



Supplement of

The biogeophysical effects of carbon fertilization of the terrestrial biosphere

Robert J. Allen

Correspondence to: Robert J. Allen (rjallen@ucr.edu)

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Supplementary Information

S1. Additional Investigation of Model Differences under PHYS-PI

Intermodel correlations between $Total_{SEB}$ and each SEB component are conducted for the global land mean, tropical land mean and extratropical land mean. The sign of all of the intermodel correlations is consistent with the multimodel mean responses from the main paper, i.e., positive intermodel correlations (although many are not significant) between $Total_{SEB}$ and α_{SEB} , SWD_{SEB} , LWD_{SEB} , and LHF_{SEB} . Similarly, a negative correlation between $Total_{SEB}$ and the SHF_{SEB} response occurs. A similar statement can be made for the additional SEB terms where positive correlations exist between $Total_{SEB}$ and $SWD_{CLR_{SEB}}$, $LWD_{CLR_{SEB}}$ and $TRAN_{SEB}$, with negative correlations for the $SWD_{CLD_{SEB}}$ (except for the tropics), $LWD_{CLD_{SEB}}$ and $EVAP_{SEB}$. Globally, the intermodel variation in $Total_{SEB}$ is largely related to the intermodel variation in the α_{SEB} , with a correlation of 0.73 (significant at the 99% confidence level). As noted in the main paper, CNRM-ESM2-1 is the lone model that yields significant surface cooling (e.g., Supp. Fig. 2f) and this is the lone model that yields cooling for α_{SEB} . Furthermore, as noted above UKESM1-0-LL and EC-Earth3-CC yield relatively large $Total_{SEB}$ warming, and they both possess relatively large α_{SEB} warming. LWD_{SEB} also yields a similar correlation at 0.73, which improves to 0.86 for $LWD_{CLR_{SEB}}$. As noted in the main paper, however, I suggest this is largely a response to the warming and not a primary driver. Interestingly, the correlation between the LHF_{SEB} and $Total_{SEB}$ is not significant at 0.13. The lone model that yields cooling for LHF_{SEB} is EC-Earth3-CC, and this is a model with relatively large $Total_{SEB}$. This implies intermodel variation in the relative importance of the individual SEB responses their total SEB response.

In the tropics, the intermodel variation in $Total_{SEB}$ is largely related to the SWD_{SEB} with a correlation of 0.70 (99%), which is largely due to $SWD_{CLD_{SEB}}$ ($r=0.74$). LHF_{SEB} is also important with a correlation at 0.54 (95%). In the extratropics, the intermodel variation in $Total_{SEB}$ is largely related to α_{SEB} with a correlation of 0.81 (99%). LWD_{SEB} term also yields a similar correlation at 0.79, which improves to 0.91 for $LWD_{CLR_{SEB}}$.

As discussed in the main text, models with a terrestrial nitrogen cycle (N models; Table S1) yield smaller increases in land carbon storage, and to some extent weaker increases in NPP and LAI, as compared to models without a terrestrial nitrogen cycle (noN models). Although most of these differences are not significant between these two model subsets, I investigate further. Interestingly, N models also tend to yield larger biogeophysical warming (but not significantly so). For example, the global mean TAS response is 0.23 ± 0.11 K in the eight N models versus 0.08 ± 0.15 K in the six noN models. Similar results occur over global land only at 0.38 ± 0.17 K versus 0.16 ± 0.20 K, respectively. To some extent this seems counterintuitive since the 15 model mean yields warming in response to the increase vegetation, and one might expect models with a larger vegetation increase to yield more biogeophysical warming. However, intermodel correlations between the vegetation responses and the land TAS response are not significant at -0.03 for LAI; -0.03 for NPP; and -0.34 for land carbon. Thus, intermodel differences in biogeophysical warming are not well correlated with intermodel differences in vegetation indices.

Consistently, the intermodel correlation between the total SEB response (i.e. biogeophysical warming) and biogeochemical cooling displays a (non-significant) positive correlation at 0.34. This correlation is identical to that above based on land carbon storage (but positive here), which is a direct consequence of inferring biogeochemical cooling from the best estimate of the TCRC and each model's land carbon response. This again implies that models that yield weaker biogeochemical cooling also tend to yield more biogeophysical warming (i.e., N models) and vice versa. In other words, N cycle models would yield less overall cooling under carbon fertilization, due to both less biogeochemical cooling associated with less carbon storage but more warming associated with biogeophysical effects. This result does not appear to be related to differences in TCR, as models with a terrestrial nitrogen cycle yield a TCR of 2.1 ± 0.20 K whereas models without a terrestrial nitrogen cycle yield a TCR of 1.9 ± 0.31 K.

I note that most of the land warming differences between N models and noN models occurs over extratropical land at 0.49 ± 0.22 K versus 0.16 ± 0.26 K, respectively. As with the global land intermodel correlations, however, there are no significant correlations between extratropical land warming and extratropical vegetation indices at -0.14 for LAI; -0.38 for NPP; and -0.38 for land carbon. Nonetheless, each extratropical SEB term response for the N models is larger in magnitude (some more positive and some more negative) as compared to the noN models. The largest extratropical difference between these two model subsets is for α_{SEB} (0.22 ± 0.14 K in the N models versus 0.11 ± 0.13 K in the noN models) and for SWD_{SEB} (0.21 ± 0.16 K in the N models versus 0.11 ± 0.10 K in the noN models). Most of the larger increase in the extratropical SWD_{SEB} in the N models is due to $\text{SWD}_{\text{CLD}_{\text{SEB}}}$ at 0.27 ± 0.12 K versus 0.14 ± 0.09 K in the noN models. I note relatively small differences in the extratropical LHF_{SEB} at 0.21 ± 0.21 K in the N models versus 0.16 ± 0.15 K in the noN models. The extratropical LHF_{SEB} response in the N models has both larger warming due to TRAN_{SEB} but also larger cooling due to EVAP_{SEB} . For example, the former term is 0.52 ± 0.19 K and the latter term is -0.35 ± 0.18 K in the N models. The corresponding responses for the noN models are 0.16 ± 0.08 K versus -0.001 ± 0.16 K. Similar statements for the global and tropical mean LHF_{SEB} , TRAN_{SEB} and EVAP_{SEB} exist. Thus, the enhanced biogeophysical warming in N models—most of which occurs in the extratropics—does not appear to be driven by LHF_{SEB} differences, and is instead related to both α_{SEB} and $\text{SWD}_{\text{CLD}_{\text{SEB}}}$. In addition to terrestrial nitrogen cycling, these two model subsets share many other differences (e.g., photosynthesis, stomatal conductance, litter/soil carbon dynamics, etc.) that likely complicate a simple interpretation.

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Table S1. CMIP6 models analyzed here. In the comment section, D represents models with a dynamic global vegetation model (i.e., vegetation type and distribution are interactive); N represents models that include a terrestrial nitrogen cycle; and C represents models that include atmospheric chemistry with interactive BVOC emissions.

Model	Atmosphere Model	Land Model	Comment	Data Reference	Main Reference
ACCESS-ESM1-5	UM7.3	CABLE2.4, CASA-CNP	N	Ziehn et al. (2019a,b,c,d)	Law et al. (2017), Ziehn et al. (2020)
BCC-CSM2-MR	BCC AGCM3 MR	BCC AVIM2		Wu et al. (2018a,b) Wu et al. (2019b,c)	Wu et al. (2019a)
CanESM5	CanAM5	CLASS3.6, CTEM1.2		Swart et al. (2019b,c,d,e)	Swart et al. (2019a)
CESM2	CAM6	CLM5	N	Danabasoglu (2019a,b,c) Danabasoglu et al. 2019	Danabasoglu et al. (2020)
CMCC-ESM2	CAM5	CLM4.5	N	Lovato et al. (2021a,b,c,d)	Lovato et al. (2022)
CNRM-ESM2-1	ARPEGE-Climate v6.3 + SURFEX v8.0	ISBA + CTRIP		Seferian et al. (2018a,b,c,d)	Seferian et al. (2019)
EC-Earth3-CC	IFS 36r4 + HTESSEL + TM5	LPJ-GUESS	N	EC-Earth Consortium (2020,2021)	Doscher et al. (2022)
GISS-E2-1-G	GISS-E2.1	GISS LSM		NASA/GISS (2018a,b; 2019a,b)	Kelley et al. (2020)
GFDL-ESM4	AM4.1	LM4.1	D, C	Krasting et al. (2018a,b,c,d)	Dunne et al. (2020)
IPSL-CM6A-LR	LMDZ6A	ORCHIDEEv2		Boucher et al. (2018a,b,c,d)	Boucher et al. (2020)
MIROC-ES2L	MIROC-AGCM + SPRINTARS	VISIT-e and MATSIRO6	N	Hajima et al. (2019a,b,c,d)	Hajima et al. (2020)
MPI-ESM1-2-LR	ECHAM6.3	JSBACH3.2	N, D	Brovkin et al. (2019a,b) Wieners et al. (2019a,b)	Mauritsen et al. (2019)
MRI-ESM2-0	MRI-AGCM3.5 + MASINGAR mk-2r4c + MRI-CCM2.1	HAL		Yukimoto et al. (2019b,c)	Yukimoto et al. (2019a)
NorESM2-LM	Modified CAM6	CLM5	N, C	Seland et al. (2019a,b) Schwinger et al. (2020a,b)	Seland et al. (2020)
UKESM1-0-LL	Unified Model + UKCA	JULES-ES-1.0	N, D, C	Tang et al. (2019a,b) Jones (2019a,b)	Sellar et al. (2019)

Table S2. Vegetation and land carbon PHYS-PI responses associated with carbon fertilization. Global, tropical and extratropical multimodel mean annual mean responses for net primary productivity (NPP; kg km⁻² day⁻¹]; leaf area index (LAI; dimensionless); litter carbon (cLitter; kgC m⁻²); soil organic matter carbon (cSoil; kgC m⁻²); vegetation carbon (cVegetation; kgC m⁻²); and land carbon (cLand; kgC m⁻²). Uncertainty represents the 90% confidence interval estimated as $\frac{1.65 \times \sigma}{\sqrt{m}}$, where σ is the standard deviation across models and m is the number of models. Responses not significant at the 90% confidence level are in bold.

