Data Repository Item: Appendix DR1

Model Description

The PETM climate simulations have been carried out with the NCAR CCSM3, a global, coupled climate model including the ocean, atmosphere, sea ice, and land surface (Collins et al., 2006a; Yeager et al., 2006; Winguth et al., 2010, and references therein). A spectral horizontal resolution of T31, corresponding to an equivalent grid spacing of approximately 3.75° in latitude and longitude, and vertically 26 unevenly spaced terrain-following levels (Collins et al., 2006b) in the atmosphere and 25 layers in the vertical coordinate (Gent et al., 2006) has been chosen to allow long-term integrations. The PETM geography is the same as the one used in Winguth et al. (2010), which has been updated from Shellito and Sloan (2006), following Sewall et al. (2000; see Figs. 1 and 2 therein) and is derived from PALEOMAP (http://www.scotese.com), with a marginal sea parameterization (Smith and Gent, 2004) for the Arctic. Further details about the model configuration and PETM parameter settings and boundary conditions are found elsewhere (Winguth et al., 2010).

The marine carbon component of the coupled climate-carbon cycle model is based upon the Ocean Carbon Model Intercomparison Project (OCMIP) (Doney et al., 2006; Najjar and Orr, 1999, http://www.ipsl.jussieu.fr/OCMIP/). The model estimates air-sea fluxes of CO_2 with the wind-dependent gas exchange coefficient (Wanninkhof, 1992) across the air-sea interface, the temperature-dependent solubility of CO_2, and the difference between the prescribed pCO_2 of the atmosphere and the pCO_2 of the uppermost layer of the ocean (Doney et al., 2006). The model's treatment of geochemical constants for the carbonate system is adapted after Panchuk et. al (2008) using solubility constants for calcite after Tyrrell and Zeebe (2004) and equilibrium constants for carbonic acid in dependence of the Mg^{2+} concentration (Zeebe and Wolf-Gladrow, 2001). The ocean carbon cycle model predicts seven prognostic variables, i.e. phosphate (PO_4), total dissolved inorganic iron (Fe), dissolved organic phosphorus and iron (DOP and DOFe), dissolved inorganic carbon (DIC), total alkalinity (TALK), and dissolved oxygen (O_2), that are transported by the ocean model POP1.4. The parameterization of biological uptake of nutrients is similar to that used in the Hamburg Model of the Ocean Carbon Cycle (HAMOCC; Maier-Reimer, 1993) and assumes a constant Redfield ratio for particulate organic matter (POM). The uptake of PO_4 is given by the turnover of biomass, modulated by surface solar irradiance, temperature, and macro- and micronutrients. The model uses a Martin power-law curve (a=-0.9) to describe the vertical particulate organic phosphorus flux profile over the full water column. The flux is altered by scavenged Fe attached to the sinking matter throughout the water column (see Doney et al., 2006, for details).

