

1 **Supplimentary Material**

2 3 **Simultaneous assimilation of satellite and eddy covariance data for improving** 4 **terrestrial water and carbon simulations at a semi-arid woodland site in Botswana**

5
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8 9 **Appendix A: Gap-filling procedure for LHF**

10 The gap-filling procedure is done in the following steps (Appendix A of Reichstein et al.,
11 2005): (1) In cases where only data of direct interest are missing, but all meteorological
12 data are available, the missing values are replaced by the average values under similar
13 meteorological conditions within a time-window of ± 7 days. If no similar meteorological
14 conditions are present within the time window, the averaging window is increased to \pm
15 14 days. (2) In cases where auxiliary data such as air temperature or VPD are missing,
16 but radiation is available, the same approach is taken, but similar meteorological
17 conditions can only be defined via shortwave radiation deviation less than 50 Wm^{-2} and
18 the window size is not further increased. (3) In cases where radiation data are also
19 missing, the missing values are replaced by the average values at the same time of the
20 day ($\pm 1 \text{ h}$), i.e. by the mean diurnal course. In this case, the window size starts with \pm
21 0.5 days, i.e. adjacent hours. If after these steps the values could not be filled, the
22 procedure is repeated with increased window sizes until the values can be filled.

1 **Appendix B: Model description of BETHY**

2 **Overview**

3 BETHY is a process-based model of the terrestrial biosphere (Knorr, 1997, 2000). It
4 simulates carbon assimilation and plant and soil respiration embedded within a full
5 energy and water balance. Hence it is structured into four compartments: (1) energy
6 and water balance, (2) photosynthesis, (3) phenology, and (4) carbon balance. BETHY is
7 driven by observed climate, and is run on a specific site, or on a regional to global spatial
8 scales. Each grid cell is designed to contain up to three different plant functional types
9 (PFTs) out of a total of 13 PFTs, with the amount specified by their fractional coverage.
10 Time steps are 1 hour for the energy balance, photosynthesis and autotrophic
11 respiration part and 1 day for the phenology, hydrology and heterotrophic respiration
12 part. Control parameters in the set-up used here affect the photosynthesis, phenology
13 and hydrology scheme. The actual parameters, which are optimized in this study, are
14 listed with their a priori values and uncertainties in Table 3.

15

16 **Photosynthesis**

17 At each model grid cell, photosynthesis is simulated following the formulations of
18 Farquhar et al. (1980) or Collatz et al. (1992) for C_3 or C_4 metabolism, respectively. In
19 the case of C_3 photosynthesis, gross primary productivity (GPP) is calculated as the
20 minimum of an electron transport limited rate, J_E , and a rate, J_C , limited by the
21 carboxylation enzyme Rubisco from which the leaf or dark respiration, R_d , is subtracted,

22

$$23 \quad \text{GPP} = \min[J_C; J_E] - R_d, \quad [\text{A1}]$$

1

2 with

3

$$4 \quad J_C = V_{\max} \frac{C_i - \Gamma^*}{C_i + K_C(1 + O_x/K_O)} \quad [A2]$$

$$5 \quad J_E = J \frac{C_i - \Gamma^*}{4(C_i + 2\Gamma^*)} \quad [A3]$$

6

7 where

8

$$9 \quad J = \frac{\alpha_q I J_{\max}}{\sqrt{J_{\max}^2 + \alpha_q^2 I^2}} \quad [A4]$$

10

11 with the parameter α_q the quantum efficiency, C_i the leaf-internal CO₂ concentration, I
 12 the photosynthetically active radiation (PAR) absorption rate, and O_x the O₂ partial
 13 pressure. The maximum electron transport, J_{\max} , varies linearly with the vegetation
 14 temperature, T_v in °C. The temperature sensitivity $a_{J,T}$ (Farquhar, 1988) is a control
 15 parameter,

16

$$17 \quad J_{\max}(T_v) = J_{\max}^{25} \times a_{J,T} \times T_v, \quad [A5]$$

18

19 with

20

$$1 \quad J_{\max}^{25} = a_{J,V} \times V_{\max}^{25} \quad [A6]$$

2

3 Equation (A6) is a simple recasting of the usual photosynthesis equations to use the
 4 parameters $a_{J,V}$ and $V_{\max}(25^{\circ}\text{C})$ rather than the usual $J_{\max}(25^{\circ}\text{C})$ and $V_{\max}(25^{\circ}\text{C})$, and
 5 thus taking into account their correlation for the optimization. Initial values of $a_{J,V}$ are
 6 calculated from the a priori values of J_{\max} and V_{\max} at 25°C . The CO_2 compensation
 7 point, Γ^* , depends linearly on the vegetation temperature with the parameter $a_{\Gamma,T}$ being
 8 the dependency factor (Farquhar, 1988),

9

$$10 \quad \Gamma^* = a_{J,T} \times T_v \quad [A7]$$

11

12 The temperature dependency of further enzyme kinetic rates such as the
 13 Michaelis-Menten constants K_O and K_C and the maximum carboxylation rate, V_{\max} , are
 14 computed from the following equation with E the respective activation energy (with T_v
 15 in $^{\circ}\text{C}$):

16

$$17 \quad r(T_v) = r^{25} \exp\left\{ \frac{(T_v - 25^{\circ}\text{C})E}{298KR(T_v - 273^{\circ}\text{C})} \right\}, \quad [A8]$$

18

19 R is the general gas constant in $\text{JK}^{-1}\text{mol}^{-1}$, r stands for the rate in question, and r^{25} the
 20 respective rates at 25°C , i.e., K_O^{25} , K_C^{25} and V_{\max}^{25} (the values of K_O , K_C , and V_{\max} at
 21 25°C). These rates and the respective activation energies (E_{K_O} , E_{K_C} , and $E_{V_{\max}}$) are
 22 taken as parameters in this study.

