Supplement S6

August 24, 2022

1 VOM Model Details

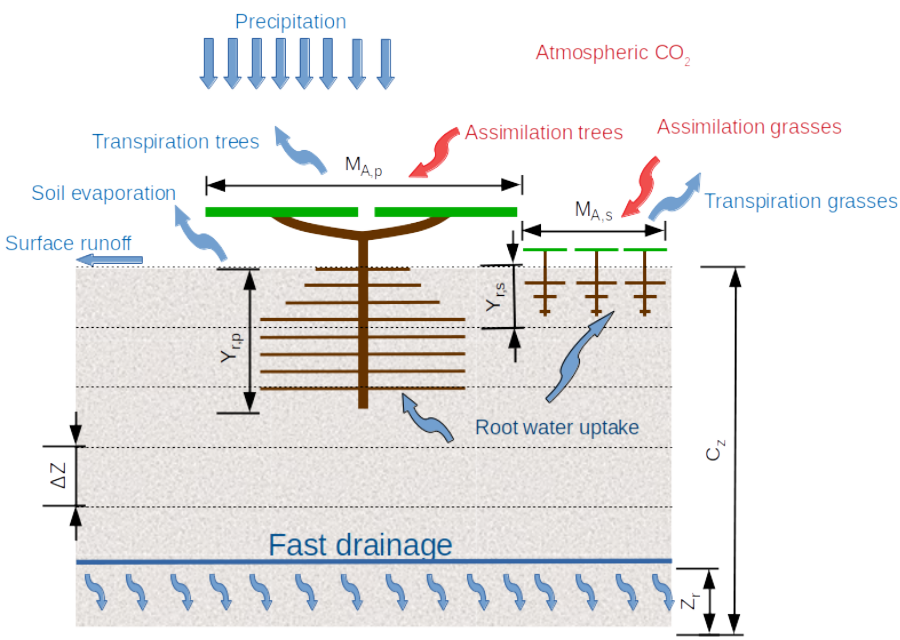

Figure S6.1. *Schematization of the Vegetation Optimality Model as two big leaves (see also Nijzink et al. (2022)), with $M_{A,p}$ and $M_{A,s}$ the fractional cover of perennial trees and seasonal grasses respectively, $y_{r,p}$ and $y_{r,s}$ the rooting depths of the perennial trees and seasonal grasses respectively, ΔZ the soil layer thickness, C_Z the total soil depth, and Z_r the drainage depth.*

The seasonal vegetation (grasses) and the perennial vegetation (trees) are represented in the VOM as two big leaves (see Figure S6.1). The photosynthesis of these leaves was modelled as a function of irradiance, atmospheric CO_2-concentrations, photosynthetic capacity and stomatal conductance von Caemmerer (2000); Schymanski et al. (2009):

$$A_g = \frac{1}{8}\left(4C_aG_s + 8\Gamma_*G_s + \left((J_e - 4R_l - 4G_s(C_a - 2\Gamma_*))^2 + 16G_s(8C_aG_s + J_e + 8R_l)\Gamma_*\right)^{\frac{1}{2}}\right) \quad (1)$$

with J_e the electron transport rate (mol m^{-2} s^{-1}), G_s stomatal conductance (mol m^{-2} s^{-1}), R_l leaf respiration (mol m^{-2} s^{-1}), C_a the mole fraction of CO_2 in the air and Γ_* the CO_2 compensation point (mol CO_2 mol^{-1} air). The electron transport rate J_e is defined as:

$$J_e = \left(1.0 - e^{\frac{0.3I_a}{J_{max}}}\right) \cdot J_{max} \cdot M_a \quad (2)$$

with I_a the irradiance (mol m^{-2} s^{-1}), J_{max} the electron transport capacity (mol m^{-2} s^{-1}) and M_a the projected cover of vegetation (dimensionless fraction). The leaf respiration R_l is:

$$R_l = \frac{M_a \cdot c_{Rl} \cdot J_{max} \cdot (C_a - \Gamma_*)}{8 \cdot (C_a + 2 \cdot \Gamma_*)} \tag{3}$$

with c_{Rl} a constant set to 0.07 (dimensionless).

