



Supplement of

Biome classification across global vegetation models reveals consistent biome shifts under future climate change

Simon Scheiter et al.

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SUPPLEMENTARY MATERIALS

S1: GVMs and PFT products

PFTs, references and responsible persons for different GVMs and PFT products used in this study. For the biome classification, we only included PFTs representing natural vegetation while bare ground and managed land were excluded. The following provides includes and excluded PFTs per GVM and PFT product.

ORCHIDEE-DGVM

included: tropical broad-leaved evergreen (trbrev); tropical broad-leaved raingreen (trbrrg); temperate needleleaf evergreen (tendev); temperate broad-leaved evergreen (tebrev); temperate broad-leaved summergreen (tebrsu); boreal needleleaf evergreen (bondev); boreal broad-leaved summergreen (bobrsu); boreal needleleaf summergreen (bondsu); C3 natural grass (c3gra); C4 natural grass (c4gra)

excluded: bare soil (bare); C3 winter crop (c3win); C3 summer crop (c3sum); C4 maize (c4mai); C4 other crops (c4oth); C3 pasture (c3pas); C4 pasture (c4pas)

Main reference: Guimberteau *et al.* (2018)

Responsible persons:

Jinfeng Chang: changjf@zju.edu.cn, Zhejiang University (China)

Philippe Ciais: Philippe.ciais@lsce.ipsl.fr, IPSL (Institute Pierre Simon Laplace) (France)

ORCHIDEE

included: tropical broad-leaved evergreen (trbrev); tropical broad-leaved raingreen (trbrrg); temperate needleleaf evergreen (tendev); temperate broad-leaved evergreen (tebrev); temperate broad-leaved summergreen (tebrsu); boreal needleleaf evergreen (bondev); boreal broad-leaved summergreen (bobrsu); boreal needleleaf summergreen (bondsu); C3 natural grass (c3gra); C4 natural grass (c4gra)

excluded: bare soil (bare); C3 winter crop (c3win); C3 summer crop (c3sum); C4 maize (c4mai); C4 other crops (c4oth); C3 pasture (c3pas); C4 pasture (c4pas)

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Jinfeng Chang: changjf@zju.edu.cn, Zhejiang University (China)

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LPJ-GUESS

included: Boreal needleleaved evergreen (BNE); Boreal shade intolerant needleleaved evergreen (BINE); Boreal needleleaved summergreen (BNS); Temperate broadleaved summergreen

(TeBS); shade intolerant broadleaved summergreen (IBS); Temperate broadleaved evergreen (TeBE); Tropical broadleaved evergreen (TrBE); Tropical shade intolerant broadleaved evergreen (TriBE); Tropical broadleaved raingreen (TrBR); C3 grass (C3G); C4 grass (C4G);

excluded: none

Main reference: Smith *et al.* (2014)

Responsible persons:

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Jörg Steinkamp: joerg.steinkamp@uni-mainz.de, Senckenberg Biodiversity and Climate Research Centre (BiK-F); now at: Data Center, Johannes Gutenberg-University Mainz (Germany)

CLM 4.5

included: needleleaf-evergreen-tree-temperate; needleleaf-evergreen-tree-boreal; needleleaf-deciduous-tree-boreal; broadleaf-evergreen-tree-tropical; broadleaf-evergreen-tree-temperate; broadleaf-deciduous-tree-tropical; broadleaf-deciduous-tree-temperate; broadleaf-deciduous-tree-boreal; broadleaf-evergreen-shrub-temperate; broadleaf-deciduous-shrub-temperate; broadleaf-deciduous-shrub-boreal; c3-arctic-grass; c3-non-arctic-grass; c4-grass

excluded: c3-crop-rainfed; c3-crop-irrigated; corn-rainfed; corn-irrigated; spring-cereal-temperate-rainfed; spring-cereal-temperate-irrigated; winter-cereal-temperate-rainfed; winter-cereal-temperate-irrigated; soybean-rainfed; soybean-irrigated

Main reference: Thiery *et al.* (2017)

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CARAIB

included: C3 herbs (humid) (c3hh); C3 herbs (dry) (c3dh); C4 herbs (c4h); Broadleaved summergreen arctic shrubs (brsuas); Broadleaved summergreen boreal or temperate cold shrubs (brsutecds); Broadleaved summergreen temperate warm shrubs (brsutewms); Broadleaved evergreen boreal or temperate cold shrubs (brevtecds); Broadleaved evergreen temperate warm shrubs (brevtewms); Broadleaved evergreen xeric shrubs (brevxs); Subdesertic shrubs (sds); Tropical shrubs (trs); Needleleaved evergreen boreal or temperate cold trees (ndevtecdt); Needleleaved evergreen temperate cool trees (ndevteclt); Needleleaved evergreen trees, drought-tolerant (ndevtedtt); Needleleaved evergreen trees, drought-tolerant, thermophilous (ndevtedttht); Needleleaved evergreen subtropical trees, drought-intolerant (nde-

vstdit); Needleleaved summergreen boreal or temperate cold trees (ndsutecdt); Needleleaved summergreen subtropical swamp trees (ndsustswt); Broadleaved evergreen trees, drought tolerant (brevdtt); Broadleaved evergreen trees, drought-tolerant, thermophilous (brevdttht); Broadleaved evergreen subtropical trees, drought-intolerant (brevstdit); Broadleaved summergreen boreal or temperate cold trees (brsuteclt); Broadleaved summergreen temperate cool trees (brsuteclt); Broadleaved summergreen temperate warm trees (brsutewmt); Broadleaved raingreen tropical trees (brrgrtrt); Broadleaved evergreen tropical trees (brevtrt);

excluded: Maize-temperate (maizetec); Maize-tropical (maizetrc); Oil crops-groundnuts oil (groundnutc) Oil crops-rapeseed (oilrapeseedc); Soybeans (soybeanc); Sunflower (sunflowerc); Other crops-temperate (othertec); Other crops-tropical (othertrc); Pulses-temperate (puls-estec); Pulses-tropical (pulsestrc) Rice (ricec); Sugarcane (sugarcane); Temperate cereals (cerealtec); Temperate roots (roottec); Tropical cereals (cerealtrc) Tropical roots roottrc C3 herbs - Pastures c3p C4 herbs - Pastures c4p

Main references: Dury *et al.* (2011); Minet *et al.* (2015); Warnant *et al.* (1994)

Responsible persons:

Louis Francois, louis.francois@uliege.be, Université de Liège (Belgium)

Alexandra Henrot: alexandra.henrot@ulg.ac.be, Université de Liège (Belgium)

ESACCI, Harper et al. (2023)

included: broad- leaved evergreen trees; broad-leaved deciduous trees; needle-leaved evergreen trees; needle-leaved deciduous trees; broad- leaved evergreen shrubs; broad-leaved deciduous shrubs; needle-leaved evergreen shrubs; needle-leaved deciduous shrubs; natural grasses

excluded: managed grasses; built-up areas; permanent inland-water bodies; bare soil; permanent snow-and-ice cover

Main reference: Harper *et al.* (2023)

Responsible persons:

Tuanmu and Jetz (2014)

included: Evergreen/deciduous needleleaf trees; Evergreen broadleaf trees; Deciduous broadleaf trees; Mixed/other trees; Shrubs; Herbaceous vegetation; Regularly flooded vegetation

excluded: Cultivated and managed vegetation; Urban/built-up; Snow/ice; Barren; Open water

Main reference: Tuanmu & Jetz (2014)

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S2: Supplementary tables and figures

Table S1: Models and scenarios included in the analysis.

RCP	Model	Climate model	Bias correction	Land use	CO ₂
RCP2.6	LPJ-GUESS	IPSL-CM5A-LR	EWEMBI	2005soc	co2
RCP2.6	ORCHIDEE	IPSL-CM5A-LR	EWEMBI	2005soc	co2
RCP2.6	ORCHIDEE-DGVM	IPSL-CM5A-LR	EWEMBI	2005soc	co2
RCP2.6	CARAIB	IPSL-CM5A-LR	EWEMBI	2005soc	co2
RCP2.6	CLM	HADGEM2-ES	EWEMBI	2005soc	co2
RCP6.0	LPJ-GUESS	IPSL-CM5A-LR	EWEMBI	2005soc	co2
RCP6.0	ORCHIDEE	IPSL-CM5A-LR	EWEMBI	2005soc	co2
RCP6.0	ORCHIDEE-DGVM	IPSL-CM5A-LR	EWEMBI	2005soc	co2
RCP6.0	CARAIB	IPSL-CM5A-LR	EWEMBI	2005soc	co2
RCP6.0	CLM	IPSL-CM5A-LR	EWEMBI	2005soc	co2
RCP8.5	LPJ-GUESS	IPSL-CM5A-LR	EWEMBI	2005soc	co2
RCP8.5	ORCHIDEE	IPSL-CM5A-LR	EWEMBI	2005soc	co2
RCP8.5	CLM	HADGEM2-ES	EWEMBI	2005soc	co2

Table S2: Examples of temperature-sensitive processes in the ISIMIP2b GVMs. The table highlights selected processes only; exact implementations are model- and version-specific.

Model	Temperature-sensitive processes
LPJ-GUESS	Temperature influences photosynthesis, respiration, and phenology. Photosynthetic and respiratory rates are temperature dependent, and the seasonal phenology of several plant functional types is controlled by temperature and the accumulation of a temperature-driven heat sum.
ORCHIDEE, ORCHIDEE-DGVM	Temperature affects photosynthesis, respiration, and phenology. Depending on the simulation round and sector, the ISIMIP2b ORCHIDEE/ORCHIDEE-DGVM configuration represents natural vegetation cover either as prescribed or as dynamically simulated; in both cases, temperature acts on physiological and phenological processes, and where dynamic vegetation is active, also on vegetation development.
CLM4.5	Temperature regulates photosynthesis, plant respiration, soil decomposition, and phenology. The ISIMIP2b simulations use CLM4.5 with an interactive carbon and nitrogen cycle (CN), and temperature affects both physiological rates and biogeochemical turnover processes.
CARAIB	Temperature affects canopy carbon assimilation, respiration, and phenology. Leaf onset and leaf fall are triggered by PFT-specific temperature thresholds, and the model uses temperature-dependent physiological responses more generally.

