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Supplement of

The response of stratospheric water vapor to climate change driven by different forcing agents

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1 **Table S1: TOA ERF (Wm^{-2}), equilibrium ΔTs (K), equilibrium $\Delta\text{Ts}/\text{ERF}$ ($\text{K}\cdot(\text{Wm}^{-2})^{-1}$), equilibrium $\Delta\text{SWV}_{\text{slow}}$ (ppmv), equilibrium $\Delta\text{SWV}_{\text{slow}}/\text{ERF}$ (ppmv $\cdot(\text{Wm}^{-2})^{-1}$), $\Delta\text{SWV}_{\text{fast}}$ (ppmv), and $\Delta\text{SWV}_{\text{fast}}/\text{ERF}$ (ppmv $\cdot(\text{Wm}^{-2})^{-1}$) from all models and perturbations and multi-model mean.**

2xCO ₂	ERF	Equilibrium ΔTs	Equilibrium $\Delta\text{Ts}/\text{ERF}$	Equilibrium $\Delta\text{SWV}_{\text{slow}}$			Equilibrium $\Delta\text{SWV}_{\text{slow}}/\text{ERF}$			$\Delta\text{SWV}_{\text{fast}}$			$\Delta\text{SWV}_{\text{fast}}/\text{ERF}$		
				TLS	NH LMS	SH LMS	TLS	NH LMS	SH LMS	TLS	NH LMS	SH LMS	TLS	NH LMS	SH LMS
CAM4	3.57	3.15	0.88	0.81	8.29	4.53	0.23	2.33	1.27	-0.02	1.16	-0.01	-0.01	0.33	-0.00
CAM5	4.00	3.83	0.96	1.17	8.29	4.72	0.29	2.07	1.18	0.07	1.76	0.06	0.02	0.44	0.02
HadGEM3	3.64	8.02	2.20	7.15	33.63	19.87	1.96	9.23	5.45	0.11	0.75	-0.04	0.03	0.20	-0.01
HadGEM2	3.73	4.10	1.10	1.21	8.99	3.02	0.33	2.41	0.81	0.12	0.78	-0.07	0.03	0.21	-0.02
CanESM2	3.57	3.97	1.11	0.94	11.26	4.57	0.26	3.15	1.28	-0.23	0.48	0.13	-0.07	0.13	0.04
IPSL-CM5A	3.36	3.83	1.14	2.05	9.80	5.86	0.61	2.91	1.74	0.28	0.62	0.29	0.08	0.18	0.09
MPI-ESM	4.14	2.20	0.53	1.82	8.49	3.87	0.44	2.05	0.93	0.29	1.03	-0.05	0.07	0.25	-0.01
GISS	3.99	2.12	0.53	0.49	2.29	1.51	0.12	0.57	0.38	-0.09	-0.18	-0.14	-0.02	-0.04	-0.04
MIROC-SPRINTARS	3.62	1.47	0.40	0.30	4.16	2.91	0.08	1.15	0.80	-0.17	0.52	-0.02	-0.05	0.14	-0.01
multi-model mean	3.74	3.63	0.98	1.77	10.58	5.65	0.48	2.87	1.54	0.04	0.77	0.02	0.01	0.20	0.01

3xCH ₄	ERF	Equilibrium ΔTs	Equilibrium $\Delta\text{Ts}/\text{ERF}$	Equilibrium $\Delta\text{SWV}_{\text{slow}}$			Equilibrium $\Delta\text{SWV}_{\text{slow}}/\text{ERF}$			$\Delta\text{SWV}_{\text{fast}}$			$\Delta\text{SWV}_{\text{fast}}/\text{ERF}$		
				TLS	NH LMS	SH LMS	TLS	NH LMS	SH LMS	TLS	NH LMS	SH LMS	TLS	NH LMS	SH LMS
CAM4	1.23	1.07	0.87	0.33	2.47	1.55	0.27	2.01	1.25	-0.01	-0.01	0.01	-0.01	-0.01	0.00
CAM5	0.96	0.73	0.76	0.34	1.46	0.83	0.35	1.51	0.87	0.24	0.25	0.40	0.25	0.26	0.42
HadGEM3	1.39	2.37	1.70	1.71	7.98	4.86	1.23	5.72	3.49	0.16	0.35	0.05	0.12	0.25	0.04
HadGEM2	1.25	1.43	1.14	0.37	2.62	0.92	0.29	2.10	0.74	0.17	0.27	0.03	0.13	0.22	0.03
CanESM2	1.36	0.78	0.58	-0.01	1.71	0.57	-0.01	1.26	0.42	0.31	0.83	0.21	0.23	0.61	0.15
IPSL-CM5A	1.63	1.50	0.92	0.38	3.21	1.96	0.24	1.97	1.21	0.09	0.24	0.02	0.06	0.15	0.01
MPI-ESM	0.95	0.58	0.61	0.37	1.80	0.54	0.38	1.90	0.57	0.28	0.51	0.30	0.29	0.54	0.32
GISS	1.34	0.42	0.32	0.11	0.43	0.41	0.08	0.32	0.31	-0.05	-0.26	-0.37	-0.04	-0.19	-0.28
MIROC-SPRINTARS	0.78	0.28	0.35	0.00	0.81	0.55	0.00	1.04	0.70	0.34	0.34	0.32	0.43	0.44	0.41
multi-model mean	1.21	1.02	0.81	0.40	2.50	1.36	0.32	1.98	1.06	0.17	0.28	0.11	0.16	0.25	0.12

2%Solar	ERF	Equilibrium ΔTs	Equilibrium $\Delta\text{Ts}/\text{ERF}$	Equilibrium $\Delta\text{SWV}_{\text{slow}}$			Equilibrium $\Delta\text{SWV}_{\text{slow}}/\text{ERF}$			$\Delta\text{SWV}_{\text{fast}}$			$\Delta\text{SWV}_{\text{fast}}/\text{ERF}$		
				TLS	NH LMS	SH LMS	TLS	NH LMS	SH LMS	TLS	NH LMS	SH LMS	TLS	NH LMS	SH LMS
CAM4	3.95	2.83	0.72	0.91	7.83	4.92	0.23	1.98	1.24	0.16	1.59	0.20	0.04	0.40	0.05
CAM5	4.32	3.54	0.82	1.20	9.11	5.30	0.28	2.11	1.23	0.19	1.46	0.30	0.04	0.34	0.07
HadGEM3	4.36	9.65	2.21	9.34	46.76	27.55	2.14	10.73	6.32	0.21	0.88	0.08	0.05	0.20	0.02
HadGEM2	4.28	3.11	0.73	1.45	8.64	2.78	0.34	2.02	0.65	0.27	0.89	0.20	0.06	0.21	0.05
CanESM2	4.09	3.02	0.74	1.43	13.34	5.06	0.35	3.26	1.24	0.22	1.11	0.37	0.05	0.27	0.09

IPSL-CM5A	4.11	4.49	1.09	3.33	13.07	7.36	0.81	3.18	1.79	0.23	0.76	0.32	0.06	0.19	0.08
MPI-ESM	4.12	2.81	0.68	1.64	9.17	3.51	0.40	2.23	0.85	0.45	1.43	0.52	0.11	0.35	0.13
GISS	4.48	1.85	0.41	0.52	2.21	1.67	0.12	0.49	0.37	0.09	0.39	0.17	0.02	0.09	0.04
MIROC-SPRINTARS	4.15	1.36	0.33	0.18	4.61	3.64	0.04	1.11	0.88	0.20	0.69	0.21	0.05	0.17	0.05
multi-model mean	4.21	3.63	0.86	2.22	12.75	6.87	0.52	3.01	1.62	0.22	1.02	0.27	0.05	0.25	0.06

