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Impact of negative and positive CO_2 emissions on global warming metrics using an ensemble of Earth system model simulations

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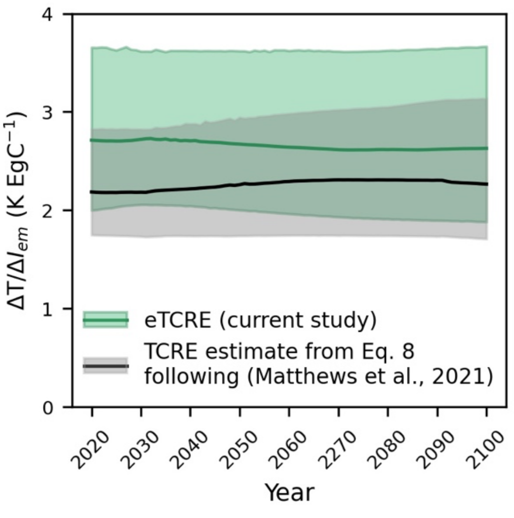

Figure S1: Effective transient climate response to the cumulative CO_2 emissions (eTCRE) (Eq. 9, current study) versus TCRE estimate from Eq. 8 following (Matthews et al., 2021) from year 2020 until 2100 for SPP1-2.6 scenario. Solid lines show the median values, and shaded areas indicate the values between the 10^{th} and 90^{th} percentiles.