	Global		Tropics		Extratropics	
	MMM	# Models	MMM	# Models	MMM	# Models
NPP	679.4 ± 140.6	15/15	1049.7 ± 248.2	15/15	516.7 ± 109.4	15/15
LAI	0.71 ± 0.25	14/15	1.12 ± 0.41	14/15	0.52 ± 0.18	14/15
cLitter	0.66 ± 0.22	13/13	0.70 ± 0.26	13/13	0.77 ± 0.28	13/13
cSoil	1.38 ± 0.49	14/14	1.68 ± 0.64	14/14	1.49 ± 0.57	14/14
cVegetation	2.48 ± 0.42	14/14	3.97 ± 0.68	14/14	1.76 ± 0.47	14/14
cLand	4.52 ± 0.68	14/14	6.35 ± 0.97	14/14	4.02 ± 0.79	14/14

Table S3. PHYS-PI climate responses associated with carbon fertilization. Global, tropical and extratropical multimodel mean annual mean responses for near-surface air temperature (TAS; K); TAS over land (TAS LND; K); surface temperature (TS; K); TS over land (TS LND; K); precipitation (PR; mm day⁻¹); PR over land (PR LND; mm day⁻¹); near-surface wind speed (WS; m s⁻¹); WS over land (WS LND; m s⁻¹); total cloud cover (CLT; %); CLT over land (CLT LND; %); tropospheric specific humidity (TQ; g kg⁻¹); TQ over land (TQ LND; g kg⁻¹); tropospheric relative humidity (TRH; %); TRH over land (TRH LND; %); tropospheric temperature (TTEMP; K); TTEMP over land (TTEMP LND; K); near-surface specific humidity (QS; g kg⁻¹); QS over land (QS LND; g kg⁻¹); near-surface relative humidity (RHS; %); RHS over land (RHS LND; %); aerosol optical depth (AOD; 10⁻³); AOD over land (AOD LND; 10⁻³); dust aerosol optical depth (DAOD; 10⁻³); DAOD over land (DAOD LND; 10⁻³); aerosol optical depth without dust (AODNOD; 10⁻³); and AODNOD over land (AODNOD LND; 10⁻³). Uncertainty represents the 90% confidence interval estimated as $\frac{1.65 \times \sigma}{\sqrt{m}}$, where σ is the standard deviation across models and m is the number of models. Responses not significant at the 90% confidence level are in bold.

	Global		Tropics		Extratropics	
	MMM	# Models	MMM	# Models	MMM	# Models
TAS	0.16 ± 0.09	13/15	0.13 ± 0.05	13/15	0.18 ± 0.10	13/15
TAS LND	0.28 ± 0.13	14/15	0.25 ± 0.09	14/15	0.33 ± 0.17	14/15
TS	0.15 ± 0.09	13/15	0.12 ± 0.05	13/15	0.16 ± 0.10	13/15
TS LND	0.26 ± 0.12	13/15	0.22 ± 0.09	13/15	0.31 ± 0.16	14/15
PR	-0.012 ± 0.009	11/15	-0.021 ± 0.009	13/15	-0.008 ± 0.009	11/15
PR LND	-0.028 ± 0.017	12/15	-0.038 ± 0.023	12/15	-0.032 ± 0.020	13/15
WS	-0.013 ± 0.009	10/15	-0.011 ± 0.011	9/15	-0.022 ± 0.010	11/15
WS LND	-0.040 ± 0.023	9/15	-0.025 ± 0.030	9/15	-0.069 ± 0.029	12/15
CLT	-0.22 ± 0.09	12/15	-0.20 ± 0.09	12/15	-0.31 ± 0.12	14/15
CLT LND	-0.52 ± 0.23	12/15	-0.56 ± 0.28	12/15	-0.64 ± 0.29	12/15
TQ	0.017 ± 0.014	11/15	0.022 ± 0.019	11/15	0.014 ± 0.011	11/15
TQ LND	0.011 ± 0.015	10/15	0.012 ± 0.019	8/15	0.012 ± 0.015	9/15
TRH	-0.09 ± 0.05	12/14	-0.11 ± 0.05	11/14	-0.11 ± 0.06	13/14
TRH LND	-0.21 ± 0.12	12/14	-0.26 ± 0.14	12/14	-0.27 ± 0.17	12/14
TTEMP	0.14 ± 0.08	13/15	0.13 ± 0.08	11/15	0.15 ± 0.07	14/15

TTEMP LND	0.18 ± 0.09	14/15	0.17 ± 0.08	14/15	0.21 ± 0.09	14/15
QS	0.041 ± 0.042	11/15	0.049 ± 0.054	10/15	0.037 ± 0.035	11/15
QS LND	-0.010 ± 0.052	9/15	-0.033 ± 0.072	9/15	0.003 ± 0.049	9/15
RHS	-0.27 ± 0.16	11/14	-0.29 ± 0.17	11/14	-0.27 ± 0.17	11/14
RHS LND	-0.87 ± 0.48	11/14	-1.09 ± 0.59	11/14	-0.92 ± 0.57	11/14
AOD	1.11 ± 1.13	5/8	1.32 ± 1.43	5/8	1.02 ± 1.21	3/8
AOD LND	1.88 ± 2.50	5/8	3.07 ± 3.00	5/8	1.23 ± 3.38	3/8
DAOD	0.34 ± 0.76	5/8	0.41 ± 0.87	4/8	0.29 ± 1.11	4/8
DAOD LND	0.40 ± 1.60	5/8	0.72 ± 1.80	5/8	0.14 ± 2.81	4/8
AODNOD	0.77 ± 0.86	4/8	0.91 ± 1.03	5/8	0.73 ± 0.89	6/8
AODNOD LND	1.49 ± 1.71	5/8	2.35 ± 2.33	5/8	1.10 ± 1.75	4/8

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Table S4. Surface energy balance (SEB) decomposition of the surface temperature response for PHYS-PI. Global, tropical and extratropical multimodel mean annual mean responses and the number of models that agree on the sign of the multimodel mean response. Terms include surface albedo (α_{SEB}); downwelling surface shortwave radiation (SWD_{SEB}); downwelling surface longwave radiation (LWD_{SEB}); surface latent heat flux (LHF_{SEB}); surface sensible heat flux (SHF_{SEB}); and the total (i.e., sum of the prior five terms; $\text{Total}_{\text{SEB}}$). Also included is SWD_{SEB} decomposed into clear-sky ($\text{SWDCLR}_{\text{SEB}}$) and cloudy-sky ($\text{SWDCLD}_{\text{SEB}}$) contributions; LWD_{SEB} decomposed into clear-sky ($\text{LWDCLR}_{\text{SEB}}$) and cloudy-sky ($\text{LWDCLD}_{\text{SEB}}$) contributions; and LHF_{SEB} decomposed into TRAN_{SEB} and EVAP_{SEB} . The SEB decomposition is performed over all land areas. Also included are the corresponding land-only surface temperature (TS) and near-surface air temperature (TAS) responses. Uncertainty represents the 90% confidence interval estimated as $\frac{1.65 \times \sigma}{\sqrt{m}}$, where σ is the standard deviation across models and m is the number of models. Responses not significant at the 90% confidence level are in bold. Units are K.

	Global		Tropics		Extratropics	
	MMM	# Models	MMM	# Models	MMM	# Models
α_{SEB}	0.11 ± 0.06	13/15	0.06 ± 0.04	11/15	0.16 ± 0.09	13/15
SWD_{SEB}	0.09 ± 0.06	12/15	0.05 ± 0.06	9/15	0.16 ± 0.10	12/15
$\text{SWDCLR}_{\text{SEB}}$	-0.05 ± 0.02	12/15	-0.05 ± 0.02	12/15	-0.05 ± 0.04	11/15
$\text{SWDCLD}_{\text{SEB}}$	0.14 ± 0.05	12/15	0.10 ± 0.05	11/15	0.21 ± 0.08	13/15
LWD_{SEB}	0.20 ± 0.13	13/15	0.15 ± 0.08	13/15	0.20 ± 0.16	13/15
$\text{LWDCLR}_{\text{SEB}}$	0.27 ± 0.13	12/14	0.22 ± 0.09	12/14	0.32 ± 0.17	12/14
$\text{LWDCLD}_{\text{SEB}}$	-0.07 ± 0.03	12/14	-0.07 ± 0.03	11/14	-0.11 ± 0.05	11/14
LHF_{SEB}	0.27 ± 0.11	13/15	0.45 ± 0.15	14/15	0.19 ± 0.12	12/15
TRAN_{SEB}	0.45 ± 0.15	13/13	0.70 ± 0.26	13/13	0.34 ± 0.13	13/13
EVAP_{SEB}	-0.19 ± 0.16	9/13	-0.26 ± 0.25	7/13	-0.17 ± 0.14	12/13
SHF_{SEB}	-0.34 ± 0.08	13/15	-0.47 ± 0.10	13/15	-0.33 ± 0.11	13/15
$\text{Total}_{\text{SEB}}$	0.33 ± 0.13	14/15	0.25 ± 0.09	13/15	0.39 ± 0.18	14/15
TS	0.26 ± 0.12	13/15	0.22 ± 0.09	13/15	0.31 ± 0.16	14/15
TAS	0.28 ± 0.13	14/15	0.25 ± 0.09	14/15	0.33 ± 0.17	14/15

Table S5. Spatial correlations between the multimodel mean surface energy balance (SEB) terms and the total SEB term for PHYS-PI. Global, tropical and extratropical multimodel mean correlations. Terms include surface albedo (α_{SEB}); downwelling surface shortwave radiation (SWD_{SEB}) and its clear-sky ($\text{SWDCLR}_{\text{SEB}}$) and cloudy-sky ($\text{SWDCLD}_{\text{SEB}}$) contributions; downwelling surface longwave radiation (LWD_{SEB}) and its clear-sky ($\text{LWDCLR}_{\text{SEB}}$) and cloudy-sky ($\text{LWDCLD}_{\text{SEB}}$) contributions; surface latent heat flux (LHF_{SEB}) and its components including TRAN_{SEB} and EVAP_{SEB} . All correlations are significant at the 90% confidence level.

	Global	Tropics	Extratropics
α_{SEB}	0.56	−0.34	0.42
SWD_{SEB}	0.55	0.53	0.51
$\text{SWDCLR}_{\text{SEB}}$	−0.53	−0.33	−0.41
$\text{SWDCLD}_{\text{SEB}}$	0.62	0.61	0.57
LWD_{SEB}	0.63	0.37	0.58
$\text{LWDCLR}_{\text{SEB}}$	0.91	0.76	0.90
$\text{LWDCLD}_{\text{SEB}}$	−0.46	−0.59	−0.50
LHF_{SEB}	0.22	0.77	0.18
TRAN_{SEB}	0.23	0.55	0.32
EVAP_{SEB}	−0.24	−0.23	−0.39
SHF_{SEB}	−0.36	−0.64	−0.34

Table S6. Vegetation and land carbon responses associated with carbon fertilization under (FULL-RAD) minus (PHYS-PI). Global, tropical and extratropical multimodel mean annual mean responses for net primary productivity (NPP; kg km⁻² day⁻¹); leaf area index (LAI; dimensionless); litter carbon (cLitter; kgC m⁻²); soil organic matter carbon (cSoil; kgC m⁻²); and vegetation carbon (cVegetation; kgC m⁻²). Uncertainty represents the 90% confidence interval estimated as $\frac{1.65 \times \sigma}{\sqrt{m}}$, where σ is the standard deviation across models and m is the number of models. Responses not significant at the 90% confidence level are in bold.

