# 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), $\Gamma_*$ 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 $\Gamma_*$ 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 ($k_{25}$):

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

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:

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

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:

$$J_i = \alpha_i I, \tag{16}$$

where $\alpha_i$ 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.

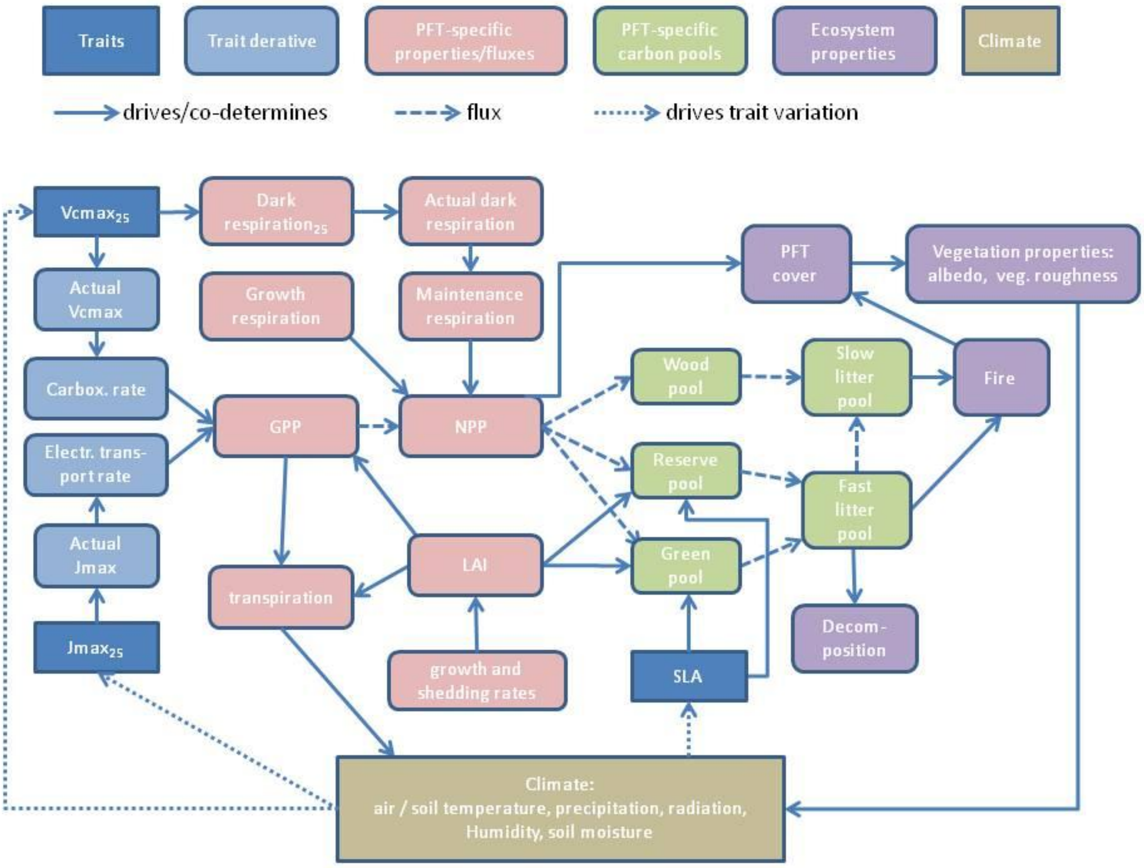


Fig. S2.1. Flowchart with the functioning of SLA, Vcmax$_{25}$ and Jmax$_{25}$ in JSBACH and their effects on PFTs, ecosystem properties and climate.