Table S3: Examples of bioclimatic limits used in the ISIMIP2b GVMs. The table summarizes only the principal climatic filters constraining vegetation establishment and persistence. Exact thresholds are model- and version-specific.

Model	Bioclimatic limits	Notes
LPJ-GUESS	Cold limits and growing-degree-day constraints for woody plant functional types.	PFT-specific climatic envelopes constrain establishment and survival of woody PFTs.
ORCHIDEE, ORCHIDEE-DGVM	Depends on simulation round and sector: none where natural vegetation cover is prescribed; climatic thresholds for establishment and persistence where vegetation is dynamic.	The ISIMIP2b ORCHIDEE/ORCHIDEE-DGVM configuration is not uniform across sectors/rounds; dynamic vegetation configuration based on an LPJ-type establishment/mortality scheme.
CLM4.5	None in the ISIMIP2b configuration.	CLM4.5 prescribes land cover from maps in ISIMIP2b.
CARAIB	Climatic and drought-related constraints on PFT survival.	CARAIB is a dynamic vegetation model (establishment, growth, decrease); cold temperature and drought act as mortality causes for PFTs.

Table S4: Strength of bioclimatic constraints for defining biome distributions. ‘T-limit’ denotes if biome boundaries are mainly constrained and defined by temperature or by other factors. In our analyses, biomes classified as ‘Partially’ were considered as ‘No’ (i.e., temperature is not the main constraint of the biome boundary).

Olson biome	T-limit	Notes	References
TrMBF	Yes	Require high, stable temperatures year-round (typically $>18^{\circ}\text{C}$); temperature minima critical.	Olson <i>et al.</i> (2001); Mucina (2019)
TrGS	Partially	Temperature important, but fire regimes and precipitation seasonality also critical.	Olson <i>et al.</i> (2001)
TrDBF	Partially	Temperature important but distribution also strongly shaped by dry season precipitation.	Olson <i>et al.</i> (2001)
TrCF	Partially	Temperature important, particularly seasonal cold limits, but precipitation also key.	Olson <i>et al.</i> (2001)
FIGS	No	Limits mainly controlled by hydrology and flooding patterns rather than temperature.	Olson <i>et al.</i> (2001)
DeXS	Partially	Temperature extremes matter (hot or cold deserts), but severe moisture limitation dominates.	Olson <i>et al.</i> (2001); Mucina (2019)
MoGS	Yes	Temperature drops with altitude define upper tree lines and biome limits.	Olson <i>et al.</i> (2001)
MeFWS	Partially	Temperature influences drought stress, but summer dry period and soils also critical.	Olson <i>et al.</i> (2001)
TeBMF	Yes	Temperature (cold winters) strongly limits range; growing season length is temperature-dependent.	Olson <i>et al.</i> (2001); Conradi <i>et al.</i> (2020)
TeCF	Yes	Strongly constrained by winter cold extremes and growing season length.	Olson <i>et al.</i> (2001)
TeGS	Yes	Temperature extremes (cold winters, warm summers) strongly influence distribution.	Olson <i>et al.</i> (2001)
BoFT	Yes	Long cold winters and short summers sharply define limits; temperature is primary driver.	Olson <i>et al.</i> (2001); Mucina (2019)
Tun	Yes	Primarily defined by extreme low temperatures, permafrost, and short growing season.	Olson <i>et al.</i> (2001); Mucina (2019); Conradi <i>et al.</i> (2020)

Table S5: Linear regression models between the number of biome types in the F31 biome maps and κ .

Model	Slope	R2	p value
CARAIB	0.00051929	0.02162	0.42993
CLM	-0.00137083	0.03119	0.34187
LPJ-GUESS	-0.00112037	0.01595	0.49839
ORCHIDEE	-0.00054955	0.00513	0.70184
ORCHIDEE-DGVM	0.00018983	0.00066	0.89071
ESACCI	-0.00096713	0.11253	0.06506
Touanmu	-0.00048656	0.14269	0.03617

Table S6: Linear regression models between the proportion of the land surface affected by biome shifts under climate change and κ .

Model	Slope	R2	p value
CARAIB	-0.21327034	0.3529	0.00043
CLM	-1.84027664	0.67317	0
LPJ-GUESS	-0.62708825	0.24688	0.00446
ORCHIDEE	-0.72792962	0.36964	0.00029
ORCHIDEE-DGVM	-0.54408676	0.4039	0.00012

Table S7: Linear regression models between the proportion of the land surface affected by biome shifts under climate change and the number of biomes in F31 biome map.

Model	Slope	R2	p value
CARAIB	0.00051929	0.02162	0.42993
CLM	-0.00137083	0.03119	0.34187
LPJ-GUESS	-0.00112037	0.01595	0.49839
ORCHIDEE	-0.00054955	0.00513	0.70184
ORCHIDEE-DGVM	0.00018983	0.00066	0.89071

Table S8: Linear regression to explain biome shifts. The response variable was the probability of biome change across all models, predictors were the selected F31 biome map, the GVM, the RCP scenario and the number of biomes in the respective biome map.

Variable	t value	Sig. code
(Intercept)	3.42e-07	***
Map	0.0479	*
GVM	0.0101	*
RCP	9.28e-05	***
NumBiomes	0.0169	*

Table S9: Model performance metrics for the Random Forest regressions. R^2 represents the out-of-bag variance explained, and RMSE denotes the Root Mean Square Error (%).

Model	R^2	RMSE
RCP 2.6	0.752	2.53
RCP 6.0	0.784	2.87
RCP 8.5	0.733	3.24
Joint	0.764	3.63

Table S10: Model performance metrics and primary interaction coefficients.

Model	R^2	RMSE (%)	Interaction Term	Estimate
Joint	0.764	3.63	d_t (Cold Baseline)	1.186
RCP 2.6	0.752	2.53	$d_t : Warm$	-0.633
RCP 8.5	0.733	3.24	$d_t : Temperate$	-0.110

Table S11: Abbreviations of Olson *et al.* (2001) biomes.

Biome	Biome full name
TrMBF	Tropical and subtropical moist broadleaf forest
TrGS	Tropical and subtropical grassland savanna and shrubland
TrDBF	Tropical and subtropical dry broadleaf forest
TrCF	Tropical and subtropical coniferous forest
FIGS	Flooded grassland and savanna
DeXS	Deserts and xeric shrubland
MoGS	Montane grassland and shrubland
MeFWS	Mediterranean forest woodland and scrub
TeBMF	Temperate broadleaf and mixed forest
TeCF	Temperate conifer forest
TeGS	Temperate grassland savanna and shrubland
BoFT	Boreal forest/taiga
Tun	Tundra

Table S12: Confusion matrix LPJ-GUESS vs Olson *et al.* (2001) biome map. Overall $\kappa = 0.73$.
See Table S11 for full biome names.

Biome	κ	1	2	3	4	5	6	7	8	9	10	11	12	13
1 TrMBF	0.79	82.8	12.8	0.0	0.0	0.0	0.6	0.1	0.0	3.8	0.0	0.0	0.0	0.0
3 TrGS	0.70	8.7	85.5	0.0	0.0	0.0	5.7	0.0	0.1	0.0	0.0	0.0	0.0	0.0
4 TrDBF	0.20	17.8	68.2	11.2	0.0	0.0	2.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0
5 TrCF	0.12	23.0	51.2	0.0	6.2	0.0	12.1	0.0	2.0	3.9	0.0	1.6	0.0	0.0
6 FlGS	0.10	7.1	55.8	0.0	0.0	5.3	12.1	0.0	0.0	11.4	0.0	6.6	0.8	1.0
7 DeXS	0.78	0.1	8.1	0.0	0.0	0.0	87.2	0.1	0.0	0.2	0.1	1.6	0.1	2.6
8 MoGS	0.42	3.7	5.6	0.0	0.0	0.0	22.0	28.2	0.2	1.8	0.9	4.0	4.1	29.5
9 MeFWS	0.26	4.4	10.1	0.0	0.0	0.0	49.3	0.2	16.2	16.3	0.4	3.1	0.0	0.0
10 TeBMF	0.78	2.5	0.6	0.0	0.0	0.0	3.4	0.0	0.2	82.3	0.2	4.6	6.3	0.1
11 TeCF	0.47	6.5	0.3	0.0	0.0	0.0	6.2	0.6	0.2	18.1	32.8	2.3	27.8	5.3
12 TeGS	0.76	1.0	2.2	0.0	0.0	0.0	13.2	0.0	0.3	6.7	0.2	71.9	3.6	0.9
13 BoFT	0.81	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.0	1.4	0.0	0.1	89.5	8.8
14 Tun	0.75	0.0	0.0	0.0	0.0	0.0	1.5	0.5	0.0	0.0	0.3	0.0	15.3	82.3

Table S13: Confusion matrix ORCHIDEE vs Olson *et al.* (2001) biome map. Overall $\kappa = 0.87$.
See Table S11 for full biome names.