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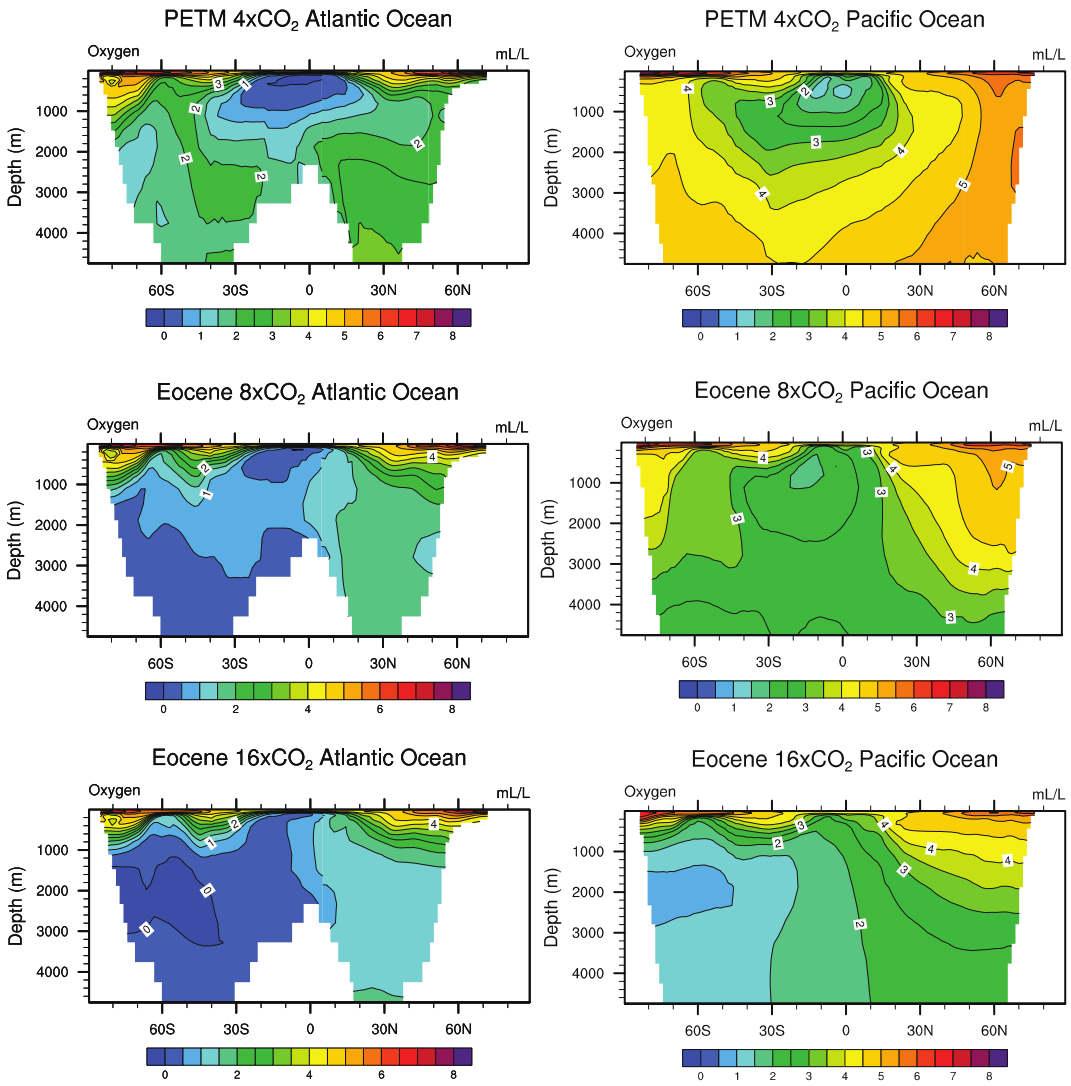
PETM 4xCO2 Atlantic Ocean
PETM 4xCO2 Pacific Ocean
Eocene 8xCO2 Atlantic Ocean
Eocene 8xCO2 Pacific Ocean
Eocene 16xCO2 Atlantic Ocean
Eocene 16xCO2 Pacific Ocean
Oxygen
mL/L
Depth (m)
1000
2000
3000
4000
60S
30S
0
30N
60N

Appendix DR2

TableDR1: Marine productivity and deep-sea dissolved oxygen tendencies across the PETM.

North Atlantic Ocean & Arctic Ocean

Sample ID		Depth [m][1]	Depth 55 Ma [m]	Latitude[2]	Long.	Latitude[3] 55 Ma	Long. 55 Ma	Product. Change[4]	$[O_2]$ Change[5]	$CaCO_3$ Dissolu-tion	Reference
1	302-4A Arctic Ocean	1288	<100-200?	87.9 °N	136.2 °E	81.5 °N	42.6 °E	++	--*	NA	Sluijs et al., 2006, 2008a; Weller and Stein, 2008
2	North Sea (shallow)	NA	100-500	51-58°N	1°W - 7 °E	46.0 - 53.0°N	2.7 °W- 4 °E	++	--	++	Bujak and Brinkhuis, 1998; King, 1989
3	North Sea (deep basin)	100-700	750-1000	51-58°N	1°W- 7 °E	46.0 - 53.0°N	2.7 °W- 4 °E	++	--	++	Gradstein et al., 1994
4	DSDP 548 DSDP 549	1251 2515	600-1500	48.9 °N 49.1 °N	12.1 °W 13.1 °W	44.3 °N 44.5 °N	13.1 °W 14.1 °W	+?	-	++	Boltovskoy et al., 1992; Berggren and Aubry 1996; Nunes and Norris, 2006

