summergreen (light green), Bare soil (yellow), C3 grasses (orange) and Tropical Broadleaved Evergreen + Tropical Broadleaved Raingreen (dark green).

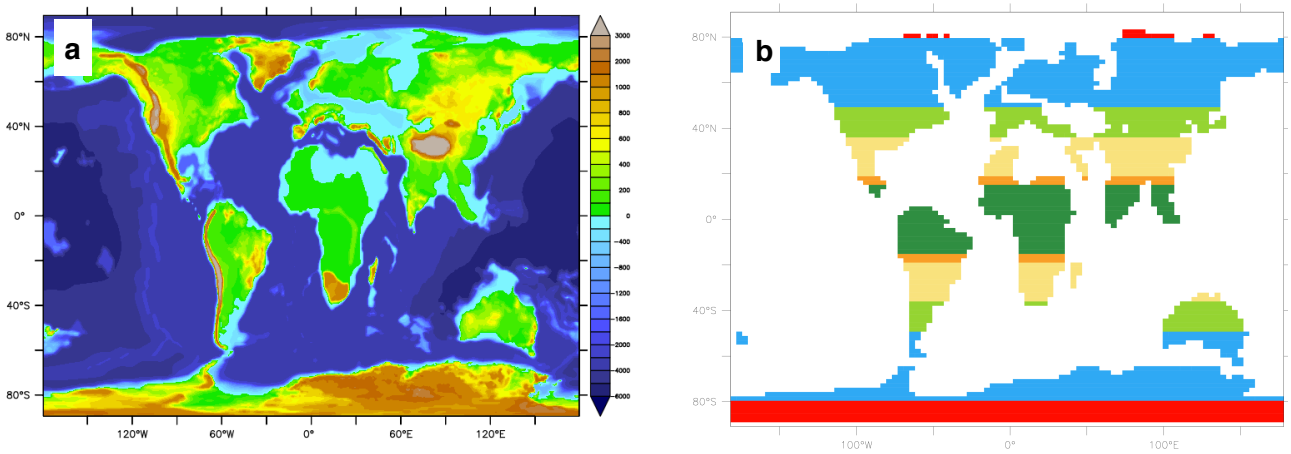


Figure 3: Oceanic heat content stability plots for the 3000 years reference simulations EOC_4X (a). Plotted depth are 5 m (black), 500 m (purple), 1800 m (red) and 4750 m (blue). The simulation shows a drift inferior to 0.1°C per century over the last 500 years for the deep ocean (4750 m).

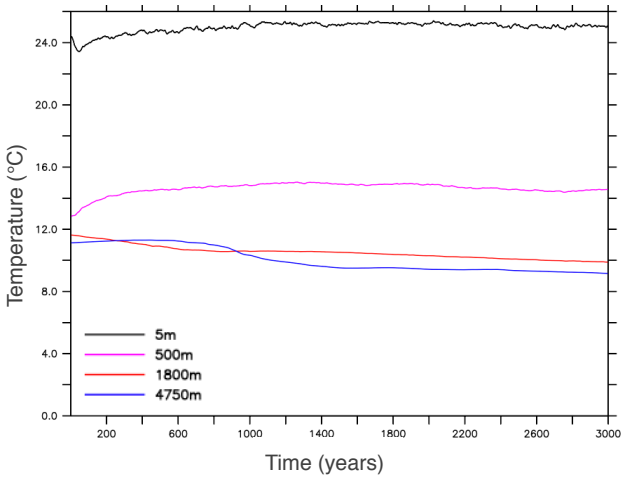


Figure 4: Regression between SST given by the proxies and the one obtained from the model.
In purple: Late-middle Eocene proxy-model regression yields a r^2=0.72, in orange: late Eocene proxy-model regression a yields r^2=0.54. The detailed proxy compilation is given in Tables 1 to 4.

