# Supplementary materials

## Text 1. Descriptions of photosynthesis module in the CABLE model

Leaf photosynthesis, stomatal conductance, and heat and water transfer in CABLE are calculated using the two-leaf approach (Wang and Leuning, 1998) for both sunlit leaves and shaded leaves. The two-leaf model uses the same set of equations for calculating photosynthesis, transpiration and sensible heat fluxes for an individual leaf, but with the bulk formulation for the parameters for all sunlit and shaded leaves separately. For a given leaf parameter *P*, the corresponding parameter values for the two big leaves are calculated as:

(big sunlit leaves) (S1)

(big shaded leaves) (S2)

is the fraction of sunlit leaves within a canopy, calculated by = exp(-, where is the extinction coefficient of direct beam radiation for a canopy with black leaves. is cumulative LAI.

CABLE calculates plant photosynthesis rate according to Leuning (1990). Leuning (1990) described a method to calculate stomatal conductance, CO2 assimilation, and intercellular CO2 by solving equations describing the supply of CO2 through stomata and demand for CO2 in photosynthesis (Farquharet al., 1980) simultaneously. Since C3 plants have similar mechanisms for photosynthesis and respond to eCO2 much stronger than C4 plants, C3 plants are only considered in this study. Canopy net photosynthesis rate is calculated as:

(S3)

(S4)

(S5)

(S6)

Where are canopy assimilation rates limited by Rubisco activity, RuBP regeneration and sink respectively. is day respiration, which is proportional to is the maximum catalytic activity of Rubisco of big leaves. is intercellular CO2 concentration. is the CO2 compensation point in the absence of day respiration. and are Michaelis-Menten constants for CO2 and O2 respectively. is intercellular oxygen concentration. , and are only functions of leaf temperature. is the maximum rate of photosynthesis at saturating for a given absorbed photo irradiance of big leaves. For sunlit and shaded leaves, and are defined as follows:

=(S7)

= (S8)

= (S9)

= (S10) Where is maximum carboxylation rate when photosynthesis is limited by Rubisco activity of a leaf. is maximum potential electron transport rate of a leaf. Subscripts “*sun*” and “*sha*” denote the sunlit and shaded components. It’s assumed =2 in the model. and describe the temperature dependence of and for sunlit leaves respectively. and describe the temperature dependence of and for shaded leaves respectively. is extinction coefficient of a canopy of black leaves for direct beam radiation. is an empirical parameter used to describe the vertical distribution of leaf nitrogen in the canopy. In our simulation, is uniformly assigned as 0.001 for different plant functional types.

is stomatal conductance, and is calculated as:

(S11)

Where is stomatal conductance when =0. and are empirical constants, is an empirical parameter describing the availability of soil water for plants. is net assimilation rate in Eq. (S3). is CO2 mol fraction at the leaf surface. is CO2 compensation point of photosynthesis is vapour pressure deficit at the leaf surface.

## Text 2. Mathematic derivations of big-leaf

Equation (S4) and (S5) can be simplified as:

(S12)

= (S13)

Where and represent leaf-level Rubisco- and RuBP-limit photosynthesis rates respectively:

= (S14)

= (S15)

is a function of LAI, indicating the scaling factor that scales fluxes at the single top leaf of the canopy to whole canopy fluxes. The formulations of for sunlit leaves and shaded leaves are:

= (S16)

= (S17)

where subscripts “*sun*” and “*sha*” denote the sunlit and shaded components of the scaling factors.

Big-leaf can be decomposed as the sum of normalized sensitivity of photosynthesis rate: and leaf-to-canopy scaling factor: as shown in Eq. (S18) and Eq. (S19). Subscripts “*sun*” and “*sha*” denote the sunlit and shaded components of leaf-level photosynthesis and leaf-to-canopy scaling factors.