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

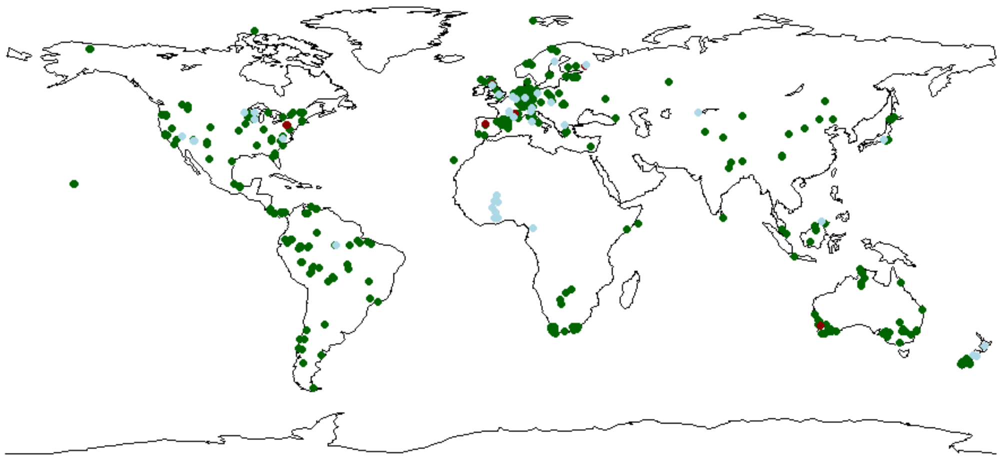

Fig S3. Locations with trait data used in this study. Green dots SLA, red dots $Vcmax_{25}$ only, and blue dots indicate locations with both $Vcmax_{25}$ and $Jmax_{25}$ data.

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

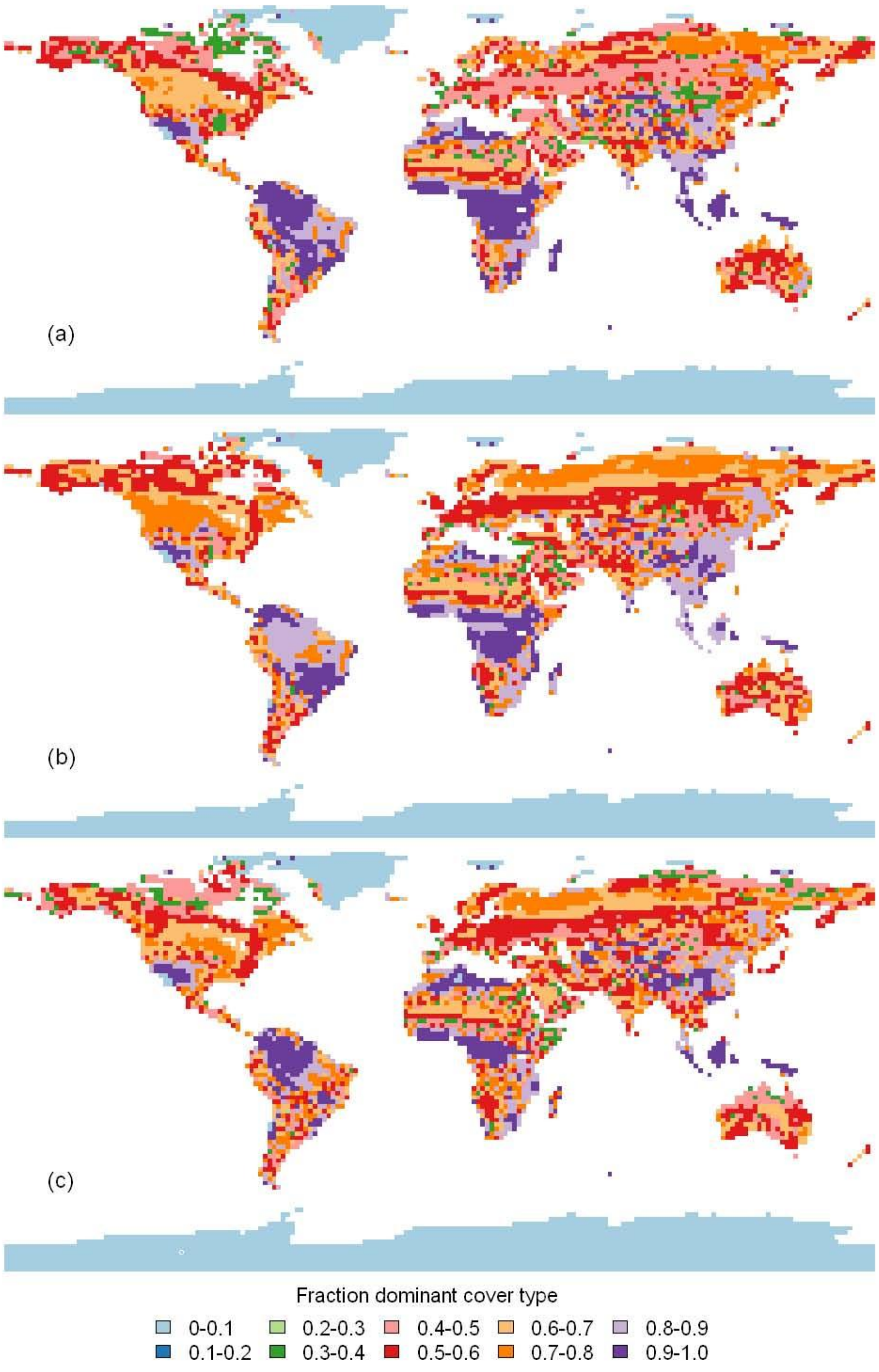


Fig. S4.1. Fractional coverage of dominant cover type (including bare soil). (a) default simulation, (b) observed traits simulation and (c) variable traits simulation.

