SWAT plant growth modification for improved modeling of tropical vegetation

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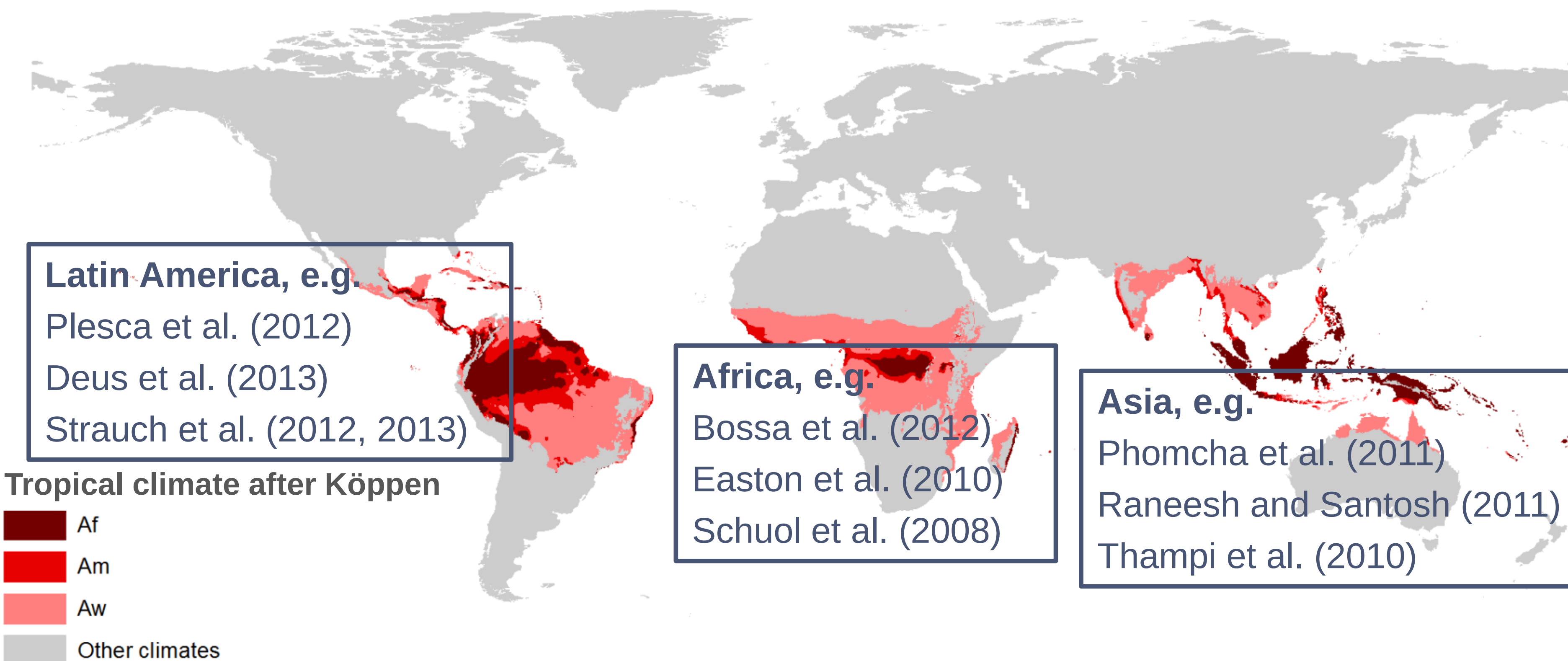
1 Introduction

SWAT is increasingly used in the tropics…

Latin America, e.g.
Plesca et al. (2012)
Deus et al. (2013)
Strauch et al. (2012, 2013)

Africa, e.g.
Bossa et al. (2012)
Easton et al. (2010)
Schuol et al. (2008)

Asia, e.g.
Phomcha et al. (2011)
Raneesh and Santosh (2011)
Thampi et al. (2010)



…but it was developed for temperate regions!
…critical evaluation of processes is often missing!

Plant growth of perennials (e.g. savanna)

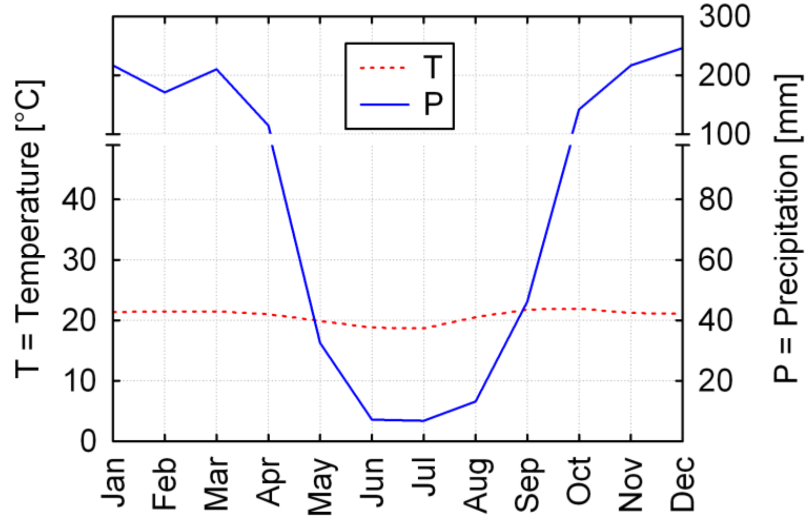

Cerrado s.s.

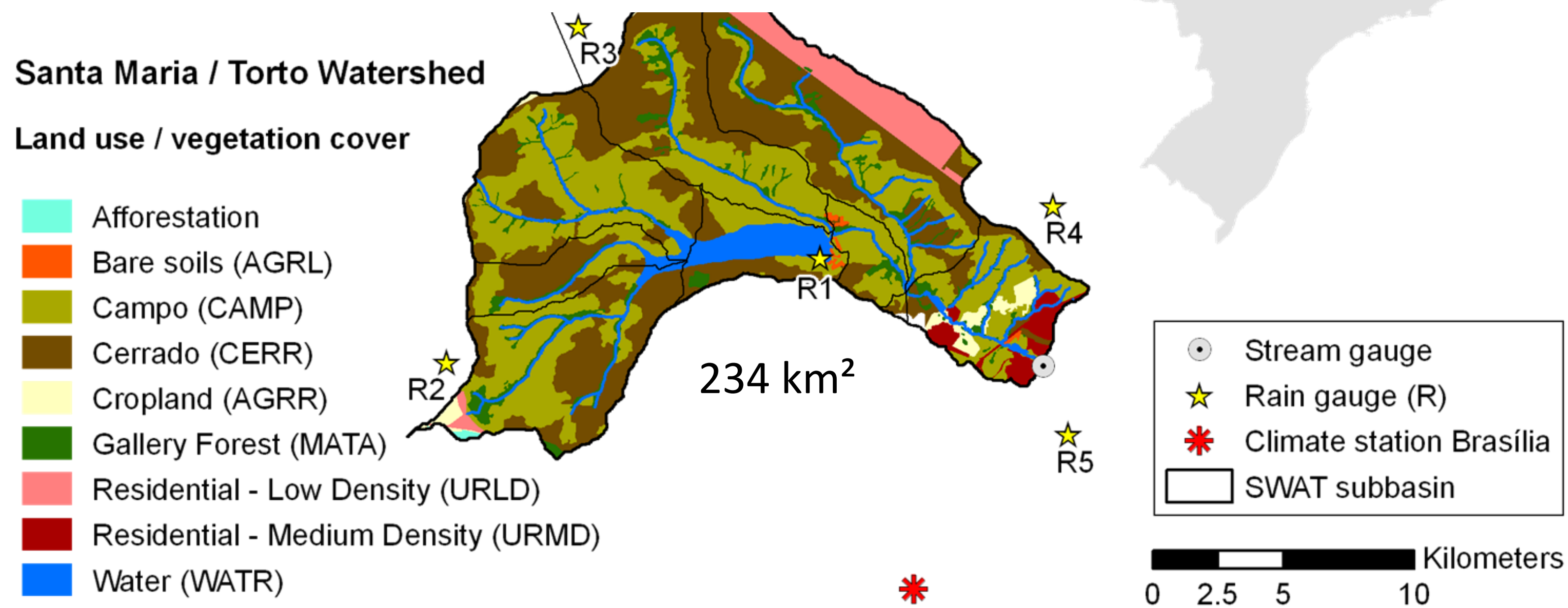

Mata ciliar /
Mata de galeria
Campo

2 Methods

Study area

Plant phenology is driven by precipitation pattern!





