SUPPLEMENTARY MATERIAL. Energy, water and carbon exchanges in managed forest ecosystems: description and evaluation of the INRAE GO+ model, version 3.0.

Virginie Moreaux[1,11], Simon Martel[1,10], Alexandre Bosc[1], Delphine Picart[1], David Achat[1], Christophe Moisy[1], Raphael Aussenac[1], Christophe Chipeaux[1], Jean-Marc Bonnefond[1], Pierre Trichet[1], Rémi Vezy[2], Vincent Badeau[3], Bernard Longdoz[3], André Granier[3], Olivier Roupsard[4], Manuel Nicolas[5], Kim Pilegaard[6], Giorgio Matteucci[7], Claudy Jolivet[8], Andrew T. Black[9], Olivier Picard[10], and Denis Loustau[1]

[1]Bordeaux-Sciences-Agro, INRAE, UMR ISPA, Villenave d'Ornon, F-33140, France
[2]AMAP, Univ Montpellier, CIRAD, CNRS, INRAE, IRD, Montpellier, France
[3]INRAE, UMR SILVA 1434, Champenoux, F-54280, France
[4]Eco&Sols, Univ. Montpellier, CIRAD, INRAE, IRD, Montpellier SupAgro, Montpellier, France
[5]ONF, Département RDI, Fontainebleau, F-77300, France
[6]Technical University of Denmark, Department of Environmental Engineering, 2800 Kgs. Lyngby, Denmark
[7]CNR,ISAFOM, I-80056 Ercolano (NA) Italy
[8]INRAE, US1106 InfoSol, Orléans, F-45075, France
[9]Faculty of Land and Food Systems, Vancouver, BC - V6T 1Z4, Canada
[10]CNPF-IDF, Paris, F-75000 France
[11]Université de Grenoble-ALpes,CNRS, UMR IGE 5001, Grenoble, F-38058, France

Correspondence: Denis Loustau (denis.loustau@inrae.fr)

1 introduction

This supplementary material is including details of the equations and algorithms cited in the main article. It is organised in different sections corresponding to specific processes included in the GO+ model. Some additional illustrations of the sensitivity analysis, uncertainty analysis and model evaluation are also provided in the last section number 9. The tables and figures are presented at the end of the document for readability. The main table,Table S1, shows the complete list of the model parameters. Each parameter refers to one or several entities that are denoted in the third column, namely:

- entire vegetation layers, either the trees, T, or understorey, U;
- individual tree, t;
- soil, S;
- "air" or "water" for the parameters related to the air or water physical constants or thermodynamic properties.

The Table S1 is organised in subsections corresponding to the physical constants, radiative transfer, latent and sensible heat transfer, physiological parameters, canopy structure, phenology, soil hydraulics and soil carbon. Further details on variables and parameters as well as the GO+V3 version code are available at https://github.com/DenisLOUSTAU/GOplus_model_INRAE.

2 Radiative transfer

2.1 Canopy foliage

We have assumed that, providing adequate values of the parameters are used, the de Pury and Farquhar (1997, further abbreviated as dPF) model for the 400–700 nm domain may be extended to the entire shortwave domain (300–1200 nm). The calculations are identical for both canopy layers and all values are expressed on a ground area basis. As the first step, the sunlit leaf area index of the layer c is given by :

$$LAI_{sun,c} = 1 - LAI_{shade,c} = \frac{1 - \exp(-k_{b,c} \times LAI_c)}{k_{b,c}} \tag{S1}$$

where LAI_c is the leaf area index and $k_{b,c}$ the canopy extinction coefficient for direct beam radiation that is:

$$k_{b,c} = \frac{k_{bh,c}}{sin\beta} \tag{S2}$$

$k_{bh,c}$ being the extinction coefficient for a beam normal to the canopy (dPF, Eq.18). The canopy reflection coefficients for direct radiation and a uniform leaf distribution are given by :

$$\rho_{b,c}(\beta) = 1 - \exp[\frac{-2 \times \rho_{h,c} \times k_{b,c}}{(1 + k_{b,c})}]$$

$$\rho_{h,c} = \frac{1 - (1 - \sigma_l)^{1/2}}{1 + (1 - \sigma_l)^{1/2}} \tag{S3}$$

where $\rho_{h,c}$ is the reflection coefficient from the horizontal surface and σ_l is the leaf scattering coefficient that is $\rho_l + \tau_l$ (dPF eq. A19 to A20). For sake of simplicity, the diffuse radiation reflection coefficient for the canopy is fixed at a constant value $\rho_{d,c} = 0.036$ rather than calculated as the $\rho_{b,c}$ integral over $\pi/2$. For accounting for the scattering of radiation, extinction coefficients including scattered radiations are introduced (dPF Eq. A4):

$$k'_{b,c} = k_{b,c}(1 - \sigma_l)^{0.5}$$

$$k'_{d,c} = k_{d,c}(1 - \sigma_l)^{0.5} \tag{S4}$$

The irradiance absorbed by the sunlit fraction of each canopy layer is given as the sum of direct, diffuse and scattered-beam components:

$$\begin{aligned} SW_a(sun) = & \\ & SW_{dir} \times (1-\sigma_c) \times [1-\exp(-k_{b,c} \times LAI_c)] \\ & + (SW_{dif}\downarrow + SW_{dif}\uparrow) \times (1-\rho_{d,c}) \times [1-\exp(-(k'_{d,c}+k_{b,c}) \times LAI_c)] \times \frac{k'_{d,c}}{(k'_{d,c}+k_{b,c})} \\ & + SW_{dir} \times (1-\rho_{b,c}) \times [1-\exp(-(k'_{b,c}+k_{b,c}) \times LAI_c) \times \frac{k'_{b,c}}{(k'_{b,c}+k_{b,c})}] \\ & -(1-\sigma_c) \times \frac{[1-\exp(-2 \times k_{b,c} \times LAI_c)]}{2} \end{aligned} \tag{S5}$$

where α, ρ_{cd} and ρ_{cb} are the leaf absorbance and diffuse and direct beam canopy reflectance respectively (Eq. 20-b, to 20-d dPF). The total amount of SW radiation absorbed is :

$$SW_a = (1-\rho_b) \times SW_b \times [1-\exp(-k'_b \times LAI)] + (1-\rho_d) \times SW_d \times [1-\exp(-k'_d \times LAI)] \tag{S6}$$

The amount of shortwave radiation that is absorbed by the shaded canopy fraction is then :

$$SW_a(shade) = SW_a - SW_a(sun) \tag{S7}$$

The longwave radiation absorbed by a canopy layer is given by:

$$LW_{a,c} = (LW\downarrow_{I,c} + LW\uparrow_{I,c}) - (LW\downarrow_{S,c} + LW\uparrow_{S,c}) \tag{S8}$$

where the subscripts I and S stand for intercepted and scattered radiation. These are calculated following Berbigier and Bonnefond (1995) assuming a fixed partitioning of the scattering of intercepted radiation between reflection (0.75) and transmission (0.25) :

$$\begin{aligned} & LW\downarrow_{I,c} = LW\downarrow_{c-1} \times (1-\exp[(k_{LW1}+k_{LW2} \times LAI_c) \times LAI_c] \\ & LW\uparrow_{I,c} = LW\uparrow_{c+1} \times (1-\exp[(k_{LW1}+k_{LW2} \times LAI_c) \times LAI_c] \\ & LW\uparrow_{S,c} = (1-\epsilon) \times (LW\downarrow_{I,c} \times 0.75 + LW\uparrow_{I,c} \times 0.25) \\ & LW\downarrow_{S,c} = (1-\epsilon) \times (LW\downarrow_{I,c} \times 0.25 + LW\uparrow_{I,c} \times 0.75) \end{aligned} \tag{S9}$$

The subscript c refers to the layer number increasing from the top to the bottom of the canopy.

2.2 Canopy Woody parts

The wood area index (WAI) intercepting radiation and rainfall accounts for the interception by the tree trunks and branches. WAI is function of the stem standing stock, SD, mean trunk diameter (D_{130}, cm) and height (H_c) and a tree stand shape factor,f, that is the ratio of stand tree stem volume over the product $BA \times H_c$ (m^3), and branches biomass (kg dry matter m^{-2}) :

$$WAI = \frac{f \times SD \times H_c \times D_{130} \times \cos(75)}{100 \times area} + \frac{4 \times W_{T,branches} \times \cos(45)}{d_{wood} \times 1000 \times \Pi \times D_{130}/100/5} \tag{S10}$$

The first part of the left member refers to the stem and the second part to the branches, where the mean angle between beam radiation –or rainfall– is here 75 and 45 degrees for trunks and branches respectively and the mean branch diameter is $1/5$ of the stem diameter. These values are species specific. The interception of throughfall by the understorey woody parts is neglected.

3 Rainfall interception model

The wet and dry fractions of each canopy and soil layer are calculated dynamically using Gash's (1979) canopy water balance model resolved at an hourly time step, $S_{W,c,h}$. The rainfall amounts intercepted by the canopy, $Rain_{I,c}$, and the throughfall and stemflow dripping from the canopy layer, $Rain_{TS,c}$ are calculated :

$$Rain_{I,c} = Rain \times [1 - \exp(k_{R,f} \cdot LAI + k_{R,w} \cdot WAI))] \tag{S11}$$

$$Rain_{TS,c} = [S_{w,c,h-1} + Rain_{I,c} - E_{wet,c}] - S_{Wmax,c} \tag{S12}$$

$$S_{W,c,h} = S_{w,c,h-1} + Rain_{I,c} - E_{wet,c} - Rain_{TS,c} \tag{S13}$$

$$f_{dry,c,h} = 1 - \frac{S_{W,c,h}}{S_{Wmax,c}} \tag{S14}$$

where k_R are rainfall extinction coefficients for the canopy and $S_{Wmax,c}$ the canopy storage capacity that is $(LAI_c \times S_{Wmax,f} + WAI_c \times S_{Wmax,w})$ with S_{Wmax} the storage capacity per unit area of LAI or WAI area.

4 Water transfer model

- The mean tree water capacitance, C_T (kg H$_2$O m^{-2} leaf area MPa^{-1}, Eq. 21) is taken from Loustau et al. (2000).

  $$C_T = \frac{0.07 \times W_T}{13} \tag{S15}$$

  where W_T is the tree biomass (kg d.m. m^{-2}soil area).

- The calculation of soil water potential in the soil rooted zone comes from Van Genuchten (1980):

  $$\psi_{soil} = \frac{-1}{\alpha_{VG}} \times [(\frac{\theta_{rootlayer} - \theta_{WP}}{\theta_{FC} - \theta_{WP}})^{\frac{-1}{m_{VG}}} - 1]^{1-m_{VG}} \times 10^{-3} \tag{S16}$$

  where 10^{-3} converts unit from kPa to MPa.

