Supplementary Material

S1 Functioning of traits in JSBACH.

S1.1 SLA

In JSBACH, SLA (specific leaf area (mol C m^{-2})) affects the size of the carbon pools. In the default simulation SLA is a fixed PFT-specific parameter but in the variable traits simulation it varies over time and is recalculated every year (based on local climatic conditions, see Table 2 in main text). In all other aspects, SLA functions in the same ways as in the default model (see below).

The NPP determines vegetation carbon pools. NPP is allocated using fixed proportions into green (living, both above and below ground), wood (both above and below ground) and reserve pools, as well as root exudates. Limits are set to the different pools; the wood pool has a PFT-specific maximum carbon content. For the green pool, SLA determines in combination with LAI (-) and a pool-specific ratio of pool carbon to leaf carbon (c_g, 4.0 (-) for all PFTs) the maximum amount of carbon that can be stored in the green pool (C_G^{max}):

$$C_G^{max}(t) = \frac{c_g}{SLA} LAI(t) \quad (1)$$

For the reserve pool not the maximum but an optimal amount of carbon content (C_R^{opt}) is set by the same formula (only with a different ratio-parameter, (c_r, with a value of 2.0 (-) for forests and shrubs and 4.0 (-) for grasses), as this pool is not emptied when LAI decreases. Consequently the reserve pool can be larger than the optimal value:

$$C_R^{opt}(t) = \frac{c_r}{SLA} LAI(t). \quad (2)$$

Reference:

Parida, B.R.: The influence of plant nitrogen availability on the global carbon cycle and N_2O emissions, MPI-M report on the Earth System Science, nr. 92, 141 pp, 2011. (http://www.mpimet.mpg.de/fileadmin/publikationen/Reports/WEB_BzE_92.pdf)

S1.2 $Vcmax_{25}$ and $Jmax_{25}$

$Vcmax_{25}$ and $Jmax_{25}$ (maximum carboxylation and electron transport rate at a reference temperature of 25 °C (µmol m^{-2} s^{-1}), respectively) are used to calculate Vcmax and Jmax values at actual temperatures. In the default simulation $Vcmax_{25}$ and $Jmax_{25}$ are PFT-specific fixed values but in the variable traits simulation they vary over time. They are recalculated every year (based on local climatic conditions, see Table 2 in main text). Afterwards, the same photosynthesis routine as the default mode is followed (see equations below taken after Knorr (1997)).

C3 plants

For C3 plants, the temperature dependence of Vcmax and Jmax is calculated following Farquhar (1988):

$$Vcmax = Vcmax_{25} f(T) exp((\frac{T}{T_{ref}} - 1)\frac{E_V}{RT}) \quad (3)$$

$$Jmax = Jmax_{25} f(T) exp(\left(\frac{T - T_0}{T_{ref} - T_0}\right)) \quad (4)$$

T is the temperature in °K, E_V is the activation energy (58520 J mol^{-1})) and R is the gas constant (8.314 J mol^{-1} K^{-1}). T_{ref} (298.15 K) and T_0 (273.15 K) are reference temperatures. In either formula, $Vcmax_{25}$ and $Jmax_{25}$ are fixed in the default simulation but vary in the variable traits simulation. For both Vcmax and Jmax, an additional formula accounting for high temperature inhibition (f(T)) is included (Collatz et al. 1991):

$$f(T) = \frac{1}{\left(1+e^{1.3(T-T_1)}\right)}, \quad (5)$$

with T_1 as reference temperature (328 K).

Actual Vcmax is then used to calculate carboxylation rate (J_C) (Farquhar et al. (1980)):

$$J_C = Vcmax \frac{c_i - \Gamma_*}{c_i + K_C(1+O_i/K_O)} \quad (6)$$

Here c_i and O_i are the CO_2 and O_2 concentrations inside the leaf (µmol (CO_2) mol^{-1} (air) and mol (O_2) mol^{-1} (air), respectively), Γ_* is the CO_2 compensation point (µmol (CO_2) mol^{-1} (air)) and K_C and K_O are the Michaelis-Menten constants for CO_2 and O_2 (µmol (CO_2) mol^{-1} (air) and mol (O_2) mol^{-1} (air), respectively). K_C, K_O and Γ_* are temperature dependent, see Farquhar (1988) for equations.