2 Methods

Plant growth & water balance in SWAT

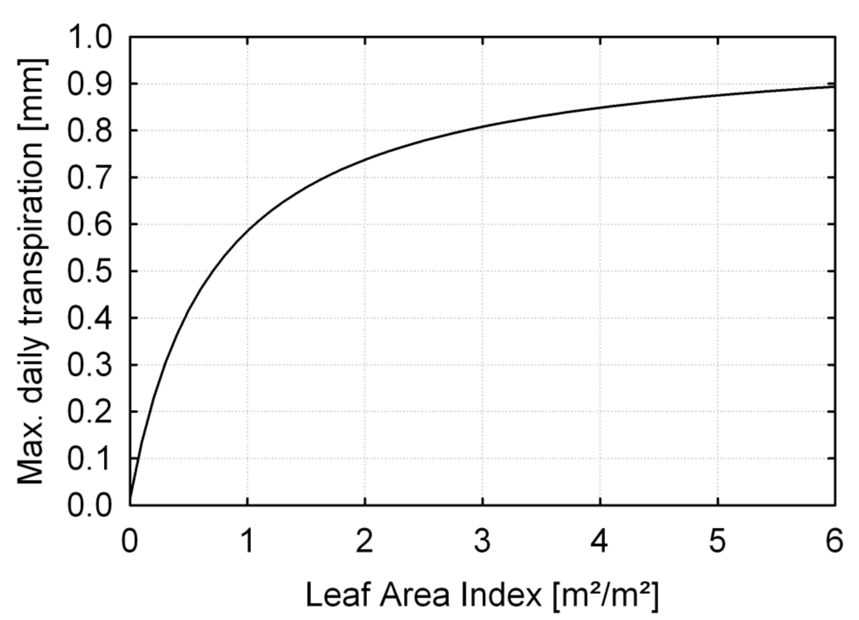
Water balance: $$SW_t = SW_0 + \sum_{i=1}^{t} (R - Q - ET - P - QR) \quad (1)$$

Calculating PET using Penman-Monteith:

$$\lambda E = \frac{\Delta \cdot (H_{net} - G) + \rho_{air} \cdot c_p \cdot \left[e_z^o - e_z\right] / r_a}{\Delta + \gamma \cdot (1 + r_c / r_a)} \quad (2)$$

Influence of LAI:

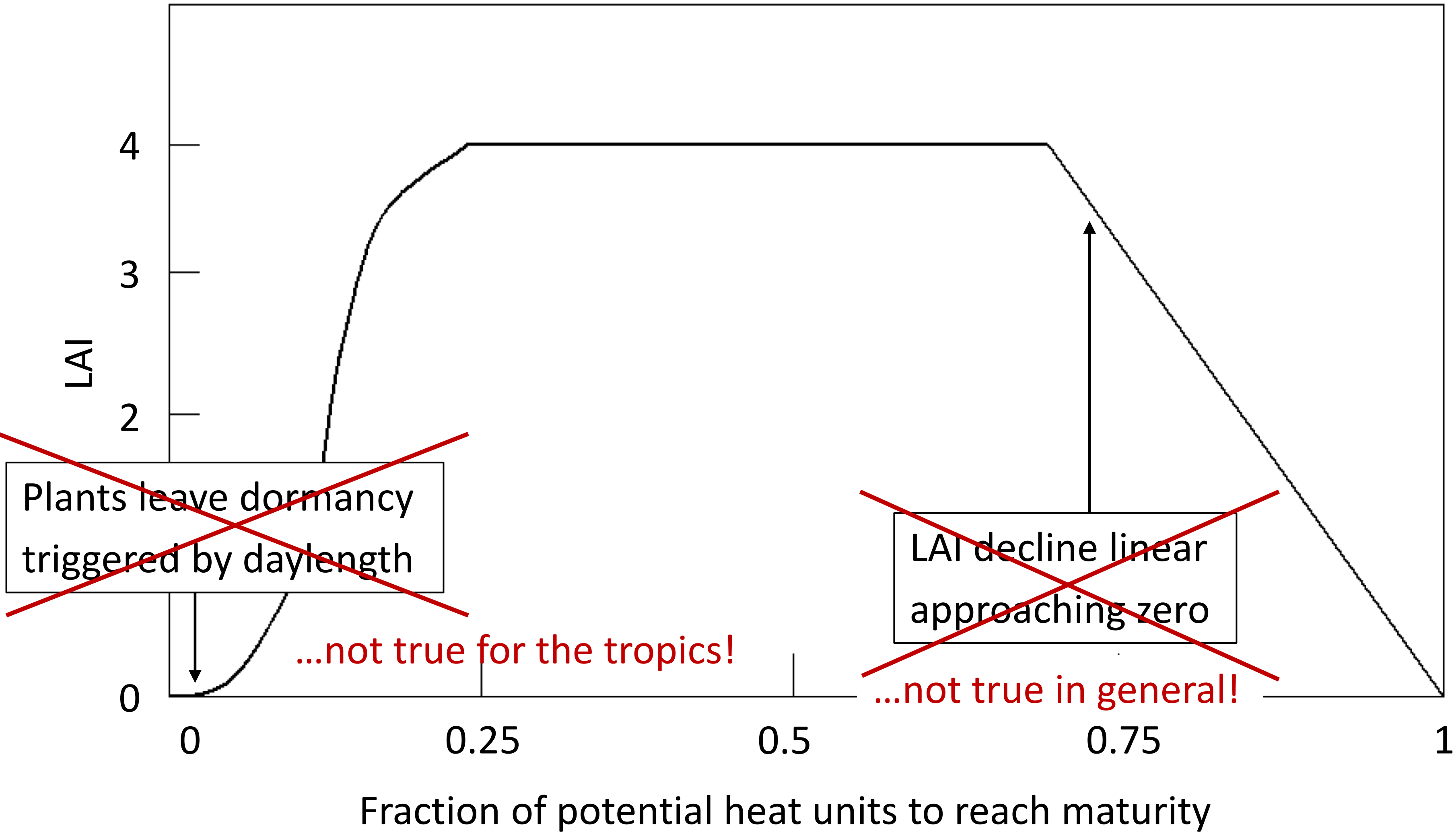
$$r_c = r_\ell / (0.5 \cdot LAI) \quad (3)$$



… assuming each parameter in (2) and (3) except LAI is constant with a value of 1