[1] Present-day water depth for marine cores.
[2] Present-day position of marine cores or sections.
[3] The 55Ma core position has been calculated with the PointTracker v.4 software from PALEOMAP (Scotese, 2011). PointTracker software rotates locations back to their paleo-position.
[4] Changes in productivity follow designation by authors and re-evaluation. Low productivity estimates rely on composition of planktic assemblages (nannolankton or planktic foraminifera); high productivity estimates are commonly based on microfossil assemblages (dinocysts, diatoms, radiolarians). Low oxygen conditions are assessed using sedimentary structure (lamination, lack of ichnofossils, high organic carbon content and specific biomarkers), as well as benthic foraminiferal assemblages. Benthic foraminiferal species indicative of high food supply or low oxygen conditions (or some combination of both) are interpreted as indicative of lowered oxygen conditions if other data (e.g., calcareous nannofossil assemblages) indicate overall low productivity. Where no data were given by authors on $CaCO_3$ in drill cores, core photographs and descriptions were checked (see also Thomas, 1998).
[5] * indicates the presence of isorenieretane (Weller and Stein, 2008), an indicator of anoxic conditions in the photic zone. The descriptions of the pre-PETM to PETM (at the CIE) changes are inferred from stable carbon isotope analyses.

North Atlantic Ocean (continued)

Sample ID		Depth [m]	Depth 55 Ma [m]	Latitude	Long.	Latitude 55 Ma	Long. 55 Ma	Product. Change	[O_2] Change	$CaCO_3$ Dissolu-tion	Reference
5	DSDP 401	2495	~1800	47.3 °N	8.5 °W	42.5 °N	10.3 °W	-?	-	?	Schnitker, 1979; Pak and Miller, 1992; Pardo et al., 1997; Nunes and Norris, 2006; Tremolada and Bralower, 2004
6	Zumaya Sect.	N/A	~1000	43.3 °N	2.2 °E	38.2 °N	3.2 °W	0?	-	+	Ortiz, 1995; Schmitz et al., 1997; Alegret, 2009a; Rodriguez-Tovar et al., 2011
7	New Jersey Wilson Lake Bass River	N/A N/A	50-150	39.7 °N 39.6 °N	75.1 °W 74.4 °W	39.8 °N 39.6 °N	57.4 °W 56.7 °W	+	-	0	Gibbs et al., 2006, 2010; Harris et al., 2010; John et al., 2008; Sluijs et al., 2008b; Kopp et al., 2009; Stassen et al., 2009, 2011
8	DSDP 605	2195	1800-2300	38.0 °N	72.6 °W	37.7°N	55.4 °W	-	-?	+	Hulsbos, 1987; Thomas, 1998, unpub.
9	ODP 999	2828	1500-2000	12.7 °N	78.7 °W	12.3 °N	77.0 °W	+	--	--	Bralower et al., 1997
10	ODP 1260	2548	?	9.3 °N	54.5 °W	6.4 °N	42.6 °W	-?	-	-	Mutterlose et al., 2007
11	ODP 929	4356	~3500	6.0°N	43.7 °W	0.7°N	31.1 °W	-	-	++	Thomas and Roehl, 2002; Thomas, 2007