5 Photosynthesis

The photosynthetic carbon uptake by each canopy layer is formalised in GO+ following de Pury and Farquhar (1998) and Farquhar et al. (1980) as :

$$Anet_c = (1 - \frac{\Gamma^*}{c_c}) \times min(W_{c,c}, W_{c,j}) - R_d \tag{S17}$$

The net carbon assimilation is calculated separately for shaded and sunlit fractions of the foliage but apart from the amount of light absorbed per unit leaf area, the calculations are identical and are not duplicated here. The two terms $W_{c,c}$ and $W_{c,j}$ are the Ribulose biPhosphate carboxylation rate limited by the RubisCO activity and the rate of regeneration of Ribulose -biPhosphate limited by electron transport respectively.

$$W_{c,c} = \frac{c_c \times V_{cmax,c}}{c_c + K_c \times (1 + O_2/K_o)} \qquad W_{c,j} = \frac{J_{c,c}}{4 + 8 \times \Gamma^*/c_c} \tag{S18}$$

The electron transport rate, J_c (μmol e- m^{-2} s^{-1}), with $Q_{c,a}$ being the amount of light absorbed by unit leaf area (μmol photons m^{-2} s^{-1}) and α the quantum efficiency of electron transport (mol e- mol photons $^{-1}$), is:

$$J_c = \frac{\alpha \times Q_{c,a} + J_{max,c} - \sqrt{(\alpha \times Q_{c,a} + J_{max,c})^2 - 4 \times \theta \times \alpha \times Q_{c,a} \times J_{max,c}}}{2 \times \theta} \tag{S19}$$

The conversion of the amount of SW radiation absorbed by a vegetation layer and exposure class — sunlit or shaded —, $SW_{a,c,s}$, into moles of photons in the band 400-700 nm absorbed by a unit area of leaf, $Q_{a,c,s}$, is:

$$Q_{a,c,s} = \frac{SW_{a,c,s}}{LAI_{c,s}} \times 4.6 \times 10^{-6} \tag{S20}$$

For tree species, the internal leaf conductance to the CO2 transport, $g_{m,c}$ (mol m $^{-2}$ s^{-1}) is taken from Ellsworth et al. (2015):

$$g_{m,c} = r_{m,c}^{-1} = -0.04 \times 10^{-6} + 1.34 \times g_{s,c,t} \tag{S21}$$

For understorey species, no internal resistance is included. In Eq. S18 to S21, parameters are the mean value for the entire layer and may differ from values obtained using e.g. gas exchange measurements calculations at leaf level. Following Bernacchi et al. (2001) and Medlyn et al. (2002) and with $k_{\mathrm{T,\,c}}$ a temperature factor used for describing the temperature dependency of metabolic parameters, the following temperature response functions are used:

$$k_{\mathrm{T},c} = \frac{T_{\mathrm{K,c}} - T_{\mathrm{K,ref}}}{\mathsf{R} \times T_{\mathrm{K},c} \times T_{\mathrm{K,ref}}} \tag{S22}$$

$$V_{cmax,c} = V_{cmax25,c} \times \exp(Ea(Vc) \times k_{\mathrm{T},c}) \tag{S23}$$

$$J_{max,c} = J_{opt,c} \times \frac{H_d \times \exp(H_a \times k_{\mathrm{Topt},c})}{H_d - H_a \times (1 - \exp(H_d \times k_{\mathrm{Topt},c}))} \tag{S24}$$

$$K_{c,c} = K_{c25,c} \times \exp(Ea(Kc) \times k_{\mathrm{T},c}) \tag{S25}$$

$$K_{o,c} = K_{o25,c} \times \exp(Ea(Ko) \times k_{\mathrm{T},c}) \tag{S26}$$

$$K_{m,c} = K_{c,c} \times (1 + O_2/K_{o,c}) \tag{S27}$$

$$\Gamma_c^* = \Gamma_{25}^* \times \exp(Ea(\Gamma^*) \times k_{\mathrm{T},c}) \tag{S28}$$

where $T_{\mathrm{K},c}$ is the mean temperature of foliage layer (in K), and other parameters are detailed in the Table S1.

6 Calculation of the total amount of nitrogen in the tree living biomass

The living fraction of the stem biomass in a tree, $W^*_{stem,t}$, is estimated for each individual tree t as follows:

$$W^*_{\text{stem},t} = W_{\text{stem},t} \times (1 - W^+_{\text{stem, t}}) \tag{S29}$$

where the heartwood biomass,$W^+_{stem,t}$, is:

$$W^+_{\text{stem},t} = d_{wood} \times [(\pi \times (\frac{D_{130,t}}{4})^2 - SA_t)] \times \frac{h_t}{3} \tag{S30}$$

and the living wood — or sapwood — cross sectional area, SA_t, is derived from McDowell et al. (2002),assuming the ratio between the canopy leaf area and the cross sectional sapwood area at 1.3m height, $A_l{:}A_s$, is related to the tree height.

$$SA_t = \frac{A_{l,t}}{A_l{:}A_s}$$

and

$$A_l{:}A_s = k_{H,1} + k_{H,2} \times h_t^{k_H,3} \tag{S31}$$

The amount of nitrogen in the living stem biomass, N^*_{stem}, is :

$$N^*_{stem} = kN_{stem} \times W^*_{stem} \tag{S32}$$

where kN_{stem} is the nitrogen content of living stem part and W^*_{stem} the living stem biomass (kg d.m. m^{-2}). Whereas the live fraction of the foliage and fine roots is assumed constant to 0.8 for coniferous and 1.0 for broadleaf species, the live fraction of the other tree parts (the branches and root parts), W^*_x, is assumed to be linearly depending on the tree age:

$$W^*_x = k_{mx,x} - (k_{mx,x} - k_{mn,x}) \times \frac{Age}{100} \qquad \text{if Age<100,}$$

$$W^*_x = k_{mn,x} \qquad \text{otherwise.} \tag{S33}$$

The Table S1 lists the kN_x and $k_{mn,mx,x}$ default values used of the maritime Pine species.

7 Carbon allocation and growth

This section details the allocation equations used for different tree species in the GO+ model. The parameter values for tree biomass, D_{130} and height computations are summarised in Table S2. This section details the equations used for three species.The following equations continue the main text Eq. (31). The stem diameter,tree height and biomass values are in cm, m and kg dry matter tree^{-1} respectively.

1. Maritime pine (*Pinus pinaster* Ait.)

The allocation algorithm was derived from allometric equations (Shaiek et al. 2011, Achat et al. 2018). For clarity, we keep the same parameter name (k_1 to k_4) throughout the equations, their default values being listed in Table S2.

Step 3.1. Calculation of stem diameter, D_{130} and height, h, from the tree aboveground biomass, $W_{a,i}$.

$$D_{130_i} = k_1 \times W_{a,i,}^{k_2} \times Age^{k_3}, \tag{S34}$$

$$h_{i,} = k_1 \times W_{a,i,}^{k_2} \times Age^{k_3} \tag{S35}$$

Step 3.2. Calculation of the biomass of each tree parts (subscript i is not repeated for clarity).

$$W_{leaf,cohort=1} = k_1 \times W_a^{k_2} \times Age^{k_3} \tag{S36}$$

$$W_{stem} = k_1 \times W_a^{k_2} \times Age^{k_3} \tag{S37}$$

$$W_{leaftotal} = k_1 \times W_a^{k_2} \times Age^{k_3} \tag{S38}$$

$$W_{branches} = W_a - W_s - W_l \tag{S39}$$

$$W_{tr} = W_r \times min(k_1, k_2 \times D_{130}^{-k_3}), \tag{S40}$$

$$W_{cr} = W_r \times max(k_1, k_2 \times log(D_{130}) - k_3), \tag{S41}$$

$$W_{sr} = W_r \times min(k_1, k_2 \times D_{130}^{-k_3}), \tag{S42}$$

$$W_{fr} = W_r - W_{tr} - W_{cr} - W_{sr} \tag{S43}$$

where W_{tr}, W_{cr}, W_{sr} and W_{fr} are biomass variables of taproot, coarse roots (> 20 mm), small roots (2-20 mm) and fine roots (< 2 mm), respectively.

2. Douglas fir (*Pseudotsuga menziesii*)

Allometric equations of aboveground compartments were derived from Gholz et al. (1979). The relationship between height and aboveground biomass was computed using the GIS coop database (Seynave et al., 2018).

$$D_{130} = k_1 \times W_a^{k_2} \tag{S44}$$

$$h = k_1 \times W_a^{k_2} \tag{S45}$$

$$W_{stem} = k_1 \times W_a^{k_2} \tag{S46}$$

$$W_{leaf,cohort=1} = k_1 \times W_a^{k_2} \times Age^{k_3} \tag{S47}$$

$$W_{leaftotal} = k_1 \times W_a^{k_2} \tag{S48}$$

$$W_{branches} = W_a - W_{stem} - W_{leaftotal} \tag{S49}$$

The biomass of different root classes are simulated as follows (Achat et al. 2018):

$$W_{cr} = W_r \times max(k_1, k_2 \times log(D_{130}) - k_3), \tag{S50}$$

$$W_{fr} = W_r \times min(k_1, k_2 \times D_{130}^{-k_3}), \tag{S51}$$

$$W_{tr} = (W_r - W_{cr} - W_{fr}) \times \frac{(-k_1 \times D_{130} + k_2)}{(-k_1 \times D_{130} + k_2) + (-k_3 \times D_{130} + k_4)}, \tag{S52}$$

$$W_{sr} = (W_r - W_{cr} - W_{fr}) \times \frac{(-k_3 \times D_{130} + k_4)}{(-k_1 \times D_{130} + k_2) + (-k_3 \times D_{130} + k_4)}, \tag{S53}$$

where W_{tr}, W_{cr}, W_{sr} and W_{fr} are biomasses of stump plus taproot, coarse roots (> 40 mm), small roots (2–40 mm) and fine roots (< 2 mm), respectively.

3. European beech (*Fagus sylvatica*)

Equations for the stem, branches and foliage biomass are taken from Wutzler et al. (2008) and include covariates (altitude (m), tree age (yr) or site index(m)). Biomass of root parts are simulated following Achat et al. (2018).

$$D_{130} = k_1 \times W_a^{k_2} \times h^{k_3} \tag{S54}$$

$$W_l = k_1 \times D_{130}^{k_2} \times h^{k_3} \tag{S55}$$

$$W_{stem} = k_1 \times D_{130}^{k_2} \times h^{k_3} \tag{S56}$$

$$W_{branches} = k_1 \times D_{130}^{k_2} \times h^{k_3} \tag{S57}$$

$$W_{cr} = W_r \times \begin{cases} k_1 & \text{for } D_{130} < 4 \text{ cm} \\ k_2 - k_3 \times e^{-k_4 \times D_{130}} & \text{otherwise} \end{cases} \tag{S58}$$

$$W_{fr} = W_r \times min(k_1, k_2 \times D_{130}^{-k_3}) \tag{S59}$$

$$W_{tr} = (W_r - W_{cr} - W_{fr}) \times \frac{(k_1 \times D_{130} + k_2)}{(k_1 \times D_{130} + k_2) + (-k_3 \times D_{130} + k_4)} \tag{S60}$$

$$W_{sr} = (W_r - W_{cr} - W_{fr}) \times \frac{(-k_3 \times D_{130} + k_4)}{(k_1 \times D_{130} + k_2) + (-k_3 \times D_{130} + k_4)} \tag{S61}$$

The algorithm for the calculation of individual tree height (Le Mogedec and Dhôte, 2012) reads:

$$\begin{aligned} m &= 1.218, \qquad K = 55 \\ Cm &= \exp(1+m) \times (1 - \log 10(1+m)) \\ H0 &= K \times \exp[-((\log 10(K/1.3))^{-m} + \frac{(0.4 \times m \times Cm)}{K} \times (Age - 5))^{-1/m}] \\ alpha &= H0 - 1.3 + \pi \times 0.412 \times D_{130,i} \\ h_i &= 1.3 + \frac{alpha - \sqrt{alpha^2 - 4 \times \pi \times 0.412 \times 0.98764 \times (h0 - 1.3) \times D_{130,i}}}{2 \times 0.98764} \end{aligned} \tag{S62}$$

where W_{tr} , W_{cr} , W_{sr} and W_{fr} are the biomass of stump, coarse roots (> 40 mm), small roots (2-40 mm) and fine roots (< 2 mm), respectively.