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10xBC	ERF	Equilibrium ΔTs	Equilibrium ΔTs/ERF	Equilibrium ΔSWV _{slow}			Equilibrium ΔSWV _{slow} /ERF			ΔSWV _{fast}			ΔSWV _{fast} /ERF		
				TLS	NH LMS	SH LMS	TLS	NH LMS	SH LMS	TLS	NH LMS	SH LMS	TLS	NH LMS	SH LMS
CAM4	0.77	0.43	0.55	0.06	2.40	0.54	0.08	3.12	0.70	0.63	3.33	0.76	0.82	4.32	0.99
CAM5	0.43	0.38	0.89	-0.10	1.07	0.06	-0.24	2.48	0.15	0.66	2.49	0.55	1.52	5.77	1.28
HadGEM3	0.70	1.19	1.72	1.05	5.86	2.20	1.51	8.44	3.17	0.47	0.80	0.14	0.68	1.15	0.20
HadGEM2	3.17	2.14	0.68	1.62	6.09	1.44	0.51	1.92	0.46	3.27	5.58	0.93	1.03	1.76	0.30
CanESM2	1.55	1.77	1.14	-0.03	6.22	1.72	-0.02	4.01	1.11	1.99	2.56	1.70	1.28	1.65	1.09
IPSL-CM5A	0.81	1.47	1.81	0.38	4.09	1.31	0.47	5.03	1.61	1.28	2.42	0.81	1.57	2.98	1.00
GISS	1.23	0.46	0.37	0.16	1.41	0.30	0.13	1.14	0.24	0.30	0.97	0.42	0.24	0.79	0.34
MIROC-SPRINTARS	0.63	0.13	0.20	-0.06	-0.04	0.37	-0.10	-0.06	0.59	0.28	0.97	0.15	0.44	1.54	0.24
multi-model mean	1.16	1.00	0.92	0.38	3.39	0.99	0.29	3.26	1.00	1.11	2.39	0.68	0.95	2.50	0.68

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5xSO ₄	ERF	Equilibrium ΔTs	Equilibrium ΔTs/ERF	Equilibrium ΔSWV _{slow}			Equilibrium ΔSWV _{slow} /ERF			ΔSWV _{fast}			ΔSWV _{fast} /ERF		
				TLS	NH LMS	SH LMS	TLS	NH LMS	SH LMS	TLS	NH LMS	SH LMS	TLS	NH LMS	SH LMS
CAM4	-2.16	-1.49	0.69	-0.37	-3.33	-1.37	0.17	1.54	0.64	-0.01	-1.12	-0.09	0.00	0.52	0.04
CAM5	-2.10	-1.79	0.85	-0.27	-4.25	-2.41	0.13	2.02	1.15	-0.07	-0.06	0.50	0.03	0.03	-0.24
HadGEM3	-8.26	-6.70	0.81	-3.85	-15.69	-11.99	0.47	1.90	1.45	-0.10	-1.03	-0.09	0.01	0.12	0.01
HadGEM2	-3.84	-5.06	1.32	-1.53	-5.69	-1.51	0.40	1.48	0.39	-0.54	-1.00	-0.13	0.14	0.26	0.03
CanESM2	-3.25	-4.45	1.37	-0.51	-8.43	-2.26	0.16	2.60	0.70	-0.01	-0.63	-0.04	0.00	0.19	0.01
IPSL-CM5A	-2.75	-1.99	0.73	-0.78	-6.58	-4.01	0.29	2.40	1.46	0.08	-0.21	0.01	-0.03	0.08	-0.00
GISS	-2.79	-1.40	0.50	-0.28	-1.58	-0.72	0.10	0.56	0.26	0.02	-0.19	0.00	-0.01	0.07	-0.00
MIROC-SPRINTARS	-2.77	-2.12	0.77	-0.32	-3.85	-1.71	0.11	1.39	0.62	0.01	-0.66	-0.09	-0.00	0.24	0.03
multi-model mean	-3.49	-3.13	0.88	-0.99	-6.18	-3.25	0.23	1.74	0.83	-0.08	-0.61	0.01	0.02	0.19	-0.01

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10xCFC12	ERF	Equilibrium ΔTs	Equilibrium ΔTs/ERF	Equilibrium ΔSWV _{slow}			Equilibrium ΔSWV _{slow} /ERF			ΔSWV _{fast}			ΔSWV _{fast} /ERF		
				TLS	NH LMS	SH LMS	TLS	NH LMS	SH LMS	TLS	NH LMS	SH LMS	TLS	NH LMS	SH LMS
CAM4	1.54	1.34	0.87	0.43	3.01	1.84	0.28	1.96	1.20	0.21	0.47	0.30	0.13	0.31	0.19
CAM5	1.34	1.00	0.74	0.40	3.76	1.31	0.30	2.81	0.98	0.36	0.80	0.47	0.27	0.60	0.35
HadGEM3	1.51	2.70	1.78	2.17	9.50	5.39	1.43	6.27	3.56	0.37	0.66	0.23	0.24	0.44	0.15
HadGEM2	1.45	1.47	1.01	0.31	2.46	1.18	0.21	1.69	0.81	0.48	0.38	0.27	0.33	0.26	0.18
GISS	1.27	0.44	0.34	0.09	0.52	0.50	0.07	0.41	0.39	0.12	0.22	0.15	0.09	0.17	0.12

MIROC-SPRINTARS	1.20	0.48	0.40	0.07	1.27	0.86	0.06	1.06	0.72	0.32	0.42	0.15	0.27	0.35	0.13
multi-model mean	1.39	1.24	0.86	0.58	3.42	1.85	0.39	2.37	1.28	0.31	0.49	0.26	0.22	0.35	0.19

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10xCFC11	ERF	Equilibrium ΔTs	Equilibrium ΔTs/ERF	Equilibrium ΔSWV _{slow}			Equilibrium ΔSWV _{slow} /ERF			ΔSWV _{fast}			ΔSWV _{fast} /ERF		
				TLS	NH LMS	SH LMS	TLS	NH LMS	SH LMS	TLS	NH LMS	SH LMS	TLS	NH LMS	SH LMS
HadGEM2	1.20	1.43	1.20	0.69	3.24	0.85	0.58	2.70	0.71	0.37	0.34	0.24	0.31	0.29	0.20
MIROC-SPRINTARS	1.15	0.44	0.38	0.15	1.69	1.12	0.13	1.47	0.98	0.29	0.16	0.38	0.25	0.14	0.33
multi-model mean	1.21	0.94	0.79	0.42	2.47	0.99	0.35	2.09	0.84	0.33	0.25	0.31	0.28	0.21	0.26

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3xN ₂ O	ERF	Equilibrium ΔTs	Equilibrium ΔTs/ERF	Equilibrium ΔSWV _{slow}			Equilibrium ΔSWV _{slow} /ERF			ΔSWV _{fast}			ΔSWV _{fast} /ERF		
				TLS	NH LMS	SH LMS	TLS	NH LMS	SH LMS	TLS	NH LMS	SH LMS	TLS	NH LMS	SH LMS
CAM4	1.42	1.09	0.77	0.32	2.53	1.65	0.23	1.79	1.17	-0.00	0.17	-0.09	-0.00	0.12	-0.06
HadGEM2	2.19	1.46	0.67	0.73	3.58	1.47	0.33	1.63	0.67	0.43	0.40	0.26	0.20	0.18	0.12
MIROC-SPRINTARS	1.42	0.57	0.40	0.13	1.54	1.55	0.09	1.08	1.09	0.04	-0.00	-0.38	0.03	-0.00	-0.27
multi-model mean	1.68	1.04	0.61	0.39	2.55	1.56	0.22	1.50	0.97	0.16	0.19	-0.07	0.08	0.10	-0.07