The electron transport capacity J_{max} in Equations 2 and 3 is determined in the following way:

$$J_{max} = \frac{J_{max,25}\left(h_a\left(e^{-\frac{h_d(T_{opt}-298.0)}{273T_{opt}R+25.0}} - 1.0\right) + h_d\right) e^{\frac{h_a(T_a-25.0)(273.0T_{opt}R+T_{opt}-273.0)}{(T_a+273.0T_{opt}R)(273.0T_{opt}R+25.0)}}}{h_a\left(e^{\frac{h_d(T_a-T_{opt}+273.0)}{T_a+273.0T_{opt}R}} - 1.0\right) + h_d} \tag{4}$$

with h_a the rate of exponential increase of the function below the $J_{max,25}$ and h_d the rate of exponential decrease of the function above $J_{max,25}$, set to 43.79 and 200 kJ mol^{-1}, respectively.$J_{max,25}$ is the electron transport capacity at 25 ^{o}C (mol m^{-2} s^{-1}) and T_{opt} the optimal temperature (K).

Root water uptake ($Q_{r,i}$, m/s), is modelled with the following equation:

$$Q_{r,i} = S_{A,r}\frac{h_{r,i} - h_i}{\Omega_r + \Omega_{s,i}} \tag{5}$$

with $S_{A,r}$ the root surface area (m^2 m^{-2}), $h_{r,i}$ the hydraulic head in the roots (m), h_i the hydraulic head in the soil (m), Ω_r the radial root resistivity (s) and $\Omega_{s,i}$ the soil resistivity (s), with subscript i denoting the specific soil layer.

1.1 Carbon cost functions and Net Carbon Profit

Different carbon cost functions are defined in the VOM. The carbon cost related to foliage maintenance (R_f) is a linear relation between the total leaf area and a constant leaf turnover cost factor:

$$R_f = L_{AIc} \cdot c_{tc} \cdot M_{A,p} \tag{6}$$

where L_{AIc} is the clumped leaf area index (LAI of vegetated area, set to a constant 2.5 based on Schymanski et al., 2007), c_{tc} is the leaf turnover cost factor (set to 0.22 μmol^{-1} s^{-1} m^{-2}) and $M_{A,p}$ is the perennial vegetation cover fraction.

The costs for root maintenance (R_r) are:

$$R_r = c_{Rr} \cdot \left(\frac{r_r}{2} \cdot S_{A,r}\right) \tag{7}$$

where c_{Rr} is the respiration rate per fine root volume (0.0017 mol s^{-1} m^{-3}), r_r the root radius (set to 0.3*10^{-3} m). $S_{A,r}$ represents the root surface area per unit ground area (m^{2}m^{-2}).

Water transport costs (R_v) are a function of rooting depth and vegetated cover:

$$R_v = c_{rv} \cdot M_A \cdot y_r \tag{8}$$

where c_{rv} is the cost factor for water transport (set to 1.0 μmol m^{-3} s^{-1}), M_A the fraction of vegetation cover ($-$), and y_r the rooting depth (m).

Based on the carbon cost functions and the assimilated carbon by photosynthesis (A_g) the Net Carbon Profit is defined as:

$$NCP = \int \left(A_g(t) - R_f(t) - R_r(t) - R_v(t)\right) dt \quad (9)$$

with t representing the time step.

Several vegetation properties are optimized for maximum Net Carbon Profit. See Table S6.5 for the optimized vegetation properties.

Table S6.1. *Vegetation properties in the Vegetation Optimality Model optimized for maximizing the Net Carbon Profit.*