8 Vegetation phenology and growth

8.1 Tree species

Table S3 details the references used for simulating the lifecycle of the foliage for three European tree species and Table S4 lists the equations and parameters used for modelling the senescence of living organs of the individual trees. They include a temperature dependent budburst date and a fixed foliage lifecycle for the coniferous needles. The onset of senescence of beech leaves depends on the amount of incident shortwave radiation accumulated from budburst until DOY 258.

8.2 Understorey

The phenology of the understorey vegetation is shown in Table S5. It includes a simple thermal time model for leaf unfolding and a mechanistic model of foliage growth, as described in the main text, that is sensitive to temperature and soil moisture. The maximal foliage life duration is fixed and is shortened by high water deficit of the soil or low air temperature.

9 Sensitivity and uncertainty analysis

9.1 Sensitivity assessment

Figures S1 to S3 show the values of the sensitivity value index (Eq. 38 of the main text) of 14 output variables related to the main energy, water and CO_2 fluxes to 28 model parameters and for the years 1994 (wet), 2005 (wet) and the full rotation cycle 1970–2010 in a coniferous stand at Le Bray . The following figures S4 and S5 illustrate the long-term sensitivity of "fluxes" and "stocks" variables to meteorological forcing variables over a forest rotation (1970-2010).

9.2 Uncertainty assessment

The normalized uncertainty values of key model variables calculated for the Le Bray site are shown Figs. S6–S8. The variables are split by canopy layers whereas the overall ecosystem values are given in Figs. 10–11 of the main text. The uncertainty is calculated from the uncertainty of the 14 most influential parameters of the model (Table 3 of the main text) using the MonteCarlo method with 2500 runs for the year 1994 at the Le Bray site.

9.3 Model evaluation

Table S7 presents the variance fraction accounted for by model predictions at different time spans of the latent heat, net radiation Rn, latent heat flux, λE and net ecosystem exchange, NEE. It continues the table 7 of the main article.

References

Achat, D. L., Martel, S., Picart, D., Moisy, C., Augusto, L., Bakker, M. R., and Loustau, D.: Modelling the nutrient cost of biomass harvesting under different silvicultural and climate scenarios in production forests, For Ecol Manag, 429, 642-653, 2018.

Berbigier, P., and Bonnefond, J. M.: Measurement and Modeling of Radiation Transmission within a Stand of Maritime Pine (Pinus-Pinaster Ait), Ann For Sci, 52, 23-42, 1995.

Berbigier, P., Bonnefond, J. M., and Mellmann, P.: CO2 and water vapour fluxes for 2 years above Euroflux forest site, Agric For Meteorol, 108, 183-197, 2001.

Bernacchi, C. J., Singsaas, E. L., Pimentel,C., Portis Jr A. R., and Long S. P.: Improved temperature response functions for models of Rubisco-limited photosynthesis, Plant Cell Environ 24(2): 253-259, 2001.

Bosc, A., Grandcourt, A. D., and Loustau, D.: Variability of stem and branch maintenance respiration in a Pinus pinaster tree, Tree Physiol, 23, 227-236, 2003.

Chen, J. M. and Black, T. A.: Defining leaf area index for non-flat leaves, Plant Cell Environ, 15, 421-429, 1992.

Coleman K., and Jenkinson:, D.D.: RothC - 26.3 - A model for the turnover of carbon in soil. , in: Evaluation of soil organic matter models using existing, long-term datasets., edited by: Powlson D.S., Smith P., and J.U., S., NATO ASI Series I, Springer Verlag, Heidelberg, Germany, 237-246, 1996.

DePury, D. G. G. and Farquhar, G. D.: Simple scaling of photosynthesis from leaves to canopies without the errors of big-leaf models, Plant Cell Environ, 20, 537-557, 1997.

Desprez-Loustau, M. L., and Dupuis, F.: Variation in the phenology of shoot elongation between geographic provenances of maritime pine (Pinus pinaster)-implications for the synchrony with the phenology of the twisting rust fungus, Melampsora pinitorqua, Ann Sci Forest, 51, 553-568, 1994.

Ellsworth, D. S., Crous, K. Y., Lambers, H., and Cooke, J.: Phosphorus recycling in photorespiration maintains high photosynthetic capacity in woody species, Plant Cell Environ, 38, 1142-1156, 10.1111/pce.12468, 2015.

Farquhar, G. D., von Caemmerer, S., and Berry, J.: A biochemical model of photosynthetic CO2 assimilation in leaves of C3 species, Planta, 149, 78-90, 1980.

Gash, J. H. C.: Analytical model of rainfall interception by forests, Q J Roy Meteor Soc, 105, 43-55, 10.1002/qj.49710544304, 1979.

Gholz, H. L. : Limits on aboveground net primary pro- duction, leaf area, and biomass in vegetational zones of the Pacific Northwest. Dissertation. Oregon State University, Corvallis, Oregon, USA, 1979.

Granier, A., and Loustau, D.: Measuring and modelling the transpiration of a maritime pine canopy from sap-flow data, Agr Forest Meteorol, 71, 61-81, 1994.

Granier, A., Bréda, N., Longdoz, B., Gross, P., and Ngao, J.: Ten years of fluxes and stand growth in a young beech forest at Hesse, North-eastern France, Ann For Sci, 65, 704-704, 2008.

Harrington, C. A., Gould, P. J., and St Clair, J. B.: Modeling the effects of winter environment on dormancy release of Douglas-fir, Forest Ecol Manag, 259, 798-808, 10.1016/j.foreco.2009.06.018, 2010.

Kramer, K.: Selecting a Model to Predict the Onset of Growth of Fagus-Sylvatica, Journal of Applied Ecology, 31, 172-181, 1994.

Le Moguedec, G., and Dhote, J. F.: Fagacees: a tree-centered growth and yield model for sessile oak (Quercus petraea L.) and common beech (Fagus sylvatica L.), Ann Sci For, 69, 257-269, 10.1007/s13595-011-0157-0, 2012.

Loustau, D., Domec, J. C., and Bosc, A.: Interpreting the variations in xylem sap flux density within the trunk of maritime pine (Pinus pinaster Ait.): application of a model for calculating water flows at tree and stand levels, Ann Sci For, 55, 29-46, 1998.

McDowell, N., Barnard, H., Bond, B. J., Hinckley, T., Hubbard, R. M., Ishii, H., Kostner, B., Magnani, F., Marshall, J. D., Meinzer, F. C., Phillips, N., Ryan, M. G., and Whitehead, D.: The relationship between tree height and leaf area:sapwood area ratio, Oecologia, 132, 12-20, 2002.

Medlyn, B. E., Barton, C. V. M., Broadmeadow, M. S. J., Ceulemans, R., De Angelis, P., Forstreuter, M., Freeman, M., Jackson, S. B., Kellomäki, S., Laitat, E., Rey, A., Roberntz, P., Sigurdsson, B. D., Strassemeyer, J., Wang, K., Curtis, P. S., and Jarvis, P. G.: Stomatal conductance of forest species after long-term exposure to elevated CO2 concentration: a synthesis, New Phytol, 149, 247-264, 10.1046/j.1469-8137.2001.00028.x, 2001.

Medlyn, B. E., Dreyer, E., Ellsworth, D., Forstreuter, M., Harley, P. C., Kirschbaum, M. U. F., Le Roux, X., Montpied, P., Strassemeyer, J., Walcroft, A., Wang, K., and Loustau, D.: Temperature response of parameters of a biochemically based model of photosynthesis. II. A review of experimental data, Plant Cell Environ, 25, 1167-1179, 2002.

Mohren, G. M. J., and Bartelink, H. H.: Modeling the effects of needle mortality-rate and needle area distribution on dry-matter production of Douglas-fir, Neth J Agr Sci, 38, 53-66, 1990.

Moreaux, V.: Observation et modélisation des échanges d’énergie et de masse de jeunes peuplements forestiers du Sud-Ouest de la France., Ph. D.thesis., Ecole Doctorale 304 "Sciences et Environnements", Thématique "Physique de l’Environnement", Université de Bordeaux-1, Bordeaux, 262 pages pp., 2012.

Nakai, T., Sumida, A., Daikoku, K. i., Matsumoto, K., van der Molen, M. K., Kodama, Y., Kononov, A. V., Maximov, T. C., Dolman, A. J., Yabuki, H., Hara, T., and Ohta, T.: Parameterisation of aerodynamic roughness over boreal, cool- and warm-temperate forests, Agr Forest Meteorol, 148, 1916-1925, https://doi.org/10.1016/j.agrformet.2008.03.009, 2008.

Penningdevries, F. W., Brunsting, A. H., and Vanlaar, H. H.: Products, requirements and efficiency of biosynthesis - Quantitative approach, J Theor Biol, 45, 339-377, 1974.

Pilegaard, K., Ibrom, A., Courtney, M. S., Hummelshøj, P., and Jensen, N. O.: Increasing net CO2 uptake by a Danish beech forest during the period from 1996 to 2009, Agric For Meteorol, 151, 934-946, 2011.

Porté, A., and Loustau, D.: Variability of the photosynthetic characteristics of mature needles within the crown of a 25-year-old Pinus pinaster, Tree Physiol, 18, 223-232, 1998.

Ryan, M. G.: Effects of climate change on plant respiration, Ecol Appl, 1, 157-167, 1991.

Scartazza, A., Moscatello, S., Matteucci, G., Battistelli, A., and Brugnoli, E.: Seasonal and inter-annual dynamics of growth, non-structural carbohydrates and C stable isotopes in a Mediterranean beech forest, Tree Physiol, 33, 730-742, 2013.

Seynave, I., Bailly, A., Balandier, P., Bontemps, J.-D., Cailly, P., Cordonnier, T., Deleuze, C., Dhôte, J.-F., Ginisty, C., Lebourgeois, F., Merzeau, D., Paillassa, E., Perret, S., Richter, C., and Meredieu, C.: GIS Coop: networks of silvicultural trials for supporting forest management under changing environment, Ann For Sci, 75, 48, 10.1007/s13595-018-0692-z, 2018.

Shaiek, O., Loustau, D., Trichet, P., Meredieu, C., Bachtobji, B., Garchi, S., and El Aouni, M. H.: Generalized biomass equations for the main aboveground biomass components of maritime pine across contrasting environments, Ann Sci For, 68, 443-452, 2011.