1 For C₄ photosynthesis, there are three limiting rates (Collatz et al., 1992),

$$2 \quad GPP = \min[J_C; J_E; J_i] - R_d, \quad [A9]$$

$$3 \quad J_C = k \times Ci, \quad [A10]$$

$$4 \quad J_E = V_{\max}, \quad [A11]$$

$$5 \quad J_i = \alpha_i I, \quad [A12]$$

6 where in the case of C₄ photosynthesis,

$$7 \quad k^{25} = a_{J,V} \times V_{\max}^{25}, \quad [A13]$$

8 with k^{25} being the PEPcase (the initial CO₂ fixating enzyme in C₄ plants) CO₂ specificity
 9 at 25°C. The temperature dependency of k is then also calculated by equation (9) with
 10 the activation energy E_k as a parameter. Here α_i is the integrated C₄ quantum efficiency,
 11 and $a_{J,V}$ and α_i are both parameters. The dark respiration R_d is calculated as (Farquhar
 12 et al., 1980; Knorr, 1997)

$$13 \quad R_d(25^\circ C) = 0.011V_{\max}^{25}(C_3) \text{ or } 0.042V_{\max}^{25}(C_4), \quad [A14]$$

14 The temperature dependency of R_d is also given by equation (A8) with the
 15 activation energy E_R as a controlling parameter.

16 **Carbon balance**

1 The net primary productivity (NPP) is calculated as gross uptake of CO₂ by the
 2 leaves (GPP) minus total autotrophic respiration which includes plant maintenance
 3 respiration R_M and growth respiration R_G . Following Knorr (2000), R_M is calculated
 4 from the leaf respiration as

$$6 \quad R_M = R_d / f_{R,leaf}, \quad [A15]$$

7
 8 with $f_{R,leaf}$ the leaf fraction of the maintenance respiration. Growth respiration is itself
 9 proportional to NPP and calculated as follows:

$$11 \quad R_G = (f_{R,growth} - 1)NPP = (f_{R,growth} - 1)(GPP - R_M - R_G), \quad [A16]$$

12
 13 where $f_{R,growth}$ is the amount of carbon to be produced for a unit gain in vegetation
 14 biomass.

15 The net ecosystem productivity (NEP) is now defined as

$$17 \quad NEP = NPP - R_s = NPP - R_{S,f} - R_{S,s}, \quad [A17]$$

18
 19 where the heterotrophic soil respiration (R_s) is composed of respiration from a
 20 short-lived litter pool with time-varying size and a long-lived soil carbon pool (Knorr,
 21 2000). Input to the litter pool is parameterized by the annual course of LAI in the case of
 22 deciduous PFTs or, in the case of evergreen PFTs, as a constant fraction of the leaf
 23 carbon pool. Soil respiration is assumed to be temperature and soil moisture dependent

1 and calculated from the following equations:

2

$$3 \quad R_s = (1 - f_s)k_f C_f + k_s C_s, \quad [A18]$$

4

5 with the sizes of the fast or litter pool, C_f , and the slow pool, C_s . f_s is the fraction of
6 decomposition from the fast pool that goes to the long-lived soil carbon pool. The rate
7 constants k_f and k_s for fast and slow pools are

8

$$9 \quad k_f = \alpha^\kappa Q_{10f}^{T_a/10} / \tau_f, \quad [A19]$$

$$10 \quad k_s = \alpha^\kappa Q_{10s}^{T_a/10} / \tau_s, \quad [A20]$$

11

12 where T_a is the air temperature, α^κ the soil moisture dependence parameter, $Q_{10,f}$ and
13 $Q_{10,s}$ temperature dependence parameters, and τ_f and τ_s the pool turnover times at 25°C.

14 **Stomatal control**

15 The model of stomatal control follows the assumption that, in the absence of water
16 stress, leaf-level photosynthesis operates at a standard ratio between the leaf internal
17 CO₂ concentration, C_i , and the CO₂ concentration of free air, C_a . This value is given by

18

$$19 \quad C_{i,0} = f_{C_i} C_a, \quad [A21]$$

20

21 with two values for f_{C_i} , one for C3 and one for C4 vegetation. In order to determine the
22 demand for CO₂ uptake, A_n is first calculated as $A_n, 0$ for $C_i = C_{i,0}$, and $T_c = T_a$. Inversion

1 of the diffusion equation for CO₂ at the stomatal boundary is then used to compute
 2 stomatal conductance in the absence of water stress at each canopy layer (in ms⁻¹):

$$3 \quad g_{s,0} = \frac{1.6A_{n,0}}{C_a - C_{i,0}} \frac{RT_k}{p}, \quad [A22]$$

5
 6 p is air pressure (in Pa). If at the time of highest demand, D , transpiration rates exceed
 7 a root water supply rate, g_s , stomatal conductance at each canopy layer is reduced
 8 according to

$$9 \quad g_s = \frac{g_{s,0}}{1 + b_e D_a}, \quad [A23]$$

11
 12 The factor b_e is assumed to change with soil water status in such a way that during the
 13 course of a day, the transpiration rate, E_t , does not exceed a root supply rate, S ,
 14 described by Federer (1982),

$$15 \quad S = C_w \frac{W}{W_{\max}}, \quad [A24]$$

17
 18 W is the soil water content, adjusted to take soil freezing into account (Knorr, 1997),
 19 and C_w an empirical parameter representing root density. W_{\max} is the maximum plant
 20 available soil water and used as a parameter here.

1 Next, the canopy temperature, T_c , is computed consistent with the energy balance
 2 after integrating g_s over the canopy to obtain the canopy conductance used in the
 3 Penman–Monteith equation. Then, the photosynthesis model is run again, but at a fixed
 4 stomatal conductance, g_s , which yields the final GPP.

