Atlantic-Pacific seesaw and its role in outgassing CO_2 during Heinrich events - Supplementary material

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1. Additional sensivity experiments

To test the robustness of our results a set of sensitivity experiments is performed with both LOVECLIM and the UVic ESCM forcing the models with different salt fluxes over the Southern Ocean, the Eastern Equatorial Pacific and/or the North Pacific (Table S1). The main results of these experiments are shown in Table S2. Results of all these experiments were incorporated into Figure 8 of the main manuscript, thus showing the dependency of deep Pacific carbon on changes in Antarctic Bottom Water (AABW) and North Pacific Deep Water (NPDW) transport.

In addition, to better compare our results with the ones of Schmittner et al. [2007] and Schmittner and Galbraith [2008], we performed an additional experiment with the UVic ESCM by adding 0.2 Sv of freshwater in the North Atlantic for 500 years (U-fNA-500). The results are shown in Figure S1.

1.1. Influence of the Gent and McWilliams thickness diffusion coefficient

To test the dependence of the results on the Gent and McWilliams thickness diffusion coefficient (GM) [Stocker et al., 2007], additional meltwater experiments are performed with different GM parameters within LOVECLIM. The GM parameter is varied at values of 0, 700 and 1400 m^2/s (Table S3) from the default GM value of 200 m^2/s. In the UVic ESCM, the default GM coefficient is set to 800 m^2/s. As seen in Table S3, the GM parameter has an impact on pCO_2 changes. However, the mechanism described in this study holds independently of the GM parameter used: i.e. enhanced AABW and NPDW transport during an AMOC shutdown induce a release of deep Pacific carbon through the Southern Ocean. This implies that our results are robust across different GM diffusion values and across different EMICs. The results of these experiments are also incorporated into Figure 8.

1.2. Influence of stronger Southern Hemispheric Westerlies

A shutdown of the AMOC in LOVECLIM leads to a weakening of the Southern Hemispheric Westerlies (SHW). A standard meltwater experiment as well as an experiment with global salinity compensation were performed with an imposed strengthening of the SHW in LOVECLIM (L-fNAW-G700 and L-fNAcW-G700). The strengthening of the SHW is imposed progressively during the first 400 years of the run until reaching a 60% increase. These experiments were performed with a GM parameter of 700 m^2/s. As seen in Table S3, an increase in the SHW during an AMOC shutdown leads to a 3.6 ppmv increase in pCO_2, in agreement with previous results [Menviel et al., 2008]. The stronger SHW enhance the formation of Antarctic Intermediate Water and AABW, thus slightly increasing the ventilation of deep Pacific carbon. In the deep Atlantic Ocean, the DIC content is only slightly reduced with stronger SHW.

1.3. Dependence on the initial state of the AMOC

In the default LOVECLIM setting, the LGM AMOC is relatively strong (22 Sv), whereas benthic δ^{13}C records from the glacial Altantic Ocean suggest a weaker AMOC at the LGM than at pre-industrial times [Curry and Oppo, 2005]. Some additional experiments are performed from a LGM state featuring a weaker AMOC. The weaker Atlantic overturning is obtained by adding freshwater into the North Atlantic at a rate of 0.05 Sv for 7000 years and 5000 years for experiments with a GM parameter of respectively 200 and 700 m^2/s. The new LGM control runs feature an AMOC strength of 17 Sv and 14 Sv respectively, which is comparable to the strength of the LGM AMOC simulated by the UVic ESCM (15 Sv). From these new states we then perform three additional experiments similar to the ones previously described. In particular, in L-fNA$_L$-G700, we add 0.2 Sv in the North Atlantic for 1000 years. While in L-fNA$_{LSONP}$ and L-fNA$_{LSONP}$-G700 we add 0.2 Sv in the North Atlantic and -0.15 Sv in the Southern Ocean and North Pacific Oceans for 1000 years. The greater DIC content in the deep Pacific Ocean at the start of the AMOC shutdown in experiments L-fNA$_L$-G700, L-fNA$_{LSONP}$-G700 and L-fNA$_{LSONP}$ effectively leads to a greater CO_2 outgassing. As seen in Tables S2 and S3, the deep Pacific carbon anomalies are more negative (or less positive) in experiments L-fNA$_{LSONP}$, L-fNA$_{LSONP}$-G700 and L-fNA$_L$-G700 than in their counterparts L-fNA$_{SONP}$, L-fNA$_{SONP}$-G700 and L-fNA-G700. The results of these experiments were also incorporated into Figure 8 of the main manuscript.

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Table S 1. **Idealized experiments performed:** Experiments performed under constant LGM conditions and with standard mixing scheme parameters. 0.2 Sv for 1000 years is added in the North Atlantic Ocean in all the experiments. SO, NP and EEP indicates the freshwater flux (Sv) added in respectively the Southern Ocean, the North Pacific Ocean and the Eastern Equatorial Pacific for 1000 years. A negative freshwater flux indicates that salt is added. Experiment L-fNA$_{LSONP}$ is further described in section 1.3.