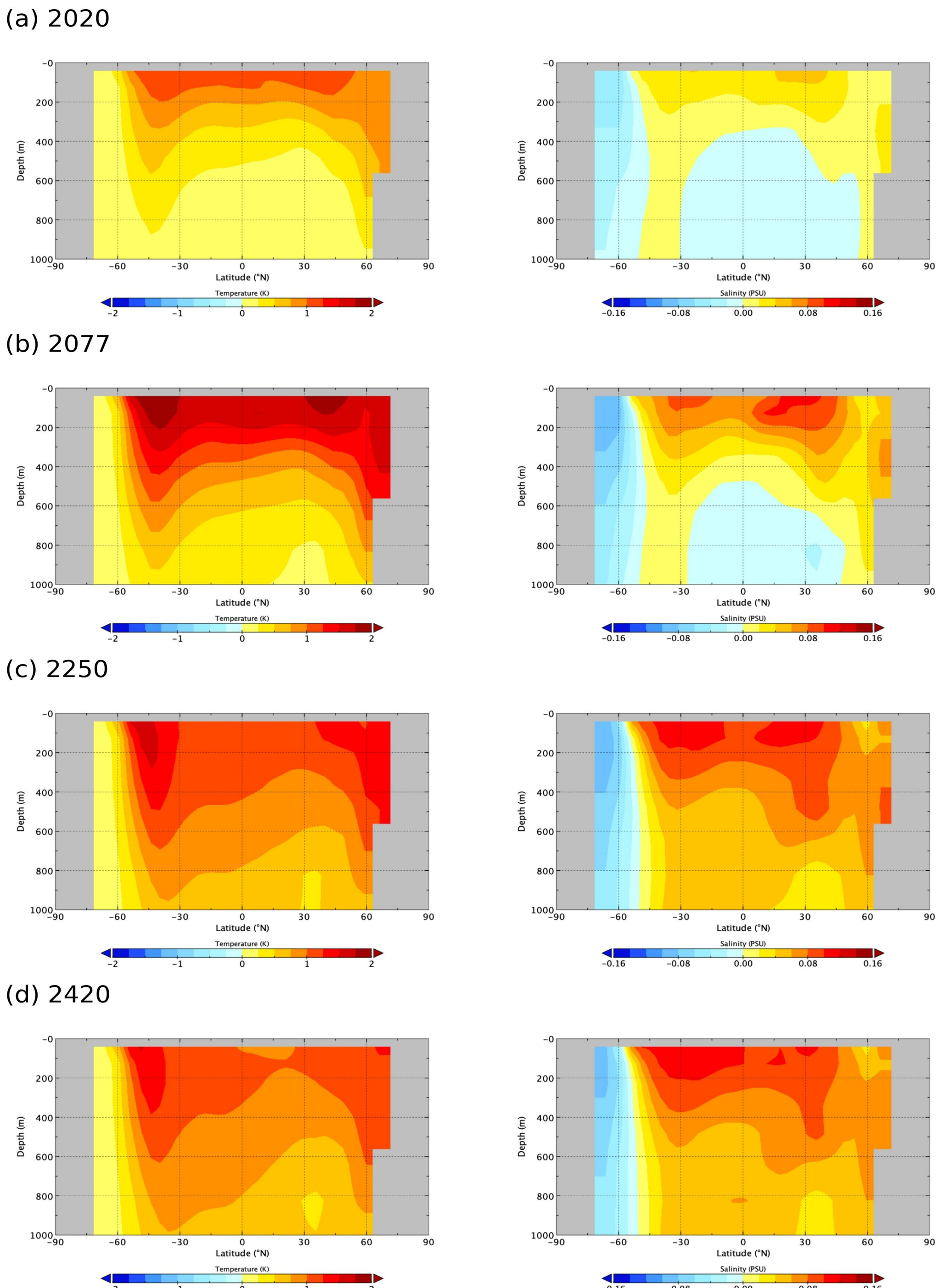

Figure S2: The change in temperature (in K) (left column) and salinity (in PSU) (right column) in Atlantic cross section at (a) 2020, (b) 2077, (c) 2250 and (d) 2420 relative to the year 850 CE in SSP1-2.6 scenario.