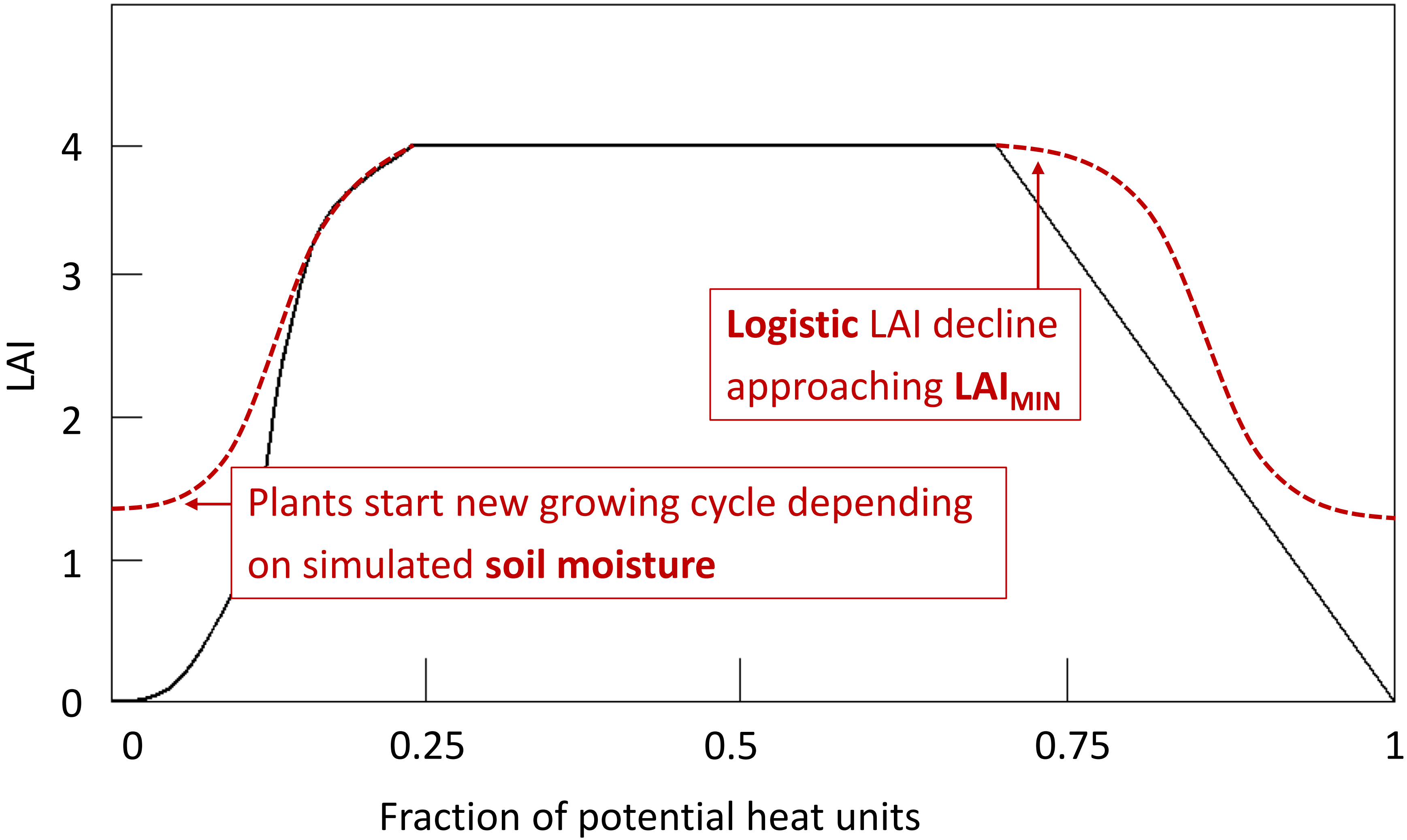
2 Methods

LAI calculation (default)



2 Methods

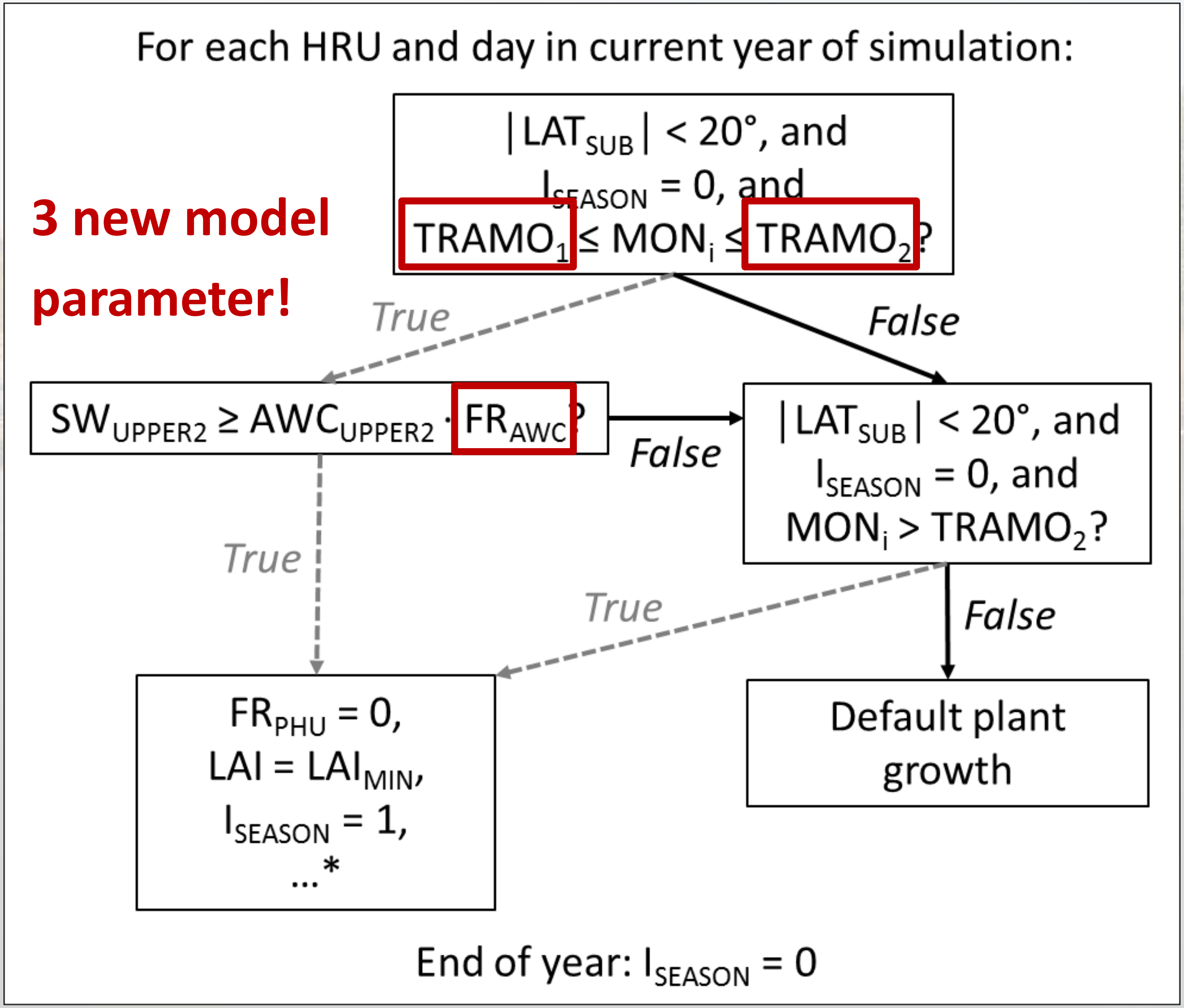
LAI calculation (modified)



2 Methods

Adaptation I:

Transition between 'growing seasons'

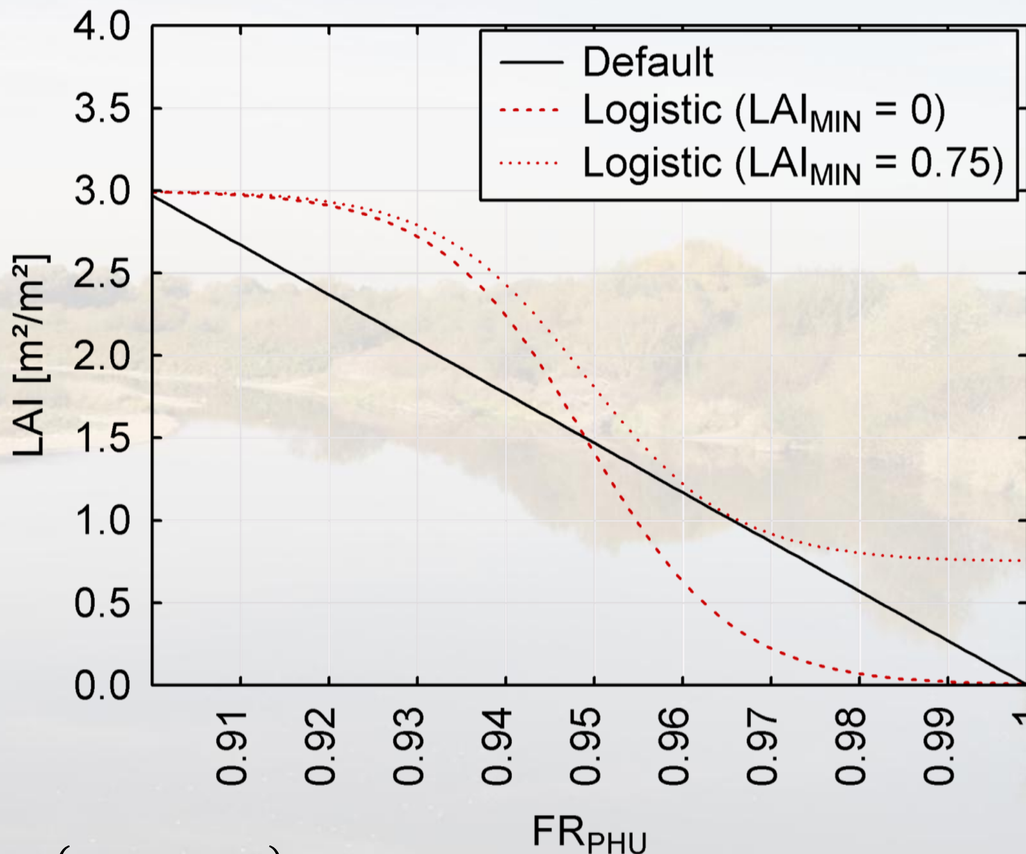


2 Methods

LAI declines when $FR_{PHU,i} > FR_{LAIopt}$ (DLAI)