Biome	κ	1	2	3	4	5	6	7	8	9	10	11	12	13
1 TrMBF	0.91	94.8	3.8	0.2	0.0	0.0	0.1	0.1	0.0	0.6	0.1	0.4	0.0	0.0
3 TrGS	0.86	4.5	90.1	0.0	0.0	0.0	4.0	0.0	0.0	0.4	0.1	0.9	0.0	0.0
4 TrDBF	0.69	23.7	17.5	56.0	0.0	0.0	1.0	0.1	0.0	1.3	0.0	0.5	0.0	0.0
5 TrCF	0.70	10.6	7.1	8.2	54.5	0.0	10.2	0.0	1.2	6.7	1.2	0.4	0.0	0.0
6 FlGS	0.40	10.1	30.7	0.5	0.0	25.6	16.6	0.0	0.5	8.5	0.8	6.8	0.0	0.0
7 DeXS	0.90	0.3	3.3	0.1	0.0	0.0	93.9	0.1	0.2	0.2	0.6	1.2	0.0	0.0
8 MoGS	0.78	2.6	3.0	0.1	0.0	0.1	14.4	65.7	0.2	3.1	2.5	6.4	1.0	1.2
9 MeFWS	0.82	0.2	0.9	0.0	0.0	0.0	7.6	0.1	73.3	10.5	1.1	6.2	0.0	0.0
10 TeBMF	0.89	1.4	0.1	0.0	0.0	0.1	0.9	0.0	0.2	90.8	0.8	1.8	3.8	0.1
11 TeCF	0.77	0.2	0.0	0.0	0.0	0.0	3.7	0.9	0.3	5.5	70.6	2.2	15.6	1.0
12 TeGS	0.86	0.0	2.0	0.0	0.0	0.0	2.2	0.0	0.2	3.6	0.7	87.7	3.4	0.2
13 BoFT	0.89	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.1	97.0	2.5
14 Tun	0.90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	12.4	87.5

Table S14: Confusion matrix ORCHIDEE-DGVM vs Olson *et al.* (2001) biome map. Overall $\kappa = 0.89$. See Table S11 for full biome names.

Biome	κ	1	2	3	4	5	6	7	8	9	10	11	12	13
1 TrMBF	0.87	93.1	6.2	0.3	0.0	0.0	0.1	0.1	0.0	0.1	0.1	0.0	0.0	0.0
3 TrGS	0.80	8.5	89.2	0.0	0.0	0.0	2.2	0.0	0.0	0.0	0.0	0.1	0.0	0.0
4 TrDBF	0.44	36.2	33.5	29.7	0.3	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 TrCF	0.62	16.4	21.5	3.1	47.3	0.0	9.8	0.0	0.4	0.4	1.2	0.0	0.0	0.0
6 FlGS	0.44	11.8	44.1	0.0	0.0	29.8	10.0	0.0	0.0	2.3	0.0	2.0	0.0	0.0
7 DeXS	0.91	0.3	6.5	0.1	0.1	0.0	91.7	0.1	0.1	0.1	0.7	0.2	0.0	0.3
8 MoGS	0.73	2.4	4.7	0.2	0.1	0.0	11.0	62.7	0.2	1.2	3.4	2.5	0.2	11.6
9 MeFWS	0.94	0.0	0.0	0.0	0.0	0.1	5.4	0.0	91.2	2.0	0.9	0.3	0.0	0.0
10 TeBMF	0.95	0.3	0.1	0.0	0.1	0.3	0.6	0.0	0.2	95.3	1.4	0.6	0.5	0.6
11 TeCF	0.89	0.2	0.0	0.0	0.0	0.0	0.9	1.3	0.3	1.1	95.9	0.0	0.1	0.3
12 TeGS	0.94	0.0	0.3	0.0	0.0	0.0	2.0	0.0	0.2	2.1	1.5	93.2	0.5	0.1
13 BoFT	0.95	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.5	0.3	0.5	93.0	5.1
14 Tun	0.93	0.0	0.0	0.0	0.0	0.0	0.2	0.9	0.0	0.0	0.1	0.0	0.1	98.7

Table S15: Confusion matrix CLM vs Olson *et al.* (2001) biome map. Overall $\kappa = 0.69$. See Table S11 for full biome names.

Biome	κ	1	2	3	4	5	6	7	8	9	10	11	12	13
1 TrMBF	0.83	85.0	10.8	0.0	0.0	0.0	0.4	0.0	0.0	2.6	0.1	0.5	0.0	0.5
3 TrGS	0.59	6.3	68.6	0.0	0.0	0.0	18.6	0.0	0.1	0.1	0.0	1.6	0.0	4.7
4 TrDBF	0.03	34.1	60.5	1.7	0.0	0.0	2.3	0.1	0.0	0.0	0.0	1.0	0.0	0.4
5 TrCF	0.38	17.2	33.2	0.0	23.8	0.0	6.2	0.0	6.6	3.1	0.4	9.4	0.0	0.0
6 FlGS	0.27	4.3	47.0	0.0	0.0	15.4	11.1	0.0	0.0	7.3	0.0	9.2	0.0	5.7
7 DeXS	0.54	0.2	11.4	0.0	0.0	0.0	54.4	0.5	0.2	0.1	0.1	4.2	1.2	27.7
8 MoGS	0.67	1.6	7.2	0.0	0.0	0.0	9.6	54.1	1.3	0.5	0.1	8.9	6.3	10.5
9 MeFWS	0.63	0.1	4.5	0.0	0.0	0.0	16.6	0.5	50.9	5.2	0.0	18.0	0.1	4.1
10 TeBMF	0.85	0.6	0.8	0.0	0.0	0.0	0.9	0.1	0.5	86.5	0.1	5.4	4.1	0.9
11 TeCF	0.63	0.6	0.6	0.0	0.0	0.0	1.9	1.3	0.5	9.4	47.7	2.9	32.5	2.6
12 TeGS	0.74	0.0	4.4	0.0	0.0	0.0	6.4	1.0	0.5	3.8	0.3	78.5	3.2	2.0
13 BoFT	0.79	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.9	0.1	0.1	85.5	13.2
14 Tun	0.64	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	12.4	87.3

Table S16: Confusion matrix CARAIB vs Olson *et al.* (2001) biome map. Overall $\kappa = 0.96$.
See Table S11 for full biome names.

Biome	κ	1	2	3	4	5	6	7	8	9	10	11	12	13
1 TrMBF	0.99	99.6	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3 TrGS	0.98	1.4	98.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 TrDBF	0.96	3.5	3.6	92.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 TrCF	0.98	3.5	0.4	0.0	96.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 FlGS	0.96	0.5	6.9	0.0	0.0	92.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7 DeXS	1.00	0.0	0.3	0.0	0.0	0.0	99.4	0.2	0.0	0.0	0.0	0.0	0.0	0.1
8 MoGS	0.90	0.0	0.0	0.0	0.0	0.0	0.0	86.1	0.0	0.0	0.0	0.0	1.6	12.3
9 MeFWS	1.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0
10 TeBMF	1.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	99.8	0.0	0.0	0.1	0.0
11 TeCF	0.95	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0	0.0	90.2	0.0	5.9	2.6
12 TeGS	0.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	99.1	0.7	0.1
13 BoFT	0.92	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	92.4	7.6
14 Tun	0.88	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	5.6	93.9

Table S17: Confusion matrix ESACCI vs Olson *et al.* (2001) biome map. Overall $\kappa = 0.94$.
See Table S11 for full biome names.

Biome	κ	1	2	3	4	5	6	7	8	9	10	11	12	13
1 TrMBF	0.99	98.1	1.5	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3 TrGS	0.88	0.2	88.7	0.0	0.0	0.0	10.7	0.0	0.0	0.0	0.0	0.0	0.0	0.3
4 TrDBF	0.96	2.1	4.0	92.1	0.0	0.0	1.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0
5 TrCF	0.99	2.0	0.0	0.0	98.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 FlGS	0.77	0.0	26.9	0.0	0.0	63.1	9.8	0.0	0.0	0.0	0.0	0.0	0.0	0.3
7 DeXS	0.87	0.0	1.4	0.0	0.0	0.0	94.0	0.1	0.0	0.0	0.0	0.2	0.0	4.2
8 MoGS	0.93	0.1	4.3	0.0	0.0	0.0	5.2	89.1	0.1	0.0	0.0	0.2	0.0	1.2
9 MeFWS	0.90	0.0	5.4	0.0	0.0	0.0	7.9	0.2	81.9	0.1	0.0	0.2	0.4	4.0
10 TeBMF	0.98	0.0	0.1	0.0	0.0	0.0	2.7	0.0	0.0	96.2	0.2	0.3	0.3	0.2
11 TeCF	0.95	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.1	0.5	92.8	0.5	5.4	0.1
12 TeGS	0.93	0.0	2.0	0.0	0.0	0.0	5.7	0.2	0.0	0.1	0.0	88.7	0.2	3.1
13 BoFT	0.98	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	99.4	0.5
14 Tun	0.93	0.0	0.0	0.0	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.0	0.8	97.7

Table S18: Confusion matrix Tuanmu et al. vs Olson *et al.* (2001) biome map. Overall $\kappa = 0.99$. See Table S11 for full biome names.

