[Geophysical Research Letters]

Supporting Information for

[Tidal Mixing Intensifies the Glacial Ocean Overturning]

[A. Schmittner[1], J. A. M. Green[2], S.-B. Wilmes[2]]

[[1] College of Earth, Ocean, and Atmospheric Sciences, Oregon State University, Corvallis, Oregon, United States.

[2] School of Ocean Sciences, Bangor University, Menai Bridge, United Kingdom.]

Contents of this file

Text S1.

Comparison with M07

Fig. S1, which shows dissipation changes using a similar color scale than Fig. 1 of M07, reveals much larger changes compared to M07, particularly over the Mid-Atlantic Ridge.

Approach to equilibrium

Fig. S2 shows the approach to equilibrium for the three climate model simulations. All simulations were initialized with conditions from a previous model with PD boundary conditions but different dissipation fields. As a response to the changed dissipation fields the PD simulation shows little changes in the AMOC but an increase in CPDW flow into the Pacific. The LGM simulations, on the other hand, show large initial increases in AMOC and CPDW flow. The LGM PDmix AMOC displays a large vascillation before settling to a steady state, whereas the PD AMOC is initially steady but finally settles into a oscillatory state with a period of ~60 years during the second half of the integration and the LGM AMOC exhibits a smoother and more monotonous approach to equilibrium. These time series and others (not shown) leave little doubt that the final 500 years represent a valid approximate equilibrium.

Sensitivity to feedbacks between stratification, dissipation, and circulation

Additional experiments were conducted using total dissipation E instead of E_w as input to the climate model. In these experiments we also explored the effects of changing stratification by feeding climate model simulated values of N back into a second iteration with the tide model. Subsequently the resulting fields of *E* were used again in the second iteration LGM simulation with the climate model. The results from these experiments (Tab. S1, Fig. S3) indicate that the results shown in the main part of the paper are robust with respect to feedbacks and modest changes in stratification. Effects of feedbacks as indicated by differences between LGMit1 and LGMit2 are much smaller than effects of glacial-interglacial changes in tidal energy dissipation (LGM PDmix vs LGMitx).

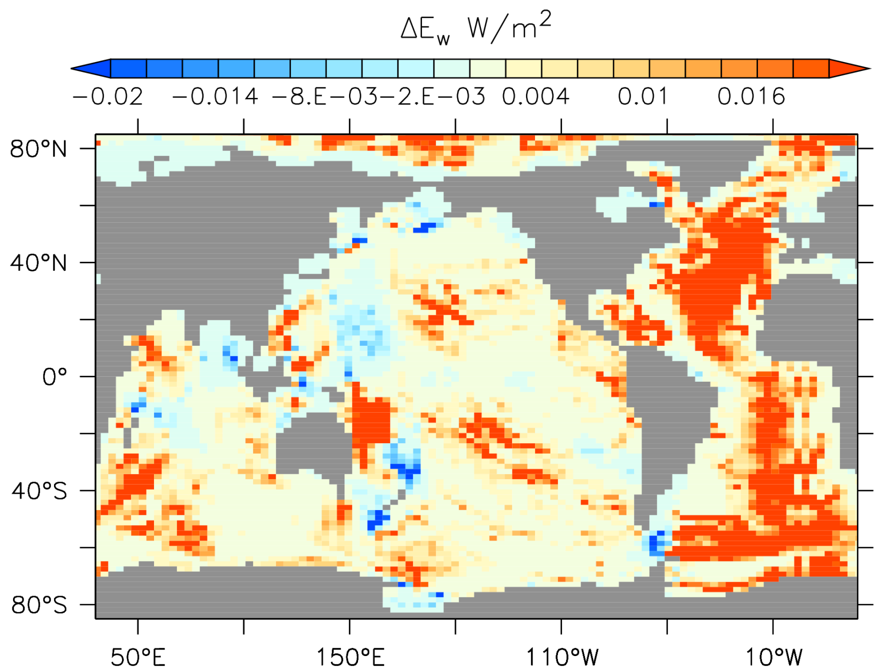

Figure S1. Changes in tidal energy dissipation due to internal wave drag between LGM and PD tide model runs mapped onto the climate model grid.