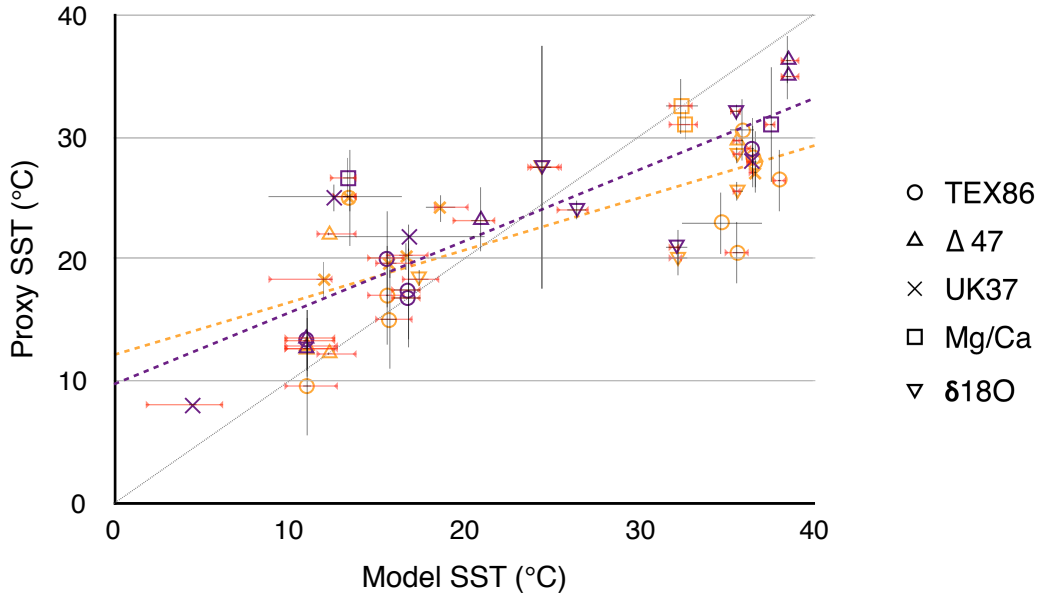
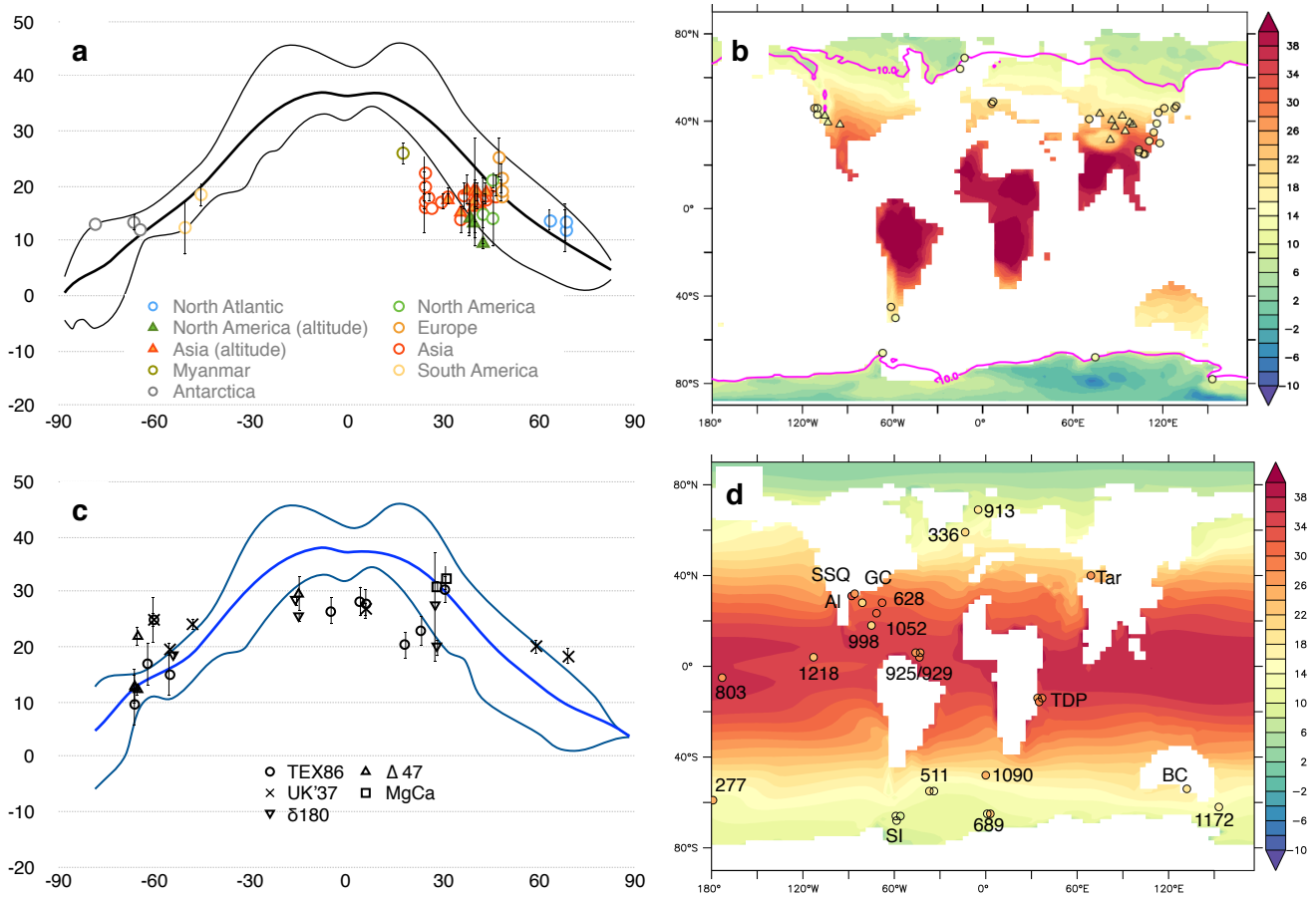