Biome	κ	1	2	3	4	5	6	7	8	9	10	11	12	13
1 TrMBF	1.00	99.8	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3 TrGS	0.98	0.0	97.8	0.0	0.0	0.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.6
4 TrDBF	1.00	0.0	0.0	99.9	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 TrCF	1.00	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 FlGS	0.99	0.0	0.8	0.0	0.0	98.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7 DeXS	0.97	0.0	0.4	0.0	0.0	0.0	98.5	0.0	0.0	0.0	0.0	0.1	0.0	1.1
8 MoGS	0.98	0.0	0.9	0.0	0.0	0.0	3.1	96.0	0.0	0.0	0.0	0.0	0.0	0.1
9 MeFWS	0.98	0.0	0.0	0.0	0.0	0.0	3.3	0.0	96.7	0.0	0.0	0.0	0.0	0.0
10 TeBMF	1.00	0.0	0.1	0.0	0.0	0.0	0.4	0.0	0.0	99.6	0.0	0.0	0.0	0.0
11 TeCF	1.00	0.0	0.0	0.0	0.0	0.0	0.5	0.1	0.0	0.0	99.4	0.0	0.0	0.0
12 TeGS	0.99	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	98.8	0.0	0.0
13 BoFT	1.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0
14 Tun	0.98	0.0	0.1	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	99.3

Table S19: Biome coverage and change for Olson map. Columns are LP – LPJ-GUESS; OR – ORCHIDEE; OD – ORCHIDEE-DGVM; CA – CARAIB; CL – CLM4.5; c – current; f – future; s – shift between current and future.

biome	LPc	LPf	LPs	ORc	ORf	ORs	ODc	ODf	ODs	CAC	CAf	CAs	CLc	CLf	CLs
TrMBF	11.8	11.7	-0.1	12.5	12.6	0.1	12.4	16.5	4.1	11.7	13.1	1.4	11.9	11.7	-0.2
TrGS	15.4	18.0	2.6	12.7	13.5	0.7	13.5	12.3	-1.2	11.5	14.8	3.3	13.7	13.6	-0.1
TrDBF	0.2	0.0	-0.2	1.1	0.5	-0.6	0.6	0.1	-0.5	1.7	0.8	-0.9	0.0	0.0	-0.0
TrCF	0.0	0.0	-0.0	0.2	0.3	0.0	0.2	0.1	-0.2	0.4	0.1	-0.4	0.1	0.0	-0.1
FlGS	0.0	0.0	-0.0	0.2	0.1	-0.1	0.2	0.1	-0.2	0.6	0.1	-0.6	0.1	0.1	-0.0
DeXS	19.8	20.1	0.3	16.2	16.4	0.2	17.7	16.6	-1.0	17.2	16.7	-0.6	11.6	12.0	0.5
MoGS	1.1	1.4	0.3	2.4	1.6	-0.9	2.4	3.4	0.9	3.2	1.7	-1.5	2.2	2.1	-0.1
MeFWS	0.4	0.5	0.1	1.8	1.4	-0.3	2.1	2.0	-0.1	2.2	2.0	-0.2	1.4	1.4	-0.0
TeBMF	10.8	16.5	5.7	10.6	12.1	1.5	10.0	14.8	4.8	10.2	16.6	6.4	10.6	11.1	0.6
TeCF	1.2	1.0	-0.2	2.8	2.0	-0.8	3.8	3.6	-0.2	3.0	2.2	-0.8	1.8	1.6	-0.1
TeGS	7.0	5.5	-1.5	8.3	8.2	-0.2	7.8	6.8	-1.0	8.1	10.6	2.5	9.1	8.7	-0.4
BoFT	19.4	18.2	-1.1	20.0	21.3	1.3	16.0	18.1	2.1	17.1	15.3	-1.8	19.2	20.3	1.1
Tun	12.8	7.0	-5.8	11.2	10.1	-1.1	13.3	5.7	-7.6	13.0	6.0	-7.0	18.3	17.3	-1.0

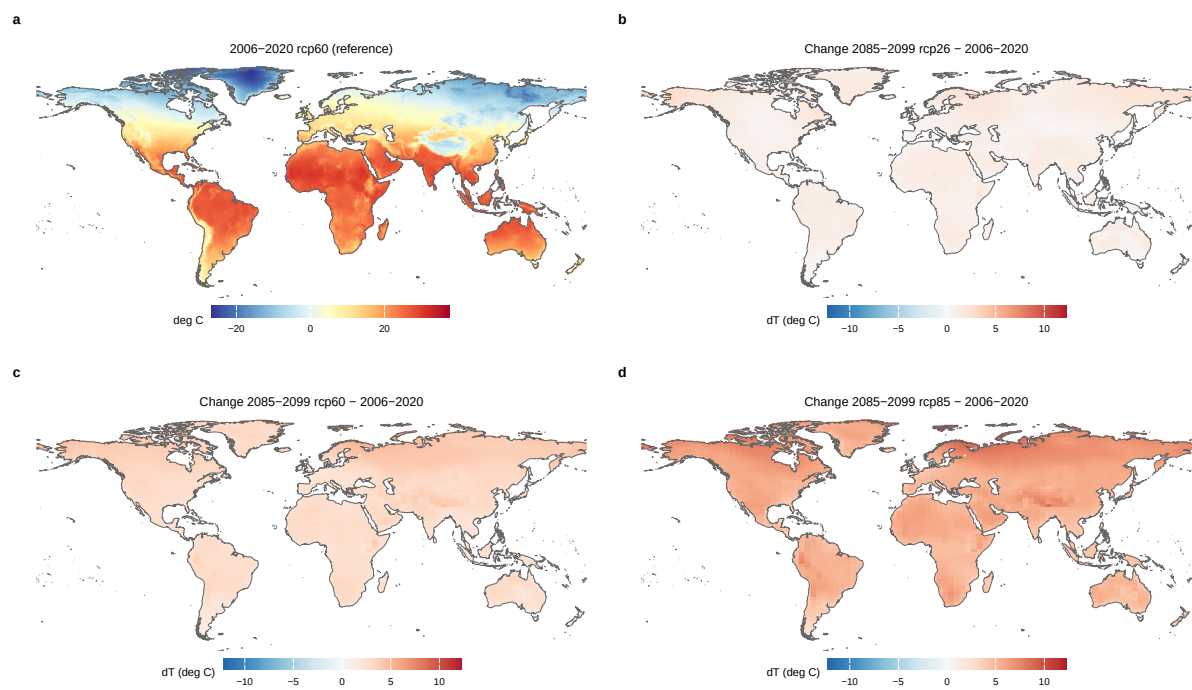


Figure S1: Temperature and temperature change in the IPSL-CM5A-LR simulations.

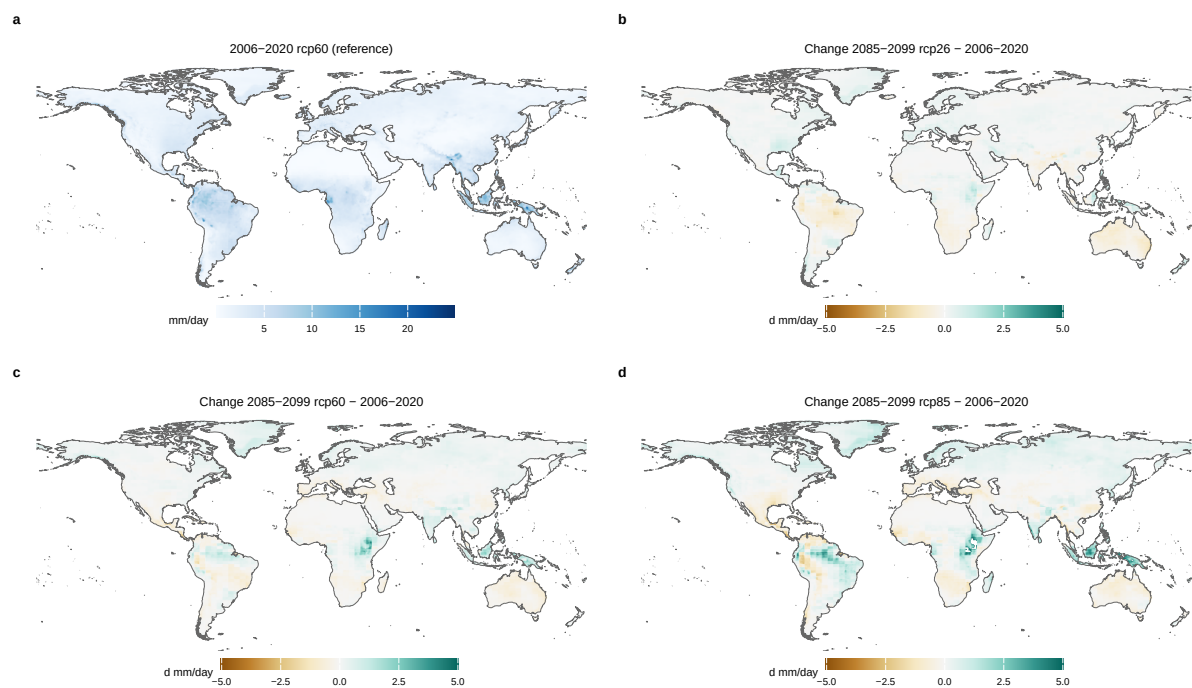


Figure S2: Precipitation and precipitation change in the IPSL-CM5A-LR simulations. For visibility, changes were cropped at ± 5 mm/day.