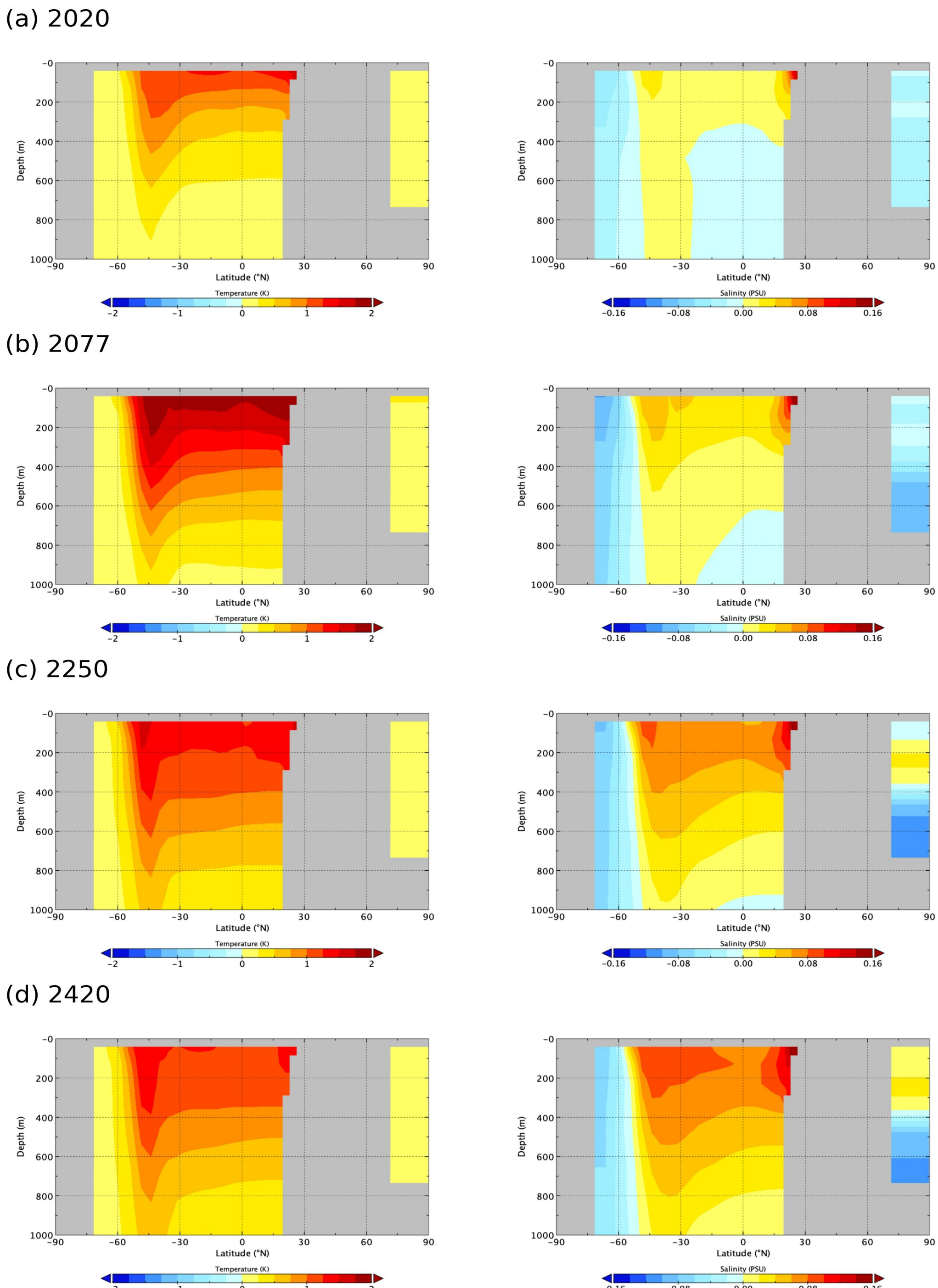

Figure S3: The change in temperature (in K) (left column) and salinity (in PSU) (right column) in Indian cross section at (a) 2020, (b) 2077, (c) 2250 and (d) 2420 relative to the year 850 CE in SSP1-2.6 scenario.