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

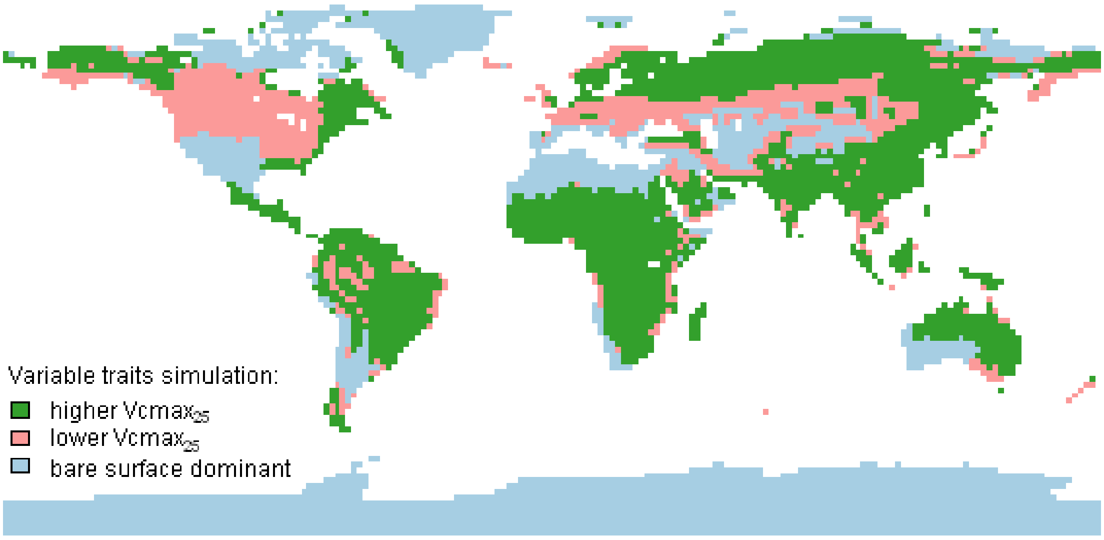


Fig.S5.1. $Vcmax_{25}$ of the dominant PFTs in the variable traits simulation relative to the default simulation. The dominant PFTs in the variable traits simulations have higher $Vcmax_{25}$ than the default simulation in the green areas and lower $Vcmax_{25}$ in the pink areas. In blue areas bare ground (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<br>temperate needleleaf evergreen forest/woodland<br>boreal evergreen forest/woodland |
| extra-tropical deciduous trees | temperate deciduous forest/woodland<br>boreal deciduous forest/woodland |
| shrubs (raingreen and deciduous) | dense shrubland<br>open shrubland |
| C3-grasses | grassland/steppe |
| C4-grasses | savanna |
| -- | tundra |
| -- | evergreen/deciduous mixed forest/woodland |