Vangenuchten, M. T.: A closed-form equation for predicting the hydraulic conductivity of unsaturated soils, Soil Sci Soc Am J, 44, 892-898, 1980.

Wutzler, T., Wirth, C., and Schumacher, J.: Generic biomass functions for Common beech (Fagus sylvatica) in Central Europe: predictions and components of uncertainty, Can J For Res, 38, 1661-1675, 10.1139/x07-194, 2008.

Table S1: List of the model parameters. Default values are for Pine species unless specified. Additional values of other tree species are downloadable with the GO+ software package.

Symbol	Definition and entity concerned		Unit	Default value	Ref
Physical constants					
γ	Psychrometric constant	air	Pa K^{-1}	66.1 at 293 K	
λ	Latent heat of vaporisation	water	MJ Kg^{-1}	2.45 at 293 K	
ρ_a	dry air density	air	kg m^{-3}	1.20 at 293 K	
σ	Stefan-Boltzmann constant	all	W $m^{-2}K^{-4}$	5.6703 E-8	
c_p	Specific heat capacity	air	J kg^{-1} K^{-1}	1010	
D_{CO2}	CO_2 diffusivity	air	m^2 s^{-1}	1.47 E-7	
D_{H2O}	H_2O diffusivity	air	m^2 s^{-1}	2.42 E-7	
g	Acceleration due to gravity	air	m^2 s^{-1}	9.8067	
k	Von Karman constant	air	-	0.41	
R	Gas constant	air	J K^{-1} mol^{-1}	8.3144	
s	Slope of temperature - saturation water vapour pressure relationship	air	Pa K^{-1}	145 at 293 K	
Radiation transfer					
α	Leaf absorptance of SW	T,U		1 - σ_l	
ϵ	Long wave emissivity	T,U,S		0.98	
τ_l	Leaf transmittance (SW)	T,U		0.014	
ρ_l	Leaf reflectance (SW)	T,U		0.09	
σ_l	Leaf scattering coefficient (SW)	T,U		0.104	
$\rho_{b,c}$	Canopy reflection coefficient in direct SW	T,U			
$\rho_{d,c}$	Canopy reflection coefficient in diffuse SW	T,U		0.036	
$\rho_{h,c}$	Canopy reflection coefficient for a beam normal to the surface	T,U		0.0274	
a	Soil albedo	S		0.25	
$k_{bh,c}$	Canopy extinction coefficient for beam normal to the surface	T,U		0.33	2
$k_{b,c}$	Canopy extinction coefficient for SW beam radiation	T,U		$= k_{bh,c} \times \sin\beta^{-1}$	

Table S1: (continued) List of the model parameters.

Symbol	Definition and entity concerned		Unit	Default value	Ref
$k'_{b,c}$	Canopy extinction coefficient for direct SW including scattering	T,U		$= k_{b,c} \times (1-\sigma_l)^{0.5}$	
$k_{d,c}$	Canopy extinction coefficient for diffuse SW radiation	T,U		0.467	2
$k'_{d,c}$	Canopy extinction coefficient for diffuse SW including scattering	T,U		$= k_{d,c} \times (1-\sigma_l)^{0.5}$	
$k_{b,w}$	Woody parts extinction coefficient for direct SW radiation	T,U		1.0	
$k_{d,w}$	Woody parts extinction coefficient for diffuse SW radiation	T,U		1.0	
k_{LW1-2}	Extinction coefficient of LW radiation	T,U		-0.548, 0.0177	2
Latent and sensible Heat transfer					
$g_{smax,c}$	Maximal stomatal conductance	T,U	m s^{-1}	0.004	
$k_{SW,c}$	parameter for g_s response to incident SW radiation	T,U	W m^{-2}, -	50	
$k_{c,1-2}$	parameters for displacement height d_c	T,U		0.000724/ 0.273	3
$k_{CO2,c}$	parameters for g_s response to the air CO$_2$ concentration	T,U	-	0.9	4
$k_{e,c,1-2}$	parameters for g_s response to the air water vapor saturation deficit	T,U	Pa^{-1}, -	750 / 1.0	
$k_{\psi,c,1-2}$	parameters for g_s response to the leaf water potential	T,U	MPa^{-1}, -	-1.45 / 15	
τ	Time constant for stomatal response	T,U	mn	12	
Physiological parameters - Photosynthesis					
α_c	Quantum efficiency of electron transport	T,U	μmol e μmol phot.$^{-1}$	0.138/ 0.187	8
Γ^*_c	Photosynthetic compensation point for CO$_2$ at 25^{o}C	T,U	μmol CO$_2$mol air^{-1}	42.75	4
$Ea(\Gamma^*)$	Activation energy for Γ^*	T,U,	J mol^{-1}	37 830	9
$Ea(K_c)$	Activation energy for K_c	T,U,	J mol^{-1}	79 430	10

Table S1: (continued) List of the model parameters.

Symbol	Definition and entity concerned		Unit	Default value	Ref
$Ea(K_o)$	Activation energy for K_o	T,U,	J mol^{-1}	36 380	10
$Ea(V_c)$	Activation energy for V_{cmax}	T,U,	J mol^{-1}	62 220	10
$H_{a,c}$	Activation energy for J_{max}	T,U	J mol^{-1}	34 830	10
$H_{d,c}$	Deactivation energy for J_{max}	T,U	J mol^{-1}	2.0E5	10
$J_{max25,c}$	Maximal electron transport rate at T=25^{o}C	T,U	μmol e$^-$ m^{-2} s^{-1}	77.37	10
$V_{cmax25,c}$	Maximal carboxylation rate	T,U	μmol CO$_2$ m^{-2} s^{-1}	45.0	10
$K_{c25,c}$	RubisCO Michaelis constant for CO$_2$	T,U,	μmol CO$_2$mol air^{-1}	404.9	10
$K_{o25,c}$	RubisCO Michaelis constant for O$_2$	T,U,	mmol CO$_2$mol air^{-1}	278.4	10
K_m	RubisCO Michaelis constant	T,U,	μmolCO$_2$ mol air^{-1}		
$Topt(J_{max})$	Optimal temperature for J_{max}	T,U	K	310.02	10
Physiological parameters - Respiration					
Q_{10}	Respiration multiplier for a 10^{o}C increase	T,U		1.7 -2.0 according to organs	11
$R_{d,T15,c}$	Foliage respiration at T=25^{o}C	T,U	μmol CO$_2$ m^{-2} s^{-1}	0.80	10
$Ea(R_d)$	Activation energy for R_d	T,U,	J mol^{-1}	46 390	10
$R_{N,T15}$	Woody parts respiration at T=15^{o}C	T,U	gC gN^{-1} hr^{-1}	0.0064	12
-	Min. and max. fractions of tissues alive in a given organ	T		0.01 -1.0 (organs)	
R_g	Respiration associated with growth	T,U	gC gC^{-1}	0.28	13
-	Photoinhibition of leaf mitochondrial respiration	T,U,	0.51 /0.65		
kN_{leaf}	Nitrogen content of foliage	T	gN kg^{-1}d.m	10	15
kN_{stem}	Nitrogen content of stem	T	gN kg^{-1}d.m	0.05	15
kN_{branch}	Nitrogen content of branches	T	gN kg^{-1}d.m	2.5	15
kN_{tr}	Nitrogen content of tap root	T	gN kg^{-1}d.m	1.2	15
kN_{cr}	Nitrogen content of coarse roots	T	gN kg^{-1}d.m	1.4	15
kN_{sr}	Nitrogen content of small roots	T	gN kg^{-1}d.m	2.9	15
kN_{fr}	Nitrogen content of fine roots	T	gN kg^{-1}d.m	8.2	15
$k_{mn,mx,br}$	parameters of the live fraction of branches	T	-, year^{-1}	0.10, 0.50	
$k_{mn,mx,tr}$	same for taproot	T	-, year^{-1}	0.05, 0.10	
$k_{mn,mx,cr}$	same for coarse roots	T	-, year^{-1}	0.05, 0.20	
$k_{mn,mx,sr}$	same for small roots	T	-, year^{-1}	0.10, 0.25	

Table S1: (continued) List of the model parameters.

Symbol	Definition and entity concerned		Unit	Default value	Ref
Physiological parameters - Plant water relations					
C_T	Global capacitance of the root-to-leaf water pathway	T	kg H_2O m^{-2} leaf area Mpa^{-1}	$0.05 \times \frac{W}{15}$	9
$k_{H,1-3}$	Leaf area to sapwood area ratio	t	m^2 cm^{-2}	0.20/ -0.07 /0.8	14
$k_{x,0-2}$	Root-to-Leaf hydraulic resistance parameters	T,U	MPa m^2LAI s kg H_2O $^{-1}$ m^{-1}	5000/7500/0.7	
Canopy structure 1. Generic					
SLA	Specific leaf area (area to mass ratio)	T,U	m^2 area kg^{-1} d.m.	6.5	
-	Biomass carbon content	T,U	gC kg d.m.$^{-1}$	480	
λ_i	Coefficient of distribution of GPP_T among tree parts	t	-	-	
d_{wood}	Wood basic density	t	10^3 kg d.m. m^{-3}	0.45	
$k_{\lambda,1-3}$	Root-shoot partitioning coefficient Λ	T	-	0.2/1.0/3.0	
$k_{N,c}$	Nitrogen content of living parts of biomass	T, U	mg N g d.m.$^{-1}$	0.5	15
$k_{R,f}$	Extinction coefficient of precipitations by foliage	T,U	-	0.3	
$k_{R,w}$	Extinction coefficient of precipitations by stem and branches	T, U	-	0.5	
$S_{wmax,c}$	Canopy water storage capacity	T,U	kg H_2O $m^{-2}LAI$ or WAI	0.2	
ξ	Leaf or needle area to LAI ratio	T,t	-	0.5	1
DPM/RPM	Decomposable over Resistant plant material ratios (organs)	T,U	-	0.15-5.0	6
	Age of plant material input into the soil	T,U	yr	1-30	6
Canopy structure 2. Understorey					
$\lambda_f, \lambda_p, \lambda_r,$	Allocation of NPP_U to understorey biomass parts	U	-	0.45/0.10/0.45	
$W_{max,f,p,r}$	Peak value of the biomass of understorey parts	U	kg d.m. m^{-2}	0.25	

Table S1: (continued) List of the model parameters.