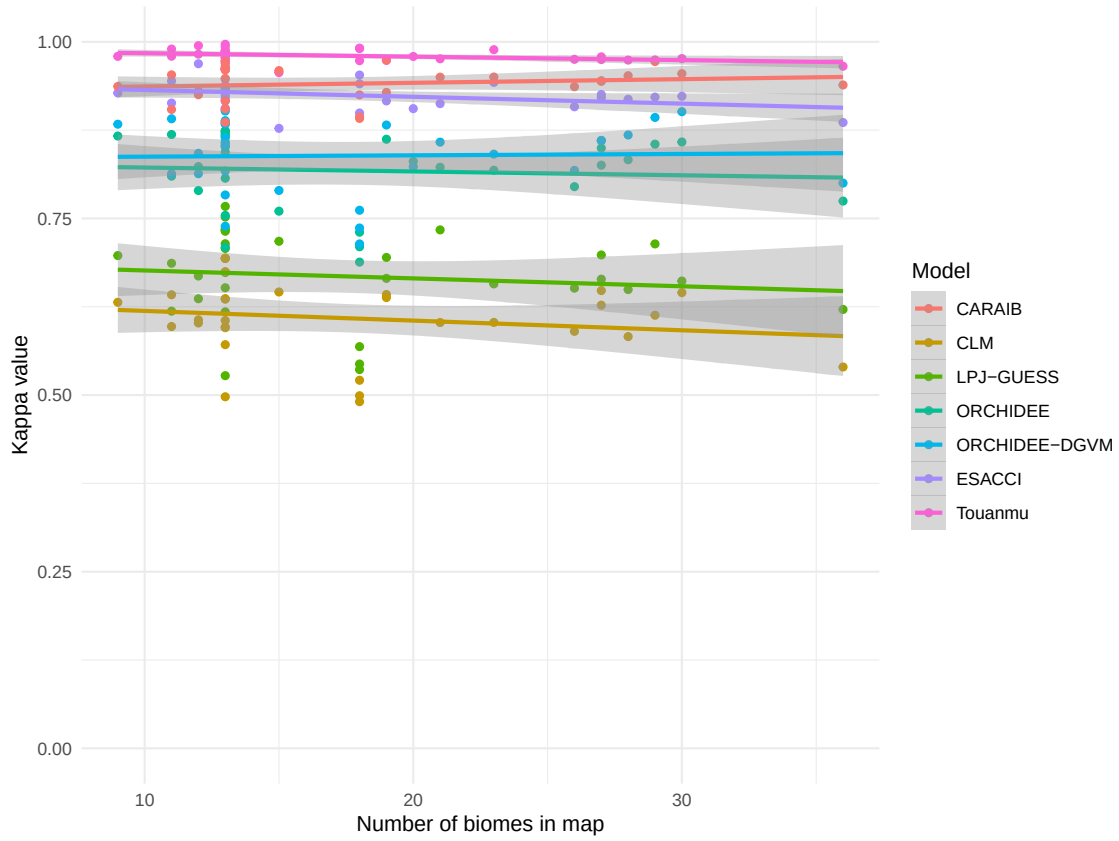


Figure S3: Data-model agreement in relation to the number of biomes in F31 biome maps. Each point represents the κ value of the biome classification with one of the F31 biome maps. Lines are linear regressions.

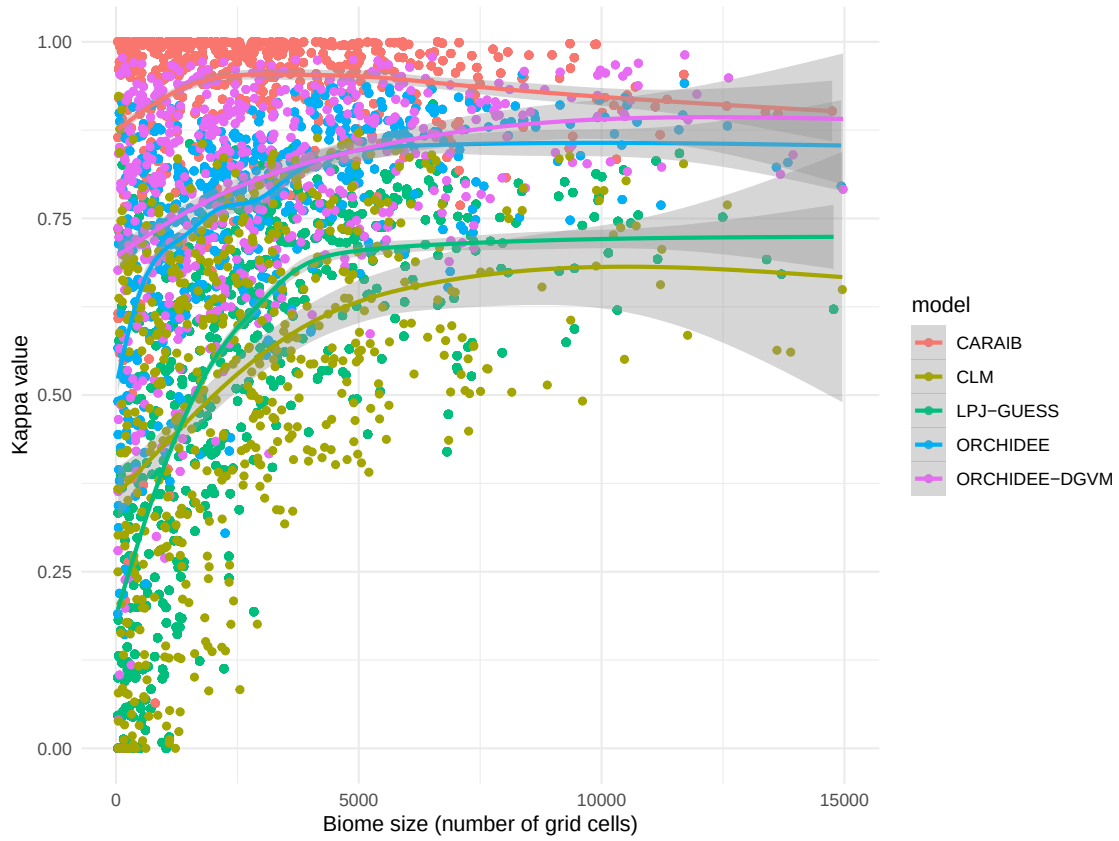


Figure S4: Data-model agreement in relation to the number of grid cells covered by each biomes in F31 biome maps. Each point represents a biome in one of the F31 biome maps. Lines are lowess smoother.

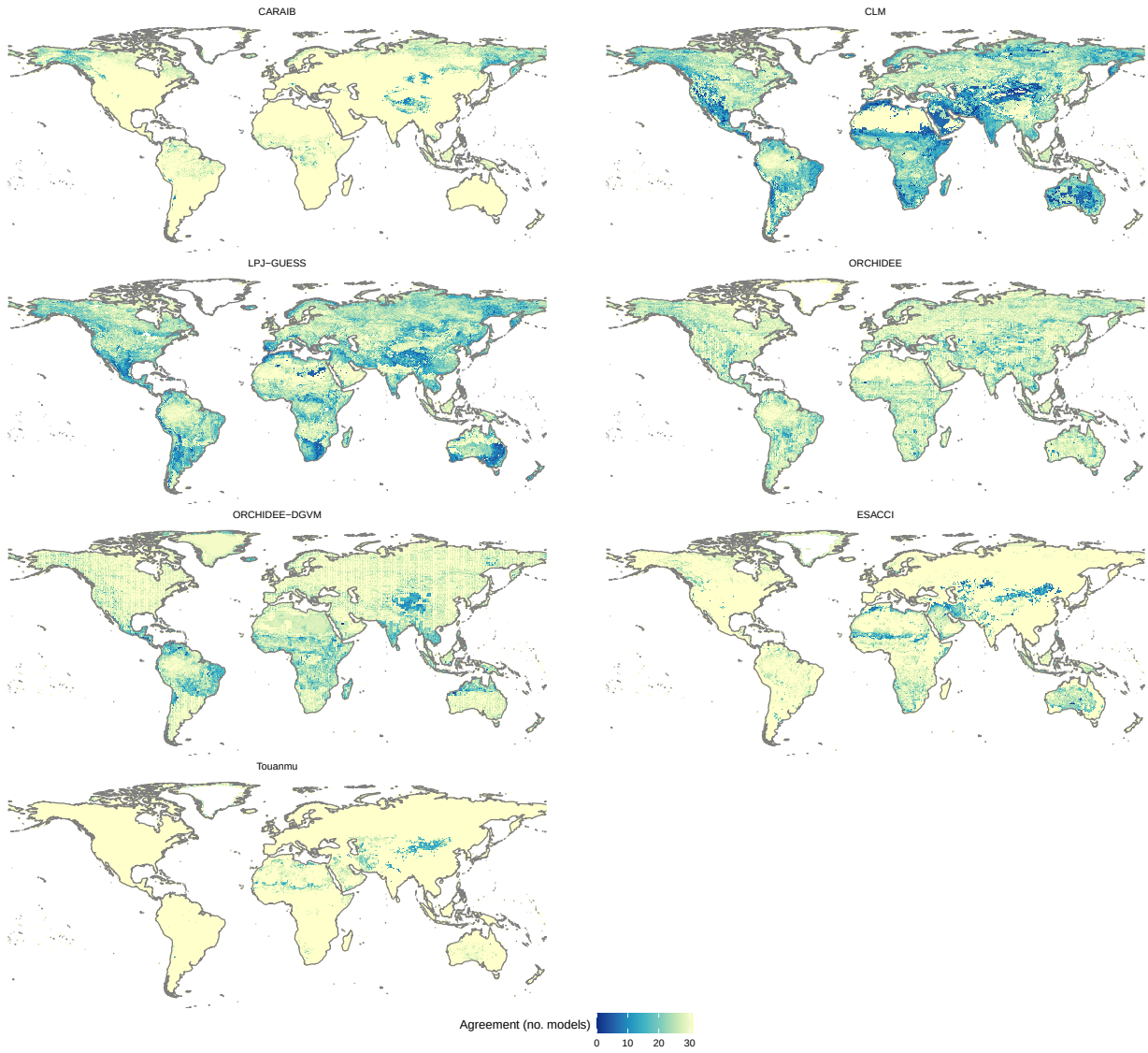


Figure S5: Data-model agreement for each GVM and PFT product. The figure shows the number of maps where the observation-based and modeled biome type agree for all combinations of the F31 biome maps, each of the five GVMs and the two PFT products. Dark blue indicates areas with low agreement.