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5xO ₃	ERF	Equilibrium ΔTs	Equilibrium ΔTs/ERF	Equilibrium ΔSWV _{slow}			Equilibrium ΔSWV _{slow} /ERF			ΔSWV _{fast}			ΔSWV _{fast} /ERF		
				TLS	NH LMS	SH LMS	TLS	NH LMS	SH LMS	TLS	NH LMS	SH LMS	TLS	NH LMS	SH LMS
MIROC-SPRINTARS	3.46	1.22	0.35	0.19	2.73	2.04	0.06	0.79	0.59	0.67	2.16	2.96	0.19	0.62	0.86

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10xBCSLT	ERF	Equilibrium ΔTs	Equilibrium ΔTs/ERF	Equilibrium ΔSWV _{slow}			Equilibrium ΔSWV _{slow} /ERF			ΔSWV _{fast}			ΔSWV _{fast} /ERF		
				TLS	NH LMS	SH LMS	TLS	NH LMS	SH LMS	TLS	NH LMS	SH LMS	TLS	NH LMS	SH LMS
CAM4	0.65	0.26	0.41	0.03	0.89	0.39	0.05	1.37	0.60	0.17	1.29	0.25	0.25	1.99	0.39
GISS	1.22	0.41	0.34	0.09	0.79	0.30	0.07	0.65	0.25	0.07	0.26	0.10	0.06	0.21	0.09
multi-model mean	0.93	0.34	0.37	0.06	0.84	0.35	0.06	1.01	0.42	0.12	0.78	0.18	0.16	1.10	0.24

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23**Table S2: ΔT_s (K), $\Delta T_s/ERF$ (K·(Wm⁻²)⁻¹), ΔSWV_{slow} (ppmv), and $\Delta SWV_{slow}/ERF$ (ppmv·(Wm⁻²)⁻¹) estimated using quantities averaged over the last 30 years of the coupled simulation.**

2xCO ₂	ΔT_s (last 30 yrs)	$\Delta T_s/ERF$ (last 30 yrs)	ΔSWV_{slow} (last 30 yrs)			$\Delta SWV_{slow}/ERF$ (last 30 yrs)		
			TLS	NH LMS	SH LMS	TLS	NH LMS	SH LMS
CAM4	3.15	0.88	0.80	8.29	4.52	0.22	2.33	1.27
CAM5	2.72	0.68	0.77	6.18	3.26	0.19	1.55	0.81
HadGEM3	3.73	1.02	2.85	13.91	7.77	0.78	3.82	2.13
HadGEM2	2.73	0.73	0.94	5.32	2.30	0.25	1.43	0.62
CanESM2	2.70	0.76	0.63	7.40	3.25	0.18	2.07	0.91
IPSL-CM5A	2.57	0.76	1.10	6.44	3.63	0.33	1.91	1.08
MPI-ESM	2.15	0.52	0.98	5.88	2.72	0.24	1.42	0.66
GISS	1.49	0.37	0.33	1.88	1.09	0.08	0.47	0.27
MIROC-SPRINTARS	1.46	0.40	0.19	3.20	1.93	0.05	0.88	0.53
multi-model mean	2.52	0.68	0.95	6.51	3.39	0.26	1.77	0.92

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3xCH ₄	ΔT_s (last 30 yrs)	$\Delta T_s/ERF$ (last 30 yrs)	ΔSWV_{slow} (last 30 yrs)			$\Delta SWV_{slow}/ERF$ (last 30 yrs)		
			TLS	NH LMS	SH LMS	TLS	NH LMS	SH LMS
CAM4	1.07	0.87	0.32	2.47	1.46	0.26	2.01	1.19
CAM5	0.54	0.56	0.20	1.37	0.62	0.20	1.43	0.64
HadGEM3	1.20	0.86	0.72	3.72	2.18	0.52	2.67	1.57
HadGEM2	0.80	0.64	0.28	1.36	0.62	0.22	1.09	0.49
CanESM2	0.60	0.44	-0.05	1.07	0.61	-0.04	0.78	0.45
IPSL-CM5A	1.06	0.65	0.37	2.37	1.47	0.23	1.45	0.90
MPI-ESM	0.44	0.46	0.27	1.28	0.47	0.28	1.35	0.50
GISS	0.42	0.31	0.10	0.49	0.26	0.08	0.36	0.20
MIROC-SPRINTARS	0.30	0.38	-0.00	0.63	0.30	-0.00	0.81	0.39
multi-model mean	0.71	0.57	0.24	1.64	0.89	0.19	1.33	0.70

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2%Solar	ΔT_s (last 30 yrs)	$\Delta T_s/ERF$ (last 30 yrs)	ΔSWV_{slow} (last 30 yrs)			$\Delta SWV_{slow}/ERF$ (last 30 yrs)		
			TLS	NH LMS	SH LMS	TLS	NH LMS	SH LMS
CAM4	2.84	0.72	0.91	7.67	4.89	0.23	1.94	1.24
CAM5	2.51	0.58	0.79	6.58	3.79	0.18	1.52	0.88
HadGEM3	4.20	0.96	3.69	18.88	10.98	0.85	4.33	2.52
HadGEM2	2.55	0.60	1.19	5.75	2.41	0.28	1.34	0.56
CanESM2	2.95	0.72	0.94	9.07	3.88	0.23	2.22	0.95
IPSL-CM5A	2.92	0.71	1.62	8.49	4.64	0.39	2.06	1.13
MPI-ESM	1.93	0.47	1.00	5.78	2.77	0.24	1.40	0.67
GISS	1.35	0.30	0.37	2.10	1.21	0.08	0.47	0.27
MIROC-SPRINTARS	1.41	0.34	0.18	4.14	2.39	0.04	1.00	0.58
multi-model mean	2.52	0.60	1.19	7.61	4.11	0.28	1.81	0.98

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10xBC	ΔT_s (last 30 yrs)	$\Delta T_s/ERF$ (last 30 yrs)	ΔSWV_{slow} (last 30 yrs)			$\Delta SWV_{slow}/ERF$ (last 30 yrs)		
			TLS	NH LMS	SH LMS	TLS	NH LMS	SH LMS
CAM4	0.42	0.55	0.06	2.11	0.50	0.08	2.74	0.64
CAM5	0.25	0.58	-0.14	0.79	0.06	-0.32	1.83	0.14
HadGEM3	0.70	1.00	0.50	3.05	1.13	0.72	4.39	1.62
HadGEM2	1.66	0.53	1.11	4.53	1.33	0.35	1.43	0.42
CanESM2	1.31	0.84	-0.22	4.05	1.48	-0.14	2.61	0.95
IPSL-CM5A	0.75	0.93	0.14	2.32	0.89	0.17	2.86	1.09
MPI-ESM	nan	nan	nan	nan	nan	nan	nan	nan
GISS	0.40	0.32	0.12	1.02	0.27	0.10	0.83	0.22
MIROC-SPRINTARS	0.16	0.25	-0.06	0.05	0.38	-0.09	0.08	0.60
multi-model mean	0.71	0.63	0.19	2.24	0.75	0.11	2.10	0.71