6 Latent heat flux

7 Latent heat flux (λE) is the sum of two terms,

$$9 \quad \lambda E = \lambda E_v + \lambda E_s, \quad [\text{A25}]$$

10
 11 where λ is latent heat, E_v is transpiration from vegetation and E_s is evaporation from
 12 soil. E_v is primarily driven by the net radiative balance of the vegetation ($R_{n,v}$) and is
 13 limited by the available amount of soil (W_s) and skin or intercepted water (W_i). If the
 14 vegetation surfaces are wet ($W_i > 0$), the canopy conductance is infinite ($G_c \rightarrow \infty$) so that
 15 evaporation follows its maximum rate, $E_{v,\max}$, with the evaporated water coming from
 16 the skin or intercepted reservoir:

$$18 \quad E_v = E_i = E_{v,\max} = \frac{sR_{n,v} + \rho C_p (e_s(T) - e_a) G_a}{s + \gamma} \quad (W_i > 0), \quad [\text{A26}]$$

19
 20 Here, it is allowed to assume negative values during dew formation. When the
 21 vegetation is dry ($W_i = 0$), evapotranspiration is determined by G_c , which is the
 22 combined conductance of all stomata within the plant canopy,:

1

$$2 \quad G_c = \int_0^{\Lambda} g_s(l) dl, \quad [A27]$$

3

4 Λ denote the leaf area index (LAI) of the canopy, and dl its differential element. The
 5 transpiration rate is then calculated from the Penman-Monteith formula (Monteith
 6 1965):

7

$$8 \quad E_v = E_t = \frac{sR_{n,v} + \rho C_p (e_s(T) - e_a) G_a}{s + \gamma(1 + G_a/G_c)} \quad (W_i = 0), \quad [A28]$$

9

10 An additional condition is given by $E_t \geq 0$, i.e. transpiration is only allowed from the
 11 vegetation to the atmosphere.

12 The daily integral of the evaporation rate E_i also depends on the size of the skin
 13 reservoir, W_i , and the rain input:

14

$$15 \quad E_i(t)\Delta t = \min \left\{ \int_{1day} E_{v,max}(t') dt'; W_i(t - \Delta t) + (P_i(t) - P_v(t))\Delta t \right\}, \quad [A29]$$

16

17 with a one-day time step Δt . In the model, this and all other daily values are
 18 approximated by integrating over the instantaneous rates given at the hourly time
 19 steps.

1 According to equation 29, transpiration can only happen when the vegetation is
 2 dry. To account for this fact when calculating the daily rate $E_v \Delta t$, a time average
 3 wetness fraction is defined:

$$4 \quad F_i = \frac{E_i(t) \Delta t}{\int_{1day} E_{v,max}(t') dt'} \quad [A30]$$

6 and daily transpiration is reduced accordingly:

$$8 \quad E_i(t) \Delta t = (1 - F_i) \int_{1day} \frac{sR_{n,v} + \rho C_p \Delta e G_a}{s + \gamma(1 + G_a/G_c)} dt' \quad [A31]$$

10 The aerodynamic exchange between the canopy and the free air is described as

$$12 \quad G_a = g_{a,v} u, \quad [A32]$$

14 with wind speed, u , and a proportionality factor serving as a free model parameter.

15 Wind speeds below 1 ms^{-1} are uniformly set to 1 ms^{-1} to avoid unrealistically high canopy
 16 temperature under conditions of extremely still air and high incoming radiation. The
 17 prior value of $g_{a,v}$ is determined from the following formula:

$$19 \quad g_{a,v} = \frac{k^2}{[\ln(h_{ref}/r_z h_c + a_z)]^2} \quad [A33]$$

20

1 h_{ref} is the reference height above canopy (10 m), h_c the canopy height, $k = 0.41$, $r_z = 0.1$
 2 and $a_z = 1$.

3

4 **Air humidity**

5 Since no reliable data of near-surface air humidity exist for purposes of global modelling,
 6 this quantity has to be estimated. It is often assumed that the daily mean of the vapour
 7 pressure is equal to the saturation vapour pressure at the daily minimum temperature.
 8 Friend (1998) has checked this assumption with climate data by Müller (1982) and has
 9 found a good agreement for Europe and North America. For weather stations in arid
 10 regions, however, agreement is much less satisfactory, resulting in an overall
 11 correlation coefficient of $= 0.87$ for 805 stations. An overestimate of the vapour pressure
 12 occurs, when the air is not saturated at the minimum temperature, T_{min} , as under
 13 severe drought (Running et al. 1987), and an underestimate, when the vapour pressure
 14 rises during the day because of evapotranspiration (Rosenberg, 1974).

15 In order to account for such findings, the daily course of the vapour pressure, $e_s(t)$,
 16 is calculated from instantaneous saturation vapour pressure, $e_s(T)$, saturation vapour
 17 pressure at sunrise, $e_s(T_{\text{min}})$, and the ratio of daily mean evapotranspiration and daily
 18 mean evaporative demand (cf. subsection “soil water balance”). Variation of the
 19 dependence is achieved through the parameters h_0 (relative humidity at sunrise, when
 20 $T = T_{\text{min}}$, and total drought, i.e. $f_e = 0$) and \hat{h} (daily amplitude of the vapour pressure
 21 under moist conditions, i.e. $= 1$, as a fraction of the amplitude at constant saturation):

22

$$23 \quad e_a = e_{a0} + f_e \hat{h} (e_s(T) - e_{a0}), \quad [\text{A34}]$$

1 where

$$2 \quad e_{a0} = (h_0 + (1 - h_0)f_e)e_s(T_{\min}), \quad [\text{A35}]$$

3 and

$$4 \quad f_e(t) = \frac{E(t - \Delta t)}{E_{t,\max}(t - \Delta t) + E_{s,\max}(t - \Delta t)}, \quad [\text{A36}]$$