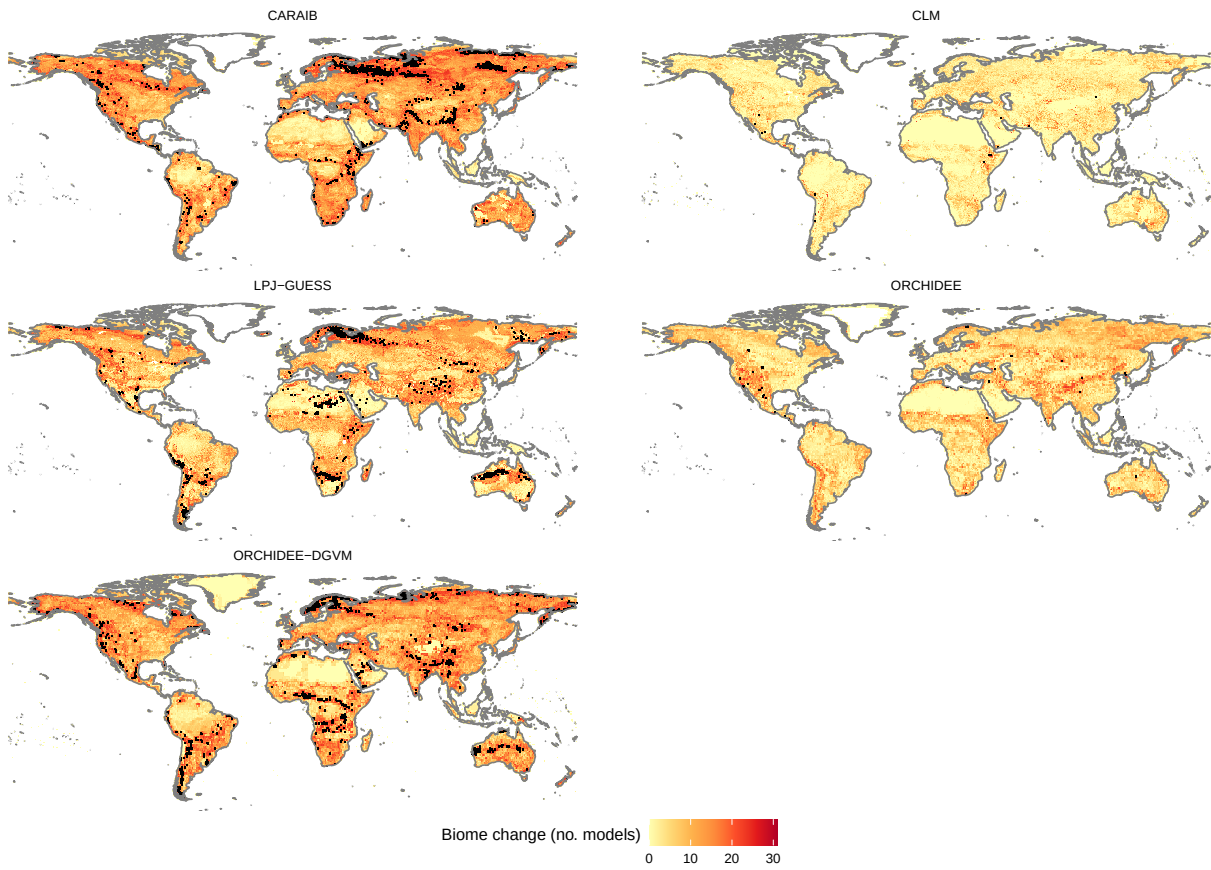


Figure S6: Susceptibility to biome change for each GVM under RCP6.0. The figure shows the number of models that project a biome change until the end of the century for all combinations of the F31 biome maps and each of the five GVMs. Dark red indicates areas with high susceptibility to biome change.

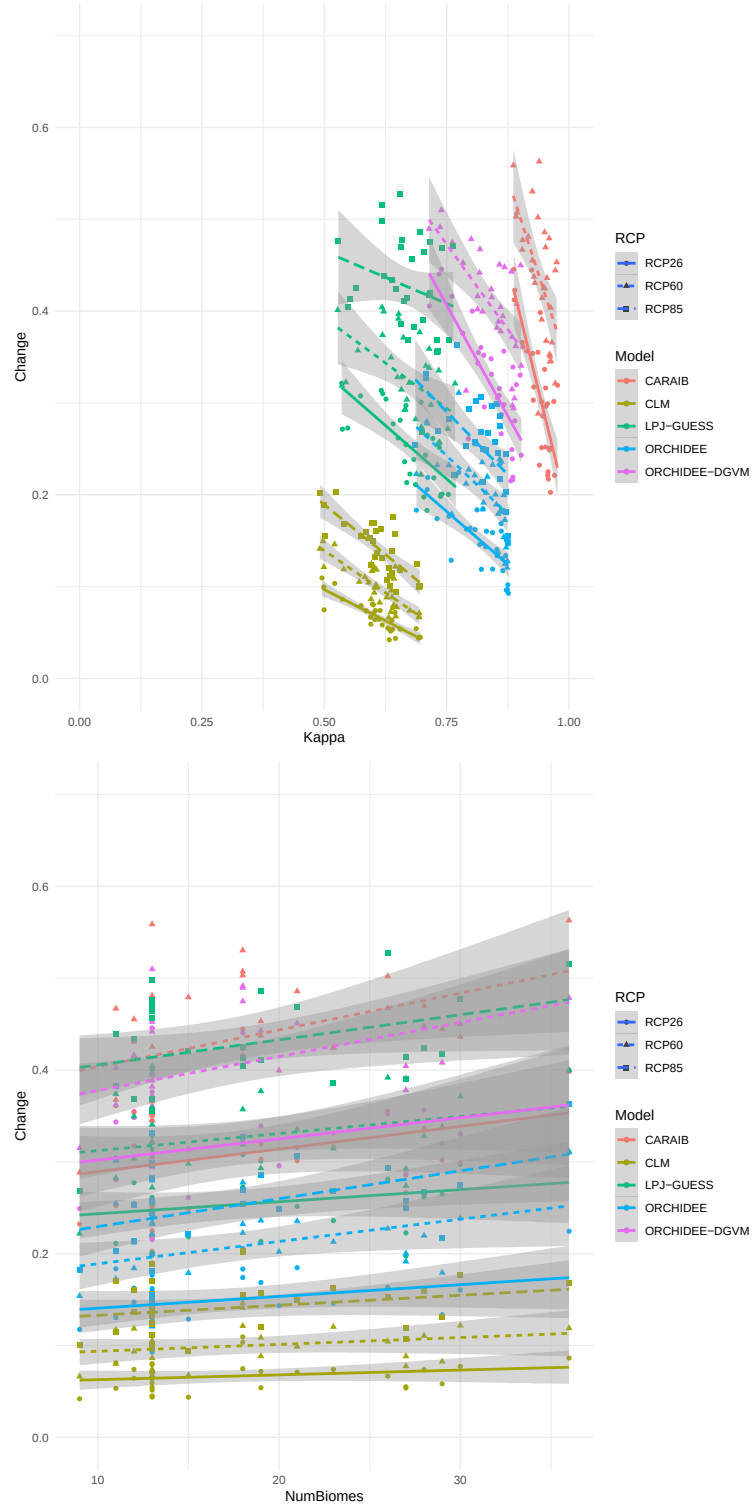


Figure S7: Rate of biome change in relation to data-model agreement and the number of biomes. Each point represents a biome classification for one of the F31 biome maps. The κ values were calculated for all biomes in the respective data-model combination. Different point and line types represent different RCPs. Change represents the proportion of grid cells undergoing biome transitions until the end of the century for a given GVM and biome classification.

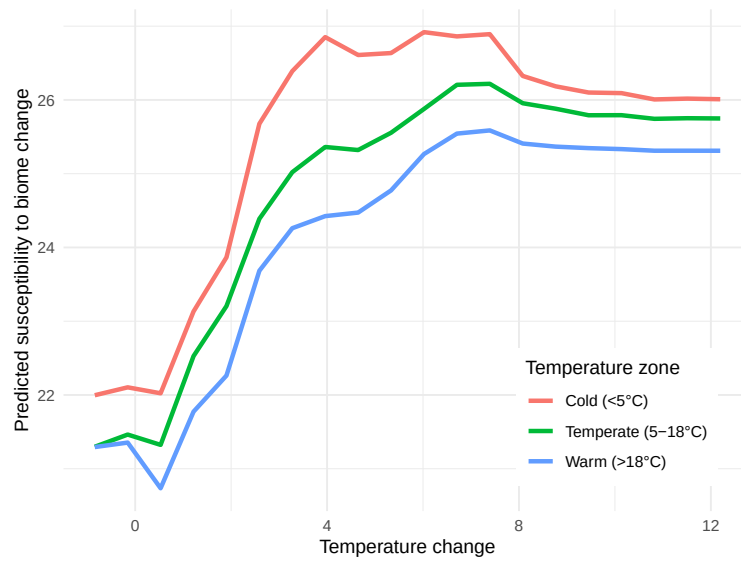


Figure S8: Partial dependence of susceptibility to biome change in relation to temperature change. The results are based on random forest regressions for the susceptibility to biome change, with climatic variables as predictors. All RCPs were merged for the analysis.