	Global		Tropics		Extratropics	
	MMM	# Models	MMM	# Models	MMM	# Models
NPP	66.3 ± 65.1	9/13	25.8 ± 95.5	9/13	125.0 ± 66.5	11/13
LAI	0.11 ± 0.05	11/13	0.10 ± 0.06	10/13	0.14 ± 0.07	13/13
cLitter	-0.07 ± 0.06	7/11	-0.09 ± 0.08	7/11	-0.07 ± 0.09	7/11
cSoil	-0.06 ± 0.25	6/12	-0.04 ± 0.12	5/12	-0.03 ± 0.39	4/12
cVegetation	0.29 ± 0.18	9/12	0.26 ± 0.25	9/12	0.40 ± 0.22	11/12

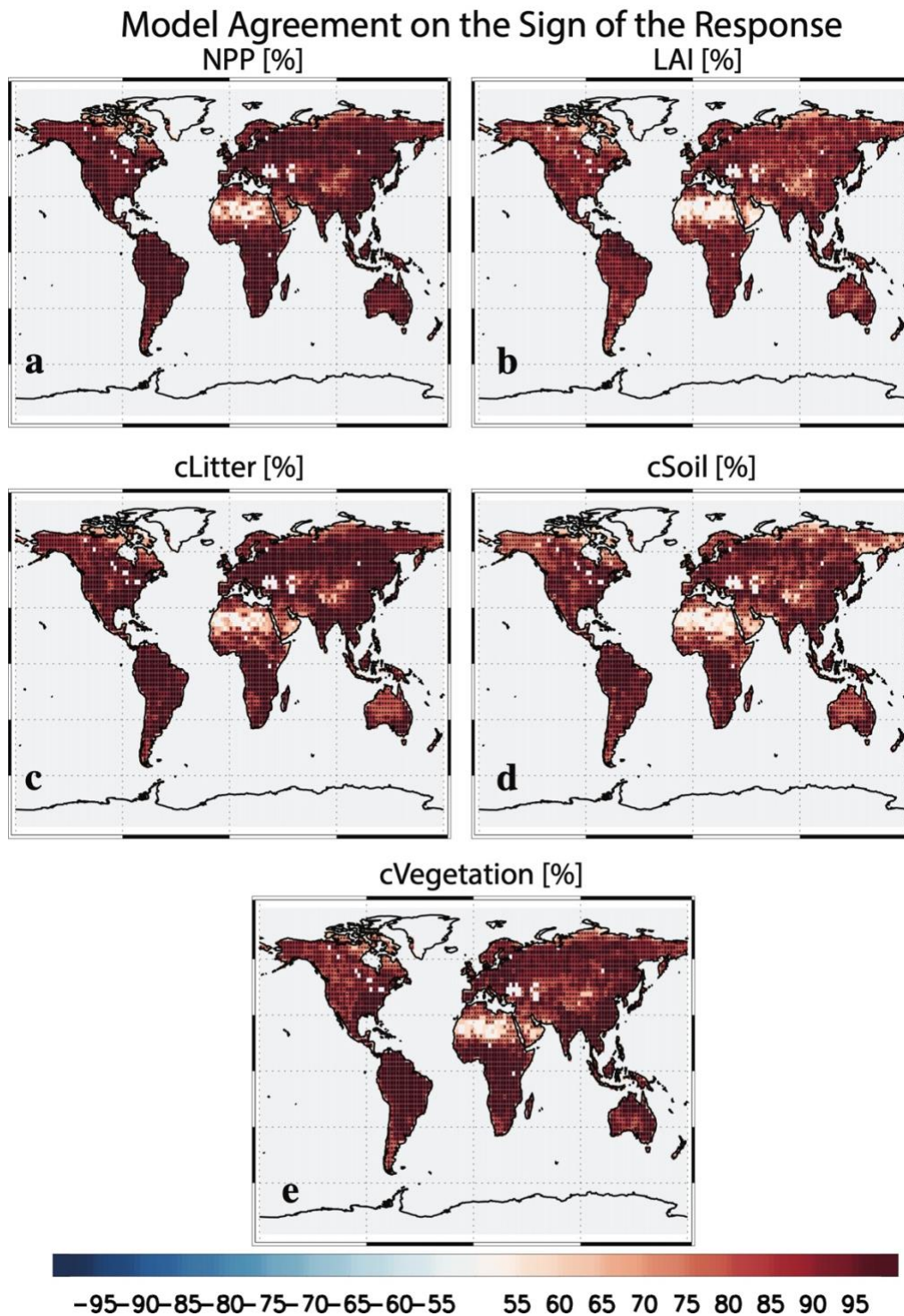


Figure S1. Model agreement on the sign of the vegetation and land carbon PHYS-PI responses. Model agreement on the sign of the response [% of models] for (a) net primary productivity (NPP); (b) leaf area index (LAI); (c) litter pool carbon (cLitter); (d) soil pool carbon (cSoil); and (e) vegetation carbon (cVegetation). Red (blue) colors indicate model agreement on an increase (decrease). Symbols represent significant model agreement at the 90% confidence level based on a two-tailed binomial test.

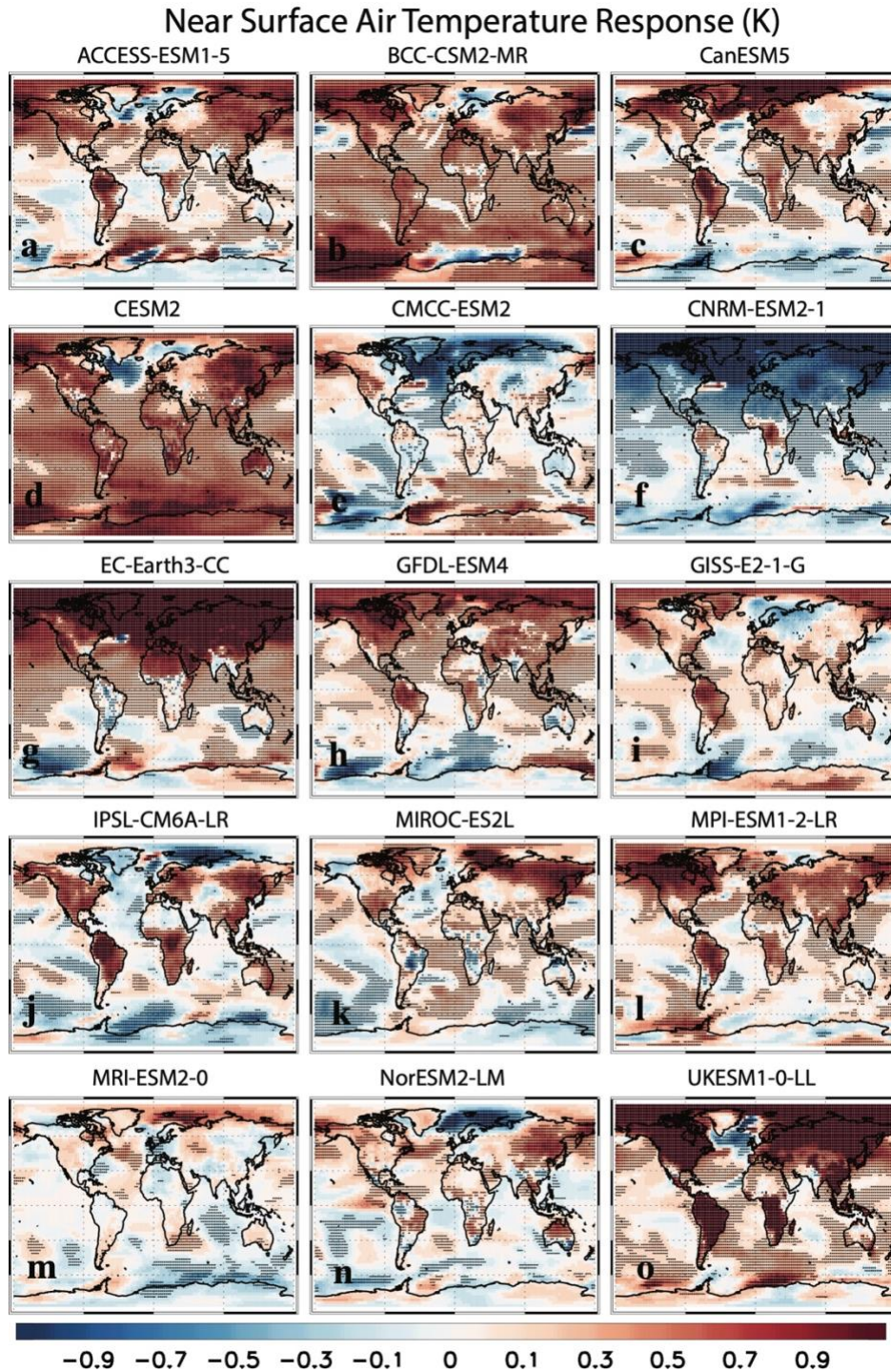


Figure S2. Annual mean near surface air temperature PHYS-PI response for each model. ΔT_{AS} (K) for (a) ACCESS-ESM1-5; (b) BCC-CSM2-MR; (c) CanESM5; (d) CESM2; (e) CMCC-ESM2; (f) CNRM-ESM2-1; (g) EC-Earth3-CC; (h) GFDL-ESM4; (i) GISS-E2-1-G; (j) IPSL-CM6A-LR; (k) MIROC-ES2L; (l) MPI-ESM1-2-LR; (m) MRI-ESM2-0; (n) NorESM2-LM; (o) UKESM1-0-LL. Symbols denote a response significant at the 90% confidence level based on a two-tailed pooled t-test.