Symbol	Definition and entity concerned		Unit	Default value	Ref
h_{max}	Maximal height of understorey canopy	U	m	0.8	
Phenology- 1.Tree species					
BB_T	Heat sum for Pine needles bud burst	T	^oC day	1400	18
-	Life duration of leaf cohort	T	days	1002	17
-	fractions of needle cohort lifecycle - (fixed)	T		0.42/0.55/0.80	17
-	parameter Tmin of the equation of chilling rate	T		-17.02	19
-	parameter Tmax of the equation of chilling rate	T		92.15	19
-	parameter Topt of the equation of chilling rate	T		-1.34	19
-	base temperature of the sequential phenology model	T	degC	0.0	19
-	chilling rate threshold (fitted)	T	degC day	102.83	19
-	forcing rate threshold (fitted)	T	deg daysC	7.05	19
-	k parameters of the forcing rate equation	T		1.0/-0.12/-20.54	19
-k_{1-2}	parameters 1-2 of the broadleaf leaf life duration	T	days $(Wm^{-2})^{-1}$	0.0023/110	
-	parameter a/b/c of secondary growth model (-)	T		105.5/2.084/62.8	
$k_{S1,S2,S3}$	Parameters of branch turn-over rate	t	yr^{-1}, -,-	0.3678/1.097/-1.256	
$k_{S1,S2,S3}$	Parameters of root turn-over rate	t	yr^{-1}, -,-	0.8/0.5/0.0	
Phenology- 2.Understorey					
BB_U	Heat sum for understorey foliage bud burst	T	^oC day	600	
GD	Maximal duration of understorey growth	U	day	130	
$k_{S1,S2}$	Parameters setting up understorey leaf senescence	T	day m^{-2} W^{-1}	7.5E-3, -63.4	
k_p	Sigmoid function parameter	U	-	calculated	

Table S1: (continued) List of the model parameters.

Symbol	Definition and entity concerned		Unit	Default value	Ref
k_s	Flattening coefficient of the derivative of the sigmoid growth function	U	-	0.01	
$SMD_{G,U}$	Soil moisture deficit limiting growth	U	-	0.85	
$T_{G,U}$	Temperature threshold of growth	U	^oC	0.85	
T_{MU}	Temperature threshold for mortality	U	K	273, 265, 273	
DOY_{MU}	day of the year triggering mortality	U	-	315	
SMD_{MU}	Soil moisture deficit threshold of mortality	U	-	0.85	
M_{rate}	Rate of mortality (Date/air T/Soil moisture)	U	day^{-1}	0.05/0.025/0.005	
Soil hydraulics					
$c/si/s$	soil clay/silt/sand contents	S	pct		
-	Basic density	S	t m^{-3}		
α_{VG}	Van Genuchten α	S	cm^{-1}	0.0003	5
m_{VG}	Van Genuchten m	S	cm^{-1}	0.75	5
θ_{FC}	Water content at Field capacity	S	kg H_2O m^{-3}	150	16
θ_{SAT}	Water content at saturation	S	kg H_2O m^{-3}	275	16
θ_{WP}	Water content at wilting point	S	kg H_2O m^{-3}	65	16
$Tref_S$	Reference temperature of the soil	S	^{o}C	13.5	
D_{max}	Maximal drainage rate	S	kg H_2O m^{-2} d^{-1}	2.5	
z_{min}	Depth at which groundwater discharge = 0	S	m	2.5	
k_w	Power of the discharge curve equation	S		2.0	
h	Thermal conductivity	S	J m^{-2} s^{-1}	1.7	
z_{root}	Rooting depth	S	m	0.8	
Soil carbon					
k_{Ta}	parameters of the force-restore model of the soil temperature for respiration	S	-	0.005	
k_{Tref}	parameters of the force-restore model of the soil temperature for respiration	S	-	0.005	
k_{HUM}	decomposition rate of the HUM fraction	S	yr^{-1}	0.02	6
k_{BIO}	decomposition rate of the BIO fraction	S	yr^{-1}	0.66	6

Table S1: (continued) List of the model parameters.

Symbol	Definition and entity concerned		Unit	Default value	Ref
k_{DPM}	decomposition rate of the DPM fraction	S	yr^{-1}	10	6
k_{RPM}	decomposition rate of the RPM fraction	S	yr^{-1}	0.16	6
k_{plow}	amplification factor of decomposition rate by plowing	S	-	3.0	7
τ_{plow}	half time duration of the plowing effect	S	day	182	7

(1) Chen et al. (1991), (2) Berbigier and Bonnefond (1995), (3) Nakai et al. (2008), (4) Medlyn et al. (2001)

(5) Van Genuchten (1980),(6) Coleman and Jenkinson (1996), (7) Moreaux (2012), (8) Porte and Loustau (1998)

(9) Loustau et al. (1998), (10) Medlyn et al. (2002),(11) Bosc et al.(2003), (12) Ryan (1991), (13) Penning de Vries et al. (1974)

(14) McDowell et al. (2002), (15) Achat et al. (2018), (16) Roman-Dobarco et al. (2019)

(17) Granier and Loustau. (1994), (18) Desprez-Loustau and Dupuis (1994),(19) Kramer (1994)

Table S2. Allometric coefficient values used for *Pinus pinaster, Pseudotsuga menziesii* and *Fagus sylvatica*.

Tree species	Tree part	k_1	k_2	k_3	k_4	Eq.	Reference
$Pinus$ $pinaster$	D_{130}	3.221	0.0403	0.0	-	S34	Shaiek et al. (2011)
	h	1.60	0.381	0.12	-	S35	Shaiek et al. (2011)
	W_{stem}	0.344	1.063	0.131	-	S37	Shaiek et al. (2011)
		1.010	0.796	-0.694	-	S36	Shaiek et al. (2011)
	$W_{leafcohort=1}$						
	$W_{leaftotal}$	1.563	0.835	-0.67	-	S38	Shaiek et al. (2011)
	W_{tr}	0.285	0.499	0.21	-	S40	Achat et al. (2017)
	W_{cr}	0	0.206	0.2218	-	S41	Achat et al. (2017)
	W_{sr}	0.159	0.262	0.259	-	S42	Achat et al. (2017)
$Pseudotsuga$ $mensiezii$	D_{130}	2.574	0.403	0	-	S44	Gholz et al. (1979)
	h	2.10	0.41	0	-	S45	GIS Coop data set
	W_{stem}	0.686	1.037	0	-	S46	Gholz et al. (1979)
		0.401	0.796	-0.602	-	S47	
	$W_{leafcohort=1}$						
	$W_{leaftotal}$	0.290	0.686	0	-	S48	Gholz et al. (1979)
	W_{tr}	0.002	0.400	0.003	0.315	S52	Achat et al. (2017)
	W_{cr}	0	0.212	0.335	-	S50	Achat et al. (2017)
	W_{sr}	0.002	0.400	0.003		S53	Achat et al. (2017)
	W_{fr}	0.606	0.512	0.603	-	S51	Achat et al. (2017)
$Fagus$ $sylvatica$	D_{130}	$k_1 = 0.0551 + 30 \quad 2.39 \quad 10^{-4} \quad 4.68 \quad 10^{-6} \quad Altitude$				S54	(site index=30)
			$k_2 = 2.11$				Wutzler et al. (2008)
				$k_3 = 0.589 + 4.06 \quad 10^{-4} \quad Age$			
	h		cf. Eq. S62		Le Moguedec and Dhote (2012)		
	W_l	0.038	2.43	-0.913	-	S55	Wutzler et al. (2008)
	W_{stem}	$k_1 = 0.00347 + 30 \quad 6.72 \quad 10^{-4} + 8.11 \quad 10^{-6} \quad Altitude$					Wutzler et al. (2008)
			1.84	1.04		S56	(site index=30)
	W_{branch}	0.122	3.09		-	S57	Wutzler et al. (2008)
		$k_3 = \quad 0.151 \quad 0.0309 \quad 30 \quad 9.87 \quad 10^{-4} \quad Altitude + 3.06 \quad 10^{-5} \quad 30 \quad Altitude$					
	W_{tr}	0.0023	0.082	0.001	0.234	S60	Achat et al. (2017)
	W_{cr}	0	0.542	0.757	0.115	S58	Achat et al. (2017)
	W_{sr}	0.002	0.082	0.001	0.234	S61	Achat et al. (2017)
	W_{fr}	0.489	4.670	1.106	-	S59	Achat et al. (2017)

Table S3. Models of phenology and life cyle of leaf cohorts implemented in the GO+ v3.0

Model type (species)	Budburst	Lifecycle	End of senescence
Thermal time (Maritime Pine)	$\sum_{DOY=1}^{n} T_{a,mean}(DOY) = 1400^{o}C$ Desprez-Loustau and Dupuy (1994)	Beadle et al. (1982) Granier and Loustau (1994)	$age = 1002$ days
Parallel (Douglas Fir)	Harrington et al. (2010)	Mohren and Bartelink (1990)	$age = 2555$ days
Alternate (European Beech)	Kramer (1994)		$BB + [k_1 \quad \sum_{BB}^{258} SW \#] \quad k_2$

$SW\downarrow$ is the daily mean incident shortwave radiation, k_1 and k_2 are parameters listed in Table S1.

Table S4. Equations and parameters used for modelling the senescence of living organs of the individual trees.

Tree part	Senescence model	Reference
Branch	$S_{br}(\text{kg dmyear}^{-1}) = k_{\mathrm{S},1} \quad W_{br}^{k_{\mathrm{S},2}} \quad Age^{k_{\mathrm{S},3}}$	unpublished
Roots	$S_{r}(\text{kg dmyear}^{-1}) = k_{\mathrm{S},1} \quad \frac{W_r}{1+W_r^{1-k_{\mathrm{S},2}}} \quad Age^{k_{\mathrm{S},3}}$	unpublished

Table S5. Models of phenology and life cycle of the understorey vegetation parts implemented in the GO+ v3.0

Phase	Model	Reference
Budburst	$\sum_{DOY=1}^{n} T_{a,mean} = 600^{o}C$	unpublished
Growth	Soil moisture and Temperature threshold : SMD_{GU}, T_{GU}	Moreaux (2012)
	$dW_{l,p,r} = min($Max. Growth rate, C available$)$	
Senescence	Temperature: $T_{MU,l,p,r}$) $M_{rate} = 0.05, 0.001, 0.05 day^{-1}$	Moreaux (2012)
	Soil moisture :$SMD_{MU,l,p,r}$) $M_{rate} = 0.025, 0.003, 0.025 day^{-1}$	
	Date: $DOY_{MU,l,p,r}$) $M_{rate} = 0.05, 0.001, 0.05 day^{-1}$	

Table S6. Characteristics of the sites selected for long term series of tree (ΔD_{130}) and stand growth (ΔBA)