With actual Jmax electron transport rate (J_E) is calculated (Farquhar et al. (1980)):

$$J_E = J(I)\frac{c_i - \Gamma_*}{4(c_i+2\Gamma_*)}, \quad (7)$$

with the function J(I):

$$J(I) = Jmax \frac{\alpha I}{\sqrt{J_{max}^2 + \alpha^2 I^2}}, \quad (8)$$

where I = I_{PAR} / E_{PAR}. I_{PAR} is the PAR absorption rate (W m^{-2}) and E_{PAR} is the energy content of PAR (220 kJ mol^{-1} (photons)) and α (0.28, (-)) is the quantum efficiency for photon capture.

Net carbon assimilation (A) is the minimum of Eq. (6) and Eq. (7) minus dark respiration:

$$A = min(J_C, J_E) - R_d \quad (9)$$

Dark respiration at a references temperature of 25 °C ($R_{d,25}$) is a fixed fraction of $Vcmax_{25}$, meaning that in contrast to a fixed values in the default simulation, $R_{d,25}$ varies as well in the variable traits simulation:

$$R_{d,25} = \gamma Vcmax_{25}, \quad (10)$$

with γ (-) having a value of 0.011 (Farquhar 1980). Actual R_d is calculated following Von Caemmerer (2000)):

$$R_d = R_{d,25} f(T) g(Ir) exp((\frac{T}{T_{ref}} - 1)\frac{E_R}{RT}), \quad (11)$$

where E_R is the activation energy (45000 J mol^{-1}). Irradiance inhibition (g(Ir)) is calculated as follows:

$$g(Ir) = 0.5\,(1 + e^{-Ir/10}), \quad (12)$$

with Ir being total irradiance at the surface (mol (photons) m^{-2} s^{-1}).

C4 plants

C4 plants follow a similar routine as C3 plants; only the equations for carboxylation and electron transport rate differ (Collatz et al (1992)). Carboxylation rate is calculated using PEPcase CO_2-specificity (k (mol m^{-2} s^{-1})) instead of Jmax:

$$J_C = kc_i, \quad (13)$$

with k being calculated from a reference k at 25 °C (k_{25}):

$$k = k_{25}\, exp\left(\left(\frac{T}{T_{ref}} - 1\right)\frac{E_K}{RT}\right) \quad (14)$$

As with $Jmax_{25}$ for other PFTs, k_{25} is fixed in the default simulation and recalculated every year in the variable traits simulation before being input in the above formula. E_K is the activation energy (50967 J mol^{-1}).

Electron transport rate is calculated as follows:

$$J_E = \frac{1}{2\Theta_s}\left(Vcmax + J_i - \sqrt{(Vcmax + J_i)^2 - 4\theta_s Vcmax J_i}\right) \quad (15)$$

Vcmax is calculated from $Vcmax_{25}$ in the same way as C3 plants, and θ is the curve parameter for J_E (0.83 (-)), and J_i calculated as:

$$J_i = \alpha_i I, \quad (16)$$

where α_i is the integrated C4 quantum efficiency (0.04 mol (C) m^{-2} s^{-1}). As for C3 plants, $R_{d,25}$ is also proportional to $Vcmax_{25}$ (Eq. (10)), but with a γ of 0.042.

References:

Collatz, G.J., Ball, J.T., Grivet, C. and Berry, J.A.:, Physiological and environmental regulation of stomatal conductance, photosynthesis and transpiration: a model that includes a laminar boundary layer, Agr. Forest Meteorol., 54, 107-136, doi: 10.1016/0168-1923(91)90002-8 1991.

Collatz, G. J., Ribas-Carbo, M., and Berry, J. A.: Coupled photosynthesis-stomatal conductance model for leaves of C_4 plants, Aust. J. Plant Physiol., 19, 519-538, 1992.

Farquhar, G.D.: Models relating subcellular effects of temperature to whole plant responses, in: Plants and Temperature, Long,S.P. and Woodward, F.I. (Eds), 1988, Biologists Limited, Cambridge, U.K., 395-409, 1988.

Farquhar, G. D., Caemmerer, S. V., and Berry, J. A.: A biochemical model of photosynthetic CO_2 assimilation in leaves of C_3, Planta, 149, 78-90, doi: 10.1007/BF00386231, 1980.