South Atlantic Ocean

Sample ID		Depth [m]	Depth 55 Ma [m]	Latitude	Long.	Latitude 55 Ma	Long. 55 Ma	Product. Change	[O_2] Change	$CaCO_3$ Dissolu-tion	Reference
12	ODP 1262	4755	3400	27.2 °S	1.6 °E	33.9 °S	10.5 °W	-	0	++	Zachos et al., 2005; Chun et al., 2010; Thomas et al., 2010, unpub.
13	DSDP 527	4428	3500	28.0 °S	1.8 °E	34.8 °S	10.5 °W	-	0	++	Thomas and Shackleton, 1996
14	DSDP 20C	4506	2500-3000	28.3 °S	26.5 °W	31.5 °S	14.7 °W	0	0	+	Tjalsma and Lohmann, 1983; Müller-Merz and Oberhänsli, 1991
15	ODP 1263	2717	1500	28.5 ºS	2.8 °E	35.4 °S	9.6 °W	-	--	++	Zachos et al. 2005; Chun et al., 2010; Paytan et al., 2007; Thomas et al., 2010, unpub.
16	ODP 1266	3798	2600	28.5 ºS	2.4 °E	35.3 °S	10.0 °W	-	0	++	Zachos et al., 2005; Chun et al., 2010; Thomas, unpubl.
17	DSDP 525	2467	1400	29.1 °S	3.0 °E	36.0 °S	9.5 °W	-	-?	++	Thomas and Shackleton, 1996
18	DSDP 516	1313	100-200	30.3 °S	35.3 °W	33.3 °S	23.4 °W	0	0	+	Dailey, 1983; Boltovskoy et al., 1995
19	ODP 698	2137	800-900	51.5 °S	33.1 °W	54.5 °S	21.0 °W	-?	0	+	Katz and Miller, 1991
20	ODP 700	3601	2200-2400	51.5 °S	30.3 °W	54.5 °S	14.0 °W	0?	0?	?	Katz and Miller, 1991
21	ODP 689	2080	1100	64.3 °S	3.1 °E	64.8 °S	5.2 °W	-	-	0	Thomas, 1990; Steineck and Thomas, 1996; Thomas, 2007
22	ODP 690	2941	1900	65.2 °S	1.2 °E	65.6 °S	7.2 °W	-	-	0-	Bralower, 2002; Thomas, 1990, 2003, 2007

North Pacific Ocean

Sample ID		Depth [m]	Depth 55 Ma [m]	Latitude	Long.	Latitude 55 Ma	Long. 55 Ma	Product. Change	$[O_2]$ Change	$CaCO_3$ Dissolution	Reference
23	ODP 883	2407	2000	51.2 °N	167.8 °E	41.4 °N	161.1°W	0	0	?	Pak and Miller, 1995
24	Hokkaido Tokachi district	N/A	500-1000	~42.9 °N	143.7 °E	47.0 °N	136.5 °E	+	-	-	Kaiho, 1988
25	ODP 1209	2387	1900	32.7 °N	158.3 °E	23.5 °N	171.1°W	0-	-	0-	Bralower et al., 2006; Takeda and Kaiho, 2007; Gibbs et al., 2010
26	DSDP 577	2675	1800-2100	32.5 °N	157.9 °E	23.4 °N	171.9°W	0-?	0	-0?	Pak and Miller, 1992; Paytan et al., 2007
27	ODP 1211	2907	2400	32.5 °N	158.7 °E	23.4 °N	171.0°W	-	-	0-	Takeda and Kaiho, 2007
28	ODP 1210	2573	2100	32.2 °N	158.3° E	23.1 °N	171.1°W	-	-	0-	Takeda and Kaiho, 2007
29	ODP 1212	2681	2200	32.0 °N	158.9 °E	22.8 °N	171.3°W	-	-	0-	Takeda and Kaiho, 2007
30	DSDP 305	2903	?	32.0 °N	157.8 °E	22.9 °N	171.8°W	+?	-	?	Paytan et al., 2007
31	ODP 865	1518	~1500	18.5 °N	179.6°W	8.3 °N	151.4°W	-	-	-0?	Bralower et al., 1995a, b; Thomas, 1998, 2007; Thomas et al., 2000
32	ODP 1221	5174	~3000	12.0 °N	143.7°W	3.1 °N	116.5°W	-	0	--	Nomura and Takata, 2005; Nunes and Norris, 2006
33	ODP 1220	5218	~3000	10.1°N	142.5°W	1.3 °N	115.1°W	-	-	--	Nomura and Takata, 2005; Nunes and Norris, 2006