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5xSO ₄	ΔT_s (last 30 yrs)	$\Delta T_s/ERF$ (last 30 yrs)	ΔSWV_{slow} (last 30 yrs)			$\Delta SWV_{slow}/ERF$ (last 30 yrs)		
			TLS	NH LMS	SH LMS	TLS	NH LMS	SH LMS
CAM4	-1.47	0.68	-0.37	-3.33	-1.37	0.17	1.54	0.64
CAM5	-1.20	0.57	-0.23	-3.11	-1.57	0.11	1.48	0.75
HadGEM3	-6.62	0.80	-2.49	-11.37	-7.79	0.30	1.38	0.94
HadGEM2	-2.72	0.71	-0.58	-3.60	-1.42	0.15	0.94	0.37
CanESM2	-2.71	0.84	-0.49	-5.59	-2.23	0.15	1.72	0.69
IPSL-CM5A	-1.93	0.70	-0.56	-4.02	-2.10	0.20	1.46	0.76
GISS	-0.93	0.33	-0.20	-1.38	-0.60	0.07	0.49	0.21
MIROC-SPRINTARS	-1.17	0.42	-0.21	-2.49	-1.12	0.08	0.90	0.40
multi-model mean	-2.35	0.63	-0.64	-4.36	-2.28	0.16	1.24	0.60

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10xCFC12	ΔT_s (last 30 yrs)	$\Delta T_s/ERF$ (last 30 yrs)	ΔSWV_{slow} (last 30 yrs)			$\Delta SWV_{slow}/ERF$ (last 30 yrs)		
			TLS	NH LMS	SH LMS	TLS	NH LMS	SH LMS
CAM4	1.34	0.87	0.43	3.01	1.84	0.28	1.96	1.20
CAM5	0.95	0.71	0.36	2.30	1.08	0.27	1.72	0.81
HadGEM3	1.27	0.84	0.94	3.94	2.46	0.62	2.60	1.62
HadGEM2	0.82	0.56	0.33	1.55	0.62	0.23	1.07	0.43
GISS	0.40	0.31	0.10	0.56	0.33	0.08	0.44	0.26
MIROC-SPRINTARS	0.48	0.40	-0.00	1.15	0.88	-0.00	0.96	0.73
multi-model mean	0.88	0.62	0.36	2.10	1.21	0.25	1.47	0.84

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10xCFC11	ΔT_s (last 30 yrs)	$\Delta T_s/ERF$ (last 30 yrs)	ΔSWV_{slow} (last 30 yrs)			$\Delta SWV_{slow}/ERF$ (last 30 yrs)		
			TLS	NH LMS	SH LMS	TLS	NH LMS	SH LMS
HadGEM2	0.95	0.79	0.47	1.83	0.65	0.39	1.53	0.54
MIROC-SPRINTARS	0.45	0.39	0.01	1.27	0.61	0.00	1.10	0.53

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multi-model mean	0.81	0.66	0.27	1.89	0.94	0.22	1.54	0.76
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3xN ₂ O	ΔTs (last 30 yrs)	ΔTs/ERF (last 30 yrs)	ΔSWV _{slow} (last 30 yrs)			ΔSWV _{slow} /ERF (last 30 yrs)		
			TLS	NH LMS	SH LMS	TLS	NH LMS	SH LMS
CAM4	1.09	0.77	0.32	2.49	1.62	0.23	1.76	1.15
HadGEM2	1.44	0.66	0.54	2.59	1.01	0.25	1.18	0.46
MIROC-SPINTARS	0.58	0.41	0.06	1.30	0.98	0.04	0.91	0.69
multi-model mean	1.04	0.61	0.31	2.13	1.20	0.17	1.28	0.77

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5xO ₃	ΔTs (last 30 yrs)	ΔTs/ERF (last 30 yrs)	ΔSWV _{slow} (last 30 yrs)			ΔSWV _{slow} /ERF (last 30 yrs)		
			TLS	NH LMS	SH LMS	TLS	NH LMS	SH LMS
MIROC-SPINTARS	1.22	0.35	0.19	2.73	1.61	0.05	0.79	0.46

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10xBCSLT	ΔTs (last 30 yrs)	ΔTs/ERF (last 30 yrs)	ΔSWV _{slow} (last 30 yrs)			ΔSWV _{slow} /ERF (last 30 yrs)		
			TLS	NH LMS	SH LMS	TLS	NH LMS	SH LMS
CAM4	0.26	0.41	0.03	0.85	0.38	0.05	1.30	0.58
GISS	0.35	0.29	0.09	0.74	0.29	0.07	0.61	0.24
multi-model mean	0.31	0.36	0.06	0.80	0.33	0.06	0.96	0.41

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Table S3: Comparison of multi-model mean values with Richardson et al. (2019). In the parentheses, we list 2.5%-97.5% percentile of the model samples as described in Section 2.2 of the submitted manuscript for experiments that are performed by three or more models. We note that Richardson et al. (2019) did not include CAM4 in their multi-model mean computation; they included results from NorESM. These could account for some minor differences between our results and Richardson et al. (2019) shown in Table S3 below.

	2xCO ₂	3xCH ₄	2%Solar	10xBC	5xSO ₄	10xCFC-12	10xCFC-11	3xN ₂ O	5xO ₃	10xBCSLT
ERF _{sst} (Wm ⁻²) from Richardson et al. (2019)	3.71±0.30	1.15±0.25	4.17±0.13	1.18±0.75	-3.71±1.94	1.39 (1.21 to 1.54)	1.19 (1.17 to 1.21)	1.60 (1.23 to 2.14)	3.47 (2.45 to 4.49)	1.10
ERF (Wm ⁻²)	3.73 (3.58 to 3.89)	1.21 (1.04 to 1.37)	4.20 (4.10 to 4.31)	1.16 (0.69 to 1.80)	-3.49 (-4.94 to -2.52)	1.38 (1.28 to 1.48)	1.21	1.67	3.45	0.93

Table S4: Regression slope of $\Delta\text{SWV}_{\text{slow}}$ annual mean time series vs surface temperature change annual mean time series for all perturbations and models. Results are shown for TLS, NH LMS, and SH LMS. In each cell, the slope is listed in the unit of ppmv K⁻¹. For each model and perturbation, the uncertainty of the slope is one standard deviation estimated using a t-test. For the multi-model mean, the uncertainty is 2.5%-97.5% percentile of the model samples.

TLS SWV

	2xCO ₂	3xCH ₄	2%SOLAR	10xBC	5xSO ₄	10xCFC12	10xCFC11	3xN ₂ O	5xO ₃	10xBCSLT
CAM4	0.26±0.03	0.25±0.06	0.30±0.03	0.34±0.09	0.31±0.05	0.27±0.05	nan	0.29±0.06	nan	0.18±0.07
CAMS	0.36±0.04	0.26±0.07	0.36±0.04	0.11±0.07	0.11±0.05	0.23±0.06	nan	nan	nan	nan
HadGEM3	0.92±0.03	0.64±0.06	1.01±0.03	0.54±0.09	0.40±0.01	0.70±0.06	nan	nan	nan	nan
HadGEM2	0.46±0.04	0.43±0.06	0.60±0.04	1.78±0.12	0.35±0.03	0.63±0.11	0.67±0.08	0.66±0.07	nan	nan
CanESM2	0.27±0.02	-0.01±0.05	0.38±0.02	0.12±0.11	0.12±0.02	nan	nan	nan	nan	nan
IPSL-CM5A	0.62±0.02	0.36±0.04	0.79±0.03	0.52±0.07	0.28±0.02	nan	nan	nan	nan	nan
MPI-ESM	0.53±0.05	0.22±0.09	0.54±0.05	nan	nan	nan	nan	nan	nan	nan
GISS	0.28±0.02	0.16±0.04	0.31±0.02	0.25±0.05	0.20±0.03	0.18±0.04	nan	nan	nan	0.15±0.04
MIROC-SPRINTARS	0.08±0.03	0.11±0.04	0.14±0.03	0.09±0.04	0.09±0.02	0.14±0.04	0.10±0.04	0.08±0.04	0.05±0.04	nan
multi-model mean	0.42 (0.27 to 0.58)	0.27 (0.15 to 0.40)	0.49 (0.33 to 0.67)	0.47 (0.18 to 0.89)	0.23 (0.15 to 0.32)	0.36 (0.18 to 0.56)	0.39	0.34	0.05	0.16