Knorr, W.: Satellite remote sensing and modelling of the global CO_2 exchange of land vegetation: a synthesis study, Ph.D. thesis, University of Hamburg, Germany, 189 pp., 1997.

Knorr, W., and Heimann, M.: Uncertainties in global terrestrial biosphere modeling 1. A comprehensive sensitivity analysis with a new photosynthesis and energy balance scheme, Global Biogeochem. Cy., 15, 207-225, doi: 10.1029/1998gb001059, 2001.

Von Caemmerer, S.: Biochemical models of leaf photosynthesis, CSIRO Publishing, Collingwood, Australia, pp. 165 pp. 2000.

S2 Role of the selected traits in JSBACH processes.

Fig. S2.1 shows a flowchart with the different roles of the selected traits in JSBACH processes. It demonstrates how variation in traits might propagate in JSBACH and affect PFTs, ecosystem properties and climate.

Actual Vcmax and Jmax are used to model carboxylation and electron transport rate, which, combined with dark respiration, determine GPP (see S1.2). GPP minus growth and maintenance respiration (scaled to canopy from dark respiration) determines NPP. Productivity in turn affects transpiration, which will modify soil moisture and air temperature. Effects of variation in $Vcmax_{25}$ and $Jmax_{25}$ propagate via NPP, which determines the competitive ability of PFTs and consequently PFT cover and ecosystem properties. Differences in fractional coverage of PFTs result in differences in vegetation properties like albedo and vegetation roughness, modifying heat and water fluxes, which affect temperature and precipitation. SLA (see S1.1 for calculation of SLA) effects on climate are more moderate, but it co-determines carbon storage in the green and reserve pool and as such affects the amount of litter going to the litter pools, indirectly influencing decomposition rates and fire frequency as well.

In turn, climatic conditions are used to predict trait values on a yearly basis (dotted lines). Climate also directly drivers many other processes (e.g. actual Vcmax and Jmax, transpiration, leaf and shedding rates, fire frequency etc.) but these have been omitted for clarity.