Adaptation II:

Logistic LAI decline and minimum LAI



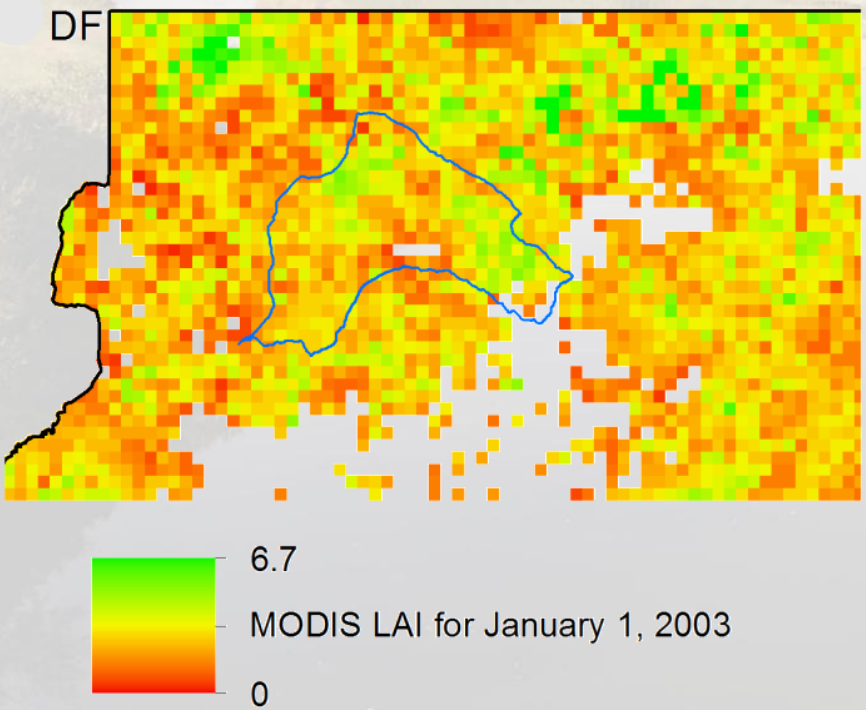
Default (linear): $LAI_i = LAI_{OPT} \cdot \frac{(1-FR_{PHU,i})}{(1-DLAI)}$

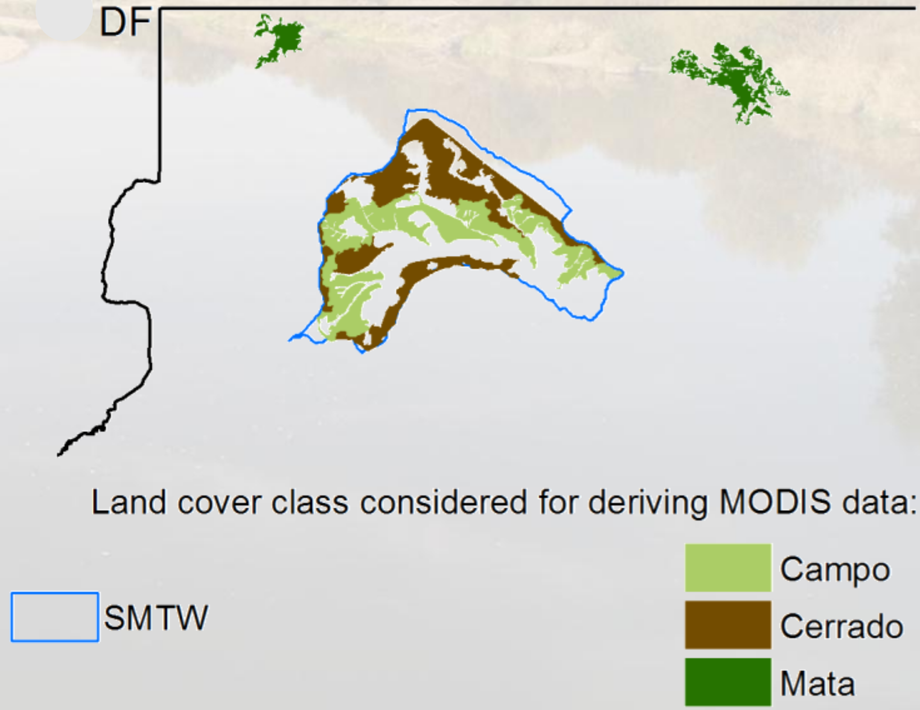
Modified (logistic): $LAI_i = \frac{LAI_{OPT}-LAI_{MIN}}{1+\exp\left(\left(\frac{(1-FR_{PHU,i})}{(1-DLAI)}-0.5\right)\cdot -12\right)} + LAI_{MIN}$

Reference data for plant phenology

MODIS LAI and ET estimations (collection 5 data)

- 1 km x 1 km, 8 day intervals
- since year 2000





2 Methods

Reference data for plant phenology

LAI MOD15A2

Myneni et al. (2002)

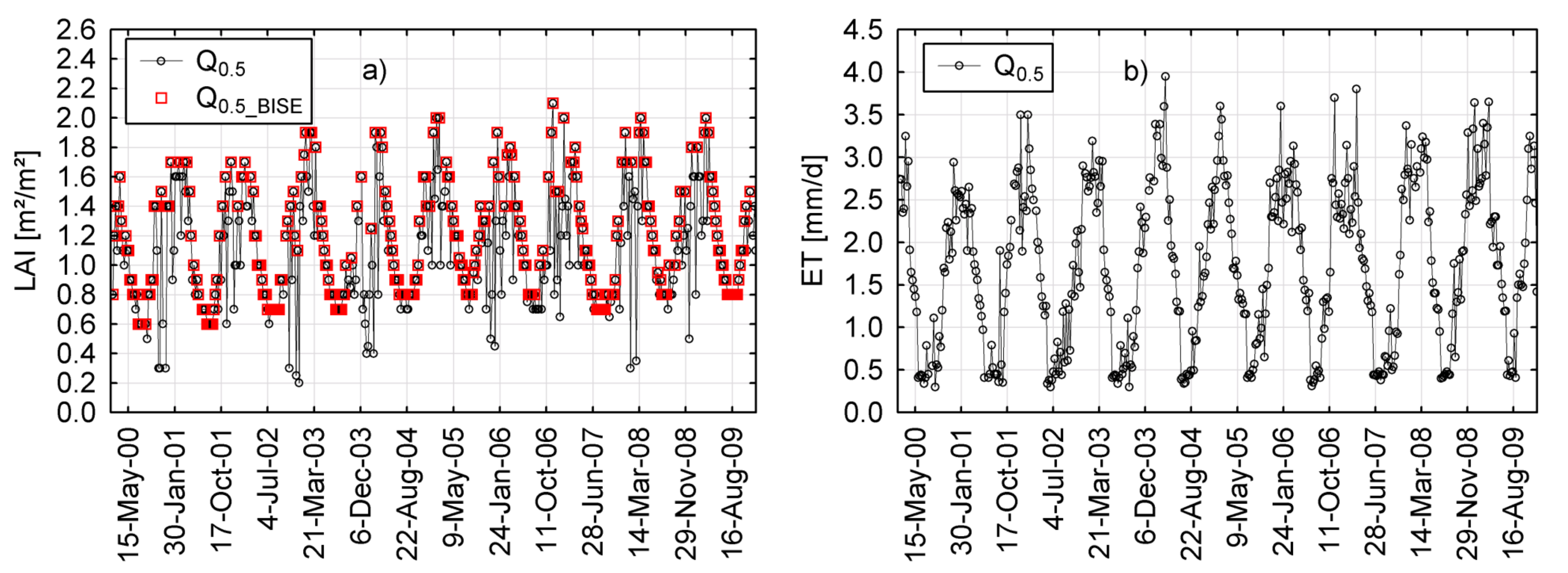
https://lpdaac.usgs.gov/

ET MOD16A2

Mu et al. (2011)