SEB Model Agreement on the Sign of the Response

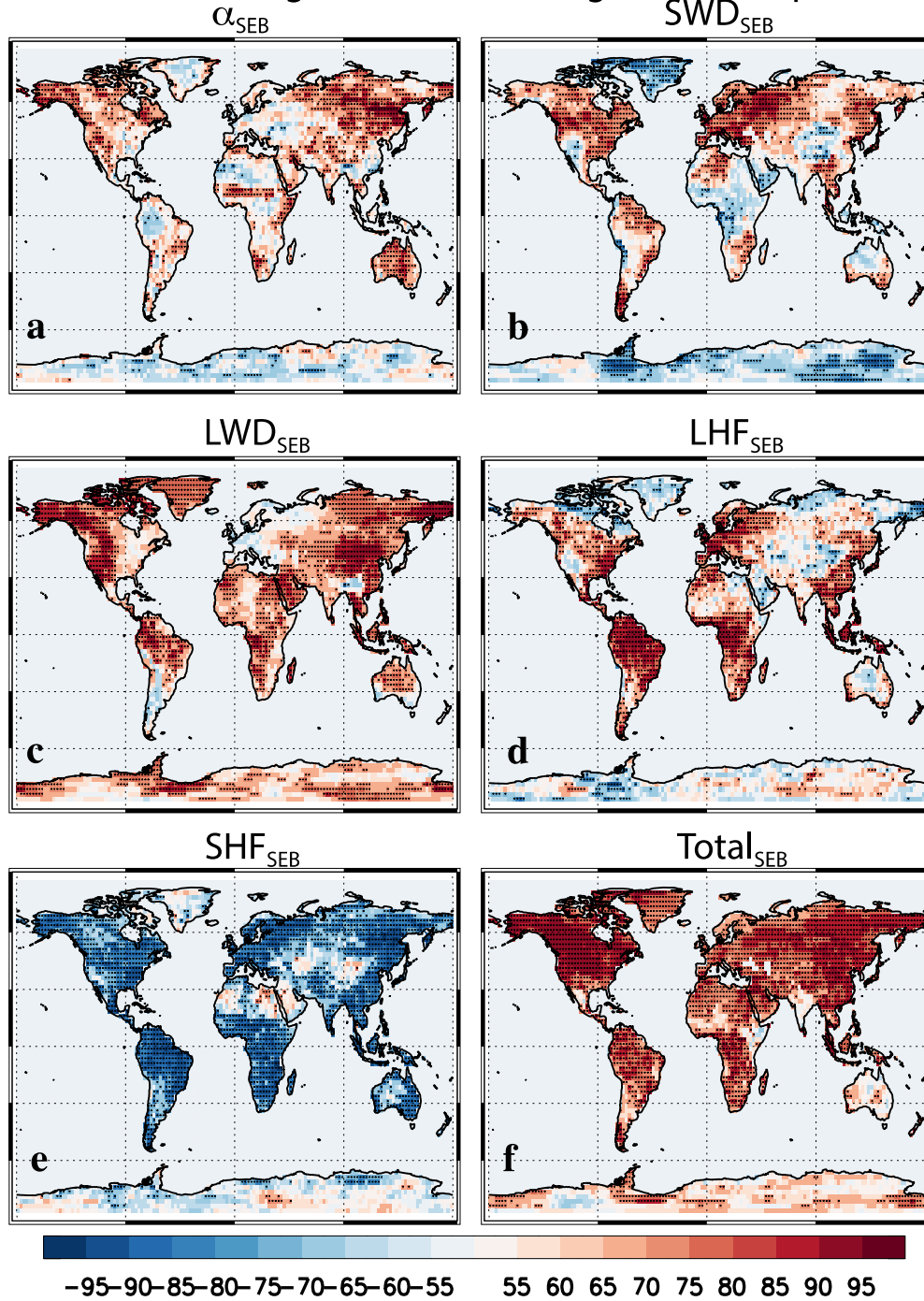
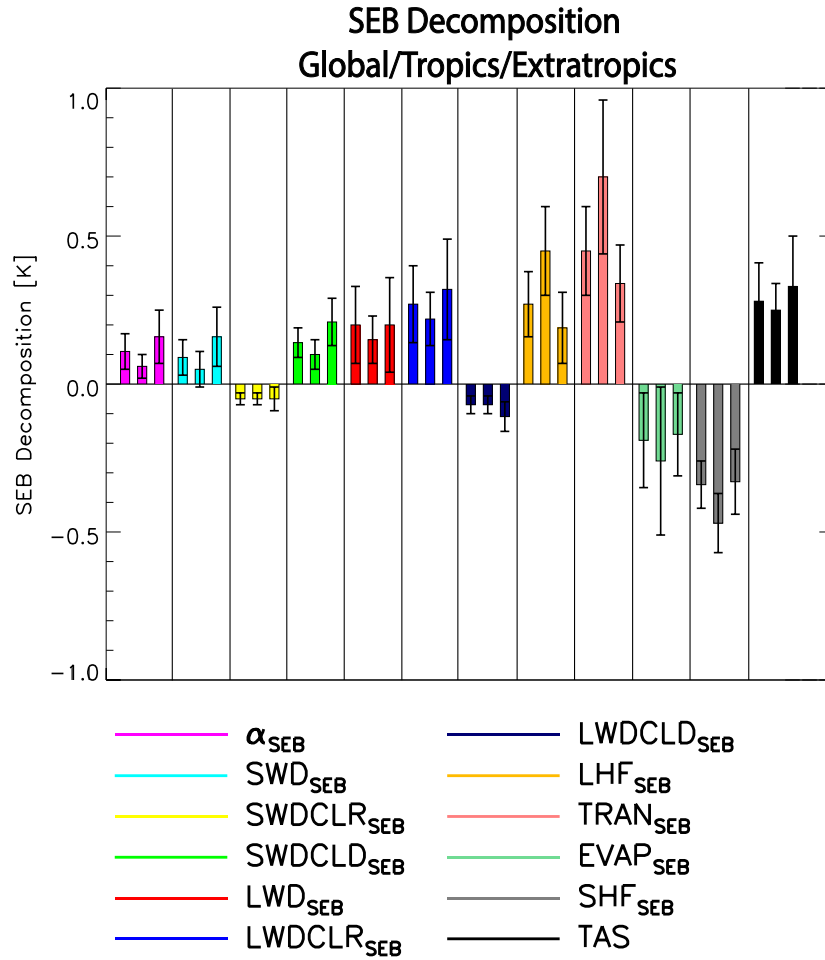


Figure S3. Model agreement on the sign of the surface energy balance (SEB) decomposition PHYS-PI responses. Model agreement on the sign of SEB responses [% of models] for (a) surface albedo (α_{SEB}); (b) downwelling surface shortwave radiation (SWD_{SEB}); (c) downwelling surface longwave radiation (LWD_{SEB}); (d) surface latent heat flux (LHF_{SEB}); (e) surface sensible heat flux (SHF_{SEB}); and (f) the total (i.e., sum of the prior five terms; $\text{Total}_{\text{SEB}}$). Red (blue) colors indicate model agreement on an increase (decrease). Symbols represent significant model agreement at the 90% confidence level based on a two-tailed binomial test.



1st bar in each like colored set of 3 bars = Global
 2nd bar in each like colored set of 3 bars = Tropics
 3rd bar in each like colored set of 3 bars = Extratropics

Figure S4. Surface energy balance (SEB) decomposition of the surface temperature response for PHYS-PI. SEB terms include α_{SEB} (purple); SWD_{SEB} (cyan) and its clear-sky ($\text{SWDCLR}_{\text{SEB}}$; yellow) and cloudy-sky ($\text{SWDCLD}_{\text{SEB}}$; bright green) contributions; LWD_{SEB} (red) and its clear-sky ($\text{LWDCLR}_{\text{SEB}}$; blue) and cloudy-sky ($\text{LWDCLD}_{\text{SEB}}$; navy) contributions; LHF_{SEB} (orange) and its transpiration (TRAN_{SEB} ; pink) and evaporation (EVAP_{SEB} ; darker green) components; SHF_{SEB} (gray); and near-surface air temperature (TAS; black). Responses are shown over global land (1st bar in each like colored set of 3 bars); tropical land (2nd bar in each like colored set of 3 bars); and extratropical land (3rd bar in each like colored set of 3 bars). Error bars show the 90% confidence level based on individual model responses. Units are K.

Additional SEB Model Agreement on the Sign of the Response $\text{SWDCLR}_{\text{SEB}}$ $\text{SWDCLD}_{\text{SEB}}$