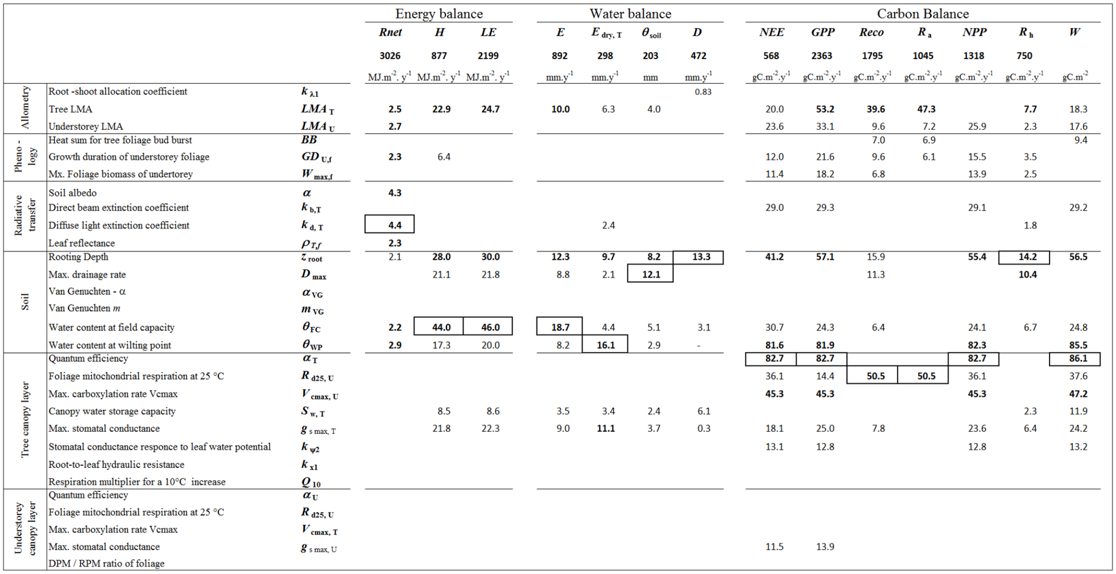
Site name (code)	Lat / Lon (°)	Annual temperature (°C) / rainfall(mm yr^{-1})	Main species	Tree age (yr)	Period	Reference
St Pardoux	45.44 / 1.45	11.5/1020	Douglas fir	28-42	1997-2011	1
Ecouves	48.50 / 0.10	11.0/750	Douglas fir	21-62	1969-2010	1
Quartier	45.80 / 3.60	11.5/720	Douglas fir	12-21	2004-2013	1
La Houve	49.35 / 5.99	10.7/760	Douglas fir	11-22	2000-2011	1
Soroe (DK-Sor)	55.49 / 11.6	8.2 / 660	European beech	88-97	2000-2009	2
Collelongo (IT-Col)	41.85 / 13.59	6.3 / 1180	European beech	130-140	2002-2012	3
Hesse	48.67 / 7.07	9.2 / 820	European beech	33-44	1999-2010	4
Solling	51.47 /9.37	6.5/1090	European beech	148	1996-2014	European database
Le Bray (FR-LBr)	44.72 / -0.77	13.5/ 930	Maritime pine	26-37	1987-2008	5
Vielle	44.03 / -0.18	9.2 / 820	Maritime pine	33-46	1991-2014	1
Pompogne	44.25 / 0.04	9.2 / 820	Maritime pine	33-43	1993-2009	1

(1) https://www6.inra.fr/giscoop, Seynave et al. (2018); (2)European database, Pilegaard et al. (2011);(3) European database, Scartazza et al. (2013); (4)European database, Granier et al. (2008); (5) European database, Berbigier et al. (2001)

Table S7. Variance fraction (R^2) of latent heat, net radiation and net ecosystem exchange accounted for by the model predictions at different time spans in five sites. The number of data values used is given in the bottom section.

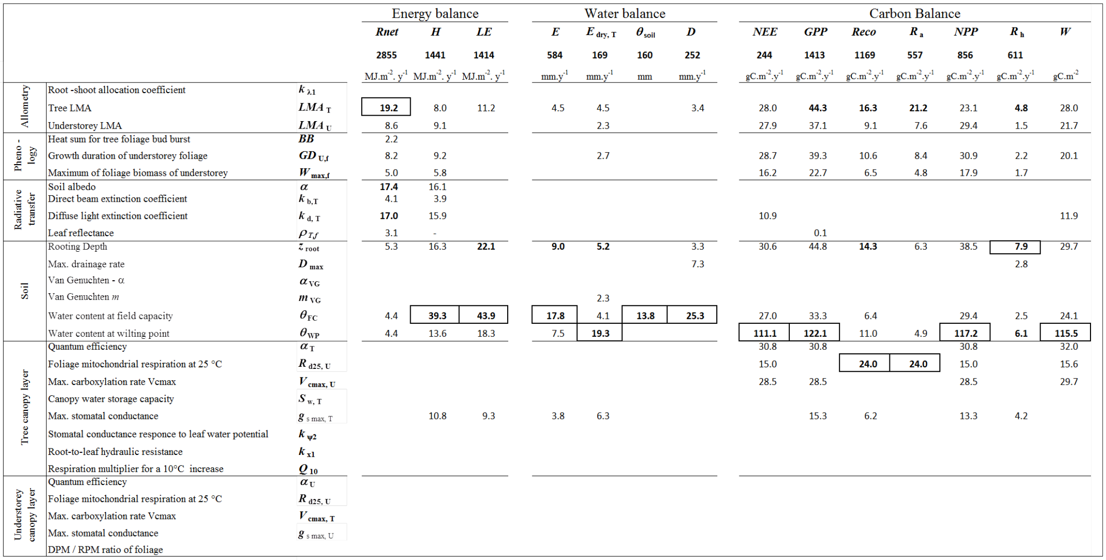
Time span: (day)	1/24	1	5	10	30	90	180	365
Rn								
BC Campbell 49		0.97	0.97	0.98	0.98	0.98	0.40	0.00
BC Campbell 88		0.95	0.97	0.97	0.97	0.97	0.95	0.33
Collelongo	0.71	0.56	0.75	0.76	0.66	0.73	0.00	0.00
Hesse		0.75	0.90	0.92	0.95	0.96	0.44	0.42
Soroe	0.71	0.63	0.86	0.90	0.92	0.85	0.07	0.35
Le Bray		0.68	0.87	0.91	0.84	0.96	0.39	0.05
λE								
BC Campbell 49		0.76	0.86	0.89	0.93	.94	0.00	0.10
BC Cambpell 88		0.68	0.75	0.77	0.81	0.84	0.20	0.77
Collelongo	0.30	0.22	0.27	0.24	0.23	0.19	0.31	0.44
Hesse		0.70	0.72	0.85	0.87	0.88	0.10	0.28
Soroe	0.28	0.44	0.63	0.69	0.78	0.87	0.09	0.10
Le Bray		0.18	0.24	0.29	0.31	0.57	0.51	0.30
NEE								
BC Campbell 49		0.67	0.70	0.70	0.72	0.85	0.81	0.14
BC Campbell 88		0.25	0.19	0.16	0.15	0.34	0.38	0.76
Collelongo	0.29	0.23	0.30	0.29	0.31	0.28	0.01	0.03
Hesse		0.57	.070	0.75	0.80	0.80	0.05	0.18
Soroe	0.32	0.34	0.44	0.47	0.50	0.47	0.08	0.14
Le Bray		0.15	0.19	0.20	0.27	0.50	0.30	0.57
Data values								
BC Campbell 49		4002	797	394	130	42	20	9
BC Campbell 88		2110	415	208	69	22	10	4
Collelongo	53601	2654	653	358	145	56	29	14
Hesse		4414	878	433	146	50	23	12
Soroe	105178	4381	886	430	145	46	22	10
Le Bray		3559	704	349	120	40	20	9

Figure S1. Values of the sensitivity index I_k of 14 model variables for the year 1994 (wet year). Variables are grouped into three processes, energy balance, water balance and carbon balance. Within each group, the heading are the variable symbol, nominal value (annual sum) and unit. The numbers in boxes are the highest I_k value per variable whereas bold numbers show I_k values that are greater than half the maximum value, $0.5 \quad I_{kmax}$, e.g. 2.2 MJ $\mathrm{m}^{-2} yr^{-1}$ for I_{Rn} (1994). The numbers in normal font show values between $0.1 \quad I_{kmax}$ and $0.5 \quad I_{kmax}$, that are within $[0.22, 2.2]$ $MJm^{-2}yr^{-1}$ for I_{Rn} (1994). Empty cells denotes $I_k$values less than $0.1 \quad I_{kmax}$.



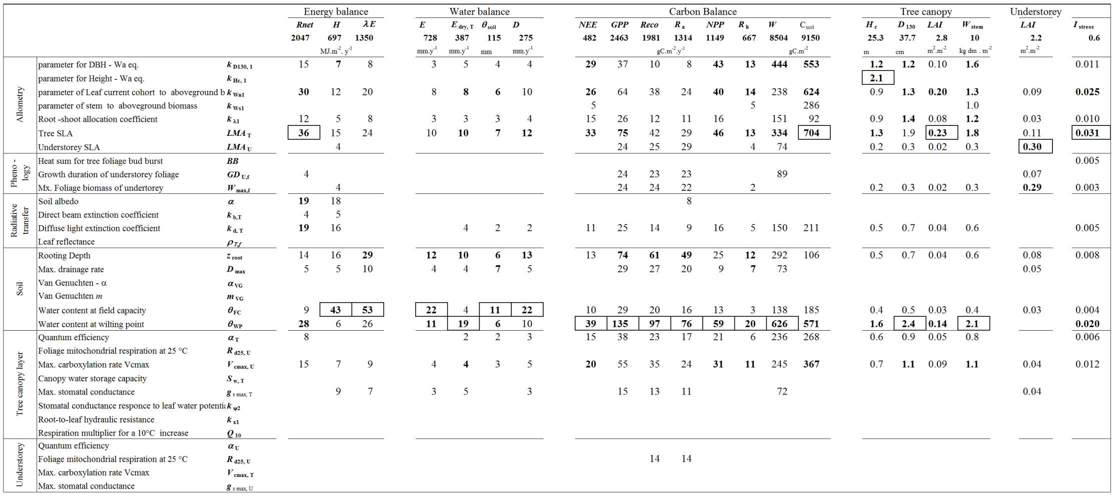
			Energy balance			Water balance				Carbon Balance						
			Rnet	***H***	***LE***	***E***	$E_{\mathrm{dry, T}}$	θ_{soil}	***D***	***NEE***	***GPP***	***Reco***	R_{a}	***NPP***	R_{h}	***W***
			3026	**877**	**2199**	**892**	**298**	**203**	**472**	**568**	**2363**	**1795**	**1045**	**1318**	**750**	
			$\mathrm{MJ.m^{-2}.y^{-1}}$	$\mathrm{MJ.m^{-2}.y^{-1}}$	$\mathrm{MJ.m^{-2}.y^{-1}}$	$\mathrm{mm.y^{-1}}$	$\mathrm{mm.y^{-1}}$	mm	$\mathrm{mm.y^{-1}}$	$\mathrm{gC.m^{-2}.y^{-1}}$	$\mathrm{gC.m^{-2}.y^{-1}}$	$\mathrm{gC.m^{-2}.y^{-1}}$	$\mathrm{gC.m^{-2}.y^{-1}}$	$\mathrm{gC.m^{-2}.y^{-1}}$	$\mathrm{gC.m^{-2}.y^{-1}}$	$\mathrm{gC.m^{-2}}$
Allometry	Root -shoot allocation coefficient	$k_{\lambda 1}$							0.83							
	Tree LMA	LMA_{T}	**2.5**	**22.9**	**24.7**	**10.0**	6.3	4.0		20.0	**53.2**	**39.6**	**47.3**		**7.7**	18.3
	Understorey LMA	LMA_{U}	**2.7**							23.6	33.1	9.6	7.2	25.9	2.3	17.6
Pheno - logy	Heat sum for tree foliage bud burst	BB										7.0	6.9			9.4
	Growth duration of understorey foliage	$GD_{\mathrm{U,f}}$	**2.3**	6.4						12.0	21.6	9.6	6.1	15.5	3.5	
	Mx. Foliage biomass of undertorey	$W_{\mathrm{max,f}}$								11.4	18.2	6.8		13.9	2.5	
Radiative transfer	Soil albedo	α	**4.3**													
	Direct beam extinction coefficient	$k_{\mathrm{b,T}}$								29.0	29.3			29.1		29.2
	Diffuse light extinction coefficient	$k_{\mathrm{d, T}}$	$\boxed{\mathbf{4.4}}$				2.4								1.8	
	Leaf reflectance	$\rho_{T,f}$	**2.3**													
Soil	Rooting Depth	z_{root}	2.1	**28.0**	**30.0**	**12.3**	**9.7**	**8.2**	$\boxed{\mathbf{13.3}}$	**41.2**	**57.1**	15.9		**55.4**	$\boxed{\mathbf{14.2}}$	**56.5**
	Max. drainage rate	D_{max}		21.1	21.8	8.8	2.1	$\boxed{\mathbf{12.1}}$				11.3			**10.4**	
	Van Genuchten - α	α_{VG}														
	Van Genuchten *m*	m_{VG}														
	Water content at field capacity	θ_{FC}	**2.2**	$\boxed{\mathbf{44.0}}$	$\boxed{\mathbf{46.0}}$	$\boxed{\mathbf{18.7}}$	4.4	5.1	3.1	30.7	24.3	6.4		24.1	6.7	24.8
	Water content at wilting point	θ_{WP}	**2.9**	17.3	20.0	8.2	$\boxed{\mathbf{16.1}}$	2.9	-	**81.6**	**81.9**			**82.3**		**85.5**
Tree canopy layer	Quantum efficiency	α_{T}								$\boxed{\mathbf{82.7}}$	$\boxed{\mathbf{82.7}}$			$\boxed{\mathbf{82.7}}$		$\boxed{\mathbf{86.1}}$
	Foliage mitochondrial respiration at 25 °C	$R_{\mathrm{d25, U}}$								36.1	14.4	$\boxed{\mathbf{50.5}}$	$\boxed{\mathbf{50.5}}$	36.1		37.6
	Max. carboxylation rate Vcmax	$V_{\mathrm{cmax, U}}$								**45.3**	**45.3**			**45.3**		**47.2**
	Canopy water storage capacity	$S_{\mathrm{w, T}}$		8.5	8.6	3.5	3.4	2.4	6.1						2.3	11.9
	Max. stomatal conductance	$g_{\mathrm{s\,max, T}}$		21.8	22.3	9.0	**11.1**	3.7	0.3	18.1	25.0	7.8		23.6	6.4	24.2
	Stomatal conductance responce to leaf water potential	$k_{\psi 2}$								13.1	12.8			12.8		13.2
	Root-to-leaf hydraulic resistance	k_{x1}														
	Respiration multiplier for a 10°C increase	Q_{10}														
Understorey canopy layer	Quantum efficiency	α_{U}														
	Foliage mitochondrial respiration at 25 °C	$R_{\mathrm{d25, U}}$														
	Max. carboxylation rate Vcmax	$V_{\mathrm{cmax, T}}$														
	Max. stomatal conductance	$g_{\mathrm{s\,max, U}}$								11.5	13.9					
	DPM / RPM ratio of foliage															