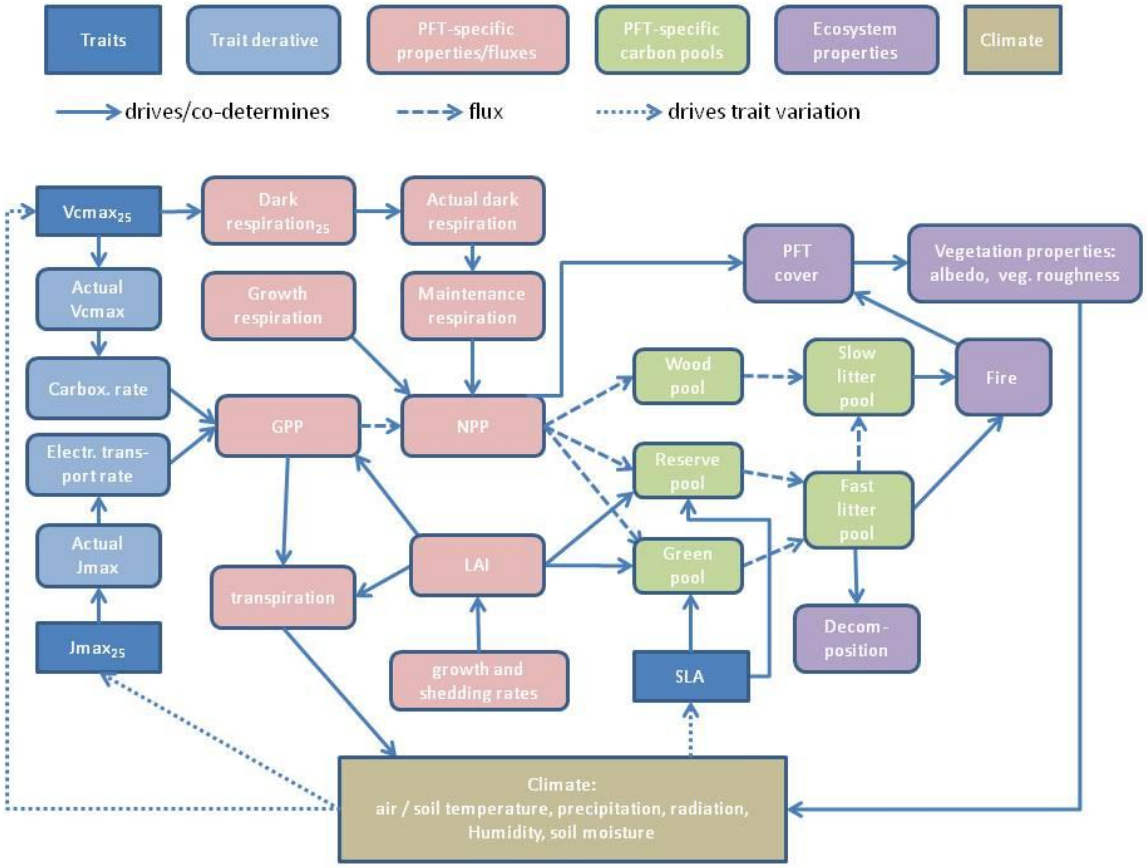
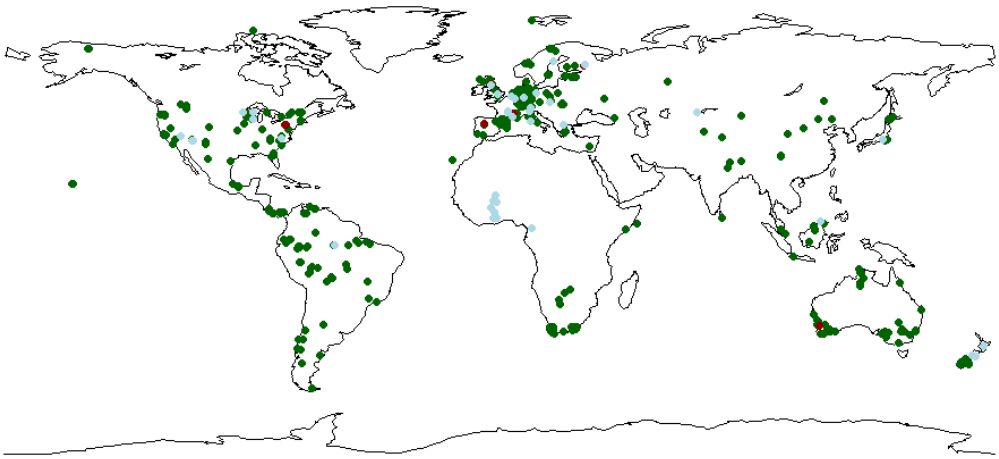


Fig. S2.1. Flowchart with the functioning of SLA, $Vcmax_{25}$ and $Jmax_{25}$ in JSBACH and their effects on PFTs, ecosystem properties and climate.

176 **S3 World map with locations from which trait data were used in this study.**



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178 Fig S3. Locations with trait data used in this study. Green dots SLA, red dots $Vcmax_{25}$ only,

179 and blue dots indicate locations with both $Vcmax_{25}$ and $Jmax_{25}$ data.

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S4 World map of fractional coverage of dominant cover type (including bare soil).