Figure 5: Late Eocene data-model comparison for MAT (a,b), ans SST (c,d). In (a, c), thick line represent the mean temperature from EOC_4X, thin lines are min and max latitudinal temperature from EOC_4X. High altitude proxies (>1000 m) are represented by triangles, others by circles. In b pink thick line represents the 10°C isotherm. Detailed compilation is provided in Table 1 and 2.



SST and terrestrial temperature compilation description

The proxy compilations used in this study were taken from an existing compilation by Baatsen et al. (2018). It was further completed with results from the available literature (Hunt et al.2001, Utescher et al. 2015, Kohn et al. 2015, Francis et al. 2007, Greenwood et al. 2010, Licht et al. 2014, Spicer et al. 2017, Hoorn et al. 2012), for the continental compilation. Since a steady declining trend in temperatures is observed through the Middle to Late Eocene (Zachos et al. 2001), samples are divided into two broad categories: «late-middle Eocene» and «late Eocene» (hereafter LME and LE, respectively), corresponding to periods of 42 to 38 Ma and 38 to 34 Ma, respectively. As no sharp variation in temperature and pCO_2 is expected between LME and LE, some samples, dated around 38 Ma, are present in both groups. Considering the scarcity of SST estimates at high northern latitudes, we exceptionally included the 44.5 Ma ACEX drilling SST proxy in the LME group, as no value is available for our period of interest, due to a hiatus in the core spanning from 44.5 to 18.3 Ma (Weller and Stein, 2008). We consider reasonable to include this value in our compilation, keeping in mind that it could present a slight overestimation of the SST at this location.

Note that several TEX_{86} calibration methods exist for SST reconstructions. Values from Liu et al. (2009) used the calibration by Kim et al. (2008), while Douglas et al. (2014) used the TEX^{L}_{86} calibration. If studies argued that TEX^{L}_{86} calibration was better adapted to high latitudes (SST below 15°C), and TEX^{H}_{86} for mid to low latitudes, Taylor et al. (2013) showed that was actually more suited for shallow water environments, independently of the SST estimated temperature. Uncertainties remain on this topic, as Ho and Laepple (2016) recently suggested that TEX^{H}_{86} might actually reflect subsurface temperatures and therefore challenge the paleoclimatic interpretations based on the usually warm polar SST values measured for the Paleocene or the Eocene periods.