South Pacific Ocean

Sample ID		Depth [m]	Depth 55 Ma [m]	Latitude	Long.	Latitude 55Ma	Long. 55 Ma	Product. Change	$[O_2]$ Change	$CaCO_3$ Dissolu-tion	Reference
34	Tawanui Section New Zealand	N/A	500-1500	40.5 °S	176.1 °E	52.6 °S	170.6°W	++	--	++	Crouch et al., 2001; Hollis et al., 2005a; Kaiho et al., 1996
35	Mead Stream, New Zealand	NA	200-1000	42.5 °S	173.5 °E	54.6 °S	173.2°W	+	--	0	Hollis et al., 2005a, b
36	DSDP 283	4729	?	43.9 °S	154.3 °E	62.7 °S	167.7 °E	--	0?	?	Kennett et al., 1975
37	ODP 1172	2622	<200	44.0 °S	149.9 °E	64.3 °S	161.5 °E	+	0?	NA	Exon et al., 2001; Roehl et al., 2004; Sluijs et al., 2011
38	DSDP 277[6]	1214	?	52.2 °S	166.2 °E	60.6 °S	170 °W	0	0	?	Shackleton and Kennett, 1975

[6] Dating of core corresponds to 51 Ma

Indian Ocean

Sample ID		Depth [m]	Depth 55 Ma [m]	Latitude	Long.	Latitude 55 Ma	Long. 55 Ma	Product. Change	$[O_2]$ Change	$CaCO_3$ Dissolu-tion	Reference
39	DSDP 237	1623	?	7.1 °S	58.1 °E	17.3 °S	50.8°E	0?	0	?	Vincent and Brün, 1974
40	DSDP 215	5309	>2000	8.1 °S	68.8 °E	32.4 °S	44.4 °E	0	0?	?	McGowran, 1974; Hovan and Rea, 1992; Thomas et al., 2000
41	ODP 762	1360	?	19.9 °S	112.3 °E	44.8 °S	98.0 °E	0	0	0	Nomura and Kennett, unpub.; Thomas, 1998, unpub.
42	ODP 752	1086	500-800	30.9 °S	93.6 °E	57.5 °S	65.6 °E	0	0	0	Nomura, 1991; Thomas, 1998, unpub.
43	DSDP 245	4857	600-1000	31.6 °S	52.3 °E	42.8 °S	45.5 °E	+?	-?	?	Simpson et al., 1974
44	ODP 747	1695	2000-3000	54.8 °S	76.8 °E	56.1 °S	71.2 °E	0?	0?	0?	Mackensen and Berggren, 1992
45	ODP 748	1921	600-2000	58.4 °S	79.0 °E	59.7 °S	73.5 °E	0?	0?	0?	Mackensen and Berggren, 1992
46	ODP 1135	1567	600-1000	59.7 °S	84.3 °E	60.9 °S	79.1 °E	-?	0	0	Jiang and Wise, 2007, 2009; Thomas, unpub.
47	ODP 738	2253	~1300	62.7 °S	82.8 °E	63.9 °S	77.6 °E	+	-	-	Lu and Keller 1993; Thomas, 1998, unpub.