Exp.	SO (Sv)	EEP/NP (Sv)	Exp.	SO (Sv)	EEP/NP (Sv)
LOVECLIM			**UVic**		
L-fNA	0	0	U-fNA	0	0
L-fNA$_{SO}$	-0.15	0	U-fNA$_{SO}$	-0.1	0
L-fNA$_{SOEEP}$	-0.15	-0.15	U-fNA$_{SOEEP}$	-0.1	-0.1
L-fNA$_{SONP}$	-0.15	-0.15	U-fNA$_{SONP}$	-0.1	-0.1
L-fNA$_{LSONP}$	-0.15	-0.15	U-fNA$_{SOw}$	-0.08	0
L-fNA$_{SOs}$	-0.2	0	U-fNA$_{SOwNP}$	-0.08	-0.1
L-fNA$_{NP}$	0	-0.15	U-fNA$_{SOwNPs}$	-0.08	-0.15
L-fNA$_{SONPw}$	-0.15	-0.1	U-fNA$_{SOs}$	-0.15	0
			U-fNA$_{SOsNPs}$	-0.15	-0.15

Table S 2. **Main results of idealized experiments:** Changes in atmospheric CO_2, deep (≥2000m for LOVECLIM, ≥2200m for UVic) carbon content (GtC) in the Atlantic and Pacific basin, Antarctic Bottom Water in the Pacific, North Pacific Deep Water (Sv), globally-averaged sea surface temperature (SST, °C) and salinity (SSS) at model year 1000 for experiments performed with LOVECLIM (L) and UVic (U). ΔpCO_2sol represents the change in pCO_2 due to the solubility effect, i.e. due to changes in SST and SSS [Takahashi et al., 1993]. AABW is defined as the minimum negative overturning streamfunction in the Pacific basin south of the equator and at depths greater than 2500m; NPDW as the maximum overturning streamfunction in the Pacific basin north of 30°N. In experiment naming (column 1), c indicates global salt compensation.

Exp.	ΔpCO_2	ΔC_{deep} Atl.	ΔC_{deep} Pac.	Δ AABW	Δ NPDW	Δ SST	Δ SSS	Δ pCO_{2sol}
	ppmv	GtC	GtC	Sv	Sv	°C		ppmv
LOVECLIM								
L-fNA	-5.0	185	74	-3	12	-0.1	-0.6	-4.2
L-fNA$_{SO}$	3.7	151	-53	0.6	14	0.2	-0.58	0.2
L-fNA$_{SOEEP}$	10.2	140	-133	2.5	18	0.16	-0.33	-0.6
L-fNAc	13.6	153	-108	3.6	17	0.82	0	6.7
L-fNA$_{SONP}$	9.0	143	-126	1.6	19	0.25	-0.5	-0.8
L-fNA$_{LSONP}$	12.6	162	-246	3.8	16	0.4	-0.42	0.4
L-fNA$_{SOs}$	6	139	-66	3	8	0.4	-0.38	1.1
L-fNA$_{NP}$	-0.5	181	-1	-2	14	0.05	-0.95	-4.9
L-fNA$_{SONPw}$	7	146	-83	2.5	13	0.3	-0.45	-0.1
UVic								
U-fNA	-6.8	100	10	-2	12	-0.12	-0.55	-4.1
U-fNA$_{SO}$	7.2	68	-38	1.6	8.9	0.28	0	2.3
U-fNA$_{SOEEP}$	18	77	-179	2.8	17	0.42	0.27	4.9
U-fNAc	5	100	-94	1	17	0.14	-0.06	0.8
U-fNA$_{SONP}$	15	37	-204	2.5	19	0.24	-0.16	1.1
U-fNA$_{SOw}$	-0.12	84	-6	-0.2	10.2	0.14	-0.11	0.5
U-fNA$_{SOwNP}$	8.8	79	-104	0.6	18	0.13	-0.11	0.4
U-fNA$_{SOwNPs}$	11	106	-188	1.6	20.5	0.14	-0.11	0.5
U-fNA$_{SOs}$	18	52	-160	2.6	7.8	0.46	0.1	4.3
U-fNA$_{SOsNPs}$	24	64	-240	4	19	0.45	0.1	4.2