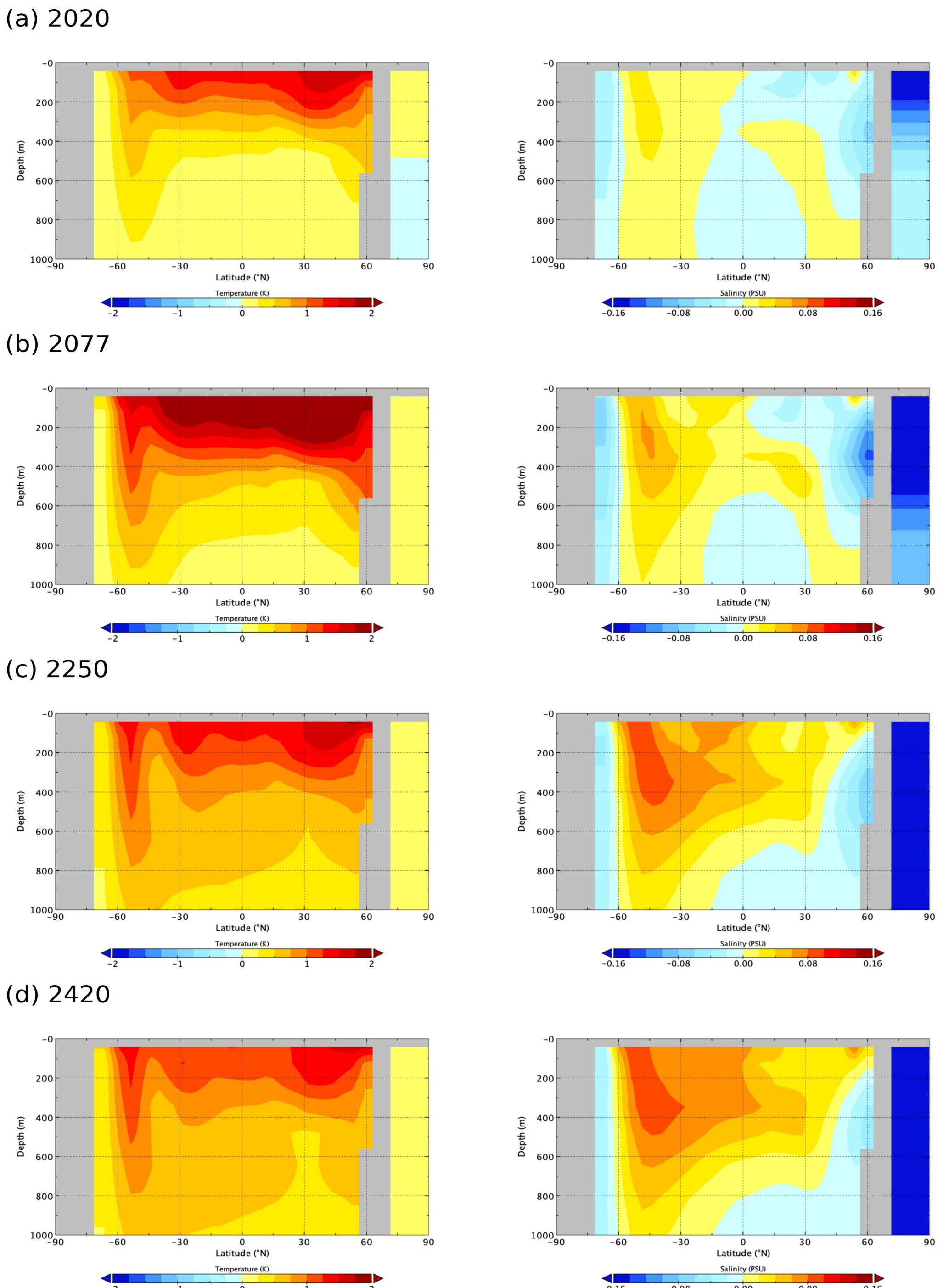

Figure S4: The change in temperature (in K) (left column) and salinity (in PSU) (right column) in Pacific cross section at (a) 2020, (b) 2077, (c) 2250 and (d) 2420 relative to the year 850 CE in SSP1-2.6 scenario.

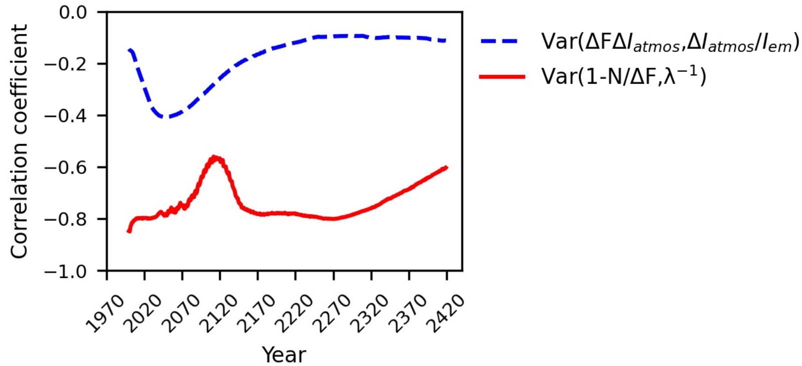

Figure S5: The correlation coefficient between the dependence of the radiative forcing on atmospheric CO_2 and airborne fraction (blue) and the fraction of the radiative forcing warming the surface and the inverse of the climate feedback (red) in SSP1-2.6 scenario.

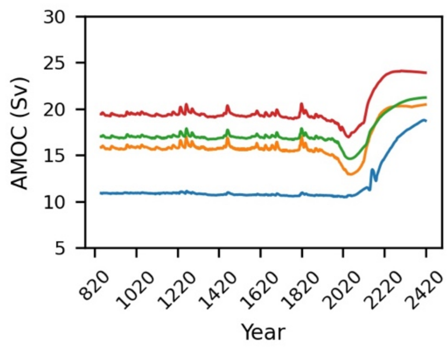

Figure S6: Abrupt re-organisation of ocean circulation during the period of negative emission phase in four ensemble members (outliers) in SSP1-2.6 scenario.

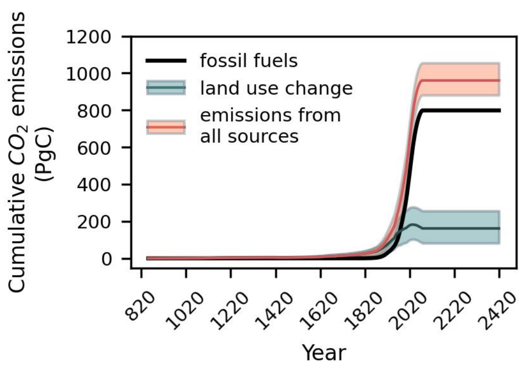

Figure S7: The cumulative CO_2 emissions from 850 CE till the end of the model integration at year 2420 in the reference scenario for the zero emissions commitment (ZEC) calculations. Solid lines show the median values, and shaded areas indicate the values between the 10th and 90th percentiles.

Table S1- The non-CO_2 fraction of total anthropogenic radiative forcing (f_{nc} in Eq. 8) for SSP1-2.6 at each decade between 2020 to 2100 based on the 86-member GENIE-1 ensemble simulations.

Year	mean (median) (%)	25-75 % range (%)
2020	18 (19)	10 to 26
2030	19 (19)	12 to 26
2040	18 (18)	11 to 25
2050	15 (16)	9 to 23
2060	14 (14)	7 to 21
2070	13 (13)	6 to 20
2080	12 (13)	5 to 20
2090	12 (13)	4 to 20
2100	12 (13)	5 to 21

Table S2: Carbon variables for the different emission phases in the SSP1-2.6 scenario. The normalised spread is quantified through the coefficient of variation ($\sigma_x/\bar{x}$).