5

6 f_e is defined as the ratio of actual evapotranspiration to potential evapotranspiration
 7 from vegetation and soil. For the computation of e_a , the value of the preceding time step
 8 Δt of one day is taken. The saturation vapour pressure over water or ice, $e_s(T)$, is
 9 calculated from Murray (1967):

10

$$11 \quad e_s(T) = \begin{cases} 610.78 \exp(17.269T/(237.3 + T)) & \text{for } T > 0 \\ 610.78 \exp(17.269T/(271.15 + T)) & \text{for } T < 0 \end{cases} \quad [\text{A37}]$$

12

13 **Energy and radiation balance**

14 PAR absorption is calculated according to the two-flux scheme by Sellers (1985) with
 15 three vertical layers of equal LAI. The diffuse fraction of PAR is calculated according to
 16 a procedure by Weiss and Norman (1985). Leaf-angle distribution is assumed to be
 17 uniform, and the only free parameters for this scheme is ω , the leaf single-scattering
 18 albedo. To determine evapotranspiration rates from the Penman–Monteith formula,
 19 BETHY computes net radiation balance of the canopy, $R_{n,c}$, according to the following
 20 equation:

21

$$1 \quad R_{n,c} = (1 - t_{1,v}) \left[(\varepsilon_a - \varepsilon_{sfc}) \sigma T_{K,a}^4 - G \right] - (1 - a_C - a_S) f_{PAR} R_S, \quad [A38]$$

2

3 ε_a and $\varepsilon_{sfc} = 0.97$ are sky and surface emissivity, respectively, $T_{K,a}$ air temperature in
 4 Kelvin, $\sigma = 5.6703 \times 10^{-8} \text{ Wm}^{-2}\text{K}^{-4}$ the Stefan–Boltzmann constant, and $t_{1,v}$ the longwave
 5 transmissivity of the vegetation, assumed $t_{1,v} = f_c \exp(-0.5A/f_c) + (1 - f_c)$. f_c is the fraction
 6 of soil covered by vegetation. For the shortwave part, R_S is incoming solar radiation
 7 (Wm^{-2}), f_{PAR} is the fraction of PAR absorbed by the vegetation and computed by the
 8 two-flux scheme, a_v the albedo of the vegetation at the limit of high LAI and closed
 9 canopy, and as the amount of solar radiation absorbed by the soil under the canopy at
 10 the same limit. G is the ground heat flux, assumed to be a fixed fraction of total net
 11 radiation. (Contrary to $R_{n,c}$, total net radiation does not depend on G , so there is no
 12 implicit equation to be solved.) The sky emissivity is computed from

$$14 \quad \varepsilon_a = \varepsilon_s \left(\frac{e_a}{T_{K,a}} \right)^{1/7} (1 + 0.22n_c^2), \quad [A39]$$

15

16 with the cloud cover fraction n_c . If no separate radiation data for PAR and solar
 17 radiation are available, R_S is calculated from PAR according to Weiss and Norman
 18 (1985).

19

20 **Phenology**

21 We assume that spatial variability within a grid cell is entirely the result of differences
 22 in the response among the existing PFTs, which are defined by threshold parameter for

1 each PFT as the trigger. This parameter is assumed to have a Gaussian probability
 2 distribution in space. There are two of those threshold parameters: \tilde{T}_ϕ and \tilde{t}_c . It is
 3 important to note that the transition to the active state requires both $\tilde{T}_\phi > T$ and $\tilde{t}_c > t_d$,
 4 where T is a temperature and t_d length of day. The tilde ($\tilde{\cdot}$) denotes that these are
 5 parameters. As shown next, these parameters are integrated over their probability
 6 distribution, replacing the integration across the space of the grid cell.

7 Before proceeding to the spatial integration, we define a generic differential
 8 equation in time for the LAI of individual plants, $\tilde{\Lambda}(t)$:

$$10 \quad \frac{d\tilde{\Lambda}(t)}{dt} = \begin{cases} f_1, & \text{if } T \geq \tilde{T}_\phi \text{ and } t_d \geq \tilde{t}_c, \\ f_2, & \text{else,} \end{cases} \quad [\text{A39}]$$

11

12 where f_1 and f_2 are some arbitrary functions of the state of the vegetation. In this
 13 discrete formulation, the response of LAI to changes in \tilde{T}_ϕ or \tilde{t}_c is usually
 14 nondifferentiable at the threshold. The continuous version of equation (A39), which is
 15 valid for the spatially integrated LAI, $\Lambda(t)$, resolves to an integral over the Gaussian
 16 probability density functions (PDF), p and q , of the two trigger variables.

17

$$18 \quad \frac{d\Lambda(t)}{dt} = f_1 \int_{-\infty}^T \int_{-\infty}^{t_d} p(\tilde{T}_\phi) q(\tilde{t}_c) d\tilde{T}_\phi d\tilde{t}_c + f_2 \left(1 - \int_{-\infty}^T \int_{-\infty}^{t_d} p(\tilde{T}_\phi) q(\tilde{t}_c) d\tilde{T}_\phi d\tilde{t}_c \right) \quad [\text{A40}]$$

19

20 The spatial PDF p is characterized by a mean T_ϕ and its standard deviation T_τ , while
 21 the mean of q is t_c and the standard deviation t_r . All four are CCDAS control

1 parameters. Note the distinction between these two spatial PDFs and the fact that their
 2 four parameters have again PDFs in the Bayesian sense in the same way as all other
 3 control parameters.

4 The previous expression simplifies to

$$5 \quad \frac{d\Lambda(t)}{dt} = ff_1 + f_2(1-f) \quad [A41]$$

6

7 With

8

$$9 \quad f = \int_{-\infty}^T p(\tilde{T}_\phi) d\tilde{T}_\phi \int_{-\infty}^{t_d} q(\tilde{t}_c) d\tilde{t}_c = \Phi\left(\frac{T-T_\phi}{T_r}\right) \Phi\left(\frac{t_d-t_c}{t_r}\right) \quad [A42]$$

10

11 where Φ is the cumulative normal distribution. f is the fraction of plants within the
 12 proportion of a grid cell occupied by each PFT that are actively growing or maintaining
 13 leaves.