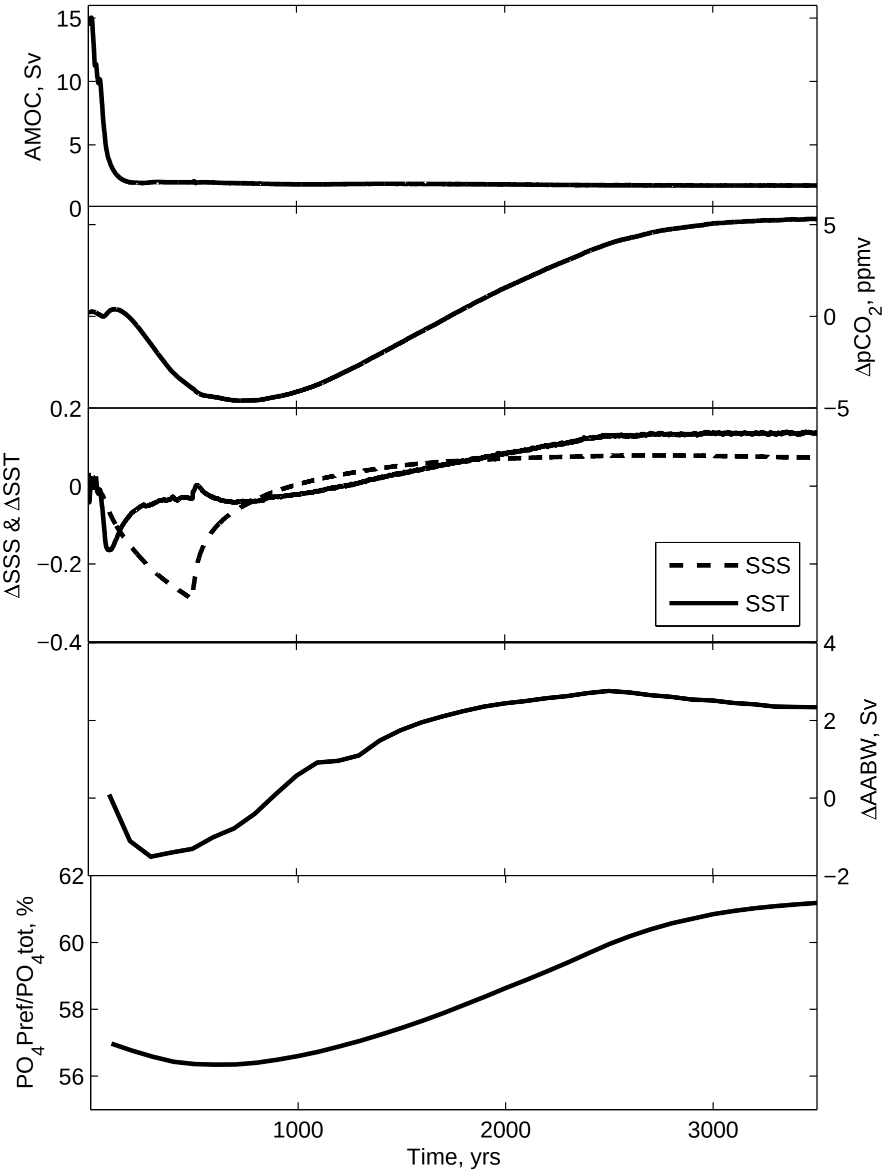

Figure S 1. **Results of experiment U-fNA-500** From top to bottom: Timeseries of changes in the Atlantic Meridional Overturning Streamfunction (Sv); changes in atmospheric CO_2 (ppmv); globally averaged SSS (g/kg) and SST (°C); AABW transport (Sv) and preformed PO_4 inventory (%).

Table S 3. **Influence of the GM diffusivity parameter:** Same as Table S2 but for experiments performed with LOVECLIM under different GM diffusivity parameters (0, 700 and 1400 m^2/s). fNA indicates a freshwater input in the North Atlantic, c indicates an experiment with salt compensation. W indicates that the SHW were strengthened by up to 60%.

Exp.	ΔpCO_2	ΔC_{deep} Atl.	ΔC_{deep} Pac.	Δ AABW	Δ NPDW	Δ SST	Δ SSS	Δ pCO_{2sol}
	ppmv	GtC	GtC	Sv	Sv	°C		ppmv
GM=0								
L-fNA-G0	-9.3	169	163	-5	10	-0.05	-1.4	-8.3
L-fNAc-G0	16.2	112	-72	3	20	0.9	-0.25	6
GM=700								
L-fNA-G700	-2.3	168	85	-3	6	0.08	-0.65	-3
L-fNAc-G700	15	161	-107	1.5	16	0.7	-0.02	5.6
L-fNAW-G700	1.3	164	49	-1.5	7	0.15	-1.05	-4.7
L-fNAcW-G700	18.7	145	-144	5	14	0.9	-0.02	7.3
L-fNA_{SONP}-G700	9	157	-102	1	14	0.28	-0.45	-0.3
L-fNA_{L}-G700	0.5	154	37	-2.5	8.5	0	-1.13	-6.3
L-fNA_{LSONP}-G700	13.7	110	-185	2.5	14	0.38	-0.44	0.6
GM=1400								
L-fNA-G1400	-3.4	168	97	-5	5	-0.02	-1.1	0
L-fNAc-G1400	16.1	145	-114	1	15	0.55	-0.12	3.8