http://www.ntsg.umt.edu/

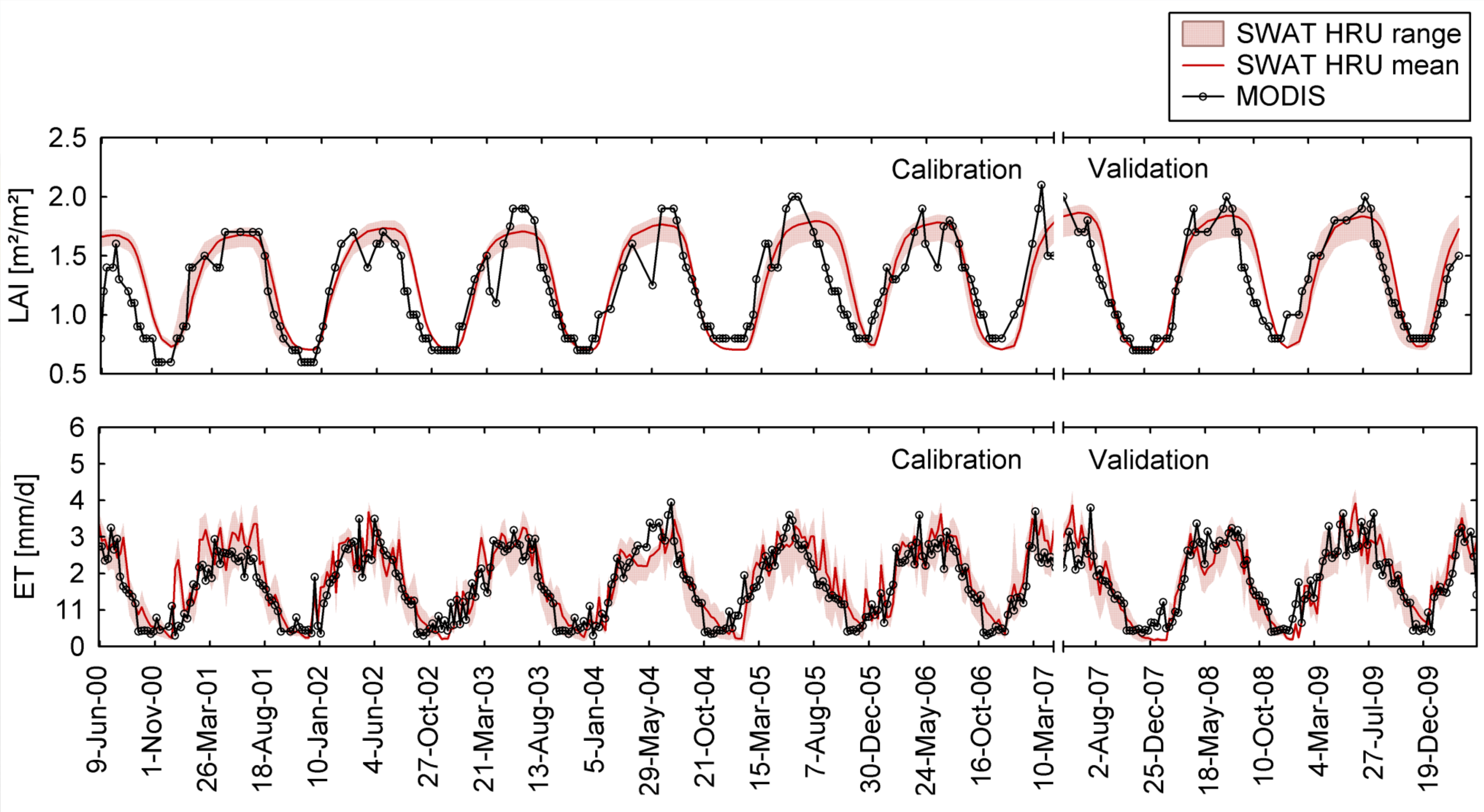
Example Cerrado (savanna):



BISE: 'Best Index Slope Extraction' (Viovy et al. 1992) using R-package 'phenex' (Lange and Doktor, 2013)

3 Results

Simulated LAI and ET, (example) Cerrado



Conclusions

- **Tropical vegetation dynamics <u>can hardly be represented</u> in SWAT (default model)**

  (e.g. no dormancy in the tropics)

- **Tropical vegetation dynamics <u>can be reasonably represented</u> in SWAT <u>when triggered by soil moisture</u> at the end of the dry season**

  (soil moisture approach is simple, but process-based)

- **Remote sensing data** (e.g. MODIS LAI and ET) **can be useful for model evaluation** (multi-objective calibration!)

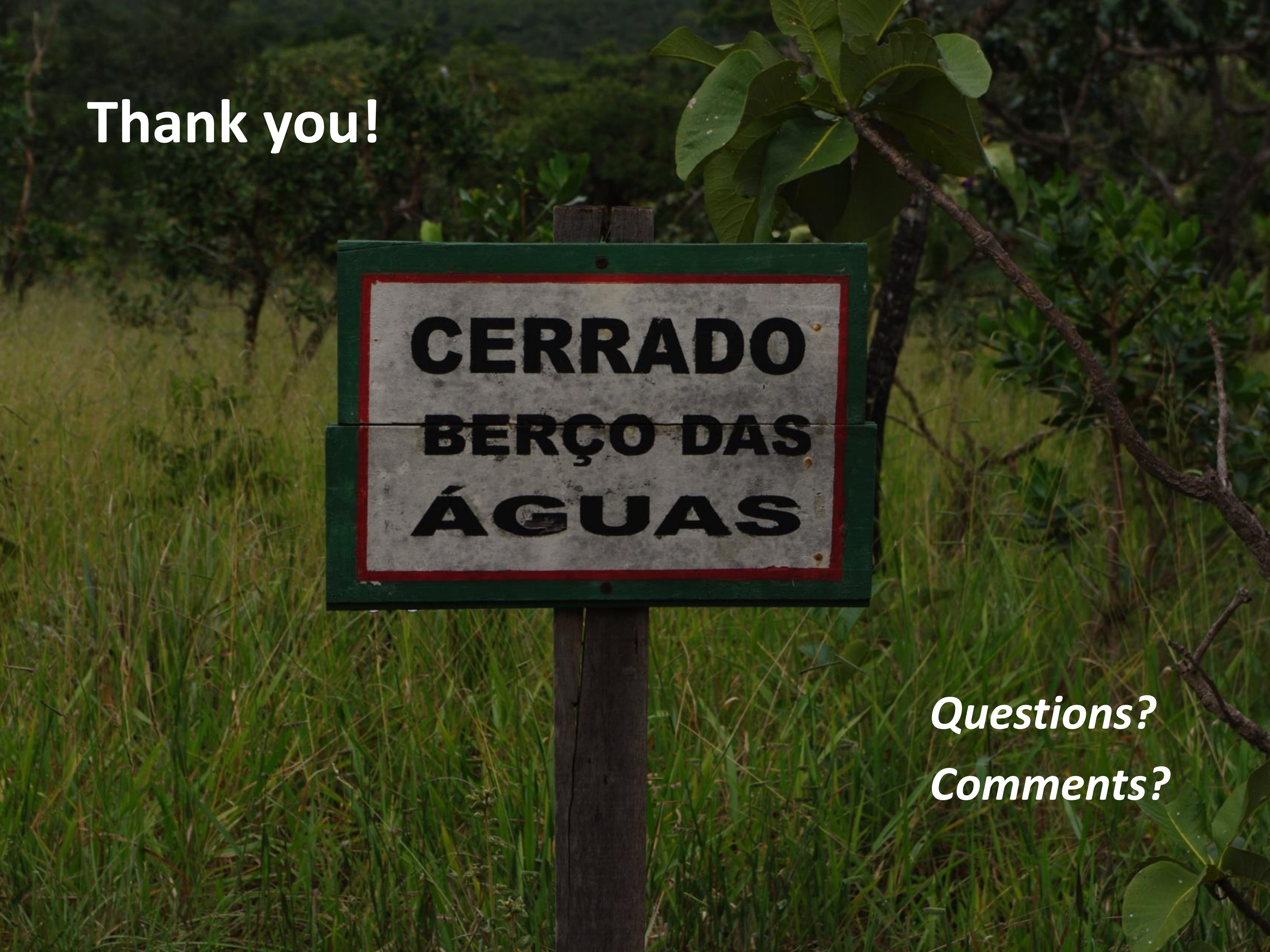
- **Plant growth module modifications affect…**

  … simulations in the tropics (soil moisture approach)**, but also**

  … simulations in general (logistic LAI decline rate)

  and might be useful for large parts of the SWAT community!

Thank you!



Questions?

Comments?