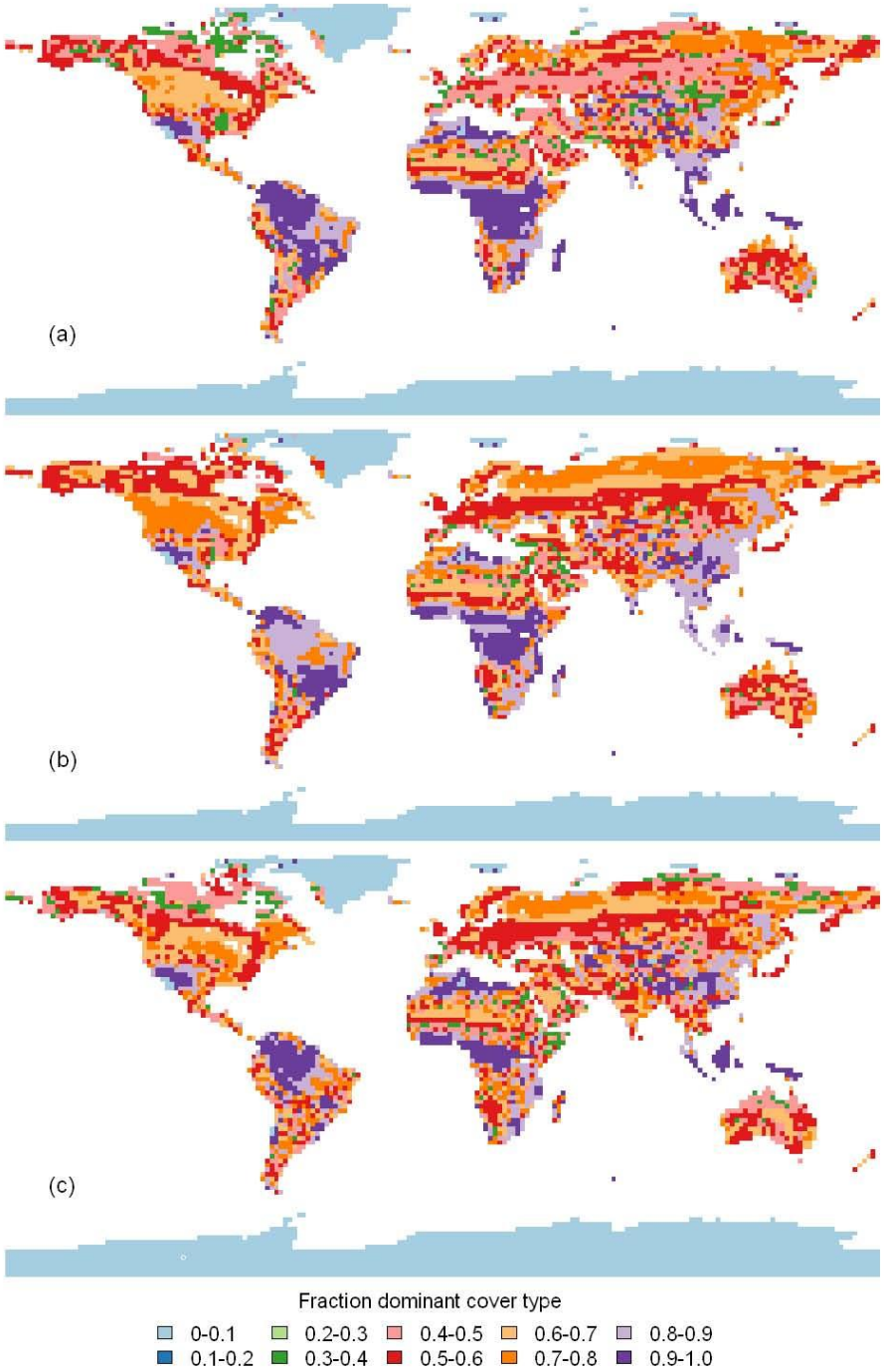


Fig. S4.1. Fractional coverage of dominant cover type (including bare soil). (a) default simulation, (b) observed traits simulation and (c) variable traits simulation.

S5 World map showing $Vcmax_{25}$ of the dominant PFTs in the variable traits simulation relative to the default simulation.