The paleolocation of the proxies was reconstructed using Gplates (www.portal.gplates.org). We differentiate terrestrial proxies results from coastal and low elevation locations from those which paleo-elevation have been estimated higher than 1000 m (when available). The interest of separating altitude records from other proxies is twofold: first, the coarse resolution of our model induces a smoothing of the elevation, hence a tendency to return higher temperature on the location of high altitude proxies ; second, as fossil material are usually found in basins, they represent the surrounding flora or fauna, whether it comes from the basin area itself or from higher elevation in the surroundings. A fossil assemblage can therefore induce a cold bias on the location of the proxy itself by representing the high altitude neighboring regions. As an elevation difference of 1000 m for a given latitude is susceptible to induce differences in temperatures of ~6.5°C, it is an important parameter to consider.

Table 1: Late Eocene (38-34Ma) terrestrial proxy compilation

Site	Location (paleo)	altitude	references	MAT (°C)	MAT error
ANTARCTICA					
McMurdo	-77,7°N, 153,2°E	?	Passchier et al. (2013)	13	0
King George	-66°N, -66,5°E	?	Passchier et al. (2013)	13	2
ODP 1166	-68°N, -66,5°E	?	Passchier et al. (2013)	12	0
SOUTH AMERICA					
Ñirihuau (Chile)	-45°N, -61°E	?	Hinojosa & Villagran (2005)	18,4	0
Gran Barranca (Argentina)	-50°N, -58°E	?	Kohn et al. (2015)	12,4	5
MYANMAR					
Pondaung	18,5°N, 90,6°E	?	Licht et al. (2014)	26	2
CHINA					
ChangChang (Hainan Island)	25°N,107°E	No	Spicer et al. (2017)	22	3
Liushagang I (Leizhou, Guangdong)	24,6°N, 106,9°E	No	Zhang 1981	16	5
Youganwo (Maoming Basin)	25°N, 108°E	No	Yu & Wu 1983	17	1
Youganwo (Maoming Basin)		No	Spicer et al. (2017)	20	3
Yongning Gr U (Ningming, Guangxi)	25,5°N, 104,2°E	No	Wang 2003	18	1
Nadu (Baise, Guangxi)	27,3°N, 103,6°E	No	Guo 1979, Liu & Yang 1999	16	0
Pinghu (Donghai)	29,7°N, 119,4°E	No	Sun 1989, Zhang 1990	17	1
Linjiang L (Qingjiang)	31,6°N,112,1°E	No	He & Sun 1977	18	1
Dagzukha (Xigaze, Tibet)	32°N,85,2°E	Yes	Li 2009	17	1
Dingyuan V (Hefei Basin)	35,5°N,114,4°E	No	Wang et al 1987	14	2
Relu U (Shiqu, Sichuan)	36,2°N,94,9°E	Yes	Chen 1983	15	0
Sanduo U (Gaoyou, Jiangsu)	36,5°N,116,6°E	No	Zhang & Qian 1992	18	3
Wanbaogou Gr U (Kulun Pass, Qinghai)	38,1°N,88,2°E	Yes	Zhu 1985	19	3
Lanzhou, Gansu	39,4°N,100,2°E	Yes	Ma 1995	14	2
Xining Gr (Minhe, Qinghai)	39,5°N,100°E	Yes	Yu 2003	16	5