Tethys and Peri-Tethys

Sample ID		Depth [m]	Depth 55 Ma [m]	Latitude	Long.	Latitude 55 Ma	Long. 55 Ma	Product. Change	[O_2] Change	CaCO3 Diss.	Reference
48	Dukla Nappe, Poland	NA	>2500	49.1 °N	22.3 °E	39.1 °N	20.4 °E	+	-	NA	Bak, 2005
49	Anthering Section (Austria)	N/A	>2000	47.9 °N	13.0 °E	44.4 °N	1.7 °W	++	--	++	Egger et al., 2000, 2003, 2009; Egger and Brueckl, 2006
50	Untersberg Section (Austria)	NA;	>2000	47.7 °N	13.0 °E	44.2	1.7 °W	++	--	++	Egger et al., 2005; Egger and Brueckl, 2006
51	Forada Creek Section (Italy)	N/A;	600-1000	46.0 °N	11.9 °E	37.1 °N	11.1 °E	++	0	++	Giusberti et al., 2007
52	Possagno Section (Italy)	N/A	500-1500	45.8 °N	11.5 °E	36.9 °N	10.7 °E	+?	-	++	Braga et al., 1975; Agnini et al., 2006
53	Aktumsuk, Uzbekistan	NA	<200?	43.9 °N	57.2 °E	40.8 °N	46.1 °E	++	--*	++	Gavrilov et al., 2003, 2009; Bolle et al., 2000
54	Kheu River, Russia	NA	<200?	43.5 °N	44.0 °E	39.6 °N	38.7 °E	++	--*	++	Gavrilov et al., 2003, 2009
55	Contessa (Italy)	NA	1000-1500	43.4 °N	13.6 °E	34.3 °N	12.1 °E	+	0	++	Giusberti et al., 2009
56	Torangly, Turkmenistan	NA	<200?	39.1 °N	56.1 °E	36.0 °N	50.7° E	?	--*	?	Gavrilov et al., 2003, 2009; Speijer et al., 1997
57	Caravaca Section (Spain)	N/A	500-1000	38.1 °N	1.9 °W	33.0 °N	3.4 °W	+	-	+	Canudo et al., 1995;Ortiz, 1995
58	Alamedilla Section (Spain)	N/A	~2000	37.6 °N	3.2 °W	32.6 °N	5.6°E	-	0	+	Lu et al., 1998; Alegret et al., 2009b, 2010
59	Wadi Nukhl (Egypt)	N/A	500-600	29.1 °N	33.3 °E	18.4 °N	28.0 °E	++	--	++	Speijer and Wagner, 2002; Speijer et al., 1997, 2000
60	Gebel Duwi (Egypt)	N/A	<100	26.1 °N	34.1 °E	15.4 °N	28.6 °E	++	--	++	Speijer and Wagner, 2002

Tethys and Peri-Tethys (continued)

Sample ID		Depth [m]	Depth 55 Ma [m]	Latitude	Long.	Latitude 55 Ma	Long. 55 Ma	Product. Change	[O_2] Change	CaCO3 Diss.	Reference
61	Dababiya (PE GSSP), Egypt	NA	100-300	25.5 °N	32.5 °E	14.9 °N	27.0 °W	++	--	++	Ouda and Aubry, 2003; Alegret et al., 2005; Ernst et al., 2006
62	Gebel Aweina (Egypt)	N/A	100-300	25.3 °N	32.9 °E	14.7 °N	27.0 °E	++	--	++	Speijer et al., 2000; Speijer and Wagner, 2002

Tendencies of the export production F_{poc} in mol m^{-2} yr^{-1} are estimated in Table 1 and Figure 2 as follows: significant increase (++; red) F_{poc} >2 mol m^{-2} yr^{-1}; slight increase (+; orange) 1 mol m^{-2} $yr^{-1} \leq F_{poc} < 2$ mol m^{-2} yr^{-1}; no significant change (0; light green) -1 mol m^{-2} $yr^{-1} \leq F_{poc} \leq 1$ mol m^{-2} yr^{-1}; slight decrease (-; dark green) -2 mol m^{-2} yr^{-1} $\leq F_{poc}$ <-1 mol m^{-2} yr^{-1}; and significant decrease (--; light blue) F_{poc} <-2 mol m^{-2} yr^{-1}. A review of Tethian carbonate platforms is found in Scheibner and Speijer (2008). Most of these platforms represent shallow marine conditions which are not resolved by the climate model used in this study.

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