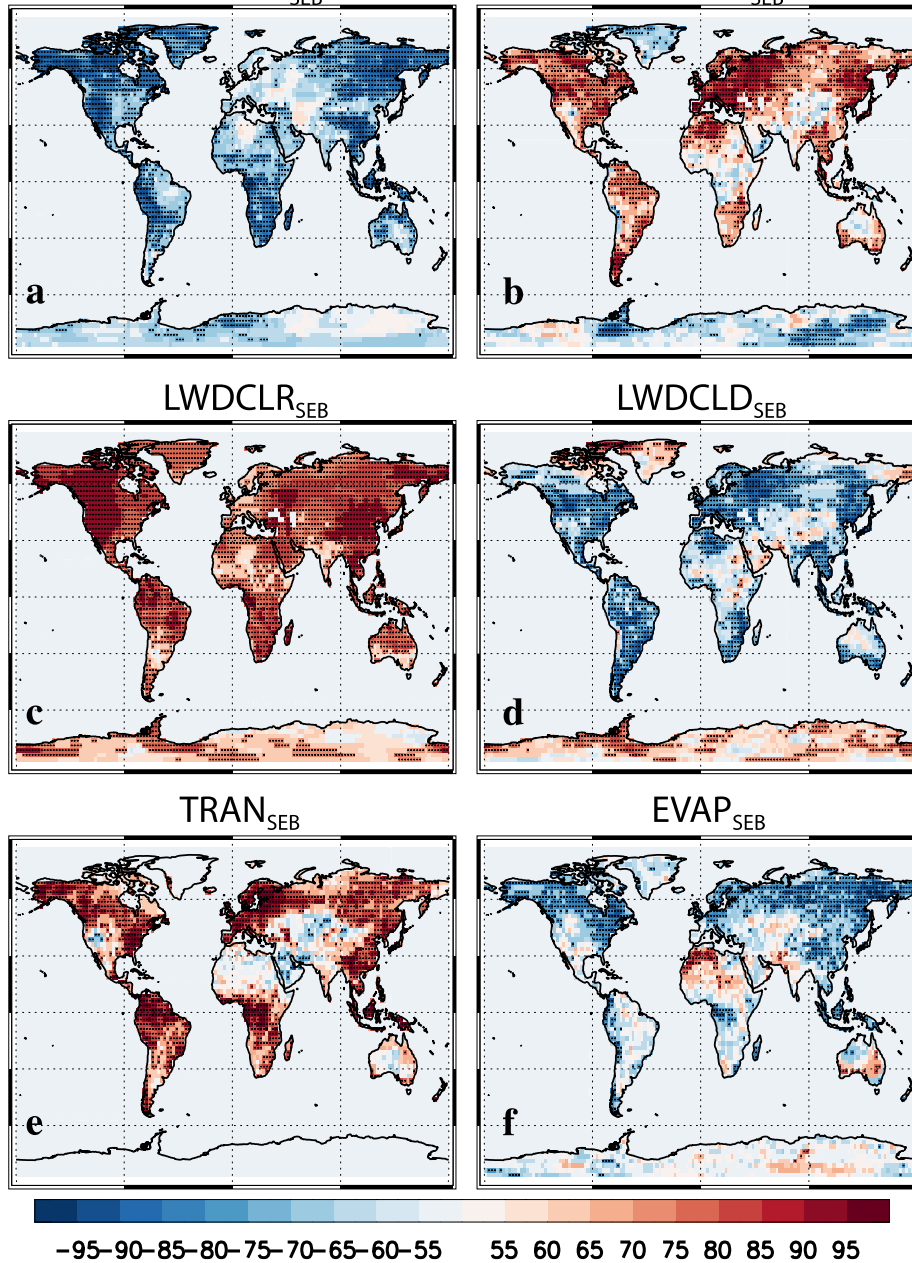


Figure S5. Model agreement on the sign of the additional surface energy balance (SEB) decomposition responses for PHYS-PI. Model agreement on the sign of SEB responses [% of models] for SWD_{SEB} decomposed into (a) clear-sky ($\text{SWDCLR}_{\text{SEB}}$) and (b) cloudy-sky ($\text{SWDCLD}_{\text{SEB}}$) contributions; LWD_{SEB} decomposed into (c) clear-sky ($\text{LWDCLR}_{\text{SEB}}$) and (d) cloudy-sky ($\text{LWDCLD}_{\text{SEB}}$) contributions; and LHF_{SEB} decomposed into (e) TRAN_{SEB} and (f) EVAP_{SEB}. Red (blue) colors indicate model agreement on an increase (decrease). Symbols represent significant model agreement at the 90% confidence level based on a two-tailed binomial test.

Multi-Model Mean Annual Mean Hydrological Responses

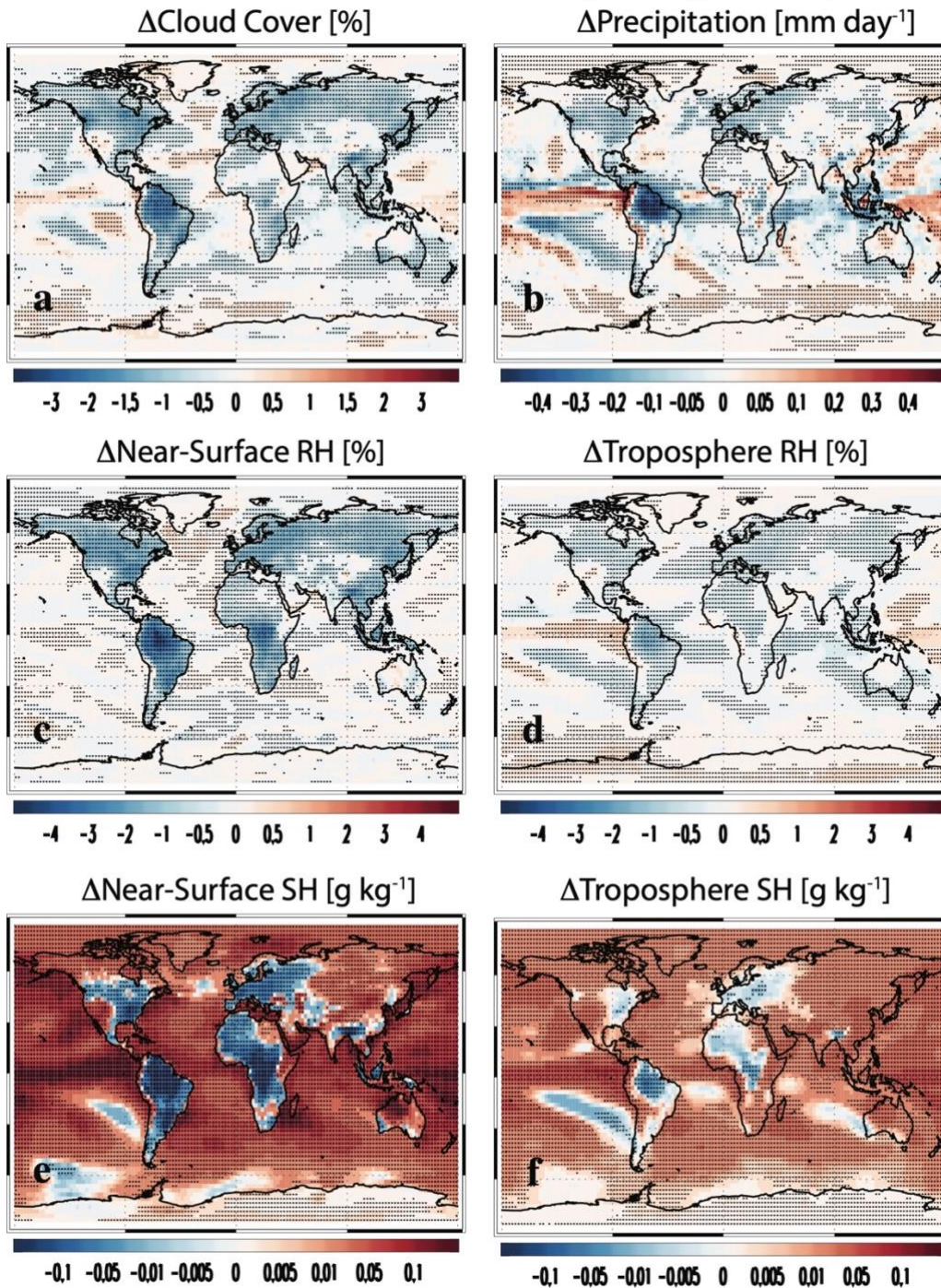


Figure S6. Multimodel mean hydrological PHYS-PI responses. Multimodel mean annual mean responses for (a) total cloud cover [%]; (b) precipitation [mm day⁻¹]; (c) near-surface relative humidity [%]; (d) tropospheric mean relative humidity [%]; (e) near surface specific humidity [g kg⁻¹]; and (f) tropospheric mean specific humidity [g kg⁻¹]. Symbols denote a response significant at the 90% confidence level based on a two-tailed pooled t-test.

Model Agreement on the Sign of the Hydrological Response

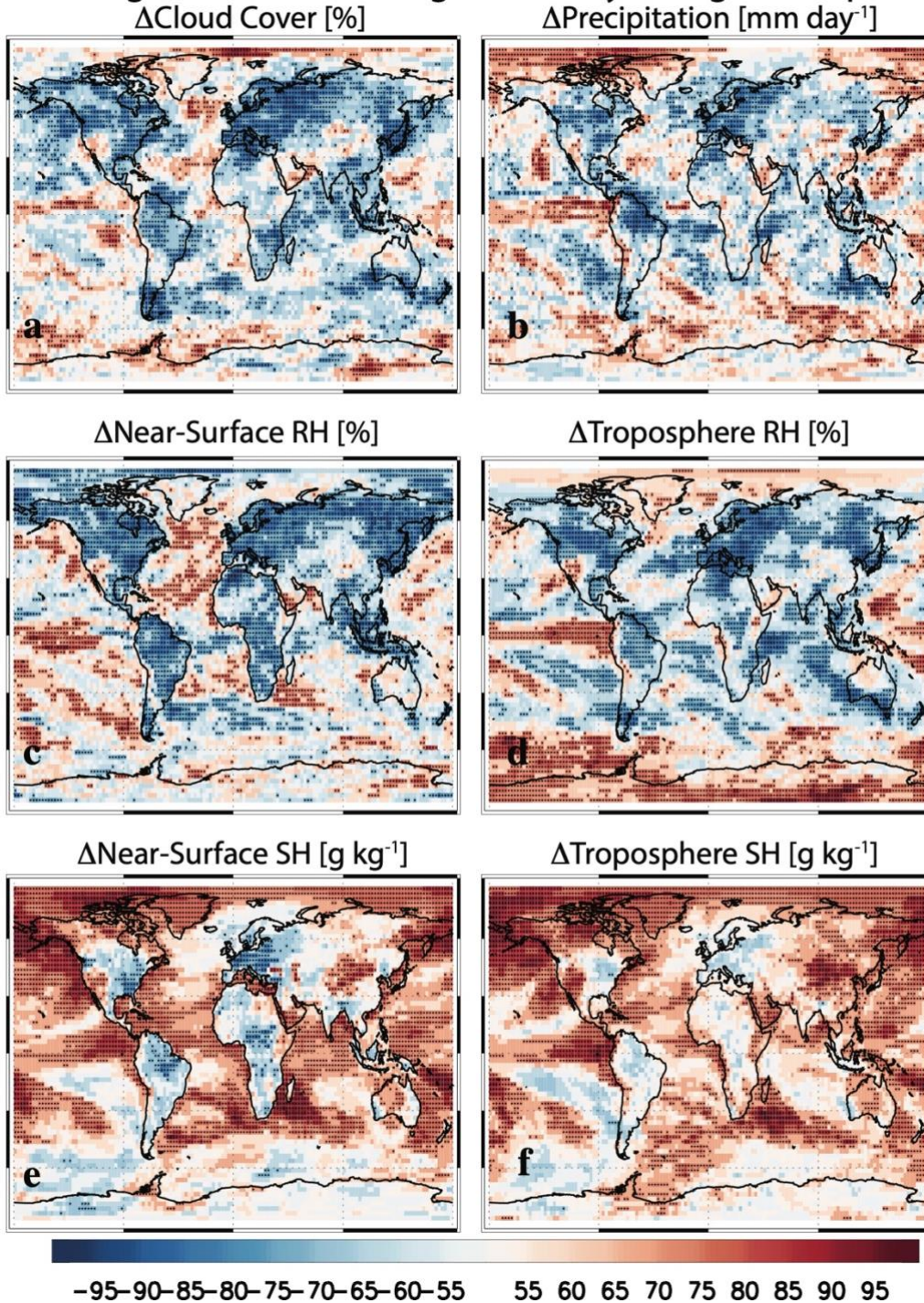


Figure S7. Model agreement on the sign of the hydrological PHYS-PI responses. Model agreement on the sign of hydrological responses [% of models] for (a) total cloud cover; (b) precipitation; (c) near-surface relative humidity; (d) tropospheric mean relative humidity; (e) near surface specific humidity; and (f) tropospheric mean specific humidity. Red (blue) colors indicate model agreement on an increase (decrease). Symbols represent significant model agreement at the 90% confidence level based on a two-tailed binomial test.