Site	Location (paleo)	altitude	references	MAT (°C)	MAT error
Honggou III, IV (Xining, Qinghai)	39,73°N,98°E	Yes	Sun 1980	17	4
Xining	40,1°N, 98,7°E	Yes	Hoorn, Han	19	10
Xining		Yes	Wang 1990		0
Bashibulake (Shache Basin, Xinjiang)	41°N, 72°E	No	Zhao 1982	19	2
Xiaganchaigou L (Mangya, Qinghai)	41,1°N, 86,4°E	Yes	Zhu 1985	17	1
Huoshaogou Qiaojia (Yumen, Gansu)	43,4°N, 92,9°E	Yes	Miao 2008	16	6
Shahejie II (Qinhuangdao, Hebei)	43,6°N,116,7°E	No	APE & NIGP 1978	17	1
Xiaokuzibai (Kuche Basin, Xinjiang)	44,1°N, 78,1°E	Yes	Zhao 1982 Zhang & Zhan 1991	19	2
Genjiajie (Fushun, Liaoning)	45,5°N,121,2°E	No	Qu 1993	18	0
Hunchun	46°N,128°E	No	Liu 1987, Zhang 1987	18	0
S Primory'e (Russia)	47°N, 129°E	?	Utescher 2015	20	2
S Primory'e (Russia)		?	Utescher 2015	18	0
EUROPE					
Stare Sedlo	48°N, 6°E	?	Uhl et al, (2007)	25	4
Weiße Elster	49°N, 6°E	?	Uhl et al, (2007)	21	3
Weiße Elster & Lausitz Basin (Knau gravel pit)		?	Utescher 2015	18	0
Weiße Elster & Lausitz Basin (Haselbach)		?	Utescher 2015	19	2
NORTH AMERICA					
Florissant CO	39,25°N, -95°E	Yes (3800m)	Boyle et al, (2008) ; Wolfe et al. (1998)	14	3
Sevier (UT)	40°N, -102,9°E	Yes (3600 +/- 700m)	Gregory-Wodzicki (1997)	13	3
Copper Basin (NV)	43,2°N, -105,4°E	yes (2000m)	Wolfe et al, (1998)	10	1
Badger's Nose (CA)	42,6°N, -109,7°E	?	Prothero (2008)	15	2
Comstosk (OR)	45,8°N, -112,3°E	No	Retallack et al, (2004)	21	1
Gray Butte (OR)	45,6°N, -110,2°E	?	Smith et al, (1998)	14	5

Site	Location (paleo)	altitude	references	MAT (°C)	MAT error
NORTH ATLANTIC					
ODP 913 MBT	69°N, -12°E	?	Schouten et al, (2008)	12	4
ODP 913 Pollen		?	Eldrett et al, (2009)	13	3
ODP 643	64°N, -15°E	?	Eldrett et al, (2009)	14	2

Table 2: Late Eocene (38-34 Ma) SST proxy compilation

Site	Location (paleo)	reference	SST (°C)	SST error	Method
Seymour Island	-65.7°N, -58°E	Douglas et al, (2014)	12,6	2,0	Δ_{47} *Cucullaea*
Seymour Island		Douglas et al, (2014)	12,9	3,0	Δ_{47} *Eurhomalea*
Seymour Island		Douglas et al, (2014)	9,6	4,0	TEX^{L}_{86}
ODP 689 (Weddell Sea)	-64.7°N, 1.2°E	Petersen and Schrag (2015)	12,3	1,0	Δ47
ODP 689 (Weddell Sea)		Petersen and Schrag (2015)	22	1,5	Δ47
ODP 1172 (Tasmania)	-62.4°N, 152.8°E	Douglas et al, (2014)	17	4,0	TEX^{L}_{86}
DSDP 277	-59.8°N, 179.3°E	Douglas et al, (2014)	25	4,0	TEX^{L}_{86}
DSDP 277		Liu et al, (2009)	25	1,1	$U^{K'}_{37}$
DSDP 511	-54.9°N, -34.1°E	Douglas et al, (2014)	15	4,0	TEX^{L}_{86}
DSDP 511		Liu et al, (2009)	19,6	1,1	$U^{K'}_{37}$
Brown Creek, Aus	-54°N, 132°E	Kamp et al, (1990)	18,4	0,7	$\delta^{18}O$
ODP 1090	-47.8°N, 0.2°E	Liu et al, (2009)	24,2	1,1	$U^{K'}_{37}$
Tanzania	-14.7°N, 33.9°E	Pearson et al, (2001)	25,5	0,7	$\delta^{18}O$
Tanzania		Evans et al, (2018)	29,7	3,2	Δ47
Tanzania Lindi	-15.7°N, 34.3°E	Pearson et al, (2001)	28,5	0,7	$\delta^{18}O$
ODP 929	-5.9°N, -43.5°E	Liu et al, (2009)	27,9	2,5	TEX_{86}
ODP 929		Liu et al, (2009)	27	1,1	$U^{K'}_{37}$
ODP 803	-5.2°N, -172.8°E	Liu et al, (2009)	26,5	2,5	TEX_{86}
ODP 1218	4°N, -113.5°E	Liu et al, (2009)	23	2,5	TEX_{86}
ODP 925	4.2°N, -43.5°E	Liu et al, (2009)	28,3	2,5	TEX_{86}
ODP 998	18.1°N, -75°E	Liu et al, (2009)	20,5	2,5	TEX_{86}
ODP 628	23.4°N, -71.7°E	Liu et al, (2009)	30,5	2,5	TEX_{86}
ODP 1052	28°N, -67.9°E	Okafor et al, (2009)	31	1,2	Mg/Ca
Gulf Coast, USA	28.4°N, -81.1°E	Kobashi et al, (2004)	20		$\delta^{18}O$