Figure S2. Values of the sensitivity index I_k of 14 model variables for the year 2005 (dry year).



			Energy balance			Water balance				Carbon Balance						
			Rnet	***H***	***LE***	***E***	$E_{\mathrm{dry, T}}$	θ_{soil}	***D***	***NEE***	***GPP***	***Reco***	R_{a}	***NPP***	R_{h}	***W***
			2855	**1441**	**1414**	**584**	**169**	**160**	**252**	**244**	**1413**	**1169**	**557**	**856**	**611**	
			$\mathrm{MJ.m^{-2}.y^{-1}}$	$\mathrm{MJ.m^{-2}.y^{-1}}$	$\mathrm{MJ.m^{-2}.y^{-1}}$	$\mathrm{mm.y^{-1}}$	$\mathrm{mm.y^{-1}}$	mm	$\mathrm{mm.y^{-1}}$	$\mathrm{gC.m^{-2}.y^{-1}}$	$\mathrm{gC.m^{-2}.y^{-1}}$	$\mathrm{gC.m^{-2}.y^{-1}}$	$\mathrm{gC.m^{-2}.y^{-1}}$	$\mathrm{gC.m^{-2}.y^{-1}}$	$\mathrm{gC.m^{-2}.y^{-1}}$	$\mathrm{gC.m^{-2}}$
Allometry	Root -shoot allocation coefficient	$k_{\lambda 1}$														
	Tree LMA	LMA_{T}	$\boxed{\mathbf{19.2}}$	8.0	11.2	4.5	4.5		3.4	28.0	**44.3**	**16.3**	**21.2**	23.1	**4.8**	28.0
	Understorey LMA	LMA_{U}	8.6	9.1			2.3			27.9	37.1	9.1	7.6	29.4	1.5	21.7
Pheno - logy	Heat sum for tree foliage bud burst	BB	2.2													
	Growth duration of understorey foliage	$GD_{\mathrm{U,f}}$	8.2	9.2			2.7			28.7	39.3	10.6	8.4	30.9	2.2	20.1
	Maximum of foliage biomass of understorey	$W_{\mathrm{max,f}}$	5.0	5.8						16.2	22.7	6.5	4.8	17.9	1.7	
Radiative transfer	Soil albedo	α	**17.4**	16.1												
	Direct beam extinction coefficient	$k_{\mathrm{b,T}}$	4.1	3.9												
	Diffuse light extinction coefficient	$k_{\mathrm{d, T}}$	**17.0**	15.9						10.9						11.9
	Leaf reflectance	$\rho_{T,f}$	3.1	-							0.1					
Soil	Rooting Depth	z_{root}	5.3	16.3	**22.1**	**9.0**	**5.2**		3.3	30.6	44.8	**14.3**	6.3	38.5	$\boxed{\mathbf{7.9}}$	29.7
	Max. drainage rate	D_{max}							7.3						2.8	
	Van Genuchten - α	α_{VG}														
	Van Genuchten *m*	m_{VG}					2.3									
	Water content at field capacity	θ_{FC}	4.4	$\boxed{\mathbf{39.3}}$	$\boxed{\mathbf{43.9}}$	$\boxed{\mathbf{17.8}}$	4.1	$\boxed{\mathbf{13.8}}$	$\boxed{\mathbf{25.3}}$	27.0	33.3	6.4		29.4	2.5	24.1
	Water content at wilting point	θ_{WP}	4.4	13.6	18.3	7.5	$\boxed{\mathbf{19.3}}$			$\boxed{\mathbf{111.1}}$	$\boxed{\mathbf{122.1}}$	11.0	4.9	$\boxed{\mathbf{117.2}}$	**6.1**	$\boxed{\mathbf{115.5}}$
Tree canopy layer	Quantum efficiency	α_{T}								30.8	30.8			30.8		32.0
	Foliage mitochondrial respiration at 25 °C	$R_{\mathrm{d25, U}}$								15.0		$\boxed{\mathbf{24.0}}$	$\boxed{\mathbf{24.0}}$	15.0		15.6
	Max. carboxylation rate Vcmax	$V_{\mathrm{cmax, U}}$								28.5	28.5			28.5		29.7
	Canopy water storage capacity	$S_{\mathrm{w, T}}$														
	Max. stomatal conductance	$g_{\mathrm{s\,max, T}}$		10.8	9.3	3.8	6.3				15.3	6.2		13.3	4.2	
	Stomatal conductance responce to leaf water potential	$k_{\psi 2}$														
	Root-to-leaf hydraulic resistance	k_{x1}														
	Respiration multiplier for a 10°C increase	Q_{10}														
Understorey canopy layer	Quantum efficiency	α_{U}														
	Foliage mitochondrial respiration at 25 °C	$R_{\mathrm{d25, U}}$														
	Max. carboxylation rate Vcmax	$V_{\mathrm{cmax, T}}$														
	Max. stomatal conductance	$g_{\mathrm{s\,max, U}}$														
	DPM / RPM ratio of foliage															

Figure S3. Values of the sensitivity index I_k of 14 model variables over a complete forest rotation from 1970 (plantation) to 2010 (clearcut).



			Energy balance			Water balance				Carbon Balance								Tree canopy				Understorey	
			Rnet	***H***	***λE***	***E***	$E_{\mathrm{dry,T}}$	θ_{soil}	***D***	***NEE***	***GPP***	***Reco***	R_{a}	***NPP***	R_{h}	***W***	C_{soil}	H_{c}	D_{130}	***LAI***	W_{stem}	***LAI***	I_{stress}
			2047	**697**	**1350**	**728**	**387**	**115**	**275**	**482**	**2463**	**1981**	**1314**	**1149**	**667**	**8504**	**9150**	**25.3**	**37.7**	**2.8**	**10**	**2.2**	**0.6**
				$\mathrm{MJ.m^{-2}.y^{-1}}$		$\mathrm{mm.y^{-1}}$	$\mathrm{mm.y^{-1}}$	mm	$\mathrm{mm.y^{-1}}$				$\mathrm{gC.m^{-2}.y^{-1}}$				$\mathrm{gC.m^{-2}}$	m	cm	$\mathrm{m^2.m^{-2}}$	$\mathrm{kg\ dm\ .\ m^{-2}}$	$\mathrm{m^2.m^{-2}}$	
Allometry	parameter for DBH - Wa eq.	$k_{\mathrm{D130,1}}$	15	**7**	8	3	5	4	4	**29**	37	10	8	**43**	**13**	**444**	**553**	**1.2**	**1.2**	0.10	**1.6**		0.011
	parameter for Height - Wa eq.	$k_{\mathrm{Hc,1}}$																$\boxed{\mathbf{2.1}}$					
	parameter of Leaf current cohort to aboveground b	k_{Wa1}	**30**	12	20	8	**8**	**6**	10	**26**	64	38	24	**40**	**14**	238	**624**	0.9	**1.3**	**0.20**	**1.3**	0.09	**0.025**
	parameter of stem to aboveground biomass	k_{Ws1}								5					5		286				1.0		
	Root -shoot allocation coefficient	$k_{\lambda 1}$	12	5	8	3	3	3	4	15	26	12	11	16		151	92	0.9	**1.4**	0.08	**1.2**	0.03	0.010
	Tree SLA	LMA_{T}	$\boxed{\mathbf{36}}$	15	24	10	**10**	**7**	**12**	**33**	**75**	42	29	**46**	**13**	**334**	$\boxed{\mathbf{704}}$	**1.3**	1.9	$\boxed{\mathbf{0.23}}$	**1.8**	0.11	$\boxed{\mathbf{0.031}}$
	Understorey SLA	LMA_{U}		4							24	25	29		4	74		0.2	0.3	0.02	0.3	$\boxed{\mathbf{0.30}}$	
Pheno - logy	Heat sum for tree foliage bud burst	BB																					0.005
	Growth duration of understorey foliage	$GD_{\mathrm{U,f}}$	4								24	23	23			89						0.07	
	Mx. Foliage biomass of undertorey	$W_{\mathrm{max,f}}$		4							24	24	22		2			0.2	0.3	0.02	0.3	**0.29**	0.003
Radiative transfer	Soil albedo	α	**19**	18									8										
	Direct beam extinction coefficient	$k_{\mathrm{b,T}}$	4	5																			
	Diffuse light extinction coefficient	$k_{\mathrm{d,T}}$	**19**	16			4	2	2	11	25	14	9	16	5	150	211	0.5	0.7	0.04	0.6		0.005
	Leaf reflectance	$\rho_{T,f}$																					
Soil	Rooting Depth	z_{root}	14	16	**29**	**12**	**10**	**6**	**13**	13	**74**	**61**	**49**	25	**12**	292	106	0.5	0.7	0.04	0.6	0.08	0.008
	Max. drainage rate	D_{max}	5	5	10	4	4	**7**	5		29	27	20	9	**7**	73						0.05	
	Van Genuchten - α	α_{VG}																					
	Van Genuchten *m*	m_{VG}																					
	Water content at field capacity	θ_{FC}	9	$\boxed{\mathbf{43}}$	$\boxed{\mathbf{53}}$	$\boxed{\mathbf{22}}$	4	$\boxed{\mathbf{11}}$	$\boxed{\mathbf{22}}$	10	29	20	16	13	3	138	185	0.4	0.5	0.03	0.4	0.03	0.004
	Water content at wilting point	θ_{WP}	**28**	6	26	**11**	$\boxed{\mathbf{19}}$	**6**	10	$\boxed{\mathbf{39}}$	$\boxed{\mathbf{135}}$	$\boxed{\mathbf{97}}$	$\boxed{\mathbf{76}}$	$\boxed{\mathbf{59}}$	$\boxed{\mathbf{20}}$	$\boxed{\mathbf{626}}$	**571**	**1.6**	$\boxed{\mathbf{2.4}}$	**0.14**	$\boxed{\mathbf{2.1}}$		**0.020**
Tree canopy layer	Quantum efficiency	α_{T}	8				2	2	3	15	38	23	17	21	6	236	268	0.6	0.9	0.05	0.8		0.006
	Foliage mitochondrial respiration at 25 °C	$R_{\mathrm{d25,U}}$																					
	Max. carboxylation rate Vcmax	$V_{\mathrm{cmax,U}}$	15	7	9	4	**4**	3	5	**20**	55	35	24	**31**	**11**	245	**367**	0.7	**1.1**	0.09	**1.1**	0.04	0.012
	Canopy water storage capacity	$S_{\mathrm{w,T}}$																					
	Max. stomatal conductance	$g_{\mathrm{s\,max,T}}$		9	7	3	5		3		15	13	11			72						0.04	
	Stomatal conductance responce to leaf water potenti	$k_{\psi 2}$																					
	Root-to-leaf hydraulic resistance	k_{x1}																					
	Respiration multiplier for a 10°C increase	Q_{10}																					
Understorey	Quantum efficiency	α_{U}																					
	Foliage mitochondrial respiration at 25 °C	$R_{\mathrm{d25,U}}$										14	14										
	Max. carboxylation rate Vcmax	$V_{\mathrm{cmax,T}}$																					
	Max. stomatal conductance	$g_{\mathrm{s\,max,U}}$																					