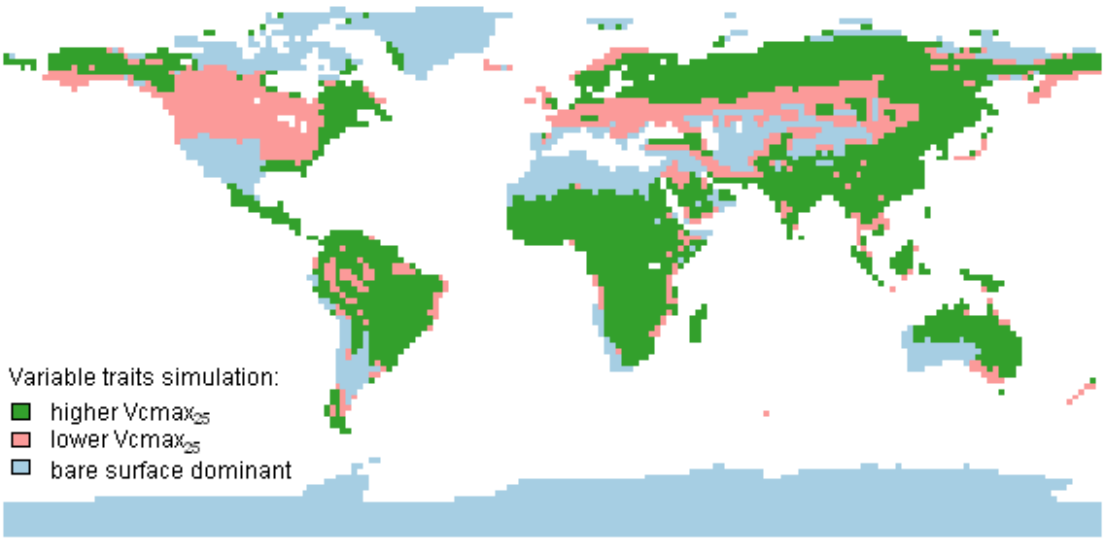


Fig.S5.1. $Vcmax_{25}$ of the dominant PFTs in the variable traits simulation relative to the default simulation. The dominant PFTs in the variable traits simulations have higher $Vcmax_{25}$ than the default simulation in the green areas and lower $Vcmax_{25}$ in the pink areas. In blue areas bare ground (or ice) is the dominant cover type.

S6 Comparisons between predicted dominant vegetation maps of the three simulations with the potential vegetation map of Ramankutty and Foley (1999).

Table S6.1. Aggregation of PFTs in Ramankutty and Foley to match JSBACH PFTs.

PFT	
JSBACH	Ramankutty and Foley
bare	desert
tropical broadleaved evergreen trees	tropical evergreen forest/woodland
tropical broadleaved deciduous trees	tropical deciduous forest/woodland
extra-tropical evergreen trees	temperate broadleaf evergreen forest/woodland temperate needleleaf evergreen forest/woodland boreal evergreen forest/woodland
extra-tropical deciduous trees	temperate deciduous forest/woodland boreal deciduous forest/woodland
shrubs (raingreen and deciduous)	dense shrubland open shrubland
C3-grasses	grassland/steppe
C4-grasses	savanna
--	tundra
--	evergreen/deciduous mixed forest/woodland