Variable	2020-2077			2077-2250			2250-2420		
	$\bar{x}$	σ_x	$\sigma_x/\bar{x}$	$\bar{x}$	σ_x	$\sigma_x/\bar{x}$	$\bar{x}$	σ_x	$\sigma_x/\bar{x}$
I_{em} (PgC)	855.29	72.63	0.08	856.45	72.63	0.08	806.38	72.63	0.09
$\Delta I_{atmos}/I_{em}$	0.49	0.10	0.20	0.33	0.07	0.21	0.25	0.04	0.16
$\Delta I_{ocean}/I_{em}$	0.33	0.06	0.18	0.53	0.09	0.17	0.67	0.10	0.15
$\Delta I_{land}/I_{em}$	0.19	0.13	0.68	0.18	0.12	0.67	0.15	0.10	0.67
$\Delta I_{veg}/I_{em}$	0.07	0.02	0.29	0.06	0.02	0.33	0.05	0.02	0.40
$\Delta I_{soil}/I_{em}$	0.12	0.11	0.92	0.12	0.11	0.92	0.10	0.09	0.90
$\Delta I_{sediment}/I_{em}$	-0.02	0.01	-0.50	-0.04	0.02	-0.50	-0.07	0.03	-0.43

Table S3: Correlation between all model parameters and $\Delta T/I_{em}$ in SSP1-2.6 scenario over different emission phases based on the coefficients of determination (R^2) (%). R^2>50 % denotes strong correlation, and R^2>10 % the moderate correlation. The values less than 10 % are shown in Italic.

Parameter	Description	2020-2077	2077-2250
AHD	Atmospheric heat diffusivity ($m^2\ s^{-1}$)	*1.8*	*0.9*
AMD	Atmospheric moisture diffusivity ($m^2\ s^{-1}$)	*0.7*	*1.5*
APM	Atlantic-Pacific moisture flux scaling	*6.3*	*5.0*
OL0	Clear skies OLR reduction (OLR: outgoing long wave radiation) (Wm^{-2})	*3.2*	*4.4*
OHD	Isopycnal diffusivity ($m^2\ s^{-1}$)	*1.1*	*1.4*
OVD	Reference diapycnal diffusivity ($m^2\ s^{-1}$)	*0.2*	*6.1*
OP1	Power law for diapycnal diffusivity depth profile	*1.1*	*0.2*
ODC	Ocean inverse drag coefficient (days)	*1.1*	*0.3*
WSF	Wind-scale factor	*<0.05*	*8.5*
SID	Sea ice diffusivity ($m^2\ s^{-1}$)	*0.9*	*4.0*
VFC	Fractional vegetation dependence on veg carbon density ($m^2\ kgC^{-1}$)	**10.9**	*6.9*
VBP	Baseline rate of photosynthesis ($kgCm^{-2}\ yr^{-1}$)	*0.4*	*0.1*
VRA	Vegetation respiration activation energy ($J\ mol^{-1}$)	*1.4*	*5.9*
LLR	Leaf litter rate (yr^{-1})	*1.0*	*1.3*
SRT	Soil respiration temperature dependence (K)	*0.2*	*2.9*
PMX	Maximum phosphate uptake (dummy parameter)	*1.1*	*1.0*
PHS	PO_4 half-saturation concentration ($mol\ kg^{-1}$)	*<0.05*	*0.2*
PRP	Initial proportion of POC export as recalcitrant fraction	*2.0*	*0.9*
PRD	e-folding remineralisation depth of non-recalcitrant POC (m)	*6.9*	*1.9*
RRS	Rain ratio scalar	*1.3*	*0.2*
TCP	Thermodynamic calcification rate power	*1.2*	*0.6*
PRC	Initial proportion of $CaCO_3$ export as recalcitrant fraction	*1.0*	*2.7*
CRD	e-folding remineralisation depth of non-recalcitrant $CaCO_3$ (m)	*0.2*	*0.1*
FES	Iron solubility	*0.5*	*1.4*
ASG	Air-sea gas exchange parameter	*0.5*	*2.6*
OL1	OLR feedback parameter ($W\ m^{-2}$)	**61.4**	*0.3*
VPC	CO_2 fertilisation (ppm)	*5.4*	**34.9**
KC	Land use change soil carbon	**11.7**	**11.2**
ALUA	Crop albedo	*1.2*	*2.0*