14

15 4.3. Time evolution of LAI

16 Describing the generic formulation for the time evolution of LAI of a single plant –
 17 which is then integrated spatially via equation (A41) – requires definition of f_1 (for
 18 plants in their growing season) and f_2 (for senescent plants). For f_1 , we assume the
 19 simplest formulation that satisfies the following two conditions: leaf growth starts
 20 immediately and is not limited by substrate availability, such as LAI itself; and growth

1 stops if a target LAI is reached that is in balance with the environmental limitations,
 2 described as Λ_{\max} . These conditions are met by the following formulation:

$$3 \quad f_1 = \xi(\Lambda_{\max} - \Lambda), \quad [A43]$$

4
 5
 6 where ξ is a linear growth constant describing the increase in LAI per time unit shortly
 7 after bud burst. This rate is chosen to be independent of carbon gains (NPP), because
 8 initial leaf development relies on buds and reserves from the previous year (Kaduk and
 9 Heimann, 1996). This formulation differs from those used in similar applications, such
 10 as the logro-P phenology model (C. Reick, personal communication, 2010, implemented
 11 by Raddatz et al., 2007) or the one by Liu et al. (2008), where the initial growth is
 12 exponential resulting in a logistic function for the time integral under constant
 13 conditions. Equation (A43) results in a time dependence described by $\Lambda(t)/\Lambda_{\max} = 1 -$
 14 $\exp(-\xi t)$ for $\Lambda(0) = 0$, which is linear for small t . The advantage of this approach is that it
 15 does not require setting a minimum LAI to set off growth, which was 0.1 in the work by
 16 Liu et al. (2008). This would not work here, because Λ_{\max} might be less than such a
 17 minimum value. The difference in approach can be explained by the fact that the work
 18 just cited is restricted only to temperature controlled phenology and does not include
 19 situations where either the temperature or the water balance only allows small values
 20 of LAI. For those plants that are outside their growth stage, we again chose the simplest
 21 formulation that allows accommodating both deciduous and evergreen phenology:

$$22 \quad f_2 = \Lambda/\tau_L, \quad [A44]$$

1

2 The new parameter α , which is related to leaf longevity, describes how quickly leaves
 3 are shed, or whether they stay inactive until the next growing season. Deciduous
 4 vegetation will normally shed leaves (which includes leaves turning brown, see above)
 5 within days to weeks. Evergreen vegetation on the other side should have values at the
 6 order of a year or more. We now consider evolution of the spatially integrated grid-cell
 7 average LAI. Inserting equation (A43) and (A44) into equation (A41) yields:

8

$$9 \quad \frac{d\Lambda(t)}{dt} = \xi[\Lambda_{\max} - \Lambda(t)]f - \frac{\Lambda(t)}{\tau_L}(1-f), \quad [\text{A45}]$$

10

11 In order to find a convenient form for integrating this expression, we define

12

$$13 \quad r = \xi f + (1-f)/\tau_L, \quad [\text{A46}]$$

14

15 and

16

$$17 \quad \Lambda_{\text{lim}} = \xi\Lambda_{\max}f/r, \quad [\text{A47}]$$

18

19 so that equation (A41) takes the form:

20

$$21 \quad \frac{d\Lambda(t)}{dt} = \xi\Lambda_{\max}f - r\Lambda(t), \quad [\text{A48}]$$

$$= r[\Lambda_{\text{lim}} - \Lambda(t)], \quad [\text{A49}]$$

2

3 As long as f and Λ_{max} (and therefore r and Λ_{min}) do not depend on t , the equation above
4 has the following solution:

5

$$\Lambda(t + \Delta t) = \Lambda_{\text{lim}} - [\Lambda_{\text{lim}} - \Lambda(t)]e^{-r\Delta t}, \quad [\text{A50}]$$

7

8 Here it is sufficient to state that Λ_{max} depends on quantities that are updated either
9 daily or every few days, while f depends on daily values of temperature and day length.

10 Therefore, the last equation can be used to integrate over a single daily time step of the
11 phenology scheme, Δt . This mixture of analytical and numerical integration is not only
12 highly efficient, it also ensures stability, i.e. it avoids negative Λ as long as Λ_{lim} and $\Lambda(0)$
13 are non-negative.

14

15 4.5. Water and structural limitations

16 On a global scale, the main limiting factor on terrestrial plant growth is not
17 temperature, but water (Woodward, 1987). Whenever photosynthesizing, plants lose
18 water by transpiration through pore openings (“stomata”) in their leaves. This
19 limitation together with any other limitation on leaf growth, here considered
20 “structural”, is described by a single state variable, Λ_{max} . If soil water is limiting, an
21 increasingly negative soil water potential leads to a falling leaf potential in a
22 complicated process involving root water uptake, xylem resistance to flow, and
23 transpiration through the leaf stomata. If stomata close, leaves can retain water, but

1 only to a degree that depends on its cuticular resistance, which in itself is dependent on
 2 the plant functional type (PFT). However, it is not possible to represent those complex
 3 mechanisms in a model designed for global-scale applications. The scheme chosen here
 4 goes back to Woodward (1987), who used annual potential evapotranspiration and
 5 precipitation to derive water limited LAI on a global scale. To accommodate the shorter
 6 time scale of our model, we have modified his scheme by using daily actual
 7 transpiration and soil moisture instead of annual potential evapotranspiration and
 8 precipitation. However, to have LAI react not to rapidly changing daily conditions but to
 9 the longer-term climatic state, the water limited LAI is averaged back in time using the
 10 same approach as for T . Generally speaking, leaf development will stop and leaves will
 11 be shed if there is insufficient soil water for transpiration. At which level this happens
 12 exactly will be a function of various drought adaptations of the PFT concerned.
 13 Independent of the details, however, adaptation will determine how long the plant at a
 14 given LAI Λ can survive with a given amount of soil moisture without rain. This time
 15 scale, τ_w , can serve as a universal parameter of water limitation. This defines a
 16 water-limited LAI, Λ_w through

17

$$18 \quad E(\Lambda_w)\tau_w = W, \quad [A51]$$

19

20 where W is plant-available soil moisture. What is needed then is the total water loss
 21 after time τ_w as a function of leaf area.