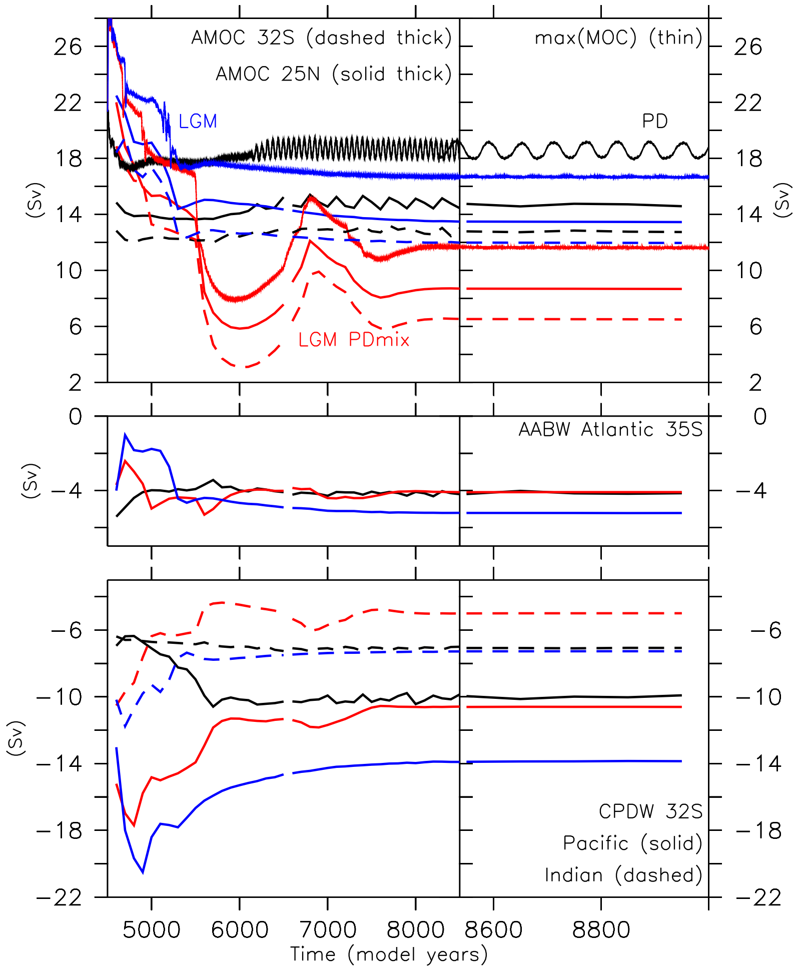

Figure S2. Timeseries of MOC indices (Tab. 1) from the climate model's approach to equilibrium. Left panels show annual mean AMOC, AABW and CPDW at 100 year intervals. Right panels show 100 year averages for AMOC, AABW and CPDW of the last 500 years on an expanded horizontal axis. The time average of the last 500 years is used in the analysis presented in the main text and Figs. 2-4. The global MOC maximum (thin lines in upper panel) is show at annual intervals in all panels illustrating oscillations in experiment PD. All model simulation were initialized from a different PD simulation at model year 4,500. The gap between years 6,500 and 6,600 is due to a restart at year 6,500 and different input files used in the plotting routine.