Figure S4. Values of the relative sensitivity index I_k of "fluxes" variables to meteorological variables over a complete forest rotation from 1970 (planting) to 2010 (clear-cut). Each box shows the relative sensitivity value of nine output variables to one of the six forcing input variables.

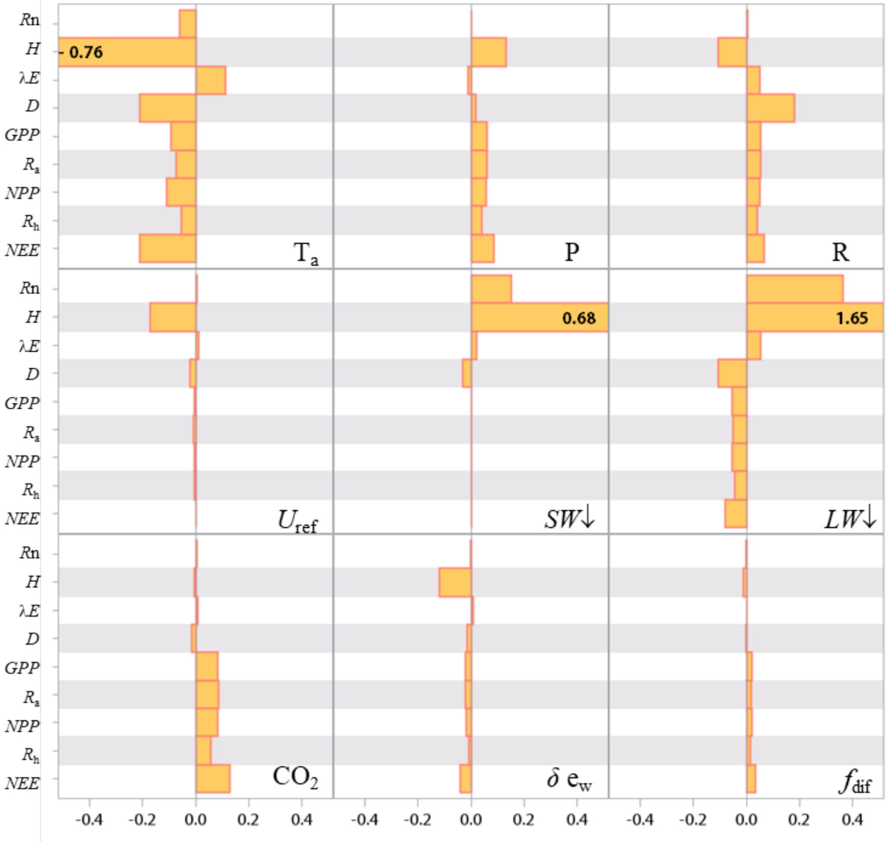


Figure S5. Relative sensitivity of soil water, stress index, tree stand variables and soil carbon stock to meteorological variables over a complete forest rotation from 1970 (planting) to 2010 (clear-cut).

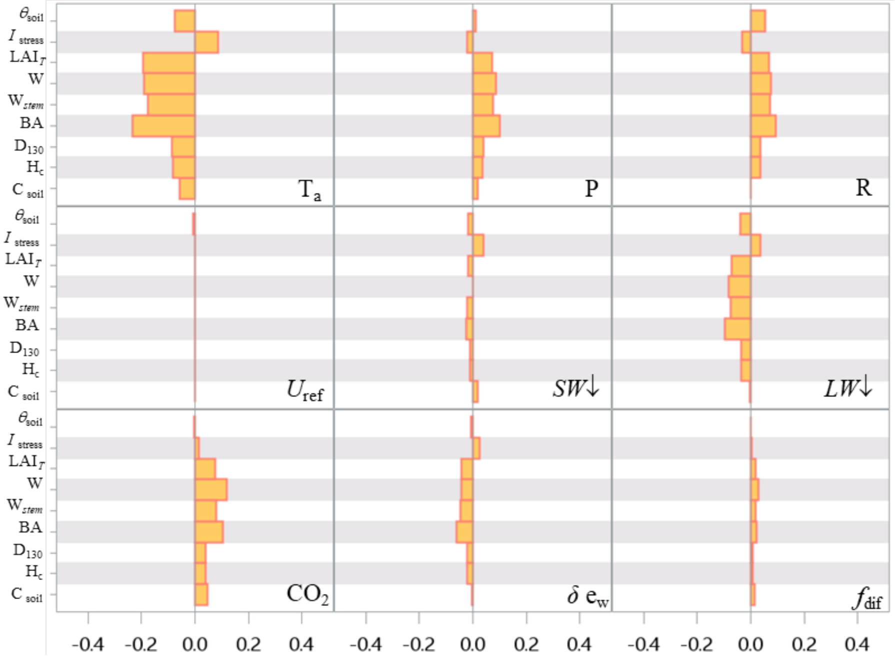


Figure S6. Normalized uncertainty of the annual mean values of the energy balance components calculated for the year 1994 at Le Bray. Red curve is the normal distribution fitted and inset numbers are the standard deviation.

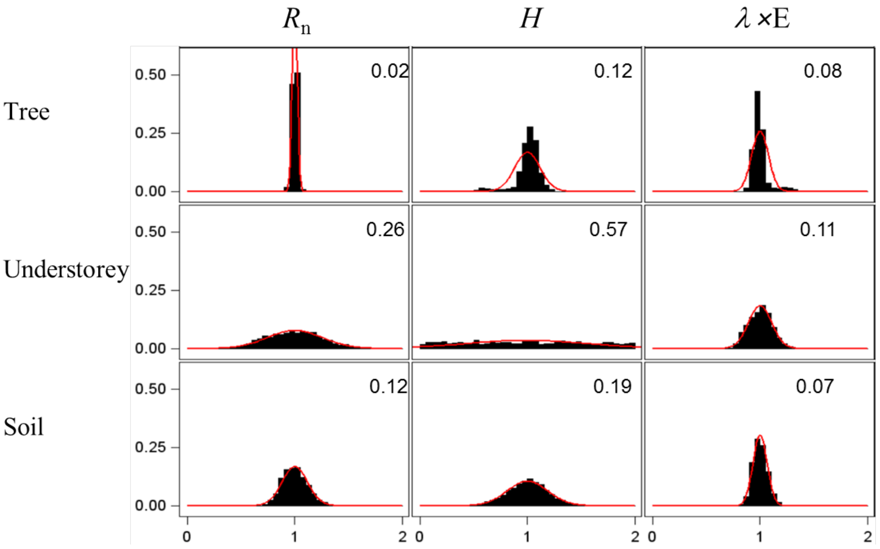


Figure S7. Normalized uncertainty of the annual mean values of the carbon balance components calculated for the year 1994 at Le Bray. The red curve is the normal distribution fitted and inset numbers are the standard deviation.

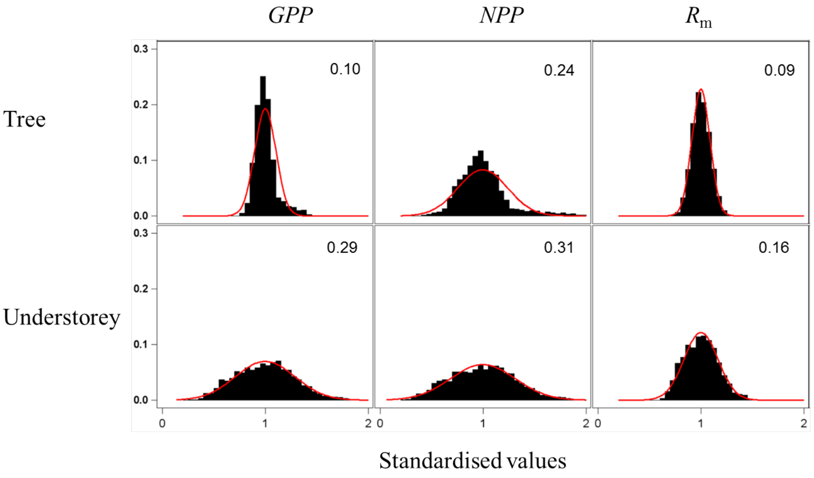


Figure S8. Normalized uncertainty of the annual mean values of the biomass components calculated for the year 1994 at Le Bray. The red curve is the normal distribution fitted and inset numbers are the standard deviation.