Site	Location (paleo)	reference	SST (°C)	SST error	Method
St Stephens Quarry	31°N, -87.8°E	Wade et al, (2012)	32,5	2,2	Mg/Ca
Alabama US	31.5°N, -88°E	Pearson et al, (2001)	26,5	0,7	$\delta^{18}O$
Tarim	40°N, 75°E	Bougeois et al. (2016)	27,5	10	$\delta^{18}O$
DSDP 336	59.1°N, -13.5°E	Liu et al, (2009)	20,2	1,1	$U^{K'}_{37}$
ODP 913	69°N, -5°E	Liu et al, (2009)	18,3	1,1	$U^{K'}_{37}$

Table 3: Late middle Eocene (42-38Ma) terrestrial proxy compilation

Site	Location (paleo)	altitude	references	MAT (°C)	MAT error
ANTARCTICA					
McMurdo	-77,7°N, 153,2°E	?	Passchier et al. (2013)	13	0
King George	-66°N, -66,5°E	?	Passchier et al. (2013)	13	2
ODP 1166	-68°N, -66,5°E	?	Passchier et al. (2013)	12	0
SOUTH AMERICA					
Ñirihuau (Chile)	-45°N, -61°E	?	Hinojosa & Villagran (2005)	18,4	0
Gran Barranca (Argentina)	-50°N, -58°E	?	Kohn et al. (2015)	12,4	5
MYANMAR					
Pondaung	18,5°N, 90,6°E	?	Licht et al. (2014)	26	2
ASIA					
ChangChang (Hainan Island)	25°N,107°E	No	Spicer et al. (2017)	22	3
Liushagang I (Leizhou, Guangdong)	24,6°N, 106,9°E	No	Zhang 1981	16	5
Youganwo (Maoming Basin)	25°N, 108°E	No	Yu & Wu 1983	17	1
Youganwo (Maoming Basin)		No	Spicer et al. (2017)	20	3
Yongning Gr U (Ningming, Guangxi)	25,5°N, 104,2°E	No	Wang 2003	18	1
Nadu (Baise, Guangxi)	27,3°N, 103,6°E	No	Guo 1979, Liu & Yang 1999	16	0
Pinghu (Donghai)	29,7°N, 119,4°E	No	Sun 1989, Zhang 1990	17	1
Linjiang L (Qingjiang)	31,6°N,112,1°E	No	He & Sun 1977	18	1
Dagzukha (Xigaze, Tibet)	32°N,85,2°E	Yes	Li 2009	17	1
Jianghan Basin	34°N, 111°E	?	Ma 2012	20	2