22 To compute this water loss, we linearize the potential rate of transpiration, E , as a
 23 function of the LAI, Λ :

1

$$2 \quad E(\Lambda) \approx \frac{\tilde{E}}{\tilde{\Lambda}} \Lambda, \quad [A52]$$

3

4 \tilde{E} is the daily mean potential rate of transpiration last computed by the model at a LAI
 5 of $\tilde{\Lambda}$. This approximation is most accurate at low values of Λ and $\tilde{\Lambda}$, where net
 6 radiation of the leaf canopy, which drives evapotranspiration (Jarvis and McNaughton,
 7 1986), can be assumed to scale linearly with LAI.

8 Combining Equ. (A51) and Equ. (A52) yields

9

$$10 \quad \Lambda_w = \frac{W\tilde{\Lambda}}{\tilde{E}\tau_w}. \quad [A53]$$

11

12 The parameter τ_w represents the expected length of drought periods. For $\tau_w \rightarrow 0$ the
 13 plant “expects” its water reserves to always be sufficient for continuing survival. In this
 14 case, $\Lambda_w \rightarrow \infty$, meaning the plant has no explicit drought adaptation in its phenology.
 15 This is assumed for the cold-deciduous and cold-evergreen PFTs. For warm-evergreen
 16 plants, we expect the value for τ_w in the region of 1 year, and for grasses and
 17 warm-deciduous plants between one and two months. Water limitation is implemented
 18 separately for each PFT to reflect differences in the water use strategy, defined mainly
 19 by τ_w .

20 Observe also that for $\tilde{E} \rightarrow 0$ we have $\Lambda_w \rightarrow \infty$, since without evaporative demand
 21 the leaf area is not water limited, as it is the case for $\tau_w \rightarrow 0$. Since the LAI cannot grow

1 indefinitely, it must be limited by other factors, such as light availability, nutrients and
 2 structure. These additional limitations are summarized into a single universal
 3 parameter $\hat{\Lambda}$ (cf., Knorr (2000)) and incorporated into the model via:

$$4 \quad \tilde{\Lambda}_{\max} = \nu(\hat{\Lambda}, \Lambda_w). \quad [A54]$$

6 $\nu(x, y)$ is a smoothed minimum function defined by

$$8 \quad \nu(x, y) = \frac{x + y - \sqrt{(x + y)^2 - 4xy}}{2\eta} \quad [A55]$$

10
 11 with $\eta = 0.99$. $\tilde{\Lambda}_{\max}$ is recomputed daily with daily values of the soil moisture, W ,
 12 whereas \tilde{E} may be recomputed at longer intervals. This allows avoiding re-computing
 13 the diurnal cycle of photosynthesis and energy balance for every simulated day, while
 14 keeping a daily time step of phenology and water balance, to save computing time with
 15 the full BETHY model (Knorr, 2000).

16 Instead of $\tilde{\Lambda}_{\max}$, equation (A43) uses Λ_{\max} , its weighted time integration
 17 computed in the same way as T from T_{2m} (equation (A42)), with the analogous
 18 definition:

$$19 \quad \Lambda_{\max}(t) = \frac{1}{\tau_S} e^{-t/\tau_S} \int_{-\infty}^t \tilde{\Lambda}_{\max}(t') e^{t'/\tau_S} dt' . \quad [A56]$$

21

1 It is computationally favourable to bring equation (A56) to an incremental form:

2

$$\begin{aligned}
 \Lambda_{\max}(t + \Delta t) &= \frac{1}{\tau_s} e^{-(t+\Delta t)/\tau_s} \int_{-\infty}^{t+\Delta t} \tilde{\Lambda}_{\max}(t') e^{t'/\tau_s} dt' \\
 3 \quad &= \frac{1}{\tau_s} e^{-\Delta t/\tau_s} e^{-t/\tau_s} \left(\int_{-\infty}^t \tilde{\Lambda}_{\max}(t') e^{t'/\tau_s} dt' + \int_t^{t+\Delta t} \tilde{\Lambda}_{\max}(t') e^{t'/\tau_s} dt' \right). \quad [\text{A57}] \\
 &= e^{-\Delta t/\tau_s} \Lambda_{\max}(t) + \frac{1}{\tau_s} e^{-(t+\Delta t)/\tau_s} \int_t^{t+\Delta t} \tilde{\Lambda}_{\max}(t') e^{t'/\tau_s} dt'
 \end{aligned}$$

4

5 If Δt is very short and thus the time incremental of Λ_{\max} is assumed to be constant, and

6 then is expressed simply:

7

$$8 \quad \Lambda_{\max}(t + \Delta t) = e^{-\Delta t/\tau_s} \Lambda_{\max}(t) + \hat{\Lambda}_{\max}(t) (1 - e^{-\Delta t/\tau_s}), \quad [\text{A58}]$$

9

10 The advantage of this scheme is that it has only one free parameter, τ_w , in addition to τ_s .

11 Since changing τ_s might lead to instabilities of the optimization in a way similar to τ_m ,

12 this parameter is also held constant at value of 30 days. Detailed information for this

13 phenology part is to be referred to Knorr et al. (2010).