NH LMS SWV

	2xCO ₂	3xCH ₄	2%SOLAR	10xBC	5xSO ₄	10xCFC12	10xCFC11	3xN ₂ O	5xO ₃	10xBCSLT
CAM4	2.67±0.22	1.55±0.39	2.47±0.25	2.41±0.68	1.91±0.32	2.08±0.32	nan	1.22±0.39	nan	0.58±0.50
CAMS	1.67±0.18	-	1.77±0.20	-	0.90±0.21	0.30±0.28	nan	nan	nan	nan
HadGEM3	4.31±0.10	3.19±0.17	5.15±0.09	3.84±0.31	1.60±0.03	3.49±0.20	nan	nan	nan	nan
HadGEM2	2.17±0.09	1.71±0.15	2.44±0.10	3.99±0.26	1.20±0.07	2.08±0.20	2.03±0.14	2.02±0.13	nan	nan
CanESM2	3.18±0.14	2.61±0.25	3.37±0.12	3.59±0.28	2.00±0.10	nan	nan	nan	nan	nan
IPSL-CM5A	2.42±0.15	1.94±0.23	2.81±0.13	2.38±0.34	1.94±0.12	nan	nan	nan	nan	nan
MPI-ESM	2.56±0.17	1.56±0.34	2.36±0.19	nan	nan	nan	nan	nan	nan	nan
GISS	1.19±0.14	0.72±0.25	1.12±0.18	1.05±0.26	0.73±0.15	0.76±0.24	nan	nan	nan	0.93±0.22
MIROC-SPRINTARS	2.45±0.23	2.30±0.26	2.40±0.22	2.81±0.32	1.85±0.13	3.00±0.28	2.42±0.27	2.20±0.23	3.36±0.32	nan
multi-model mean	2.52 (1.97 to 3.10)	1.70 (1.01 to 2.35)	2.65 (2.01 to 3.41)	2.46 (1.38 to 3.43)	1.52 (1.14 to 1.87)	1.95 (0.99 to 2.87)	2.23	1.82	3.36	0.76

SH LMS SWV

	2xCO ₂	3xCH ₄	2%SOLAR	10xBC	5xSO ₄	10xCFC12	10xCFC11	3xN ₂ O	5xO ₃	10xBCSLT
CAM4	1.67±0.11	1.53±0.22	1.88±0.11	0.61±0.29	0.84±0.19	1.76±0.18	nan	1.21±0.23	nan	0.84±0.25
CAMS	0.87±0.15	-	0.99±0.15	-	0.34±0.19	-0.38±0.23	nan	nan	nan	nan
HadGEM3	2.65±0.08	1.63±0.16	3.05±0.08	0.90±0.23	1.15±0.03	1.75±0.14	nan	nan	nan	nan
HadGEM2	0.93±0.05	0.61±0.08	0.94±0.06	1.08±0.08	0.58±0.04	0.63±0.11	0.60±0.09	0.78±0.07	nan	nan
CanESM2	1.24±0.08	0.64±0.17	1.36±0.08	1.50±0.18	0.85±0.07	nan	nan	nan	nan	nan
IPSL-CM5A	1.60±0.10	1.08±0.17	1.74±0.10	0.63±0.21	1.11±0.10	nan	nan	nan	nan	nan
MPI-ESM	1.34±0.11	0.80±0.25	1.45±0.11	nan	nan	nan	nan	nan	nan	nan
GISS	0.65±0.10	-	0.80±0.12	0.00±0.17	0.21±0.12	0.01±0.18	nan	nan	nan	0.32±0.16
MIROC-SPRINTARS	1.16±0.18	0.82±0.23	1.14±0.18	0.80±0.21	0.88±0.13	1.29±0.20	0.78±0.23	0.80±0.23	1.34±0.22	nan
multi-model mean	1.35 (1.00 to 1.75)	0.76 (0.34 to 1.18)	1.48 (1.09 to 1.96)	0.62 (0.15 to 1.06)	0.75 (0.49 to 0.98)	0.84 (0.14 to 1.51)	0.69	0.93	1.34	0.58

Table S5: Same as Table S4, but the slopes are listed in the unit of % K⁻¹.

TLS SWV

	2xCO ₂	3xCH ₄	2%SOLAR	10xBC	5xSO ₄	10xCFC12	10xCFC11	3xN ₂ O	5xO ₃	10xBCSLT
CAM4	6.35±0.66	6.19±1.55	7.27±0.76	8.44±2.30	7.64±1.30	6.50±1.17	nan	7.04±1.47	nan	4.44±1.70
CAM5	9.74±0.98	6.98±1.99	9.76±1.06	3.05±1.83	3.06±1.44	6.23±1.71	nan	nan	nan	nan
HadGEM3	17.89±0.61	12.47±1.14	19.64±0.50	10.48±1.67	7.86±0.21	13.56±1.24	nan	nan	nan	nan
HadGEM2	9.22±0.77	8.52±1.24	11.94±0.77	35.29±2.43	6.95±0.55	12.49±2.08	13.34±1.65	13.05±1.47	nan	nan
CanESM2	10.25±0.90	-0.23±1.80	14.59±0.87	4.68±4.18	4.77±0.61	nan	nan	nan	nan	nan
IPSL-CM5A	26.79±0.99	15.52±1.81	33.70±1.08	22.30±2.96	11.78±0.78	nan	nan	nan	nan	nan
MPI-ESM	12.78±1.18	5.22±2.07	12.95±1.24	nan	nan	nan	nan	nan	nan	nan
GISS	16.28±1.33	9.05±2.32	18.17±1.29	14.80±2.92	11.73±1.81	10.23±2.38	nan	nan	nan	8.53±2.13
MIROC-SPRINTARS	2.61±1.08	4.07±1.55	5.04±1.06	3.15±1.67	3.26±0.75	5.06±1.56	3.64±1.57	2.83±1.39	1.59±1.55	nan
multi-model mean	12.43 (8.20 to 17.15)	7.53 (4.29 to 10.82)	14.78 (10.01 to 20.56)	12.77 (5.80 to 21.03)	7.13 (4.78 to 9.62)	9.01 (5.86 to 12.32)	8.49	7.64	1.59	6.49

NH LMS

	2xCO ₂	3xCH ₄	2%SOLAR	10xBC	5xSO ₄	10xCFC12	10xCFC11	3xN ₂ O	5xO ₃	10xBCSLT
CAM4	11.63±0.97	6.71±1.69	10.75±1.08	10.49±2.92	8.50±1.37	8.84±1.38	nan	5.18±1.71	nan	2.44±2.14
CAM5	7.70±0.79	-0.59±1.30	8.28±0.90	-0.75±1.30	4.35±0.94	1.85±1.23	nan	nan	nan	nan
HadGEM3	27.80±0.61	20.72±1.07	33.01±0.59	24.77±1.97	10.22±0.21	22.56±1.29	nan	nan	nan	nan
HadGEM2	20.79±0.90	16.08±1.44	23.34±0.99	38.14±2.45	11.47±0.67	19.87±1.84	19.42±1.36	19.33±1.26	nan	nan
CanESM2	22.65±1.00	18.76±1.86	23.85±0.87	25.94±1.98	14.31±0.73	nan	nan	nan	nan	nan
IPSL-CM5A	16.09±1.03	13.21±1.62	18.59±0.90	15.88±2.36	13.05±0.85	nan	nan	nan	nan	nan
MPI-ESM	12.29±0.79	7.45±1.63	11.26±0.91	nan	nan	nan	nan	nan	nan	nan
GISS	15.55±1.79	8.90±3.08	14.45±2.25	13.67±3.29	8.84±1.89	9.06±3.00	nan	nan	nan	11.54±2.86
MIROC-SPRINTARS	19.18±1.74	19.20±1.97	18.69±1.60	22.27±2.48	14.13±1.03	23.59±2.11	19.15±2.09	17.99±1.77	24.67±2.39	nan
multi-model mean	17.08 (13.18 to 21.11)	12.27 (7.45 to 16.79)	18.02 (13.26 to 23.10)	18.80 (10.90 to 26.67)	10.61 (8.06 to 12.89)	14.29 (7.34 to 20.92)	19.29	14.17	24.67	6.99