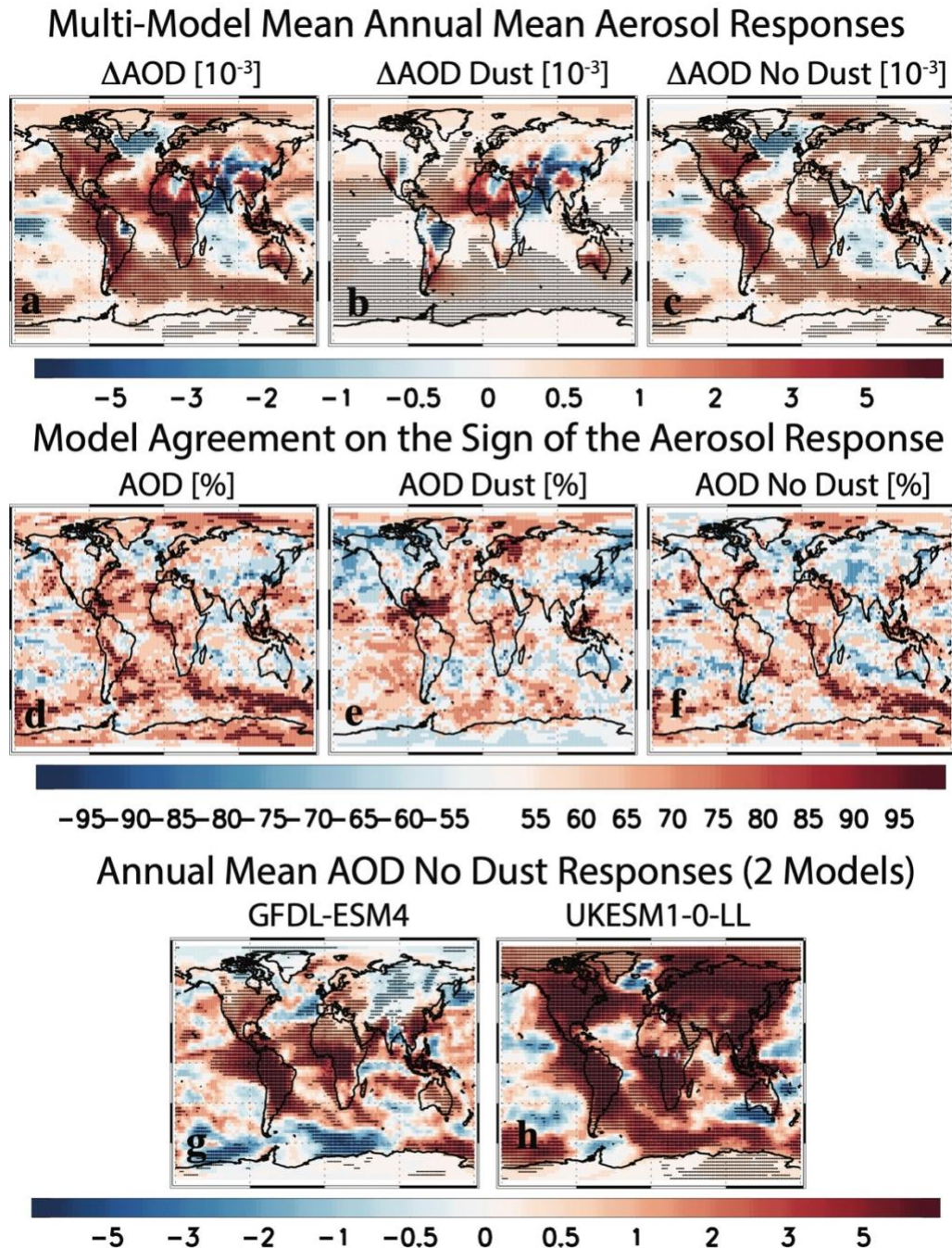
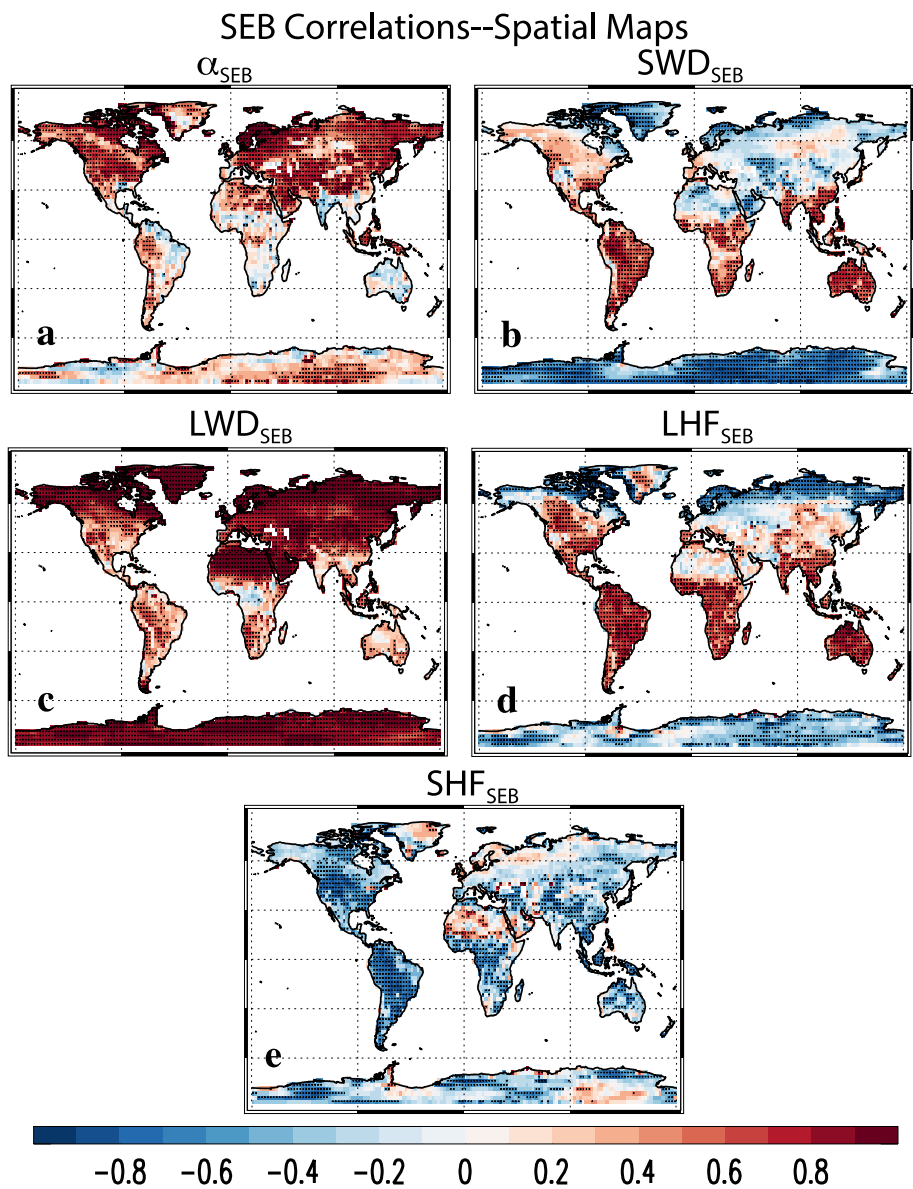


Figure S8. Aerosol optical depth PHYS-PI responses. Multimodel mean annual mean responses for (a) total aerosol optical depth [10^{-3}]; (b) dust aerosol optical depth [10^{-3}] and (c) aerosol optical depth without dust [10^{-3}]. Symbols denote a response significant at the 90% confidence level based on a two-tailed pooled t-test. Model agreement on the sign of aerosol responses [% of models] for (d) total aerosol optical depth; (e) dust optical depth and (f) aerosol optical depth without dust. Red (blue) colors indicate model agreement on an increase (decrease). Symbols represent significant model agreement at the 90% confidence level based on a two-tailed binomial test. Also included is the aerosol optical depth without dust response for two models with interactive chemistry and BVOCs including (g) GFDL-ESM4 and (h) UKESM1-0-LL.



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Figure S9. Spatial correlation maps of SEB terms across models for PHYS-PI. Correlation maps between the SEB surface temperature response and (a) surface albedo (α_{SEB}); (b) downwelling surface shortwave radiation (SWD_{SEB}); (c) downwelling surface longwave radiation (LWD_{SEB}); (d) surface latent heat flux (LHF_{SEB}); and (e) surface sensible heat flux (SHF_{SEB}). Correlations at each grid box are across the models. Symbols denote a correlation significant at the 90% confidence level based on a two-tailed t-test.