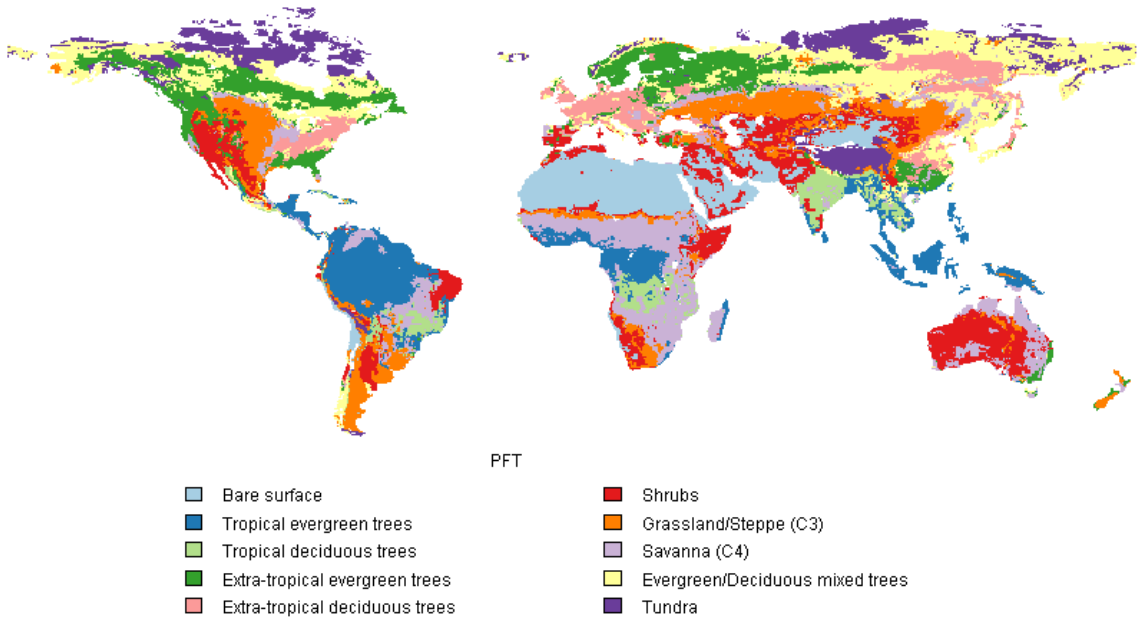
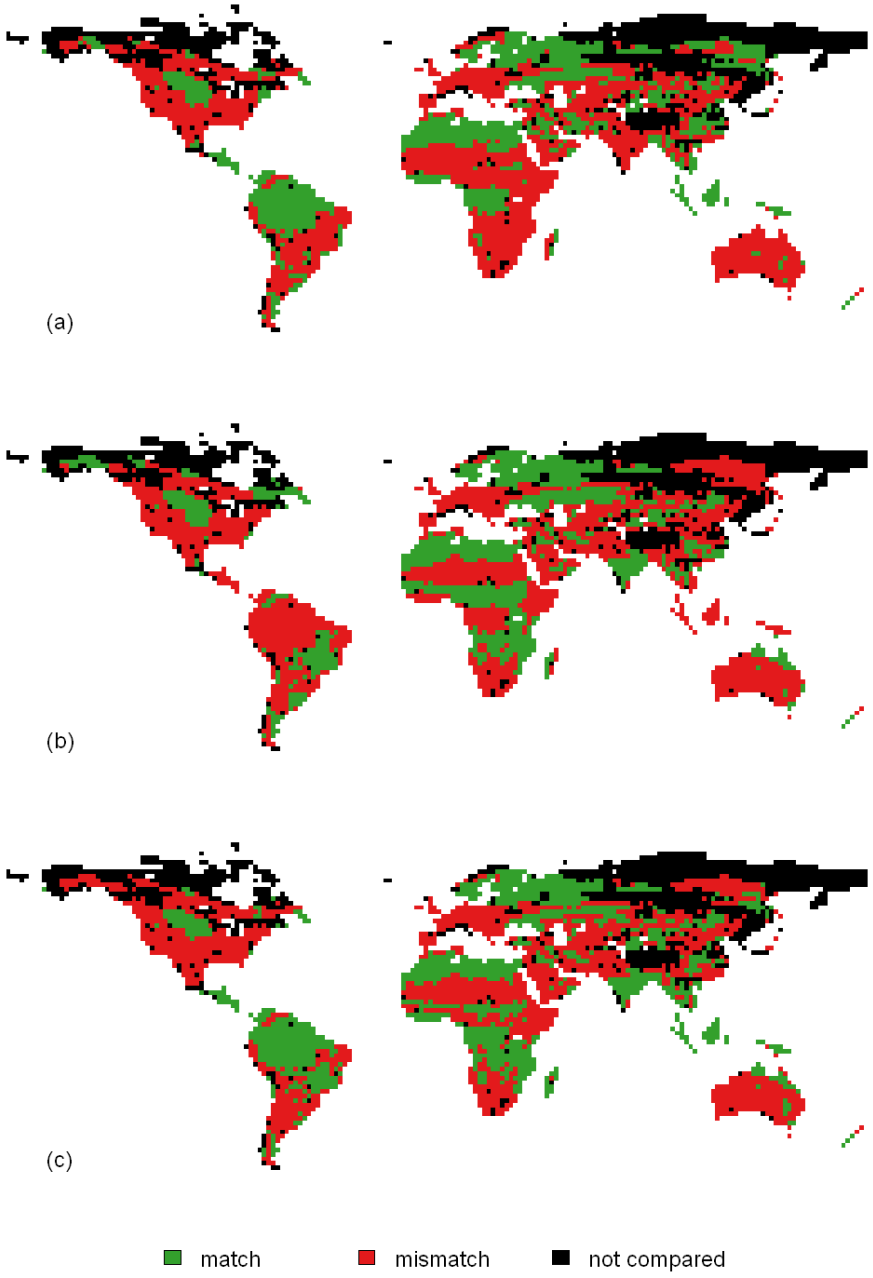


Fig. S6.1. Potential vegetation map with aggregated PFTs (see table S6.1). Evergreen/deciduous mixed forest and tundra were omitted from the comparisons with JSBACH vegetation distribution.