1 Introduction

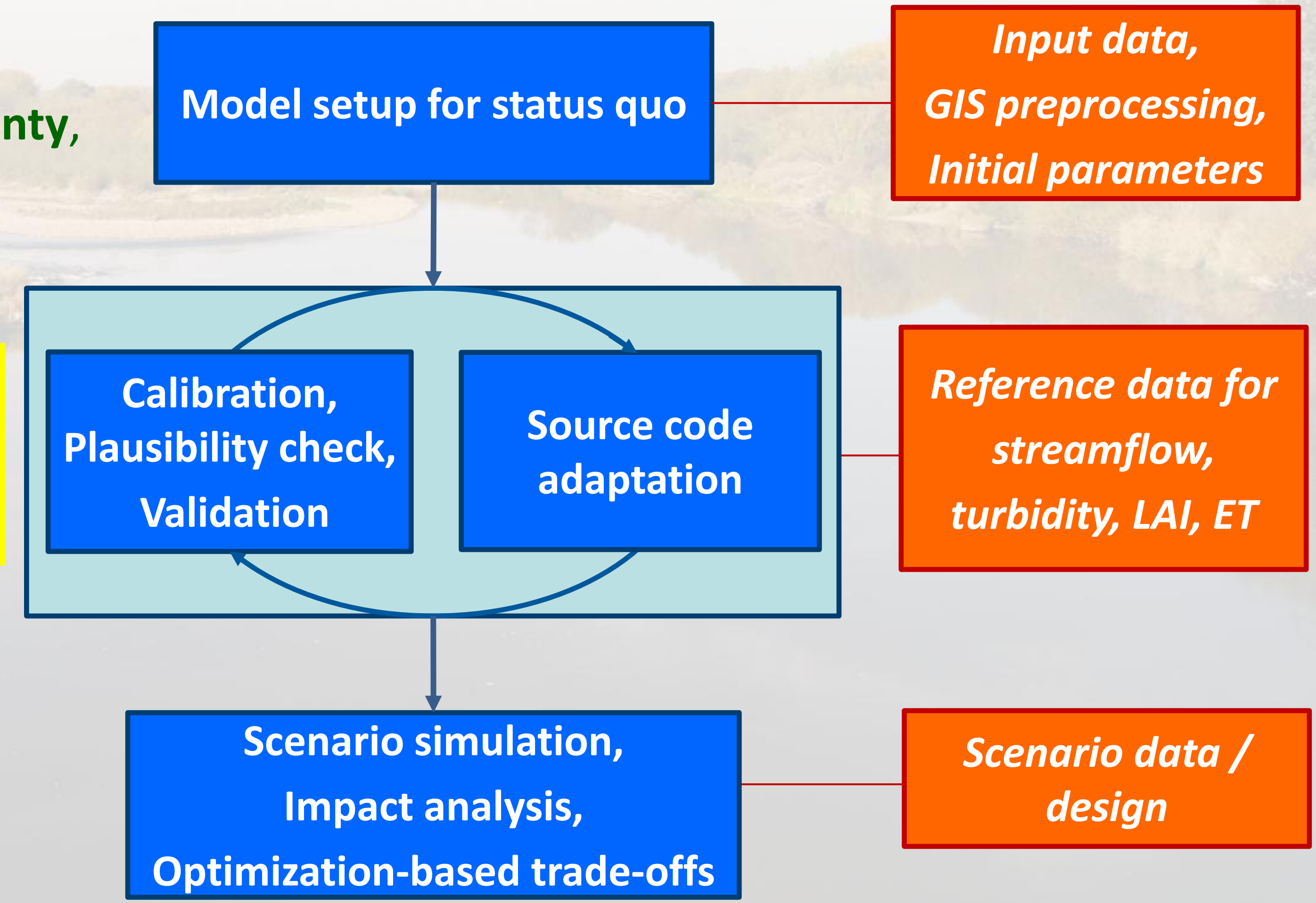
Modelling workflow

<u>**Case studies for PhD within IWAS project, Central Brazil:**</u>

Precipitation uncertainty,
Strauch et al. (2012),
J. Hydrol.

Plant growth,
Strauch & Volk (subm.),
Environ. Modell. Softw.

BMP scenarios,
Strauch et al. (2013),
J. Environ. Manage.