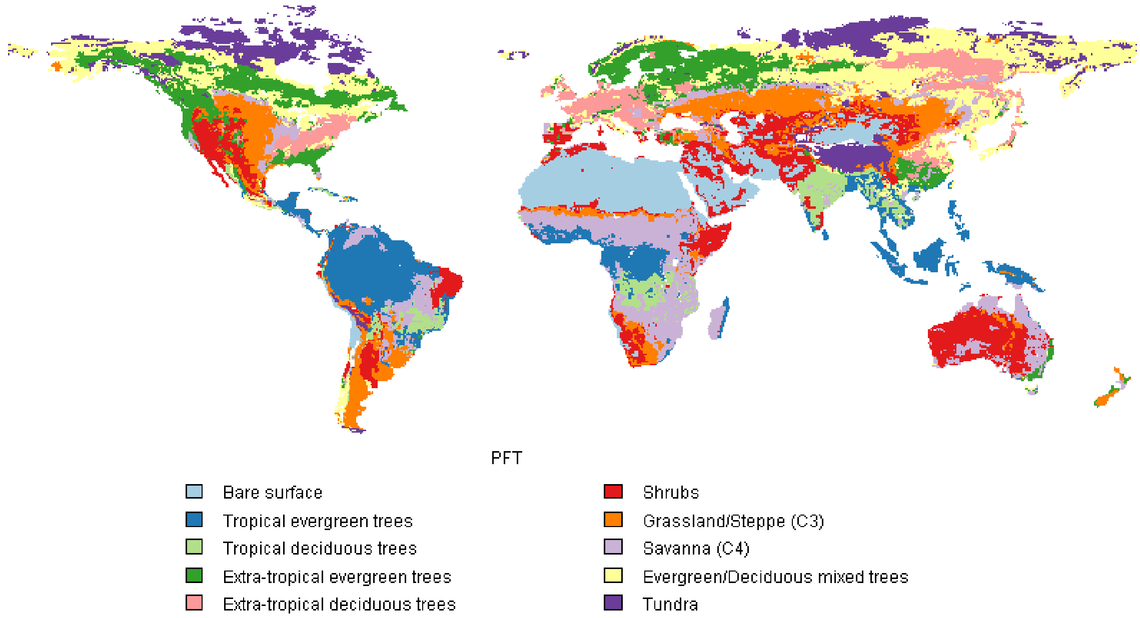


Fig. S6.1. Potential vegetation map with aggregated PFTs (see table S6.1). Evergreen/deciduous mixed forest and tundra were omitted from the comparisons with JSBACH vegetation distribution.

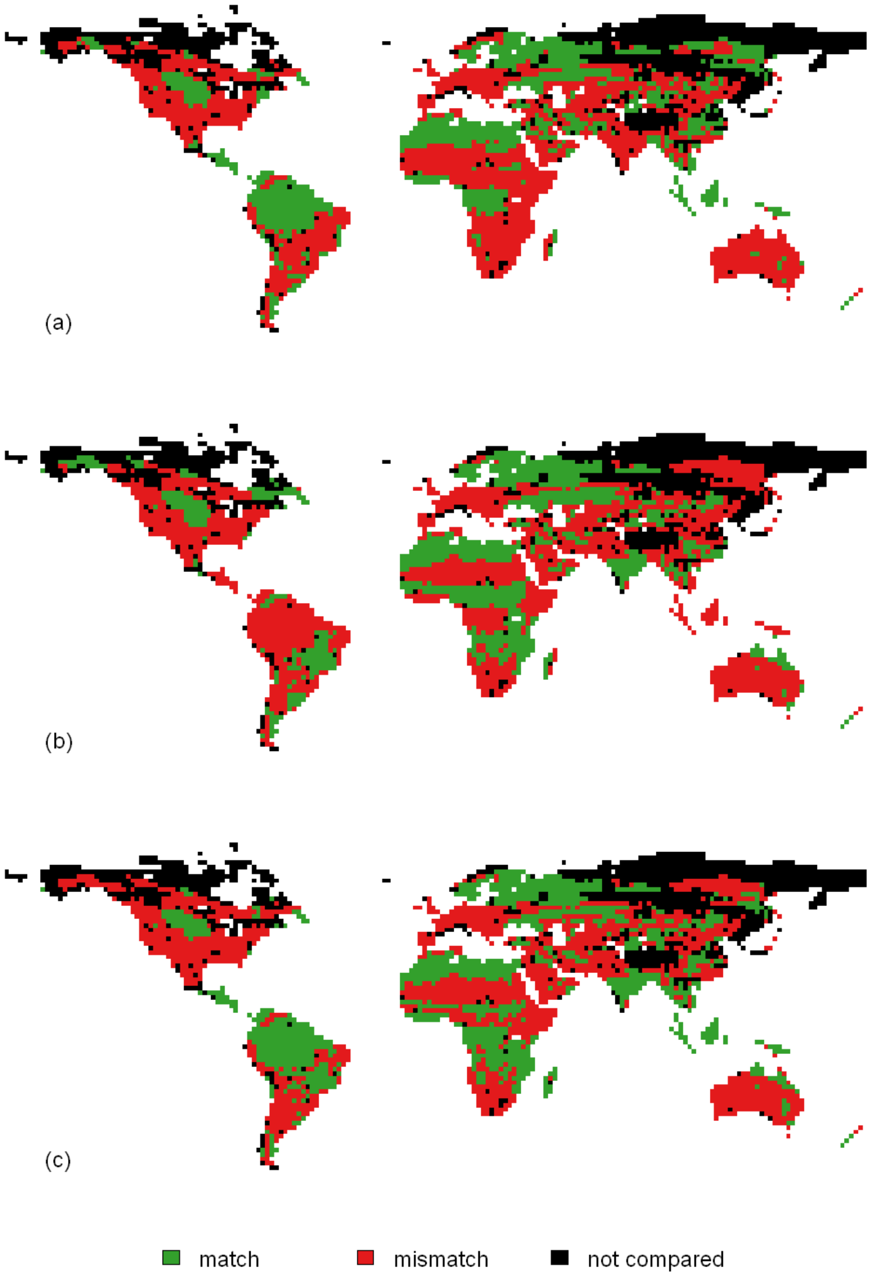


Fig. S6.2. (Mis-)match between simulations and aggregated potential vegetation map for (a) default simulation, (b) observed traits simulation and (c) variable traits simulation.