SH LMS SWV

	2xCO ₂	3xCH ₄	2%SOLAR	10xBC	5xSO ₄	10xCFC12	10xCFC11	3xN ₂ O	5xO ₃	10xBCSLT
CAM4	11.05±0.75	10.87±1.55	12.55±0.78	4.70±2.14	5.44±1.41	11.75±1.34	nan	8.44±1.54	nan	6.39±1.85
CAM5	5.60±0.87	0.47±1.50	6.22±0.90	-2.24±1.37	2.68±1.13	-1.03±1.35	nan	nan	nan	nan
HadGEM3	22.08±0.61	14.66±1.28	25.21±0.64	8.17±1.88	9.91±0.26	14.81±1.22	nan	nan	nan	nan
HadGEM2	12.88±0.73	8.59±1.15	13.33±0.75	15.47±1.09	8.10±0.53	9.15±1.59	8.67±1.21	10.96±1.02	nan	nan
CanESM2	12.11±0.80	6.68±1.69	13.02±0.75	14.70±1.75	8.19±0.73	nan	nan	nan	nan	nan
IPSL-CM5A	15.84±1.06	11.08±1.77	16.82±1.04	6.53±2.18	11.64±1.08	nan	nan	nan	nan	nan
MPI-ESM	9.87±0.84	6.12±1.93	10.76±0.87	nan	nan	nan	nan	nan	nan	nan
GISS	11.44±1.59	-0.27±2.76	14.48±1.96	1.15±2.87	4.54±1.99	1.61±3.09	nan	nan	nan	5.85±2.73
MIROC-SPRINTARS	10.88±1.61	7.72±1.99	10.63±1.56	8.10±1.83	7.93±1.09	11.97±1.73	7.49±2.02	7.81±2.00	12.30±1.91	nan
multi-model mean	12.42 (9.64 to 15.52)	7.33 (3.78 to 10.59)	13.67 (10.53 to 17.27)	7.07 (2.65 to 11.38)	7.31 (5.03 to 9.39)	8.04 (2.70 to 12.73)	8.08	9.07	12.30	6.12

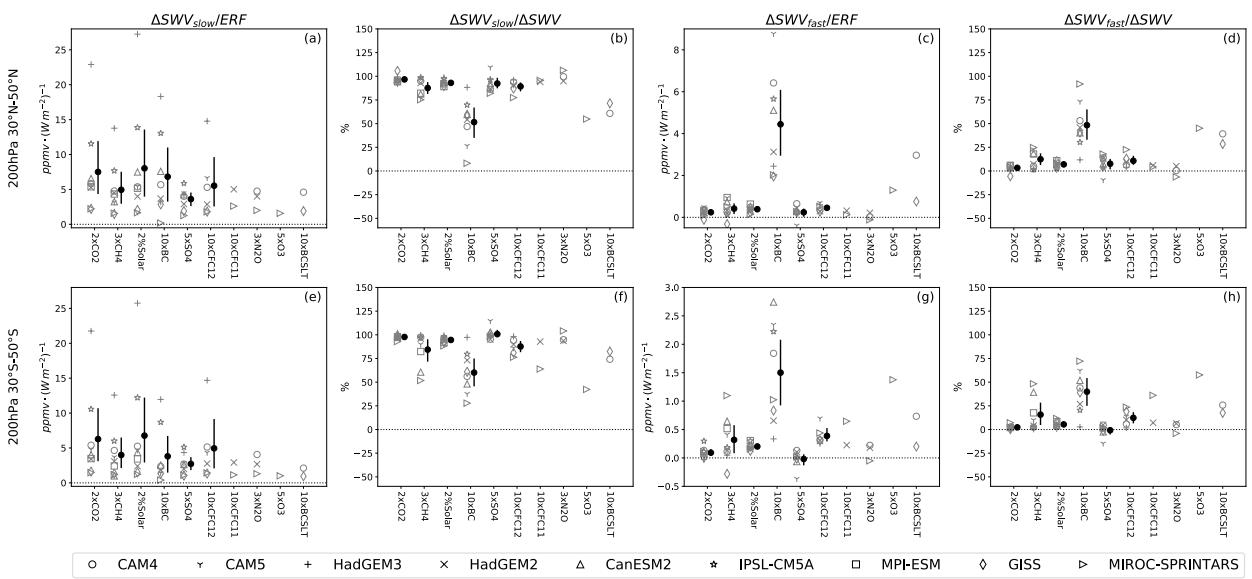


Figure S1: Same as Figure 1 in the paper, but for 200 hPa 30°N-50°N (a-d) and 200 hPa 30°S-50°S (e-h).

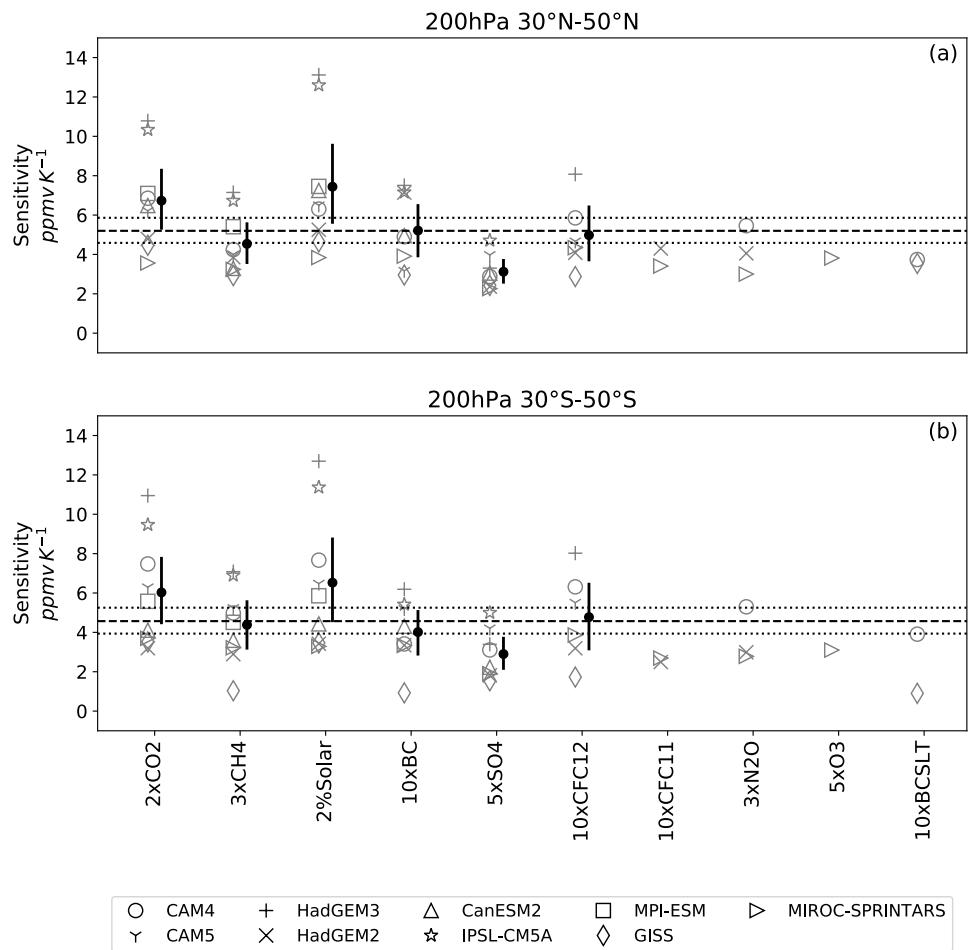


Figure S2: Same as Figure 3, but for 200 hPa 30°N-50°N (a) and 200 hPa 30°S-50°S (b).