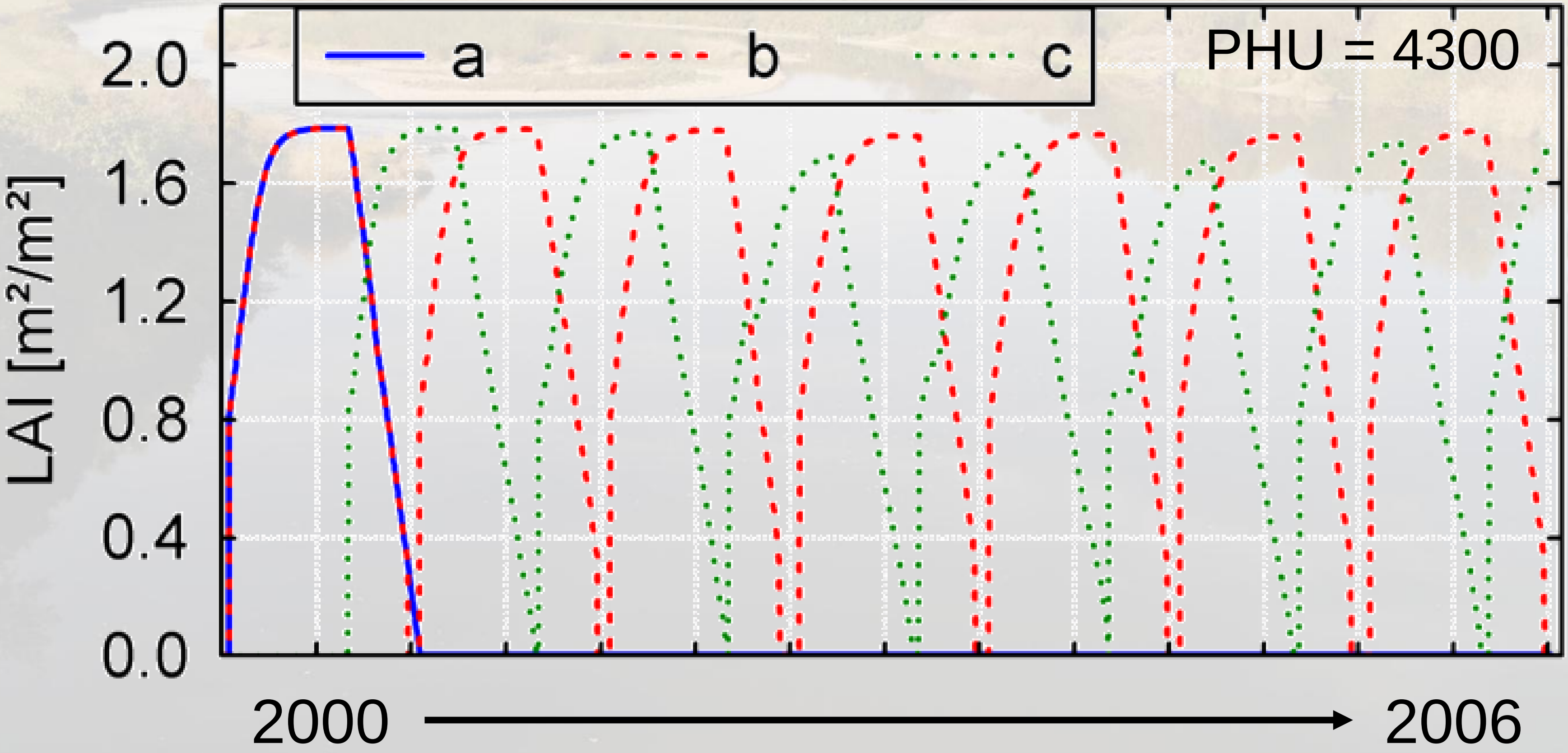


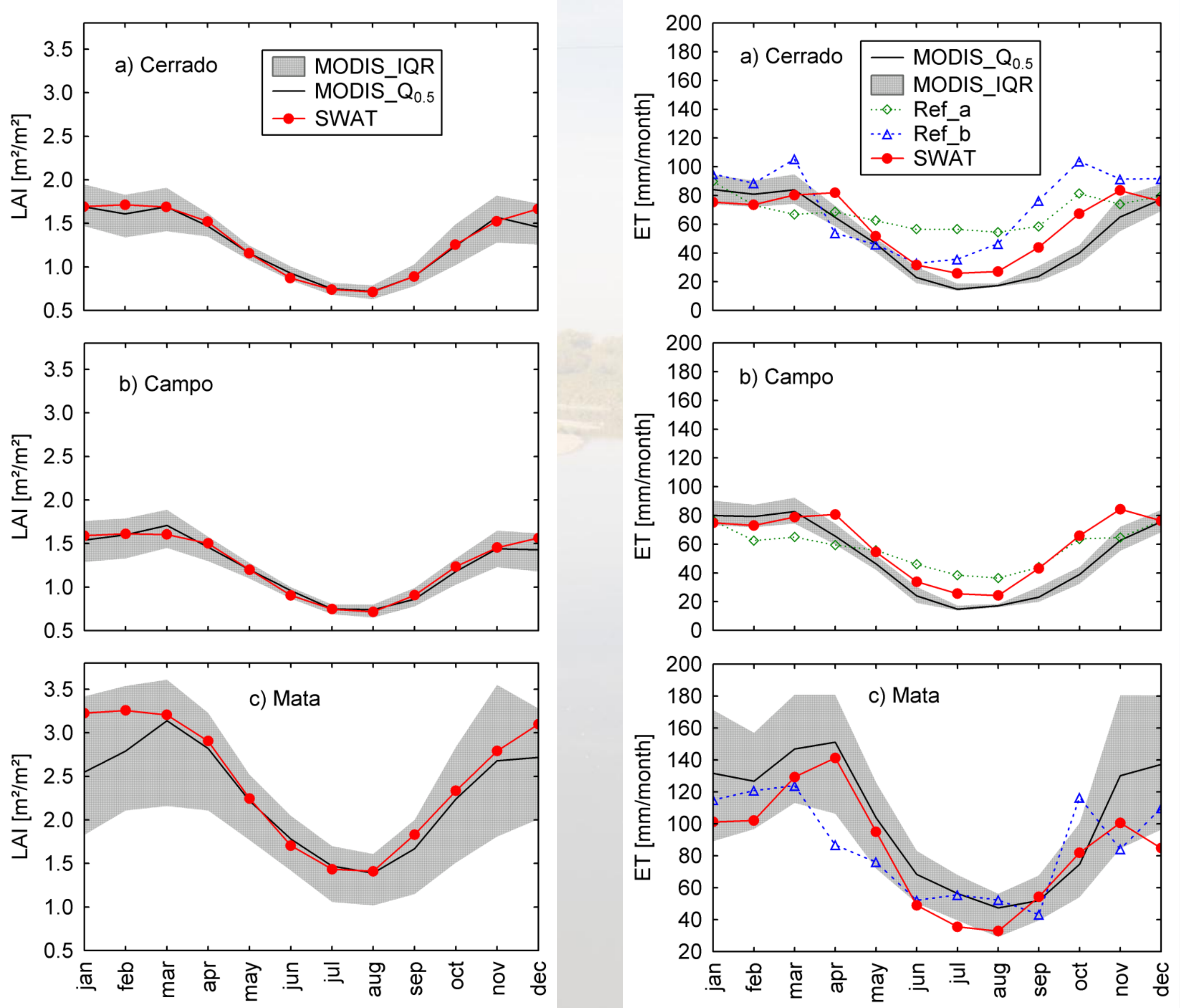
Initial tests…

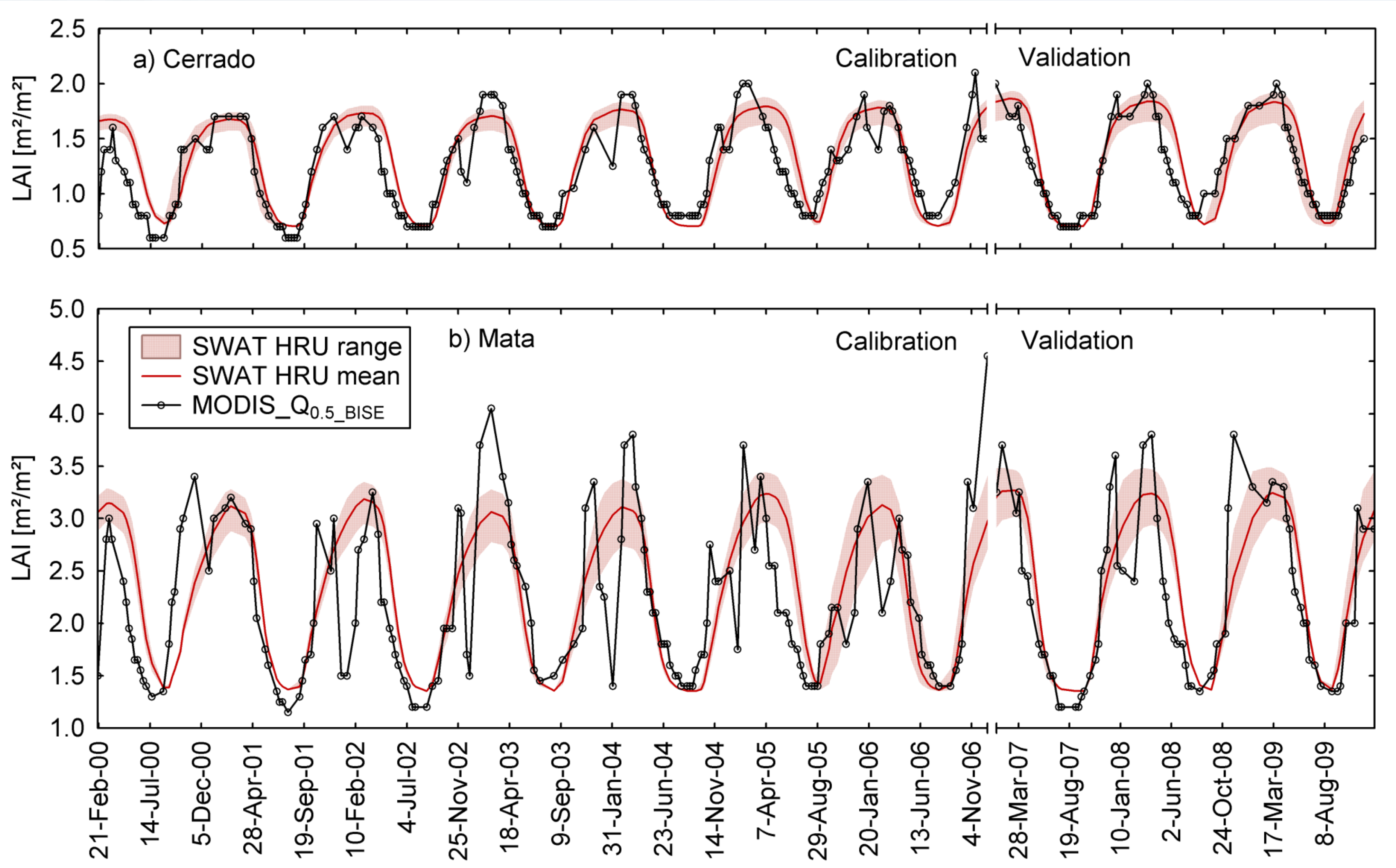
a) IGRO = 1 (vegetation is growing), no management schedule

b) Management schedule: “plant” at FR_{PHU} = 0.1,“kill” at FR_{PHU} =0.925

c) Management schedule: “plant” at Sep 1,“kill” at = Aug 31




a) Cerrado
MODIS_IQR
MODIS_Q0.5
SWAT
b) Campo
c) Mata
LAI [m²/m²]
Ref_a
Ref_b
ET [mm/month]
jan
feb
mar
apr
may
jun
jul
aug
sep
oct
nov
dec



a) Cerrado
Calibration
Validation
LAI [m²/m²]
b) Mata
SWAT HRU range
SWAT HRU mean
MODIS_Q0.5_BISE
21-Feb-00
14-Jul-00
5-Dec-00
28-Apr-01
19-Sep-01
10-Feb-02
4-Jul-02
25-Nov-02
18-Apr-03
9-Sep-03
31-Jan-04
23-Jun-04
14-Nov-04
7-Apr-05
29-Aug-05
20-Jan-06
13-Jun-06
4-Nov-06
28-Mar-07
19-Aug-07
10-Jan-08
2-Jun-08
24-Oct-08
17-Mar-09
8-Aug-09