Parameter	Description	Initial range	Timescale	Unit
$c_{\lambda f,p}$	water use parameter perennial vegetation	0.0 - 10000.0	Long-term	mol mol^{-1} m^{-1}
$c_{\lambda e,p}$	water use parameter perennial vegetation	-3.0 - 0.0	Long-term	-
$c_{\lambda f,s}$	water use parameter seasonal vegetation	0.0 - 10000.0	Long-term	mol mol^{-1} m^{-1}
$c_{\lambda e,s}$	water use parameter seasonal vegetation	-3.0 - 0.0	Long-term	-
$M_{A,p}$	fractional cover perennial vegetation	0 - 1	Long-term	-
$y_{r,p}$	rooting depth perennial vegetation	1.0 - 9.0	Long-term	m
$y_{r,s}$	rooting depth seasonal vegetation	0.05 - 2	Long-term	m
$M_{A,s}$	fractional cover seasonal vegetation	0.00 - (1.0-pct)	Daily	-
$J_{max25,p}$	electron transport capacity perennial vegetation	-	Daily	mol s^{-1} m^{-2}
$J_{max25,s}$	electron transport capacity annual vegetation	-	Daily	mol s^{-1} m^{-2}
$G_{s,p}$	stomatal conductance perennial vegetation	-	Daily	mol s^{-1} m^{-2}
$G_{s,s}$	stomatal conductance seasonal vegetation	-	Daily	mol s^{-1} m^{-2}
$S_{Adr,i,s}$	root surface area distribution of perennial vegetation	-	Daily	m^2 m^{-3}
$S_{Adr,i,s}$	root surface area distribution of annual vegetation	-	Daily	m^2 m^{-3}

Table S6.2. *Soil characteristics of the study sites along the North Australian Tropical Transect, based on data from the Soil and Landscape Grid of Australia Viscarra Rossel et al. (2014a, b, c), in addition to field measurements of J. Beringer and L. B. Hutley. Here, θ_r refers to the residual moisture content, θ_s the saturated water content, α and n the Van Genuchten soil parameters* **?** *and K_{sat} the saturated hydraulic conductivity.*

Howard Springs	Soil type	θ_r (-)	θ_s (-)	α (1/m)	n (-)	K_{sat} (m/s)
0.00-0.20m	Sandy Loam	0.065	0.41	7.5	1.89	$1.228 * 10^{-5}$
0.20-0.40m	Sandy Loam	0.065	0.41	7.5	1.89	$1.228 * 10^{-5}$
0.40-0.60m	Sandy Clay Loam	0.1	0.39	5.9	1.48	$3.639 * 10^{-6}$
0.60-bedrock	Sandy Clay Loam	0.1	0.39	5.9	1.48	$3.639 * 10^{-6}$
Adelaide River						
0.00-0.20m	Silt Loam	0.067	0.45	2	1.41	$1.25 * 10^{-6}$
0.20-0.40m	Sandy Clay Loam	0.1	0.39	5.9	1.48	$3.639 * 10^{-6}$
0.40-0.60m	Sandy Clay Loam	0.1	0.39	5.9	1.48	$3.639 * 10^{-6}$
0.60-bedrock	Sandy Clay Loam	0.1	0.39	5.9	1.48	$3.639 * 10^{-6}$
Daly River						
0.00-0.20m	Sandy Loam	0.065	0.41	7.5	1.89	$1.228 * 10^{-5}$
0.20-0.40m	Loamy Sand	0.057	0.41	12.4	2.28	$4.053 * 10^{-6}$
0.40-0.60m	Sandy Loam	0.065	0.41	7.5	1.89	$1.228 * 10^{-5}$
0.60-bedrock	Sandy Clay Loam	0.1	0.39	5.9	1.48	$3.639 * 10^{-6}$
Dry River						
0.00-0.20m	Sandy Loam	0.065	0.41	7.5	1.89	$1.228 * 10^{-5}$
0.20-0.40m	Sandy Clay Loam	0.1	0.39	5.9	1.48	$3.639 * 10^{-6}$
0.40-0.60m	Sandy Clay	0.1	0.38	2.7	1.23	$3.333 * 10^{-6}$
0.60-bedrock	Sandy Clay	0.1	0.38	2.7	1.23	$3.333 * 10^{-6}$
Sturt Plains						
0.00-0.20m	Silt Loam	0.067	0.45	2	1.41	$1.25 * 10^{-6}$
0.20-0.40m	Sandy Clay	0.1	0.38	2.7	1.23	$3.333 * 10^{-6}$
0.40-0.60m	Sandy Clay	0.1	0.38	2.7	1.23	$3.333 * 10^{-6}$
0.60-bedrock	Sandy Clay	0.1	0.38	2.7	1.23	$3.333 * 10^{-6}$