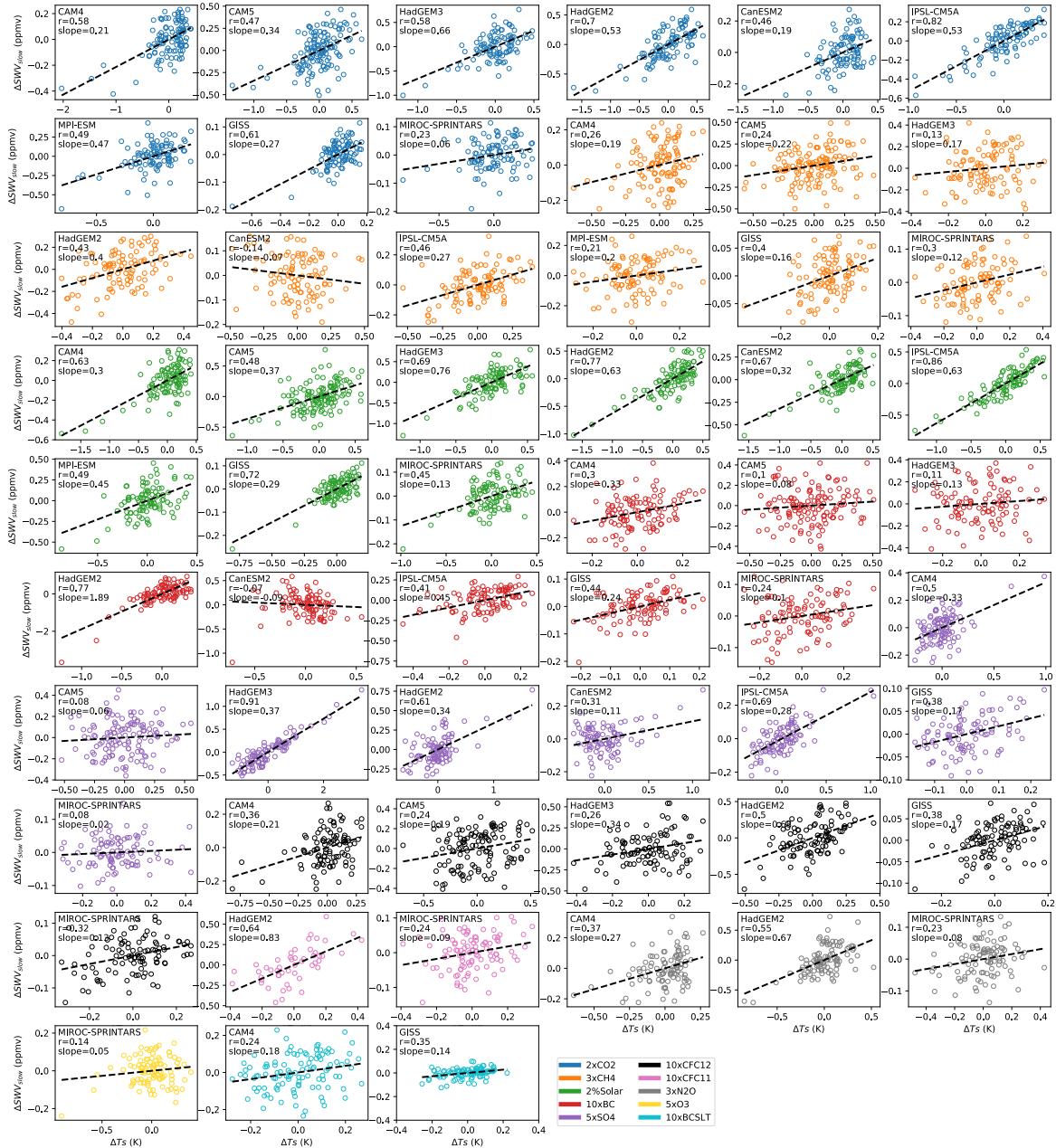
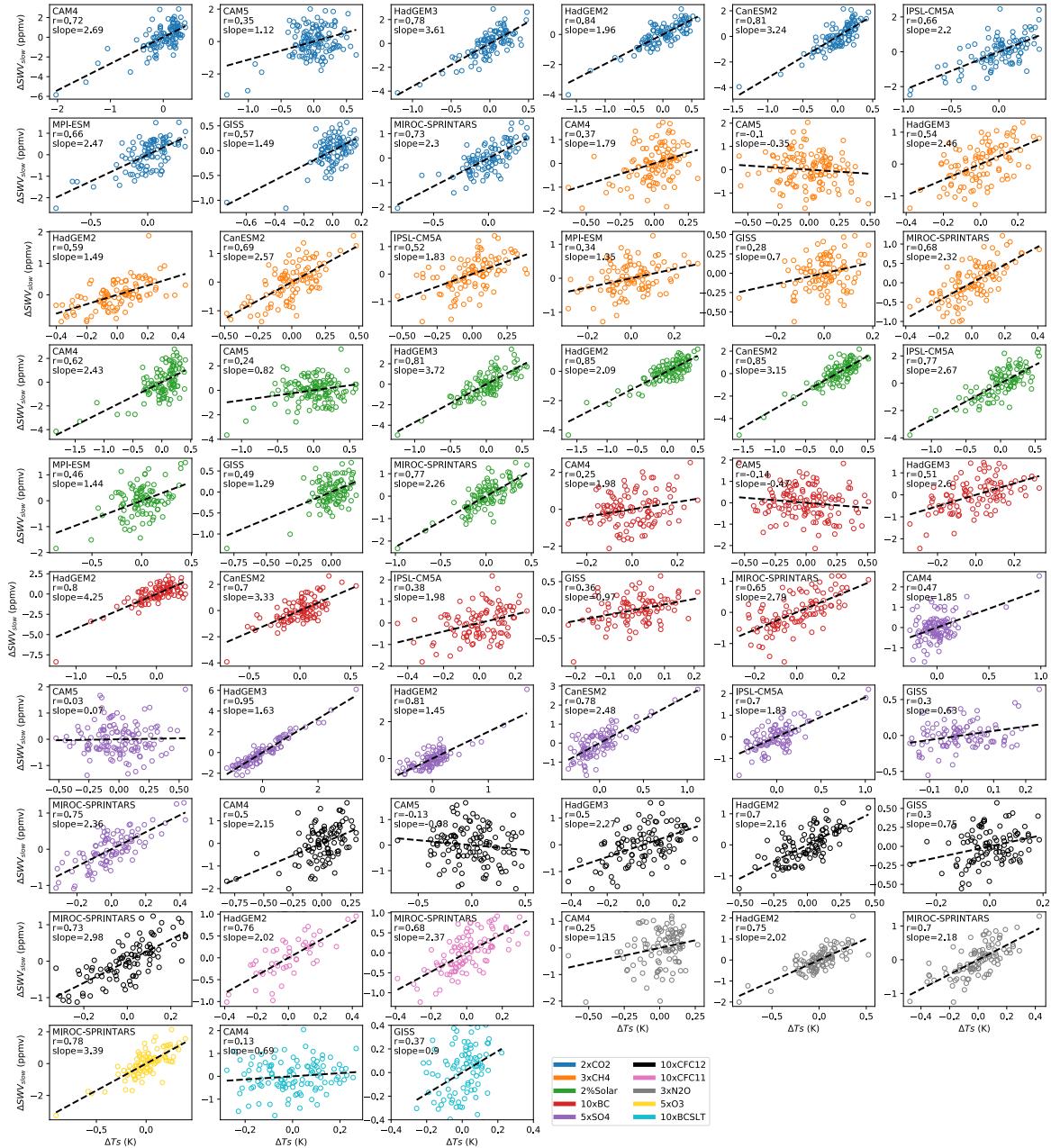


Figure S3. Linear regression between the annual mean time series of ΔSWV_{slow} (ppmv) in the TLS and the annual mean global averaged ΔTs (K) time series. In each panel, the circles are annual mean results, and the dashed line is the linear fit. The color coding indicates results from different perturbations.