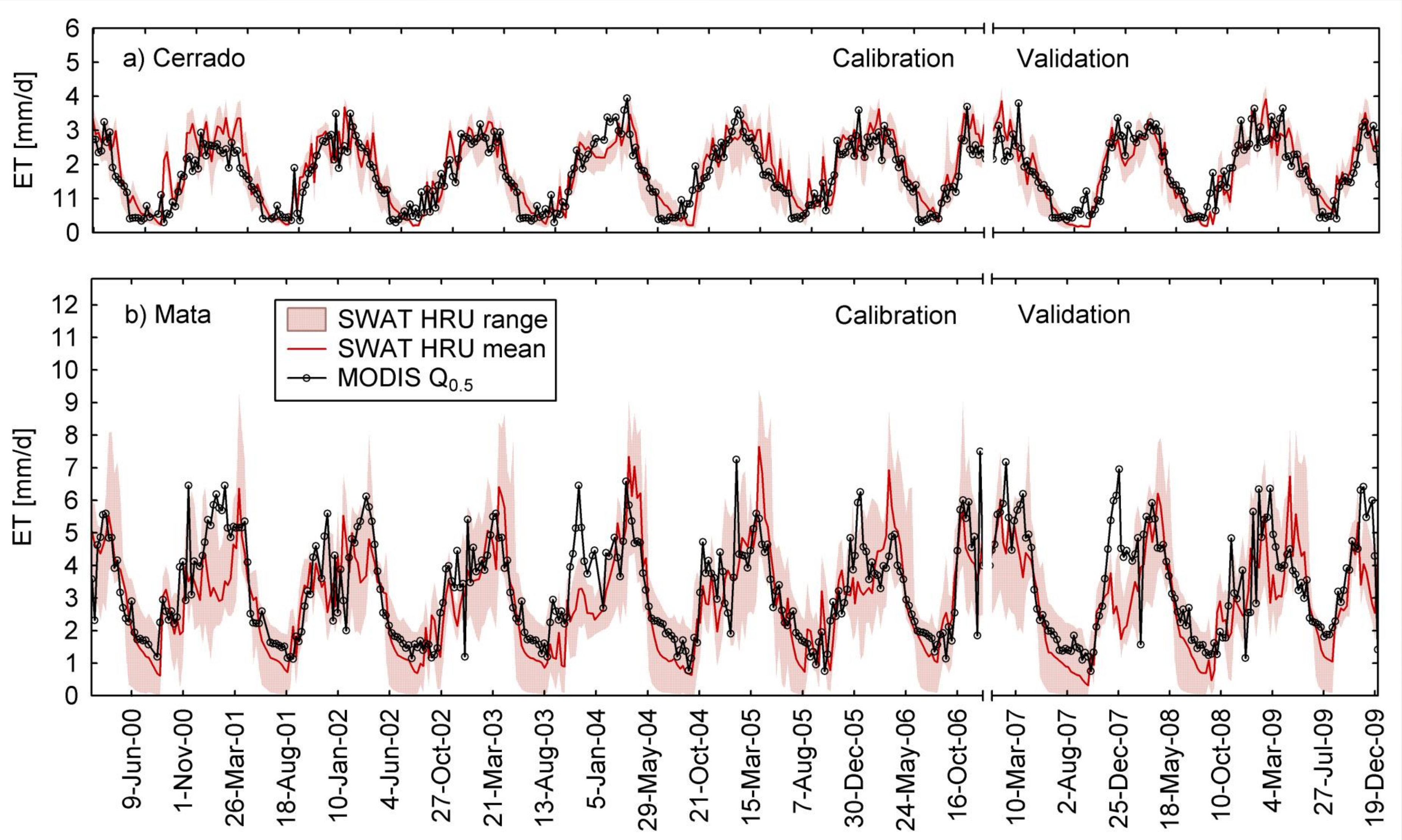

a) Cerrado
Calibration
Validation
b) Mata
SWAT HRU range
SWAT HRU mean
MODIS $Q_{0.5}$
ET [mm/d]
9-Jun-00
1-Nov-00
26-Mar-01
18-Aug-01
10-Jan-02
4-Jun-02
27-Oct-02
21-Mar-03
13-Aug-03
5-Jan-04
29-May-04
21-Oct-04
15-Mar-05
7-Aug-05
30-Dec-05
24-May-06
16-Oct-06
10-Mar-07
2-Aug-07
25-Dec-07
18-May-08
10-Oct-08
4-Mar-09
27-Jul-09
19-Dec-09

Table 4: SWAT parameters used for LAI, ET, and streamflow (Q) calibration

Parameter (model file)	Calibrated output	Parameter description	Calibrated values *(initial values)* Campo	Cerrado	Mata
ALAI_MIN (crop.dat)	LAI	Minimum leaf area index for plant (LAI_{MIN}, m²/m²)	0.7 *(-)*	0.7 *(-)*	1.35 *(0.75)*
BIO_E (crop.dat)	LAI	Radiation-use efficiency ((kg/ha)/(MJ/m²))	20 *(34)*	20 *(34)*	20 *(15)*
BLAI (crop.dat)	LAI	Maximum potential leaf area index (m²/m²)	2.1 *(2.5)*	2.3 *(2)*	3.5 *(5)*
DLAI (crop.dat)	LAI	Fraction of *PHU* when LAI begins to decline	0.58 *(0.35)*	0.54 *(0.35)*	0.53 *(0.99)*
FRAWC (crop.dat)	LAI	Fraction of available water capacity when plants begin growing season in tropics	0.1 *(-)*	0.1 *(-)*	0.1 *(-)*
FRGRW1 (crop.dat)	LAI	Fraction of *PHU* corresponding to the 1st point on the optimal leaf area development curve	0.07 *(0.05)*	0.07 *(0.05)*	0.07 *(0.15)*
FRGRW2 (crop.dat)	LAI	Fraction of *PHU* corresponding to the 2nd point on the optimal leaf area development curve	0.4 *(0.25)*	0.4 *(0.25)*	0.5 *(0.25)*
GSI (crop.dat)	ET	Maximum stomatal conductance at high solar radiation and low vapor pressure deficit (m/s)	0.0008 *(0.005)*	0.0010 *(0.005)*	0.003 *(0.002)*
LAIMX1 (crop.dat)	LAI	Fraction of *BLAI* corresponding to the 1st point on the optimal leaf area development curve	0.15 *(0.1)*	0.15 *(0.1)*	0.15 *(0.7)*
LAIMX2 (crop.dat)	LAI	Fraction of *BLAI* corresponding to the 1st point on the optimal leaf area development curve	0.95 *(0.7)*	0.95 *(0.7)*	0.95 *(0.99)*
T_BASE (crop.dat)	LAI	Minimum temperature for plant growth (°C)	10 *(12)*	10 *(12)*	10 *(0)*
VPDFR (crop.dat)	ET	Vapor pressure deficit (kPa) corresponding to the second point on the stomatal conductance curve	1 *(4)*	1 *(4)*	1.6 *(4)*
EPCO (*.hru)	ET	Plant uptake compensation factor	0.25 *(0)*	0.25 *(0)*	1 *(0)*
ESCO (*.hru)	ET	Soil evaporation compensation factor	0.9 *(0.95)*	0.9 *(0.95)*	0.01 *(0.95)*
GW_DELAY (*.gw)	Q	Groundwater delay time (days)	120 *(31)*	120 *(31)*	10 *(31)*
GWQMN (*.gw)	Q	Threshold depth of water in the shallow aquifer required for return flow to occur (mm H2O)	100 *(0)*	100 *(0)*	100 *(0)*
GWREVAP (*.gw)	ET	Groundwater "revap" coefficient	0.2 *(0.02)*	0.2 *(0.02)*	0.8 *(0.02)*
REVAPMN (*.gw)	ET	Threshold depth of water in the shallow aquifer for "revap" to occur (mm H2O)	101 *(1)*	101 *(1)*	1 *(1)*
CN2[a] (*.mgt)	Q	Initial SCS runoff curve number for moisture condition II	46 [86] *(41 [81])*	44 [84] *(39 [79])*	35 [82] *(30 [77])*
PHU_PLT (*.mgt)	LAI	Total number of heat units or growing degree days needed to bring plant to maturity	4300 *(1800)*	4300 *(1800)*	4300 *(1800)*
CH_K2[b] (*.rte)	Q	Effective hydraulic conductivity in main channel alluvium (mm/hr)	105 *(0)*		
CH_N2[b] (*.rte)	Q	Manning's "n" value for the main channel	0.1 *(0.014)*		

[a] *CN2* values for Hydrologic Soil Group A [and D], both Soil Groups are occurring in the study area

[b] Non-specific for land cover type

3 Results

Simulated daily streamflow vs. observation