## S7 World map with simulated total biomass carbon in vegetation.

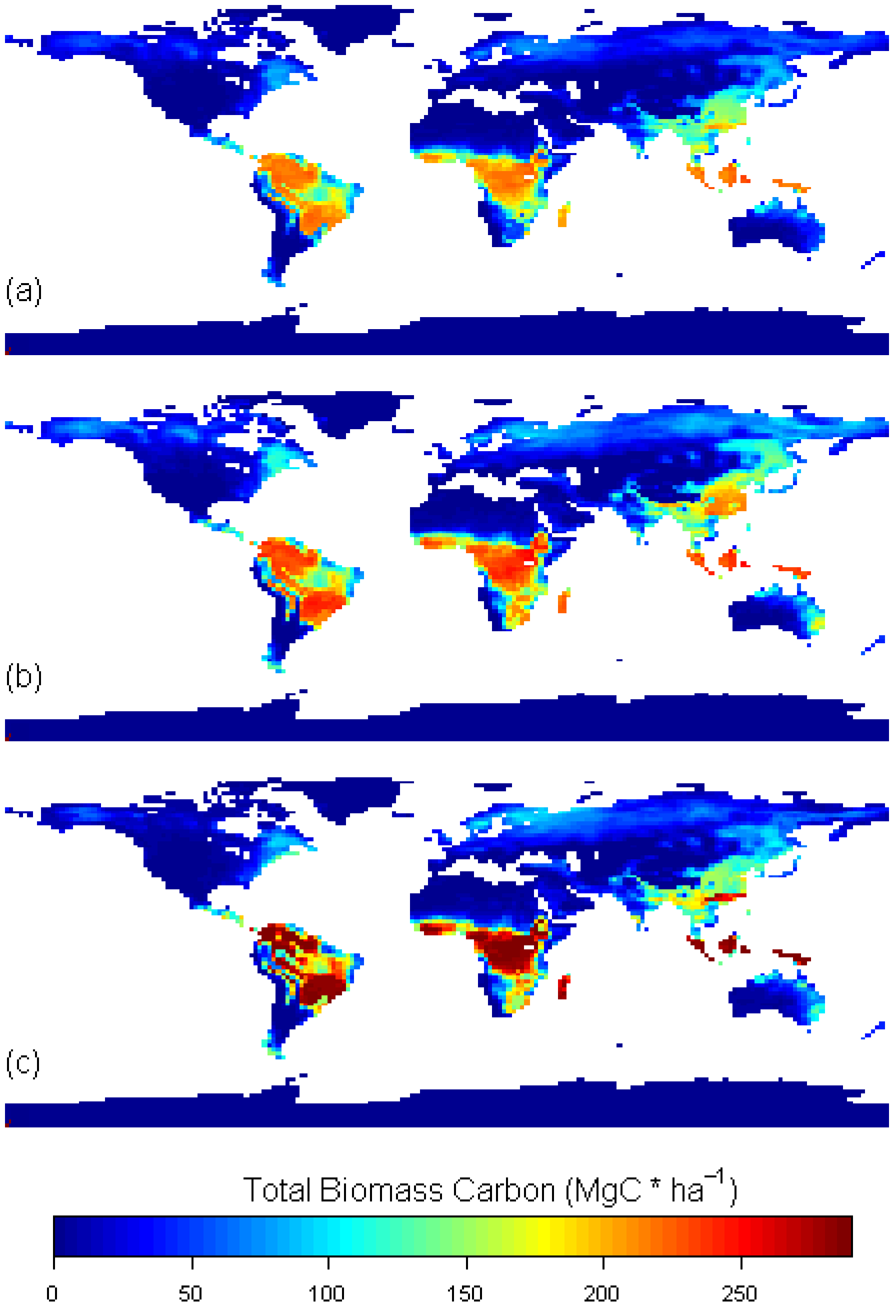


Fig. S7.1. Total biomass carbon (MgC ha$^{-1}$) of (a) default simulation, (b) observed traits simulation and (c) variable traits simulation.