14

15

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- 8
- 9
- 10

Table A1. Matrix of error co-variance in parameters in posterior runs assimilating the LHF (Experiment 1). Top rows: physiology, middle: phenology, bottom: energy and water budgets. Units of physiology parameters are V_{\max} : $\mu\text{mol}(\text{CO}_2)\text{m}^{-2}\text{s}^{-1}$, k : $\mu\text{mol}(\text{air})\text{m}^{-2}\text{s}^{-1}$, $\alpha_{\Gamma, T}$: $\mu\text{mol}(\text{CO}_2)\text{mol}(\text{air})^{-10}\text{C}^{-1}$, K_C in $\mu\text{mol}(\text{CO}_2)\text{mol}(\text{air})^{-1}$, K_O in $\text{mol}(\text{O}_2)\text{mol}(\text{air})^{-1}$, activation energies E in J mol^{-1} , τ_w in days, C_{w0} in mm hour^{-1} , W_{\max} in mm, others unitless.

Num.			1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	16	17	18	19	20	21	22	23	24
	PFT		2	10	2	10	All	All	2	2	10	2	10	2	2	2	All	All	2	10	2	10	All	All	All	All
	Parameter		V_{\max}^{25}	V_{\max}^{25}	$a_{J,V}$	k^{25}	E_{Rd}	$E_{V\max}$	E_{KO}	E_{KC}	E_k	α_q	α_i	K_C^{25}	K_O^{25}	$\alpha_{\Gamma, T}$	\mathcal{A}	ξ	τ_w^*	τ_w^*	fci_{C3}	fci_{C4}	C_{w0}	f_{RD0}	f_{RH0}	W_{\max}
1	2	V_{\max}^{25}	0.95																							
2	10	V_{\max}^{25}	0.01	0.65																						
3	2	$a_{J,V}$	0.00	0.00	1.00																					
4	10	k^{25}	0.00	0.0	0.00	1.00																				
5	All	E_{Rd}	0.00	0.00	0.00	0.00	1.00																			
6	All	$E_{V\max}$	-0.02	-0.02	0.00	0.00	0.00	0.98																		
7	2	E_{KO}	0.00	0.00	0.00	0.00	0.00	0.00	1.00																	
8	2	E_{KC}	0.01	0.01	0.00	0.00	0.00	0.02	0.00	0.99																
9	10	E_k	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00															
10	2	α_q	0.00	-0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.99														
11	10	α_i	0.00	-0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.99													
12	2	K_C^{25}	0.01	0.00	0.00	0.00	0.00	0.01	0.00	-0.01	0.00	0.00	0.00	1.00												
13	2	K_O^{25}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00											
14	2	$\alpha_{\Gamma, T}$	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00										
15	All	\mathcal{A}_{\max}	0.06	-0.09	0.00	0.00	0.00	0.06	0.01	-0.05	0.00	-0.02	-0.01	-0.02	0.00	0.01	0.75									
16	All	ξ	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00								
17	2	τ_w^*	-0.14	0.09	-0.01	0.00	0.00	0.01	0.00	0.00	0.00	-0.03	0.02	0.02	-0.01	0.03	0.06	0.00	0.33							
18	10	τ_w^*	-0.01	-0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	-0.01	0.03	0.02	-0.05	0.41						
19	2	fci_{C3}	-0.07	-0.09	-0.01	0.00	0.00	-0.02	0.00	0.01	0.00	-0.02	-0.02	0.01	0.00	0.02	0.01	0.00	-0.27	0.04	0.81					
20	10	fci_{C4}	0.00	-0.16	0.00	0.00	0.00	-0.01	0.00	0.01	0.00	-0.01	-0.02	0.00	0.00	0.01	-0.03	0.00	0.04	-0.03	-0.05	0.93				
21	All	C_w	0.00	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00			
22	All	h_0	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	
23	All	\hat{h}	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.01	0.00	0.00	1.00	
24	All	W_{\max}	0.00	0.02	0.00	0.00	0.00	-0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.02	0.01	0.02	0.00	0.00	0.01

Italic: absolute number of error co-variance, except for diagonal values, > 0.1

Table A2. Matrix of error co-variance in parameters in posterior runs assimilating the FAPAR (Experiment 2). Top rows: physiology, middle: phenology, bottom: energy and water budgets. Units of physiology parameters are V_{\max} : $\mu\text{mol}(\text{CO}_2)\text{m}^{-2}\text{s}^{-1}$, k : $\mu\text{mol}(\text{air})\text{m}^{-2}\text{s}^{-1}$, $\alpha_{\Gamma, T}$: $\mu\text{mol}(\text{CO}_2)\text{mol}(\text{air})^{-10}\text{C}^{-1}$, K_C in $\mu\text{mol}(\text{CO}_2)\text{mol}(\text{air})^{-1}$, K_O in $\text{mol}(\text{O}_2)\text{mol}(\text{air})^{-1}$, activation energies E in J mol^{-1} , τ_w in days, C_{w0} in mm hour^{-1} , W_{\max} in mm, others unitless.