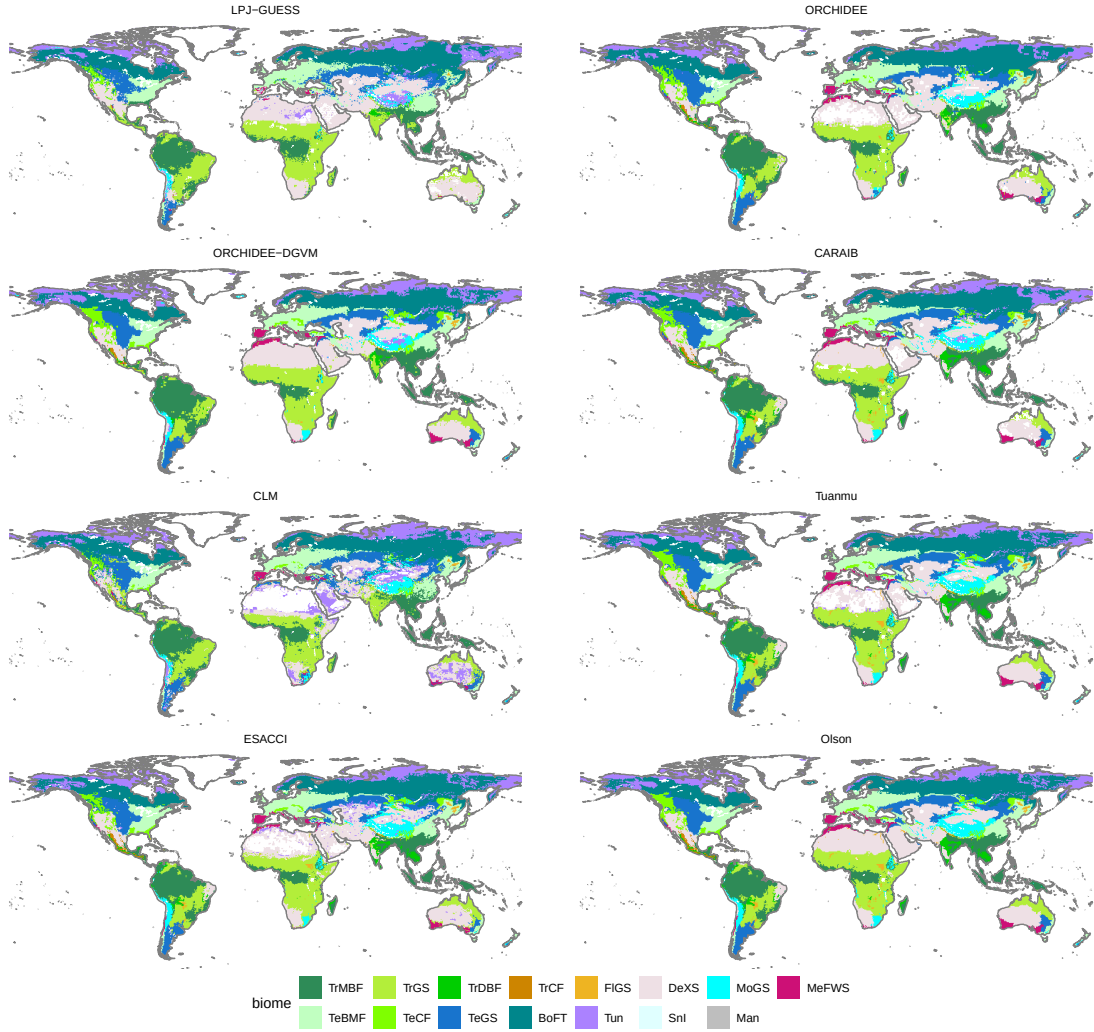


Figure S9: Modeled and observation-based biome maps. The maps show the modeled biome distributions for different GVMs and PFT products classified for the Olson *et al.* (2001) biome map for RCP6.0. Biomes: TrMBF -Tropical and subtropical moist broadleaf forest; TrGS - Tropical and subtropical grassland savanna and shrubland; TrDBF - Tropical and subtropical dry broadleaf forest; TrCF - Tropical and subtropical coniferous forest; FIGS - Flooded grassland and savanna; DeXS - Deserts and xeric shrubland; MoGS - Montane grassland and shrubland; MeFWS - Mediterranean forest woodland and scrub; TeBMF - Temperate broadleaf and mixed forest; TeCF - Temperate conifer forest; TeGS - Temperate grassland savanna and shrubland; BoFT - Boreal forest/taiga; Tun - Tundra; Sni - Snow and Ice; Man - Mangrove.

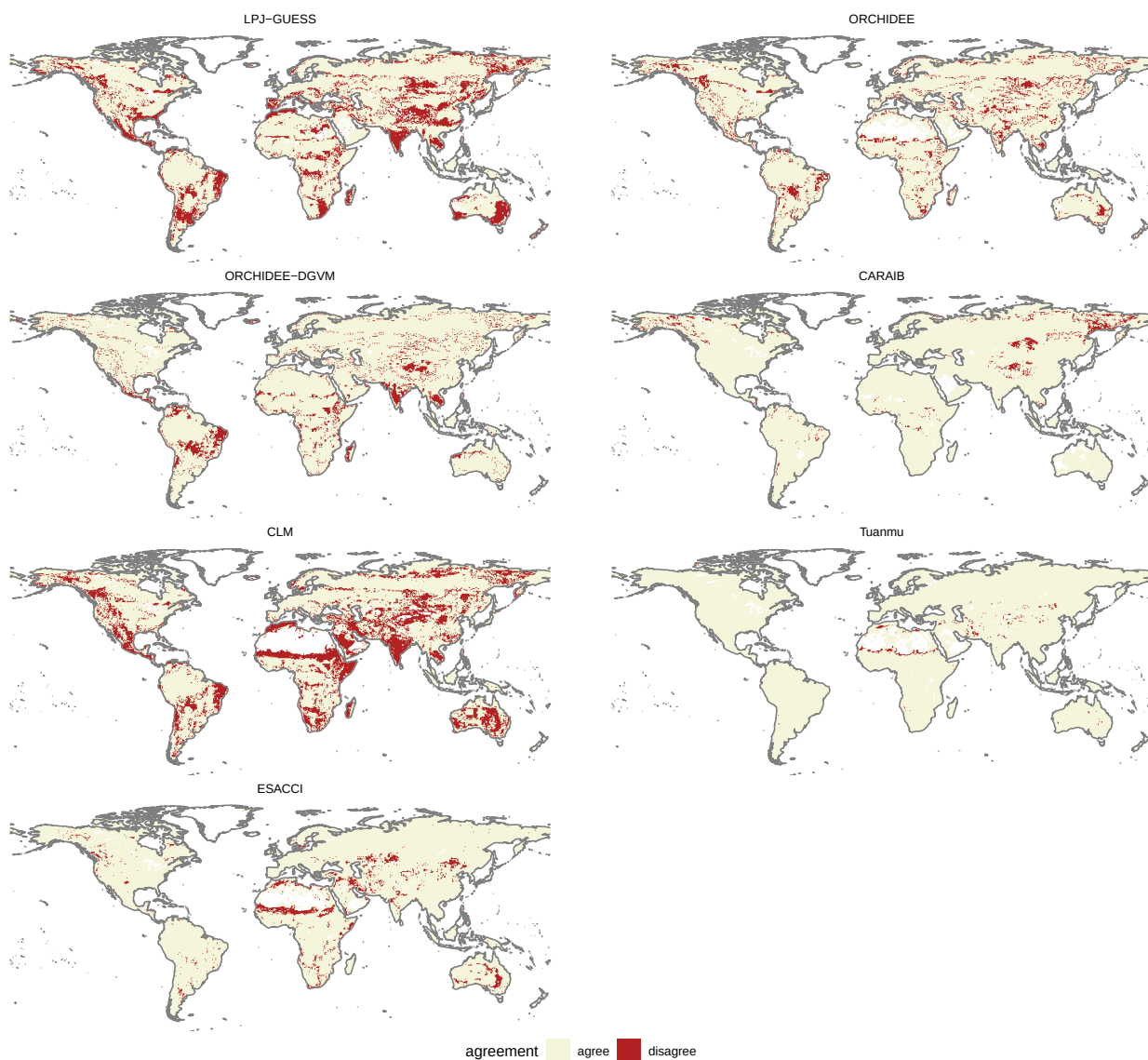


Figure S10: Agreement between Olson *et al.* (2001) biomes and modeled biomes. Biome maps for current conditions for different models are provided in Fig. 4 in the main text.