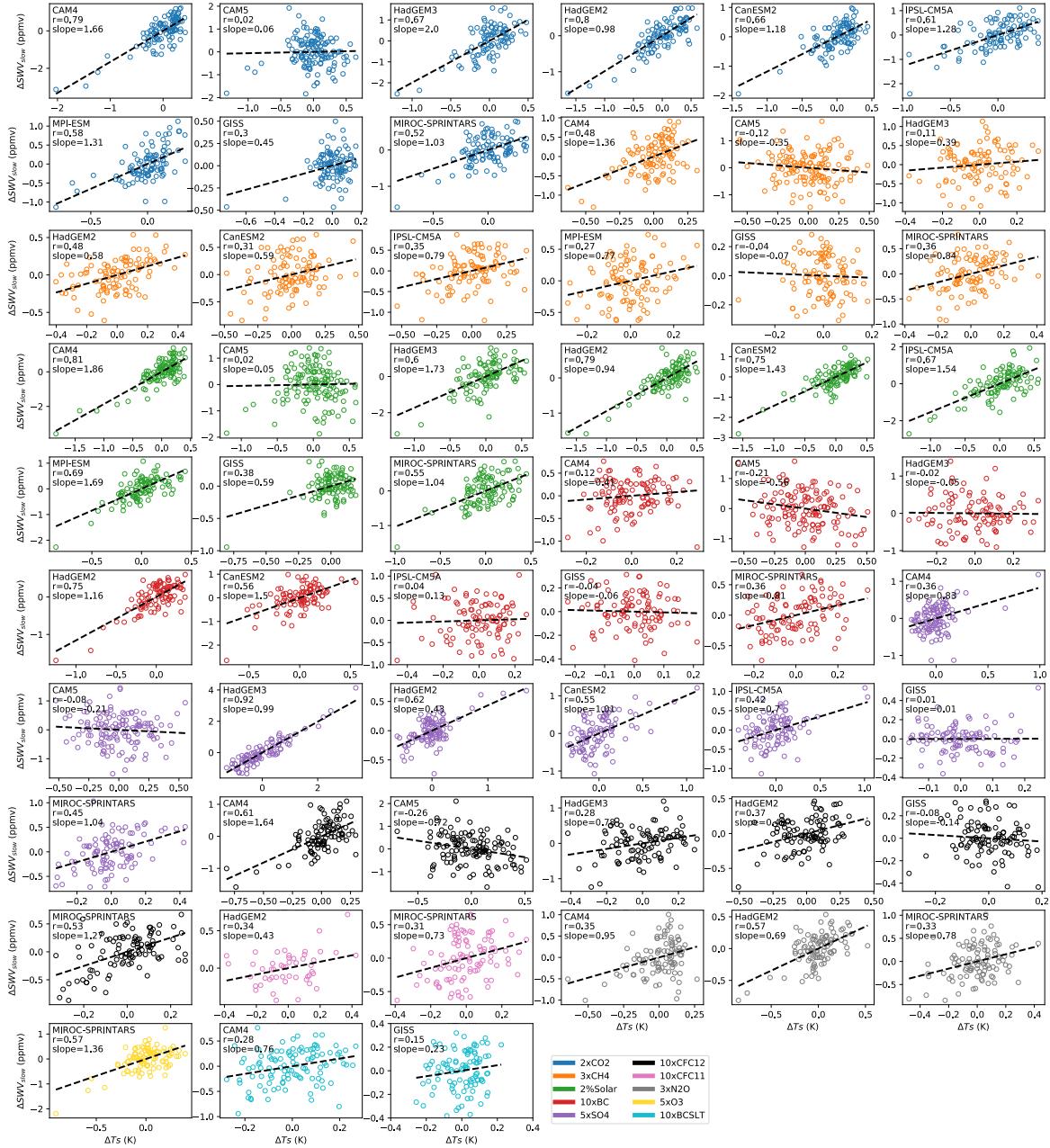


Figure S5. Same as Figure S3, but for ΔSWV_{slow} (ppmv) in the SH LMS.

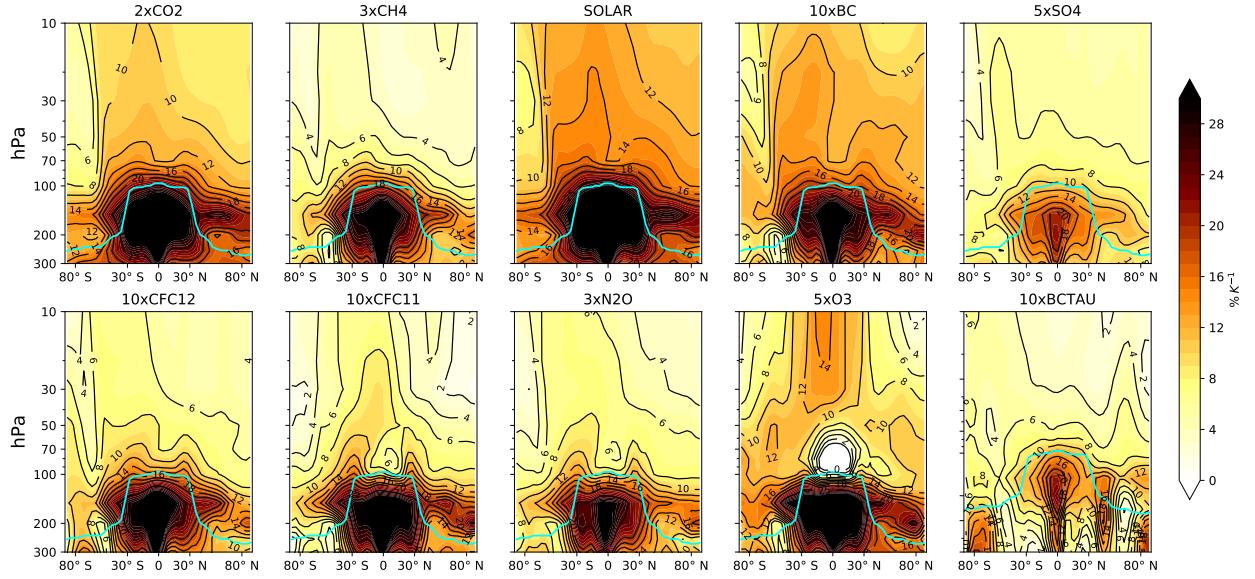


Figure S6. Multi-model mean slope (%/K) for each individual perturbation from the regression between annual mean time series of $\Delta\text{SWV}_{\text{slow}}$ at each latitude grid point and pressure level and annual mean time series of global average ΔT s. We note that the 5xO3 shows weak $\Delta\text{SWV}_{\text{slow}}$ sensitivity to ΔT s in the TLS region. This corresponds to the weak equilibrium TLS $\Delta\text{SWV}_{\text{slow}}$, which consists a small part in the total equilibrium ΔSWV (less than 30%, Fig. 1d).