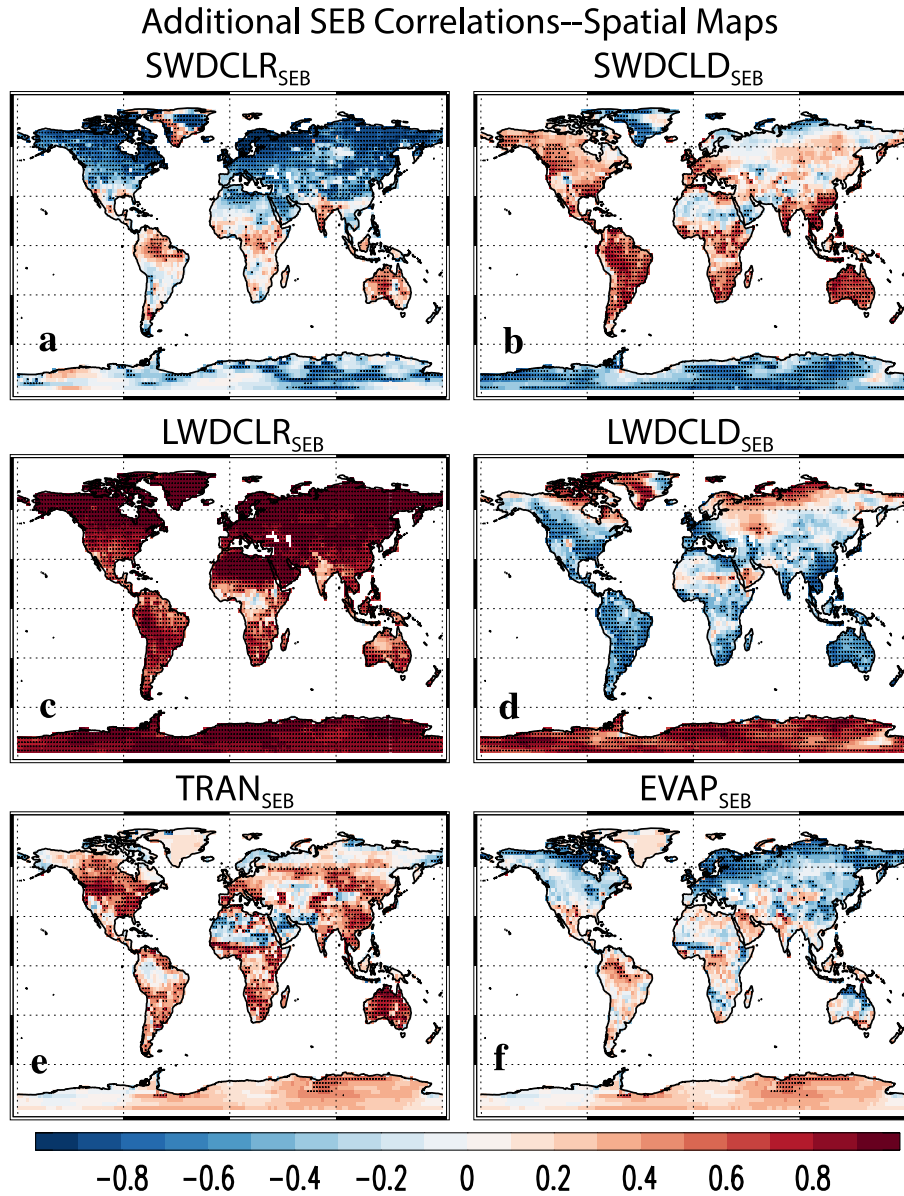


Figure S10. Spatial correlation maps of the additional SEB terms across models for PHYS-PI. Correlation maps between the SEB surface temperature response and SWD_{SEB} decomposed into (a) clear-sky ($\text{SWDCLR}_{\text{SEB}}$) and (b) cloudy-sky ($\text{SWDCLD}_{\text{SEB}}$) contributions; LWD_{SEB} decomposed into (c) clear-sky ($\text{LWDCLR}_{\text{SEB}}$) and (d) cloudy-sky ($\text{LWDCLD}_{\text{SEB}}$) contributions; and LHF_{SEB} decomposed into (e) TRAN_{SEB} and (f) EVAP_{SEB} . Correlations at each grid box are across the models. Symbols denote a correlation significant at the 90% confidence level based on a two-tailed t-test.

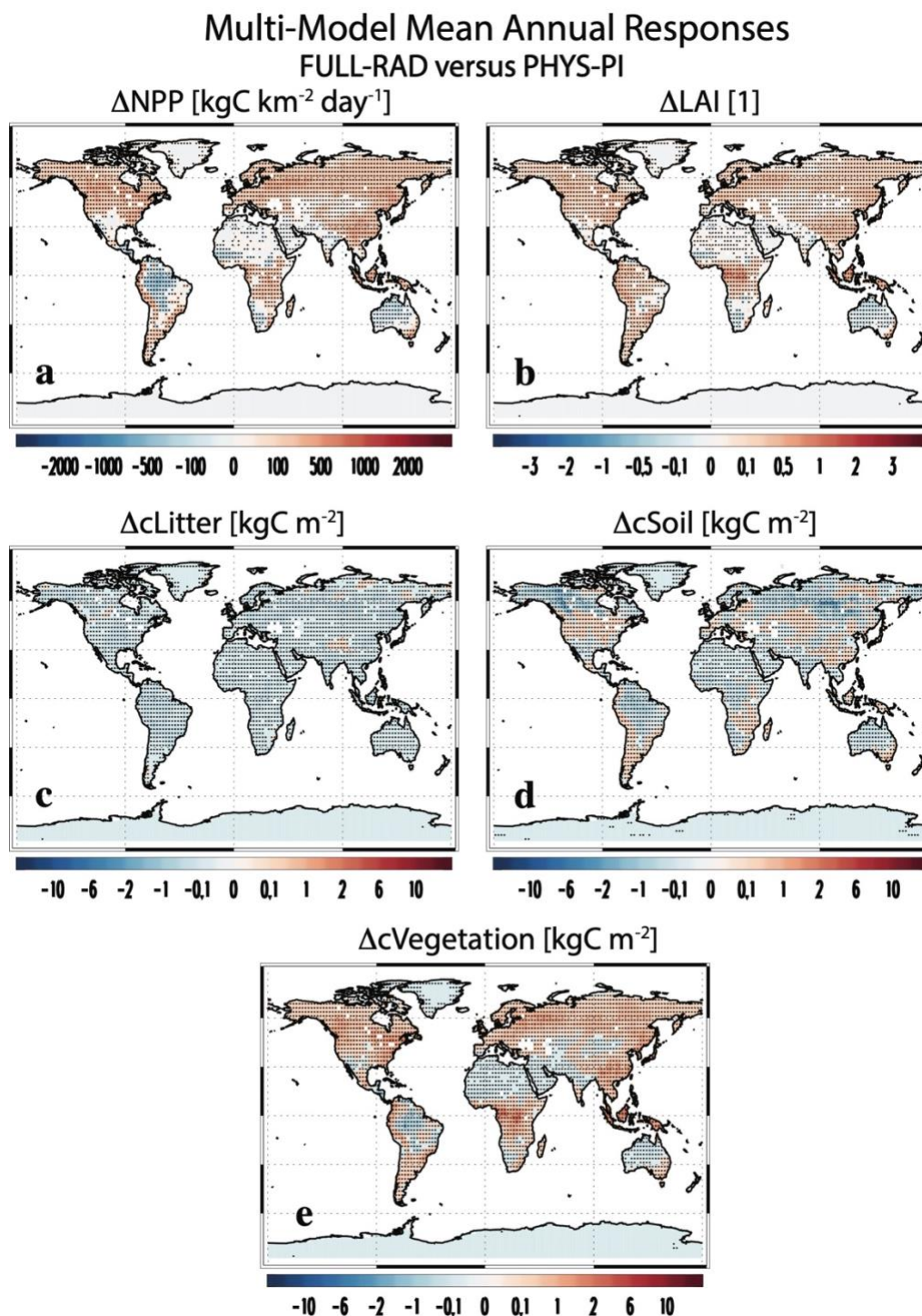


Figure S11. Vegetation and land carbon responses for (FULL-RAD) minus (PHYS-PI).

Multimodel mean annual mean responses for (a) net primary productivity (NPP; $\text{kgC km}^{-2} \text{ day}^{-1}$); (b) leaf area index (LAI; dimensionless); (c) litter pool carbon (cLitter; kgC m^{-2}); (d) soil pool carbon (cSoil; kgC m^{-2}); and (e) vegetation carbon (cVegetation; kgC m^{-2}). Symbols denote a response significant at the 90% confidence level based on a two-tailed pooled t-test.

SEB Multi-Model Mean Annual Responses [K] FULL-RAD versus PHYS-PI

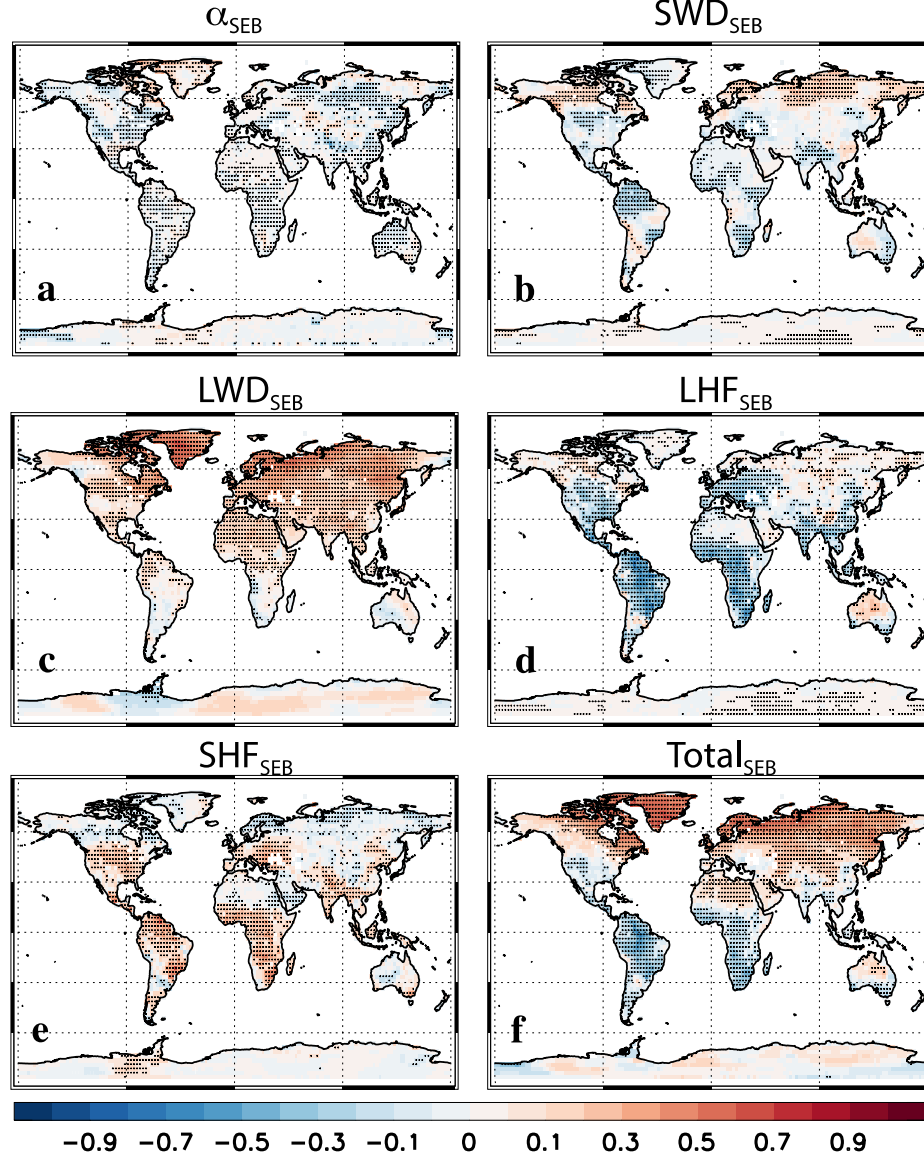


Figure S12. Surface energy balance (SEB) decomposition of the surface temperature response for (FULL-RAD) minus (PHYS-PI). Multimodel mean annual mean SEB responses for (a) surface albedo (α_{SEB}); (b) downwelling surface shortwave radiation (SWD_{SEB}); (c) downwelling surface longwave radiation (LWD_{SEB}); (d) surface latent heat flux (LHF_{SEB}); (e) surface sensible heat flux (SHF_{SEB}); and (f) the total (i.e., sum of the prior five terms; $Total_{SEB}$). Units are K. Symbols denote a response significant at the 90% confidence level based on a two-tailed pooled t-test.