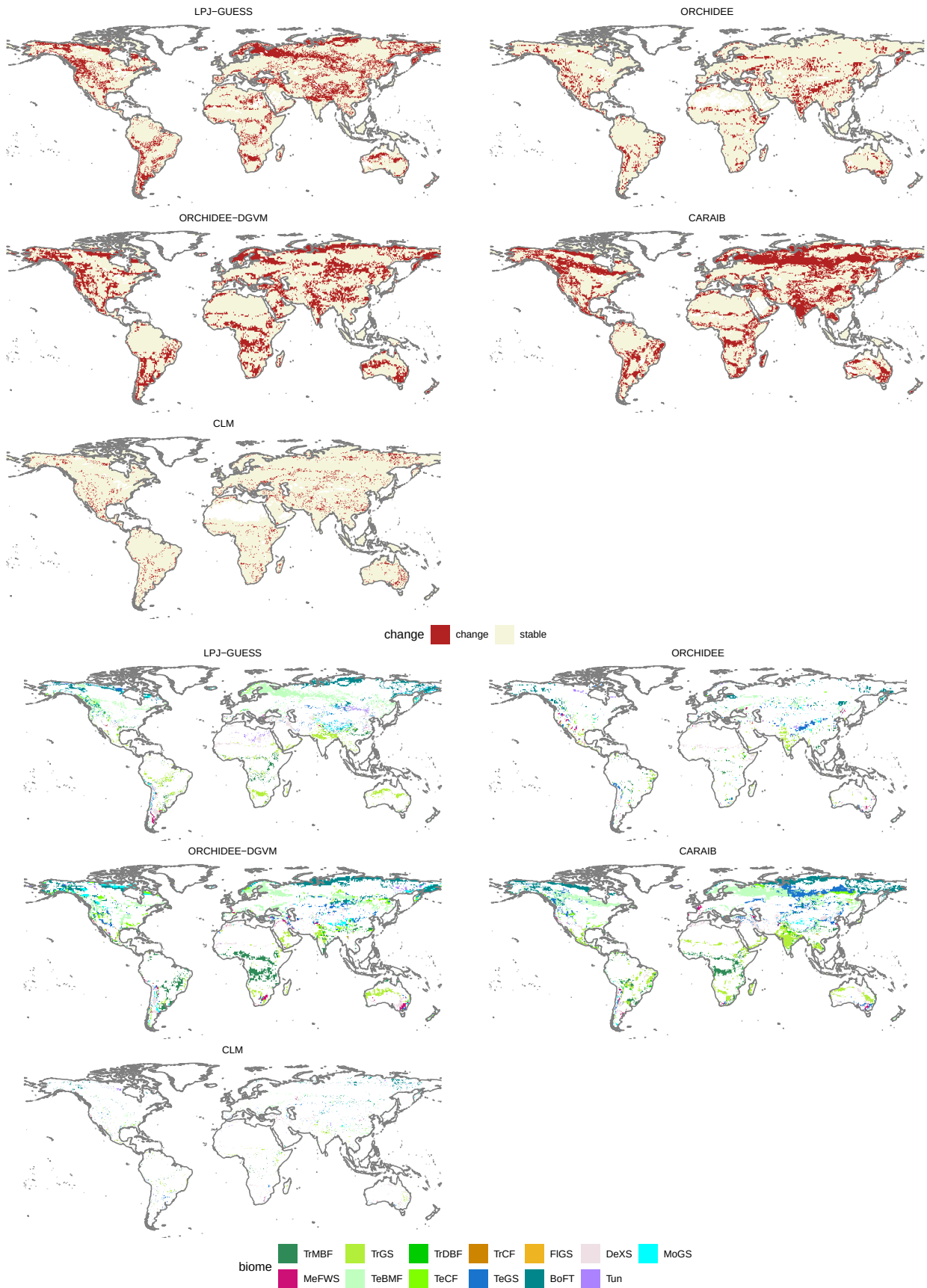


Figure S11: Biome changes projected by GVMs. Here, biome classification schemes fitted for the Olson *et al.* (2001) biome map were used. The upper panels indicate areas where biome shifts are projected, the lower panels show the biome type at the end of the century for areas where biome shifts are projected. See Table S11 for full biome names.

LPJ-GUESS

ORCHIDEE

ORCHIDEE-DGVM

CARAIB

CLM

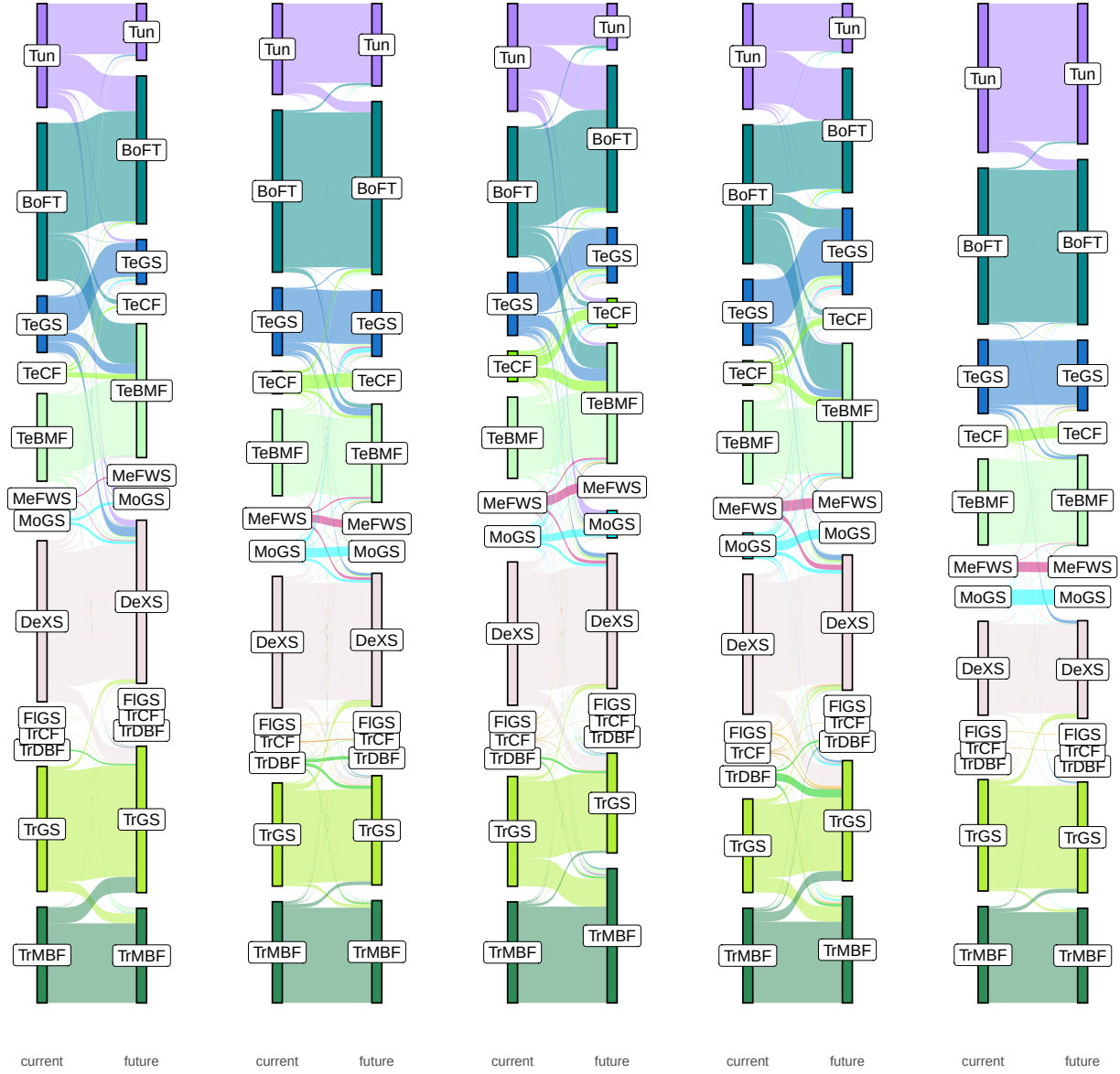


Figure S12: Biome changes projected by GVMs. The Sankey diagrams illustrate transitions between different biomes between current and future conditions for different GVMs and biome classification informed by the Olson *et al.* (2001) map. The height of the rectangles represents the biome coverage under current or future conditions, the width of the links represents the number of transitions between biomes. See Table S11 for full biome names.

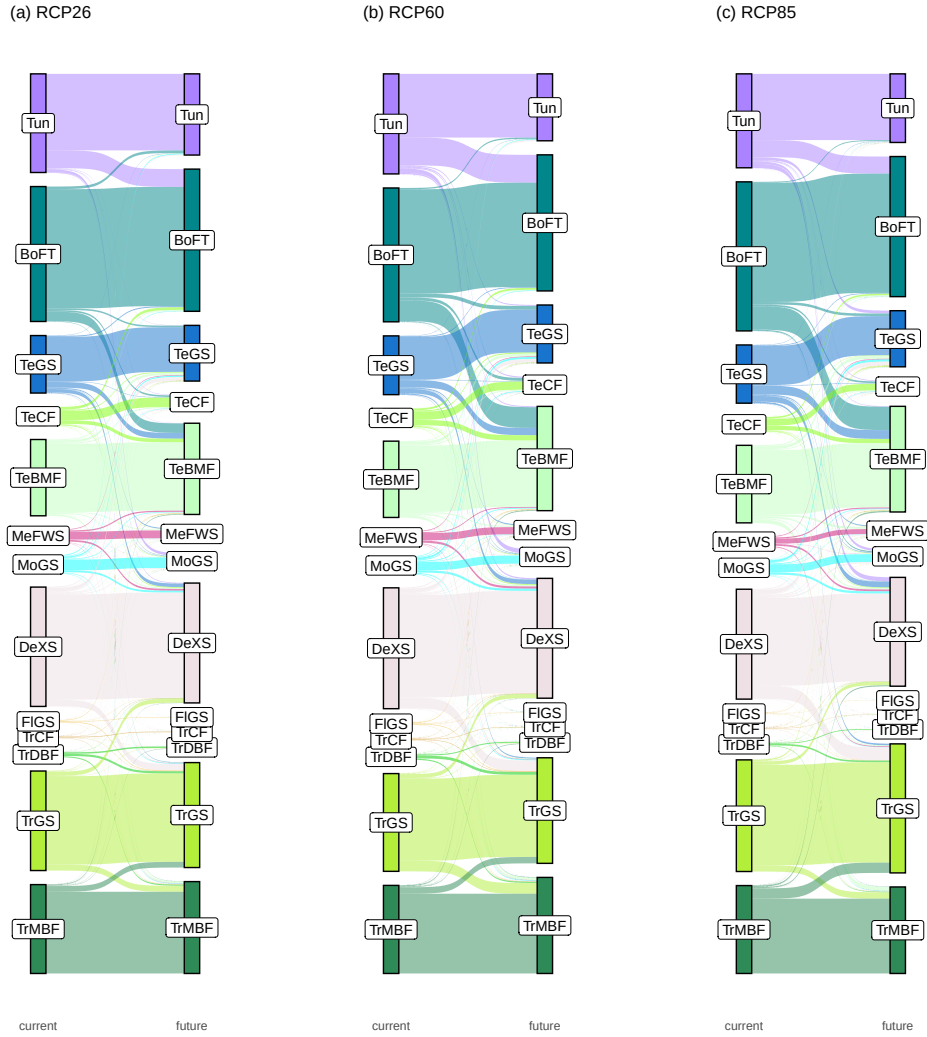


Figure S13: Biome changes projected by GVMs for different RCPs. The Sankey diagrams illustrate transitions between different biomes between current and future conditions and biome classification informed by the Olson *et al.* (2001) map. For each scenario, all available GVMs were included. See Fig. S13 for plots of individual models for RCP6.0. The height of the rectangles represents the biome coverage under current or future conditions, the width of the links represents the number of transitions between biomes. See Table S11 for full biome names.