2 FLEX Model Details

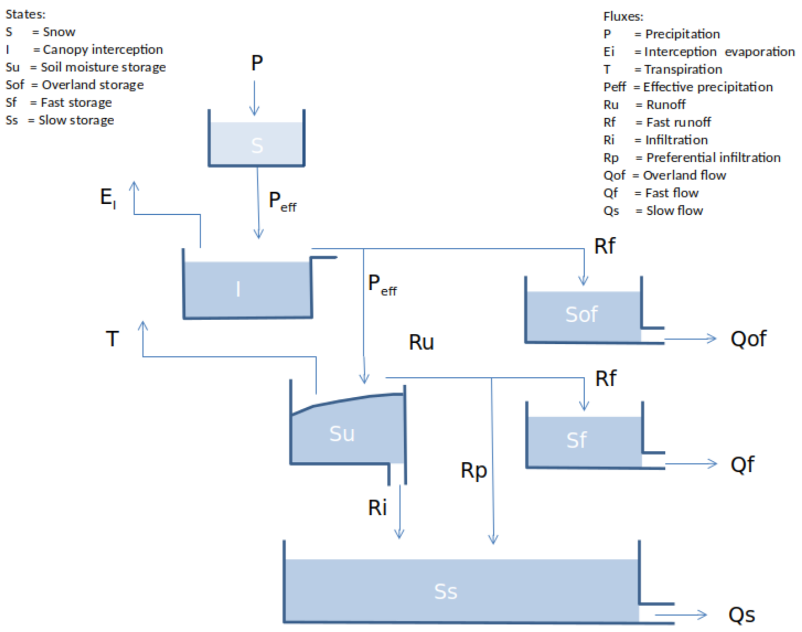

Figure S6.2. *Model structure of the FLEX model*

Table S6.3. *Calibrated parameters in the FLEX model.*

Parameter	Description	Initial range	Unit
Meltfactor	water released with per degree change in temperature	0.0 - 4.0	mm ^{o}C
Tthresh	threshold temperature to separate rain from snow	-5.0 - 0.0	^{o}C
Imax	maximum interception capacity	0.0 - 50.0	mm
Sumax	mxaimum root zone storage capacity	1.0 - 1000.0	mm
beta	shape factor soil moisture function	0.01 - 20	-
Kf	recession coefficient fast reservoir	1.0 - 30.0	days
Ks	recession coefficient slow reservoir	30.0 - 1000.0	days
LP	filling of soil moisture after which transpiration equals the potential rate	0.00 - 1.0	-
D	partition of runoff that preferentially percolates to the groundwater	0.0 - 1.0	-
Pmax	maximum percolation to the groundwater	0.0 - 50.0	mm day^{-1}
Tlagf	lag in fast flows	0.0 - 50.0	days
Tlags	lag in slow flows	0.0 - 50.0	days
InfMax	maximum infiltration	1.0 - 200.0	mm/day
Kof	recession coefficient overland flow reservoir	1.0 - 20.0	days