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215 Fig. S6.2. (Mis-)match between simulations and aggregated potential vegetation map for (a)

216 default simulation, (b) observed traits simulation and (c) variable traits simulation.

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S7 World map with simulated total biomass carbon in vegetation.

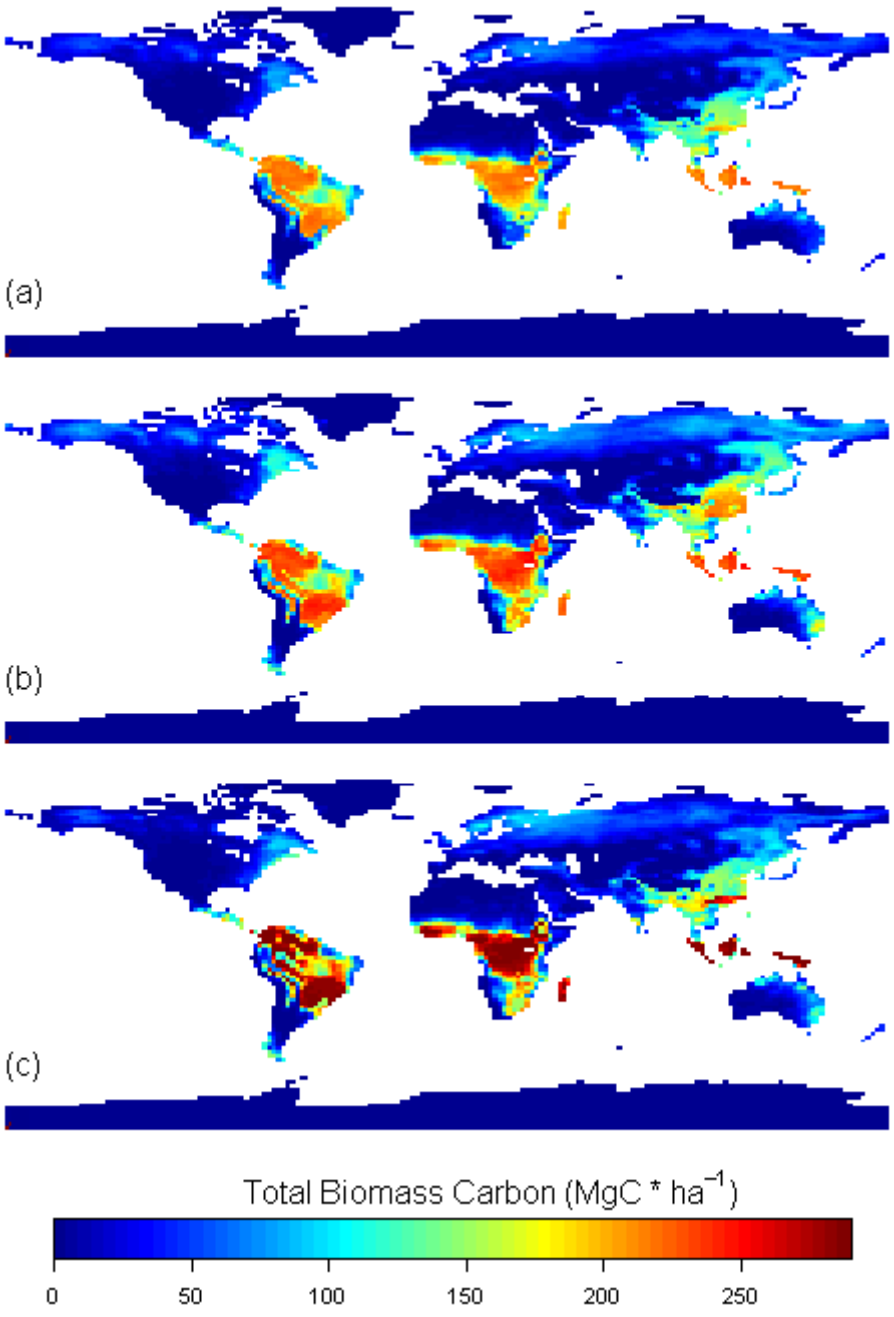

Fig. S7.1. Total biomass carbon (MgC ha^{-1}) of (a) default simulation, (b) observed traits simulation and (c) variable traits simulation.