Additional SEB Multi-Model Mean Annual Responses [K]
FULL-RAD versus PHYS-PI

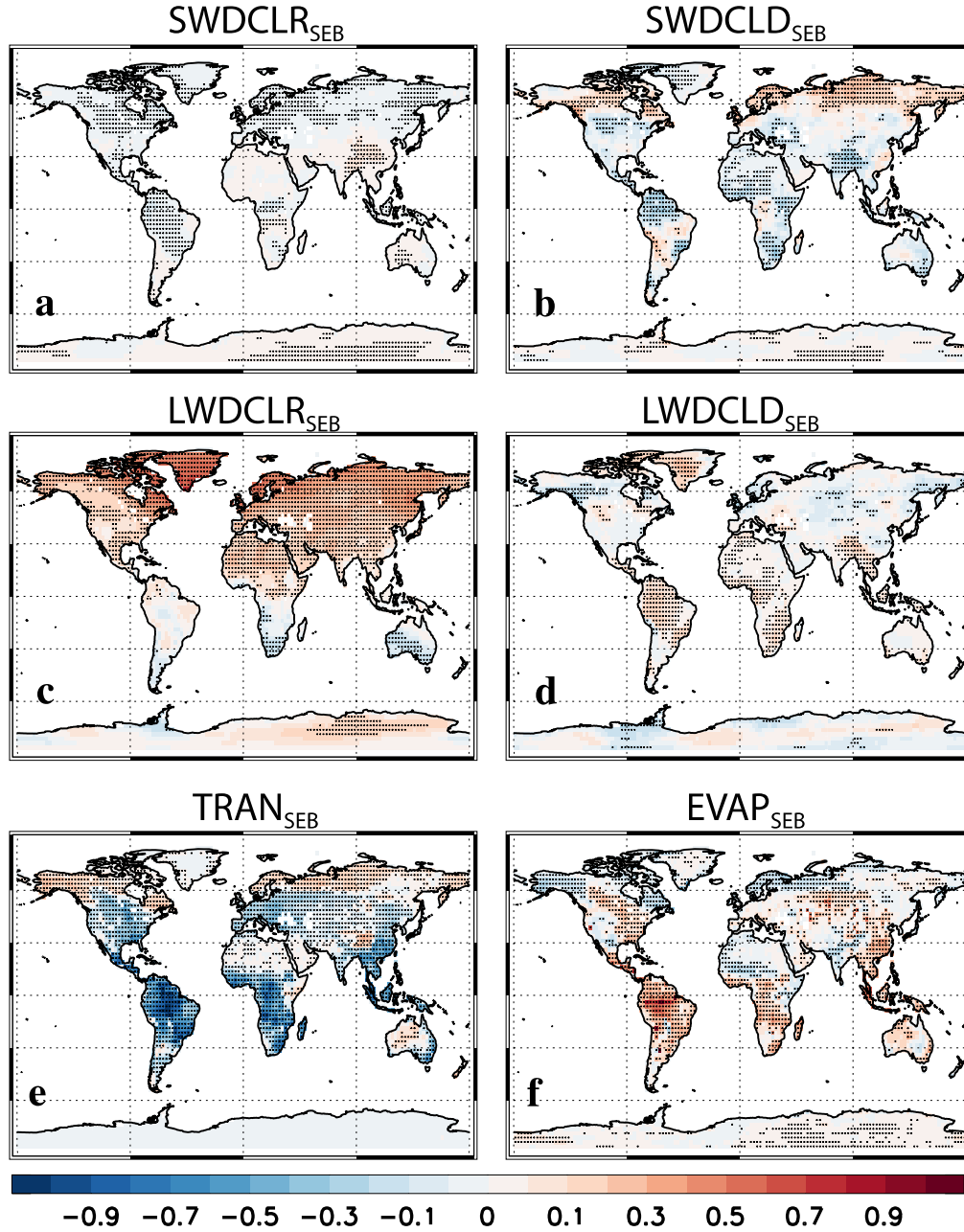
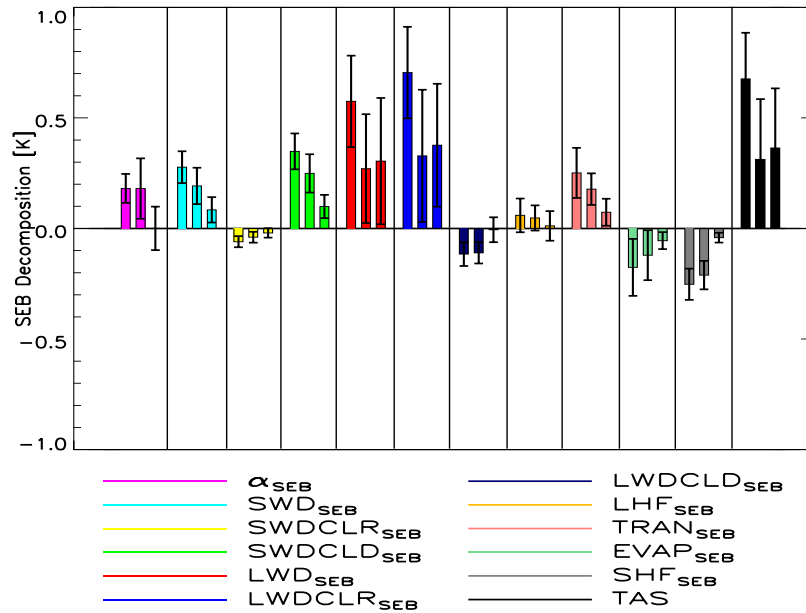


Figure S13. Additional surface energy balance (SEB) decomposition of the surface temperature response for (FULL-RAD) minus (PHYS-PI). Multimodel mean annual mean SEB responses for SWD_{SEB} decomposed into (a) clear-sky (SWDCLR_{SEB}) and (b) cloudy-sky (SWDCLD_{SEB}) contributions; LWD_{SEB} decomposed into (c) clear-sky (LWDCLR_{SEB}) and (d) cloudy-sky (LWDCLD_{SEB}) contributions; and LHF_{SEB} decomposed into (e) TRAN_{SEB} and (f) EVAP_{SEB}. Units are K. Symbols denote a response significant at the 90% confidence level based on a two-tailed pooled t-test.

SEB Decomposition FULL-RAD versus PHYS-PI NH High-Lats (>60N)



1st bar in each like colored set of 3 bars = FULL-RAD
 2nd bar in each like colored set of 3 bars = PHYS-PI
 3rd bar in each like colored set of 3 bars = (FULL-RAD)-(PHYS-PI)

Figure S14. Surface energy balance (SEB) decomposition of the surface temperature response for the NH high-latitudes (poleward of 60N). SEB terms include α_{SEB} (purple); SWD_{SEB} (cyan) and its clear-sky ($SWDCLR_{SEB}$; yellow) and cloudy-sky ($SWDCLD_{SEB}$; bright green) contributions; LWD_{SEB} (red) and its clear-sky ($LWDCLR_{SEB}$; blue) and cloudy-sky ($LWDCLD_{SEB}$; navy) contributions; LHF_{SEB} (orange) and its transpiration ($TRAN_{SEB}$; pink) and evaporation ($EVAP_{SEB}$; darker green) components; SHF_{SEB} (gray); and near-surface air temperature (TAS ; black). Responses are shown for FULL-RAD (1st bar in each like colored set of 3 bars) and PHYS-PI (2nd bar in each like colored set of 3 bars). (FULL-RAD) minus (PHYS-PI) is shown as the 3rd bar in each like colored set of 3 bars. Error bars show the 90% confidence level based on individual model responses. Units are K.

Biogeophysical Δ TAS due to Carbon Fertilization vs. TCR FULL-RAD

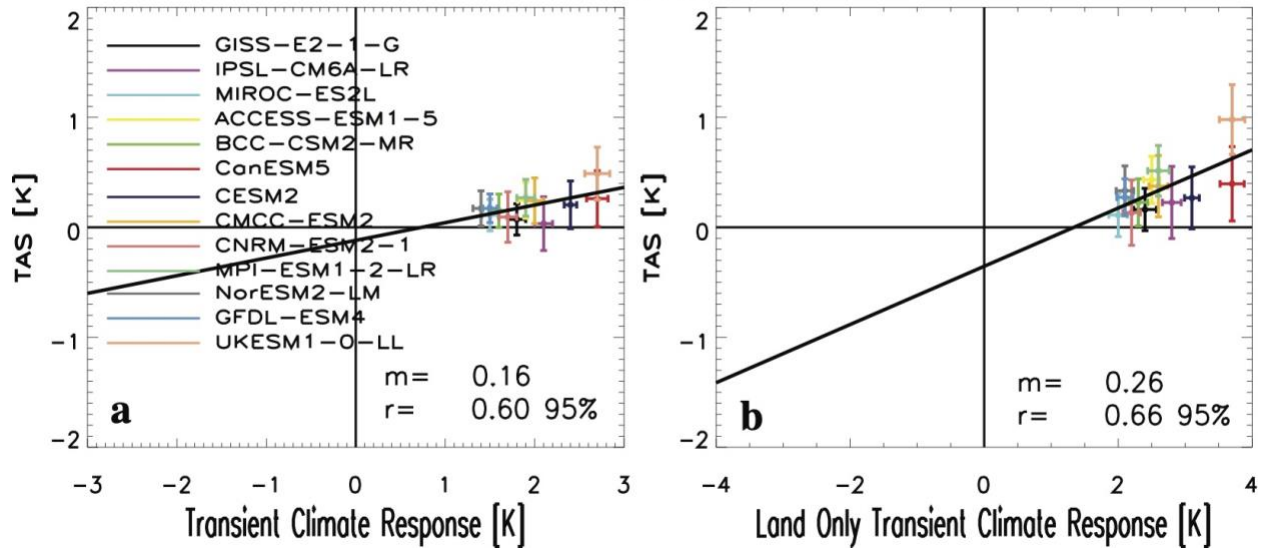


Figure S15. Scatterplots of the global mean near-surface temperature response versus the transient climate response across models. Scatterplots between the (a) global mean near-surface air temperature response (TAS, Y-axis) and the transient climate response (TCR) for FULL-RAD. Panel b is analogous but for land only. Each symbol represents an individual model (see legend). Error bars for each symbol represent the 90% confidence intervals based on a two-tailed pooled t-test. Black line represents the least squares linear regression line. The corresponding slope (m) of the regression and the correlation coefficient (r) are included. Significant correlations based on a two-tailed test at the 95% and 99% confidence level are indicated. Units are K.