Site	Location (paleo)	altitude	references	MAT (°C)	MAT error
Dingyuan V (Hefei Basin)	35,5°N,114,4°E	No	Wang et al 1987	14	2
Cheshme	36°N, 61°E	?	Akhmetiev 2014		
Relu U (Shiqu, Sichuan)	36,2°N,94,9°E	Yes	Chen 1983	15	0
Sanduo U (Gaoyou, Jiangsu)	36,5°N,116,6°E	No	Zhang & Qian 1992	18	3
Wanbaogou Gr U (Kulun Pass, Qinghai)	38,1°N,88,2°E	Yes	Zhu 1985	19	3
Lanzhou, Gansu	39,4°N,100,2°E	Yes	Ma 1995	14	2
Xining Gr (Minhe, Qinghai)	39,5°N,100°E	Yes	Yu 2003	16	5
Honggou III, IV (Xining, Qinghai)	39,73°N,98°E	Yes	Sun 1980	17	4
Xining	40,1°N, 98,7°E	Yes	Hoorn, Han	19	10
Bashibulake (Shache Basin, Xinjiang)	41°N, 72°E	No	Zhao 1982	19	2
Xiaganchaigou L (Mangya, Qinghai)	41,1°N, 86,4°E	Yes	Zhu 1985	17	1
Huoshaogou Qiaojia (Yumen, Gansu)	43,4°N, 92,9°E	Yes	Miao 2008	16	6
Shahejie II (Qinhuangdao, Hebei)	43,6°N,116,7°E	No	APE & NIGP 1978	17	1
Xiaokuzibai (Kuche Basin, Xinjiang)	44,1°N, 78,1°E	Yes	Zhao 1982 Zhang & Zhan 1991	19	2
Genjiajie (Fushun, Liaoning)	45,5°N,121,2°E	No	Qu 1993	18	0
Fushun, Liaoning	45,5°N,121,2°E	No	Ma 2012	18	2
Hunchun	46°N,128°E	No	Liu 1987, Zhang 1987	18	0
S Primorye (Russia)	47°N, 129°E	?	Utescher 2015	20	2
S Primorye (Russia)		?	Utescher 2015	18	0
S Primorye		?	Akhmetiev 2014		
Huadian Basin	47,7°N, 124°E	No	Ma 2012	17	1
Zaisan Basin	48°N, 85°E	?	Akhmetiev 2014		
Yilan-Yitong	50.5°N, 126°E	?	Ma 2012		
Turgai	51°N, 57°E	?	Akhmetiev 2014		
Pavlodar	54°N, 70°E	?	Akhmetiev 2014		
EUROPE					

Site	Location (paleo)	altitude	references	MAT (°C)	MAT error
Stare Sedlo	48°N, 6°E	?	Uhl et al, (2007)	25	4
Weiße Elster	49°N, 6°E	?	Uhl et al, (2007)	21	3
Weiße Elster & Lausitz Basin (Knau gravel pit)		?	Utescher 2015	18	0
Weiße Elster & Lausitz Basin (Haselbach)		?	Utescher 2015	19	2
NORTH AMERICA					
Florissant CO	39,25°N, -95°E	Yes (3800m)	Boyle et al, (2008) ; Wolfe et al. (1998)	14	3
Sevier (UT)	40°N, -102,9°E	Yes (3600 +/- 700m)	Gregory-Wodzicki (1997)	13	3
Copper Basin (NV)	43,2°N, -105,4°E	yes (2000m)	Wolfe et al, (1998)	10	1
Badger's Nose (CA)	42,6°N, -109,7°E	?	Prothero (2008)	15	2
Comstosk (OR)	45,8°N, -112,3°E	No	Retallack et al, (2004)	21	1
Gray Butte (OR)	45,6°N, -110,2°E	?	Smith et al, (1998)	14	5
NORTH ATLANTIC					
ODP 913 MBT	69°N, -12°E	?	Schouten et al, (2008)	12	4
ODP 913 Pollen		?	Eldrett et al, (2009)	13	3
ODP 643	64°N, -15°E	?	Eldrett et al, (2009)	14	2

Table 4: Late Middle Eocene (42-38 Ma) SST proxy compilation

Site	Location (paleo)	reference	SST (°C)	SST error	Method
Seymour Island	-65.7°N, -58°E	Douglas et al. (2014)	12,6	2,4	Δ_{47} *Cucullaea*
Seymour Island		Douglas et al. (2014)	13,5	2,0	Δ_{47} *Eurhomalea*
Seymour Island		Douglas et al. (2014)	13,4	4,0	TEX^{L}_{86}
ODP 1172	-62.4°N, 152.8°E	Bijl et al, (2009), values with TEX^{L}_{86} calibration in Douglas et al. (2014)	20	4,0	TEX^{L}_{86}
DSDP 277	-59.8°N, 179.3°E	Hines et al, (2017)	26,6	1,7	Mg/Ca
New Zealand (Hampden)	-51°N, -165°E	Hollis et al. (2012)	16,8	4,0	TEX^{L}_{86}
New Zealand (Mid Waipara)		Hollis et al. (2012)	17,4	4,0	TEX^{L}_{86}