3 TUW Model Details

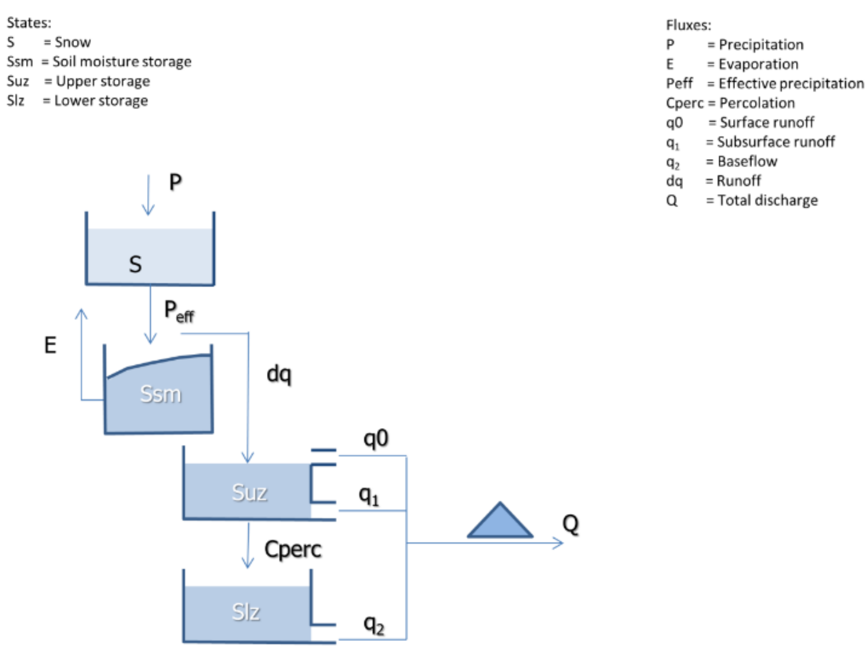

Figure S6.3. *Model structure of the TUW model, taken from the supplement of Nijzink et al. (2016)*

Table S6.4. *Calibrated parameters in the TUW model.*

Parameter	Description	Initial range	Unit
SCF	snow correction factor	0.9 - 1.5	-
DDF	degree day factor	0.0 - 5.0	mm $^{o}C^{-1}$ day^{-}
Tr	threshold temperature above which precipitation is rain	1.0 - 3.0	^{o}C
Ts	threshold temperature below which precipitation is snow	-3.0 - 1.0	^{o}C
Tm	threshold temperature above which melt starts	-2.0 - 2.0	^{o}C
LPrat	parameter related to the limit for potential evaporation	0.00 - 1.0	-
FC	field capacity, max. soil moisture storage	0.0 - 600.0	mm
BETA	non linear parameter for runoff production	0.00 - 20.0	-
K0	storage coefficient for very fast response	0.0 - 2.0	days
K1	storage coefficient for fast response	2.0 - 30.0	days
K2	storage coefficient for fast response	30.0 - 250.0	days
lsuz	threshold storage state very fast response	1.0 - 100.0	mm
cperc	constant percolation rate	0.0 - 8.0	mm day^{-1}
bmax	maximum base at low flows	0.0 - 30.0	days
croute	free scaling parameter	0.0 - 50.0	days^{2} mm^{-1}

4 GR4J Model Details

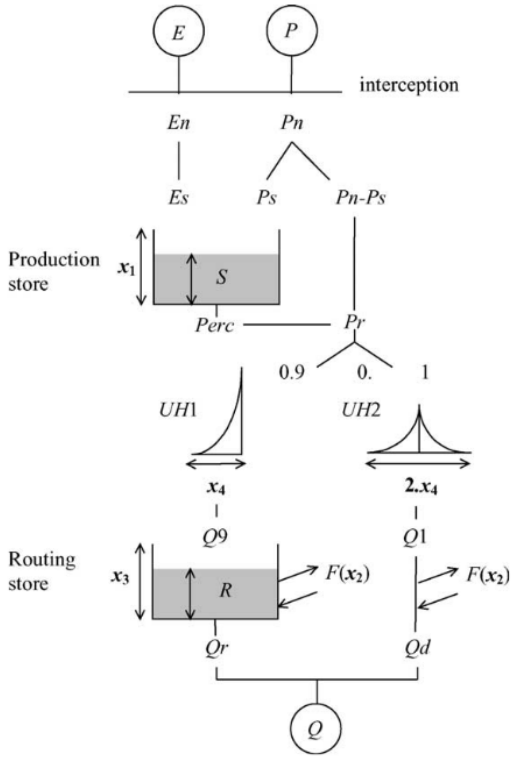

Figure S6.4. *Model structure of the GR4J model, taken from Perrin et al. (2003)*

Table S6.5. *Calibrated parameters in the GR4J model.*

Parameter	Description	Initial range	Unit
CemaNeige x_1	weighting coefficient for snow pack thermal state	100 - 1200	-
CemaNeige x_2	degree-day melt coefficient	-5.0 - 3.0	mm $^{o}C^{-1}$ day^{-}
x_1	maximum capacity of the production store	20 - 300	mm
x_2	groundwater exchange coefficient	1.1 - 2.9	mm day^{-1}
x_3	one day ahead maximum capacity of the routing store	0.0 - 1.0	mm
x_4	time base of unit hydrograph UH1	0.0 - 5.0	days

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