== += (S18)

= += (S19)

**Table S1. Prescribed minimum LAI and maximum LAI values for C3 PFTs in CABLE. Abbreviations are the same as Fig. 1.**

|  |  |  |
| --- | --- | --- |
| PFT | LAImin | LAImax |
| ENF | 0.5 | 7 |
| EBF | 1 | 7 |
| DNF | 0.35 | 7 |
| DBF | 0.35 | 7 |
| SHB | 0.1 | 3 |
| C3GRAS | 0.1 | 3 |
| TUN | 0.1 | 3 |



**Figure S1. Temporal trends of yearly average LAI for C3 PFTs from 1901 to 2100 from CABLE-C only (a), CABLE-CN (b), and CABLE-CNP (c) simulations. LAI value of evergreen broadleaf forest increases with time but gradually saturates at the prescribed maximum value from CABLE-C only simulation. LAI values of other plants also increase but are far below the prescribed maximum values at 2100 in all simulations. The inset in (c) is the enlarged view of LAI trends for shrub and tundra under RCP8.5 scenario in CABLE-CNP simulation, which show some oscillations. Abbreviations and symbols are the same as Fig. 1.**

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**Figure S2. Responses of yearly intercellular CO2 concentration () to eCO2 of a single sunlit leaf (a) and shaded leaf (b) for C3 PFTs from CABLE-CN simulation. Temporal trends of CO2 compensation point in the absence of day respiration () for sunlit leaf (c) and shaded leaf (d) during 2011 to 2100 from CABLE-CN simulation. The ratio of to (/) is approximately constant with eCO2 for each PFT and varies little across PFTs. values vary across PFTs, but do not change over time for each PFT. Abbreviations and symbols are the same as Fig. 1.**

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**Figure S3. Responses of yearly intercellular CO2 concentration () to eCO2 of a single sunlit leaf (a) and shaded leaf (b) for C3 PFTs from CABLE-CNP simulation. Temporal trends of CO2 compensation point in the absence of day respiration () for sunlit leaf (c) and shaded leaf (d) during 2011 to 2100 from CABLE-CNP simulation. The ratio of to (/) is approximately constant with eCO2 for each PFT and varies little across PFTs. values vary across PFTs, but do not change over time for each PFT. Abbreviations and symbols are the same as Fig. 1.**

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**Figure S4. Correlations between NPP and GPP with eCO2 from 2011 to 2100 for C3 PFTs from CABLE-C only simulation. Abbreviations are the same as Fig. 1.**



**Figure S5. Correlations between and for patches within each C3 PFT at the year 2023 from CABLE-C only simulation. Plants of the same type but at different locations show diverse responses of GPP primarily because the sensitivities of LAI vary. The relationships are all significant at the 0.001 level. Abbreviations are the same as Fig. 1.**



**Figure S6. Correlations between and for patches within each C3 PFT at the year 2023 from CABLE-C only simulation. Plants of the same type but at different locations show diverse responses of NPP primarily because the sensitivities of LAI vary. The relationships are all significant at the 0.001 level. Abbreviations are the same as Fig. 1.**



**Figure S7. Correlations between and for patches within each C3 PFT at the year 2023 from CABLE-C only simulation. The correlations between and are weaker than those between and . The relationships are all significant at the 0.001 level. Abbreviations are the same as Fig. 1.**



**Figure S8. Comparision between leaf-level calculated through biochemical parameters and for sunlit leaf (\_psun) and shaded leaf (\_psha) and sensitivities of GPP/LAI (\_GPP/LAI) for different C3 PFTs at the year 2023 from CABLE-C only simulation. Abbreviations are the same as Fig. 1.**



**Figure S9. Temporal trends of the leaf-to-canopy scaling factors for sunlit leaves and shaded leaves of different C3 PFTs from the CABLE-C only simulation from 2011 to 2100. The magnitudes of the scaling factors for shaded leaves are greatly larger than those for sunlit leaves for all C3 PFTs. And the scaling factors for sunlit leaves of evergreen broadleaf forest, evergreen needleleaf forest and deciduous broadleaf forest gradually saturate with eCO2.** **Abbreviations and symbols are the same as Fig. 1.**