Num.			1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	16	17	18	19	20	21	22	23	24	
	PFT		2	10	2	10	All	All	2	2	10	2	10	2	2	2	All	All	2	10	2	10	All	All	All	All	
	Parameter		V_{\max}^{25}	V_{\max}^{25}	$a_{J,V}$	k^{25}	E_{Rd}	$E_{V\max}$	E_{KO}	E_{KC}	E_k	α_q	α_i	K_C^{25}	K_O^{25}	$\alpha_{\Gamma, T}$	\mathcal{A}	ξ	τ_w^*	τ_w^*	fci_{C3}	fci_{C4}	C_{w0}	f_{RD0}	f_{RH0}	W_{\max}	
1	2	V_{\max}^{25}	0.94																								
2	10	V_{\max}^{25}	-0.03	0.96																							
3	2	$a_{J,V}$	0.00	0.00	1.00																						
4	10	k^{25}	0.00	0.00	0.00	1.00																					
5	All	E_{Rd}	0.00	0.00	0.00	0.00	1.00																				
6	All	$E_{V\max}$	0.00	-0.01	0.00	0.00	0.00	1.00																			
7	2	E_{KO}	0.00	0.00	0.00	0.00	0.00	0.00	1.00																		
8	2	E_{KC}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00																	
9	10	E_k	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00																
10	2	α_q	-0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00															
11	10	α_i	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00														
12	2	K_C^{25}	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00													
13	2	K_O^{25}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00												
14	2	$\alpha_{\Gamma, T}$	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00											
15	All	\mathcal{A}_{\max}	-0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	0.00	0.00	0.00	0.01	0.98										
16	All	ξ	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	-0.01	0.00	-0.01	0.03	0.94									
17	2	τ_w^*	-0.04	0.06	-0.01	0.00	0.00	-0.01	0.00	0.01	0.00	-0.02	0.01	0.00	0.00	0.02	-0.01	0.01	0.32								
18	10	τ_w^*	-0.05	-0.13	0.00	0.00	0.00	-0.03	0.00	0.02	0.00	0.01	-0.02	0.01	0.00	0.00	0.06	-0.04	0.12	0.40							
19	2	fci_{C3}	-0.15	-0.05	-0.01	0.00	0.00	-0.01	0.00	0.01	0.00	-0.04	0.00	0.02	-0.01	0.04	-0.06	0.14	-0.15	-0.05	0.60						
20	10	fci_{C4}	-0.01	-0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	-0.06	-0.01	0.99					
21	All	C_w	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00				
22	All	h_0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	1.00			
23	All	\hat{h}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	1.00		
24	All	W_{\max}	0.04	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	-0.01	0.00	0.00	-0.01	0.04	0.06	0.07	0.06	0.02	0.00	0.00	0.00	0.06	

Italic: absolute number of error co-variance, except for diagonal values, > 0.1

Table A3. Matrix of error co-variance in parameters in posterior runs assimilating the combination of LHF and FAPAR (Experiment 3). Top rows: physiology, middle: phenology, bottom: energy and water budgets. Units of physiology parameters are V_{\max} : $\mu\text{mol}(\text{CO}_2)\text{m}^{-2}\text{s}^{-1}$, k : $\mu\text{mol}(\text{air})\text{m}^{-2}\text{s}^{-1}$, $\alpha_{\Gamma, T}$: $\mu\text{mol}(\text{CO}_2)\text{mol}(\text{air})^{-1}\text{C}^{-1}$, K_C in $\mu\text{mol}(\text{CO}_2)\text{mol}(\text{air})^{-1}$, K_O in $\text{mol}(\text{O}_2)\text{mol}(\text{air})^{-1}$, activation energies E in J mol^{-1} , τ_w in days, C_{w0} in mm hour^{-1} , W_{\max} in mm, others unitless.

Num.			1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	16	17	18	19	20	21	22	23	24
	PFT		2	10	2	10	All	All	2	2	10	2	10	2	2	2	All	All	2	10	2	10	All	All	All	All
		Parameter	V_{\max}^{25}	V_{\max}^{25}	$a_{I,V}$	k^{25}	E_{Rd}	$E_{V\max}$	E_{KO}	E_{KC}	E_k	α_q	α_i	K_C^{25}	K_O^{25}	$\alpha_{\Gamma, T}$	λ	ξ	τ_w^*	τ_w^*	f_{ciC3}	f_{ciC4}	C_{w0}	f_{RD0}	f_{RH0}	W_{\max}
1	2	V_{\max}^{25}	0.33																							
2	10	V_{\max}^{25}	-0.01	0.19																						
3	2	$a_{I,V}$	0.00	0.00	1.00																					
4	10	k^{25}	0.00	0.00	0.00	1.00																				
5	All	E_{Rd}	0.00	0.00	0.00	0.00	1.00																			
6	All	$E_{V\max}$	-0.01	-0.03	0.00	0.00	0.00	1.00																		
7	2	E_{KO}	0.00	0.00	0.00	0.00	0.00	0.00	1.00																	
8	2	E_{KC}	0.01	0.00	0.00	0.00	0.00	0.00	0.00	1.00																
9	10	E_k	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00															
10	2	α_q	0.03	0.00	-0.02	0.00	0.00	0.01	0.00	-0.01	0.00	0.93														
11	10	α_i	0.00	-0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	0.99													
12	2	K_C^{25}	0.07	0.00	-0.01	0.00	0.00	0.01	0.00	-0.01	0.00	-0.04	0.00	0.98												
13	2	K_O^{25}	-0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	1.00											
14	2	$\alpha_{\Gamma, T}$	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.01	0.00	0.98										
15	All	λ_{\max}	-0.02	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.01	0.00	-0.01	0.94									
16	All	ξ	0.00	0.00	0.00	0.00	0.00	-0.01	0.00	0.00	0.00	0.00	-0.01	0.00	0.00	0.00	0.01	0.73								
17	2	τ_w^*	0.01	0.00	0.00	0.00	0.00	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.02							
18	10	τ_w^*	-0.03	-0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.20	0.01	0.00	0.19						
19	2	f_{ciC3}	-0.43	0.01	-0.02	0.00	0.00	0.00	0.00	0.00	0.00	-0.07	-0.01	0.00	0.00	0.05	0.00	0.00	-0.02	0.01	0.60					
20	10	f_{ciC4}	0.00	-0.25	0.00	0.00	0.00	-0.01	0.00	0.00	0.00	-0.01	-0.02	0.00	0.00	0.00	0.01	-0.01	0.00	0.01	0.00	0.92				
21	All	C_{w0}	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	-0.02	0.00	0.00	1.00			
22	All	h_0	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	1.00		
23	All	\hat{h}	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	1.00	
24	All	W_{\max}	0.00	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00

Italic: absolute number of error co-variance, except for diagonal values, > 0.1

1

2