Site	Location (paleo)	reference	SST (°C)	SST error	Method
Tanzania Lindi	-15.7°N, 34.3°E	Pearson et al, (2001)	32	0,7	$\delta^{18}O$
Java KW01	-0.4°N, 109.2°E	Evans et al, (2018)	35	2,0	Δ_{47}
Java KW01		Evans et al, (2018)	36,3	1,9	Δ_{47}
ODP 925	1.4°N, -151.4°E	Liu et al, (2009)	28	1,1	$U^{K'}_{37}$
ODP 925		Liu et al, (2009)	29	2,5	TEX_{86}
ODP 865	8.3°N, -151.4°E	Tripati et al, (2003)	31	4,7	Mg/Ca
Gulf Coast, USA	28.4°N, -81.1°E	Kobashi et al, (2004)	21	0,7	$\delta^{18}O$
Istra More 5	39°N, 10°E	Pearson et al, (2001)	24	0,7	$\delta^{18}O$
Tarim	40°N, 77°E	Bougeois 2016	27,5	10	$\delta^{18}O$
Hampshire Basin	48.4°N, -6.4°E	Evans et al, (2018)	23,2	2,6	Δ_{47}
DSDP 336	59.1°N, -13.5°E	Liu et al, (2009)	21,8	1,1	$U^{K'}_{37}$
ODP 913	69°N, -5°E	Liu et al, (2009)	25	1,1	$U^{K'}_{37}$
ACEX	87.9°N,136.2°E	Weller and Stein 2007	8	1,1	$U^{K'}_{37}$

Table 5: Qualitative proxy compilation used in Figure 4a.

Site	Location (modern)	reference	main qualitative composition
Yilan-Yitong (China)	46°N, 129°E	Ma et al. 2012	forest
Huadian (China)	43°N, 127°E	Ma et al. 2012	forest
Fushun (China)	42°N, 124°E	Ma et al. 2012	forest
Jiuquan (China)	40°N, 97°E	Ma et al. 2012	shrub/grass
Qaidam (China)	38°N, 91°E	Ma et al. 2012	shrub/grass
Dahonggou (China)	37°N, 95°E	Ma et al. 2012	shrub/grass
Xining (China)	37°N, 102°E	Hoorn et al. 2012	shrub/grass
Lushi (China)	34°N, 111°E	Ma et al. 2012	grass
Tantou (China)	34°N, 118°E	Ma et al. 2012	forest
Tailai (China)	36°N, 117°E	Ma et al. 2012	forest
Nanling (China)	31°N, 118°E	Ma et al. 2012	forest
Jianghan (China)	30°N, 113°E	Ma et al. 2012	shrub/forest
Baise (China)	22°N, 109°E	Ma et al. 2012	forest
Assam (India)	26°N, 92°E	Saxena and Trivedi 2009	forest
southern India	12°N, 79°E	Boucot et al. 2013	forest
Kashmir (India)	39°N, 75°E	Boucot et al. 2013	forest
Cambay (India)	22°N, 73°E	Boucot et al. 2013	forest
Rajasthan (India)	27°N, 74°E	Boucot et al. 2013	forest
Pondaung (Myanmar)	21°N, 94°E	Licht et al. 2014	forest
Nanggulan and Walat (Java)	6°S, 107°E	Morley 2018	forest
Mangkalihat (Kalimantan)	1°N, 118°E	Morley 2018	forest
Turgai (Russia)	51°N, 57°E	Akhmetiev and Zaporozhets 2014	forest
Zaisan (Russia)	48°N, 85°E	Akhmetiev and Zaporozhets 2014	forest
Chesme (Turkmenistan)	36°N, 61°E	Akhmetiev and Zaporozhets 2014	shrub

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