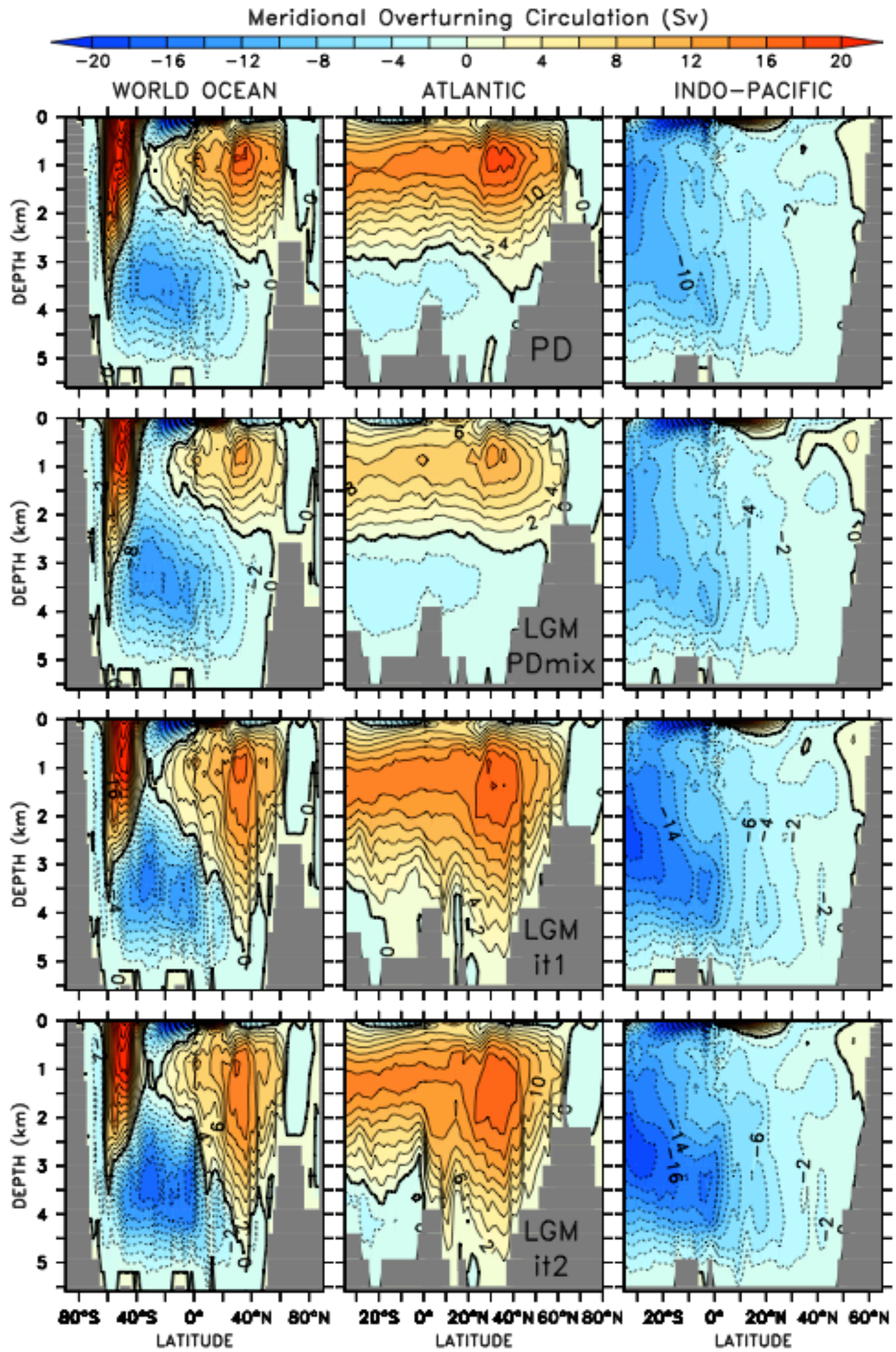

Figure S3. As Fig. 4 but for experiments with E instead of E_w as input to the climate model. The two bottom rows show two LGM iterations considering feedbacks due to changes in stratification.

	M2		*S2*		*K1*		*O1*		$\sum_{TC}$	
	E_{M2}	$E_{w,M2}$	E_{S2}	$E_{w,S2}$	E_{K1}	$E_{w,K1}$	E_{O1}	$E_{w,O1}$	$\sum E$	$\sum E_w$
PD	2.75 (2.14)	0.78 (0.83)	0.39 (0.33)	0.17 (0.14)	0.36 (0.29)	0.12 (0.18)	0.19 (0.16)	0.06 (0.08)	3.69 (2.93)	1.33 (1.23)
LGM	4.76 (4.77)	3.80 (4.04)	0.46 (0.47)	0.28 (0.17)	0.37 (0.37)	0.15 (0.30)	0.18 (0.21)	0.18 (0.22)	5.76 (5.81)	4.69 (4.72)

Table S1. Total tidal energy dissipation $E = E_b + E_w$ and dissipation from internal wave drag E_w only (shaded) for the four major tidal constituents (TC) and their sum. Numbers (in brackets) denote globally integrated values [TW] from the tidal (interpolated on the climate) model grid. Differences are due to mapping from the tide model to the climate model grid as discussed in more detail in [Schmittner and Egbert, 2014].

	mid global	deep global	AMOC 25°N	AMOC 32°S	AABW Atl	CDW Ind 32°S	CDW Pac 32°S
PD	16.8	15.7	14.7	12.8	4.1	7.1	10.0
LGM PDmix (buoyancy forc.)	11.8 (-30%)	15.5 (-1%)	8.7 (-41%)	6.5 (-49%)	4.1 (0%)	5.0 (-30%)	10.6 (+6%)
LGM (mixing)	15.6 (+24%)	21.2 (+27%)	13.5 (+36%)	12.0 (+46%)	5.2 (+21%)	7.3 (+32%)	13.9 (+24%)

Table S2. Ocean circulation indices in Sv. 'Mid global' denotes the strength of the mid-depth global meridional overturning cell calculated as the global maximum streamfunction below 400 m and north of the equator. 'Deep global' is the deep overturning cell calculated as the (negative) minimum of the global streamfunction below 1.5 km depth. 'AMOC 32°S' and 'AMOC 25°N' are the maximum streamfunction below 300 m in the Atlantic at 32°S and

25°N, respectively, 'AABW Atl' is the (negative) minimum streamfunction in the Atlantic below 1 km at 35°S. 'CDW' represents inflow of Circumpolar Deep Water into the Indian and Pacific oceans at 32°S. Averages over the last 400 years of the integrations are listed. Effects of buoyancy forcing are estimated as percentage changes in the LGM PDmix row, which denote $MOC_{LGM\ PDmix}$ / MOC_{PD} – 1, where MOC_{PD} and $MOC_{LGM\ PDmix}$ are the MOC indices for PD and LGM PDmix. Effects of mixing are estimated as percentage changes in the LGM row, which denote 1-MOC_{LGM_PDmix}/MOC_{LGM}, indicating the relative change due to mixing with respect to the stronger MOC case (LGM) in order to be better comparable to the percentage changes reported for the buoyancy forcing.

	mid global	deep global	AMOC 25°N	AMOC 32°S	AABW Atl	CDW Ind 32°S	CDW Pac 32°S
PD	18.7	14.2	16.7	14.7	4.0	7.3	10.1
LGM PDmix	13.4	14.2	10.9	9.0	3.5	5.7	10.4
LGMit1	17.3	15.2	15.5	15.6	1.7	7.0	14.9
LGMit2	16.8	18.0	15.8	15.1	2.6	7.5	15.0

Table S3. As Tab. S1 but for experiments using E instead of E_w as input to the climate model.