The Role of Plant-Growth Modelling on the Evapotranspiration Estimation in SWAT-T for Characteristic Land Cover Types of Western Africa

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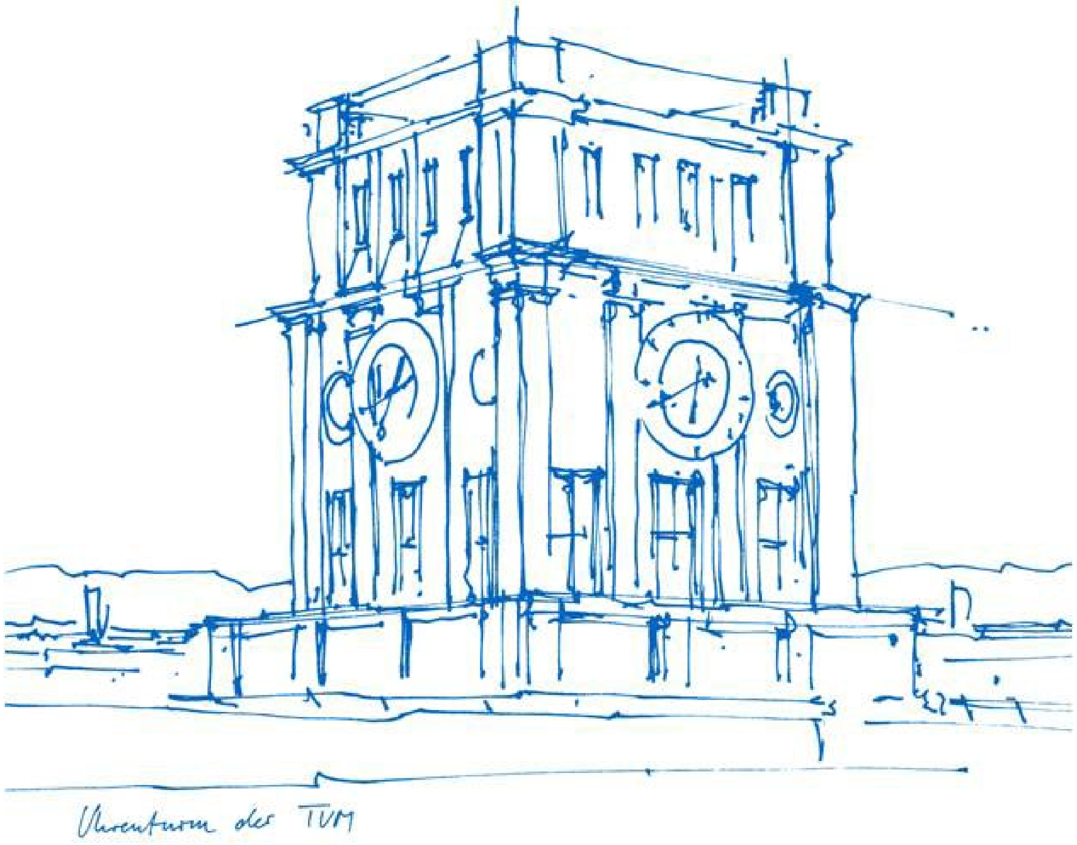
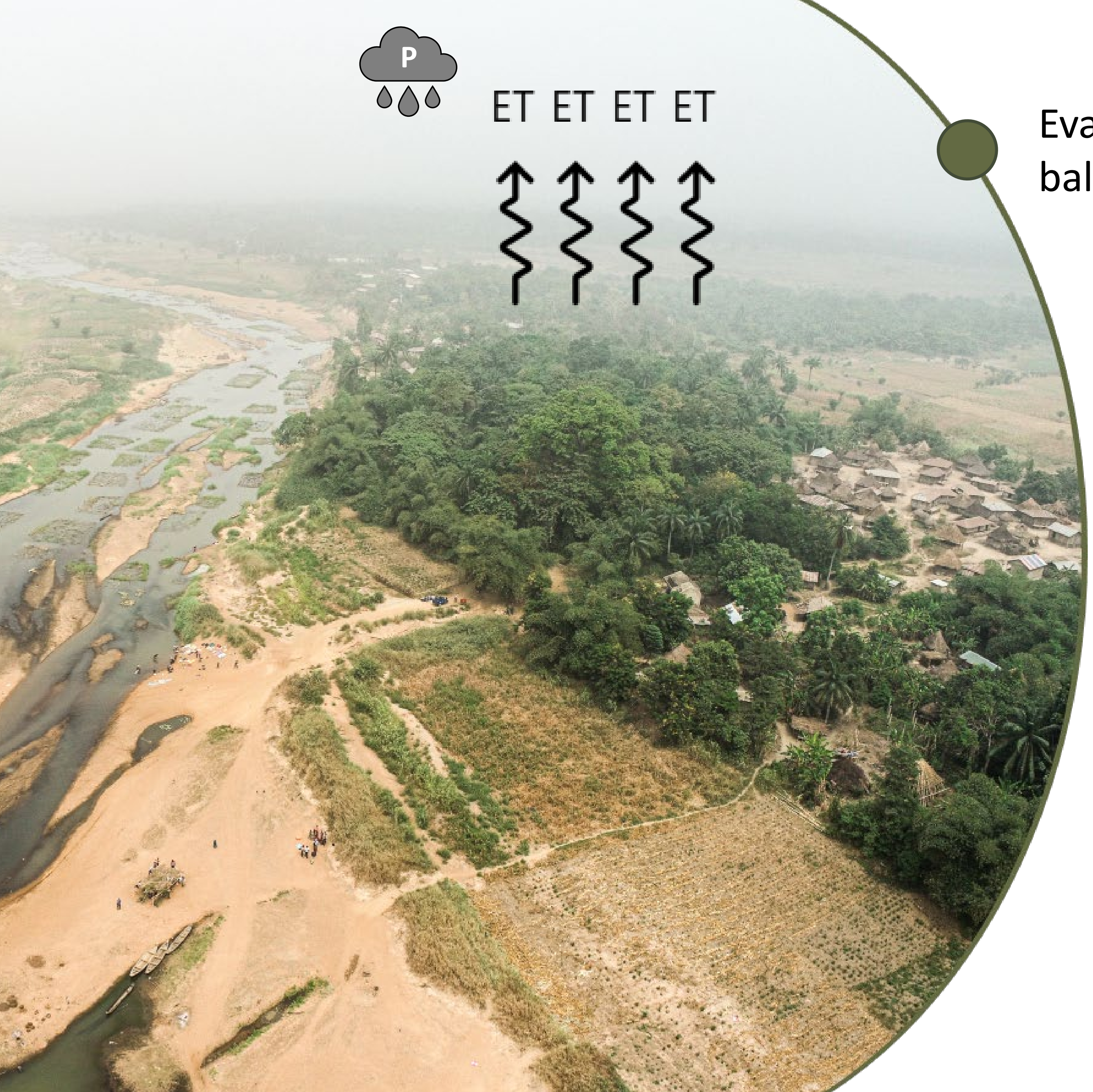
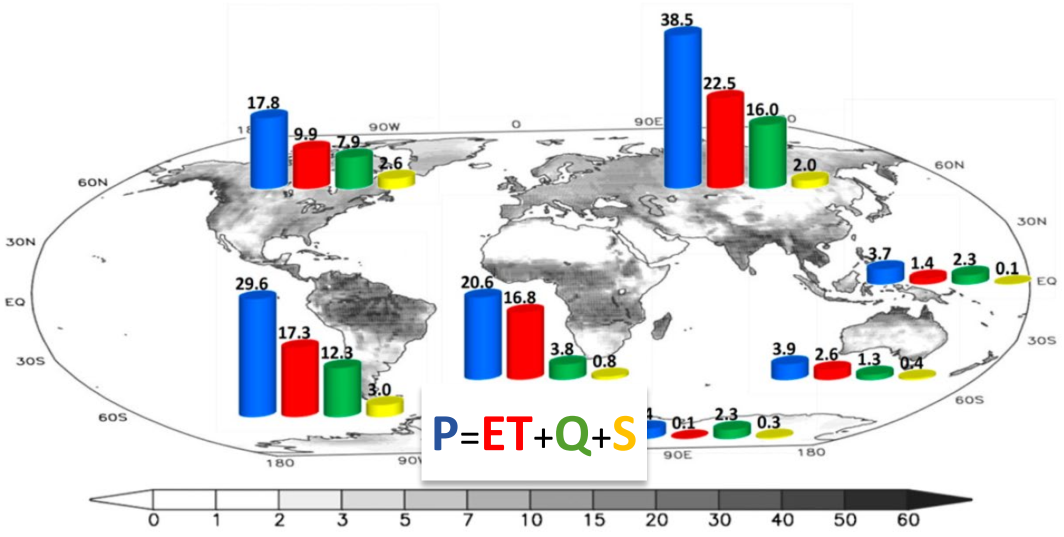


SWAT User Conference, Strasbourg

July 2024

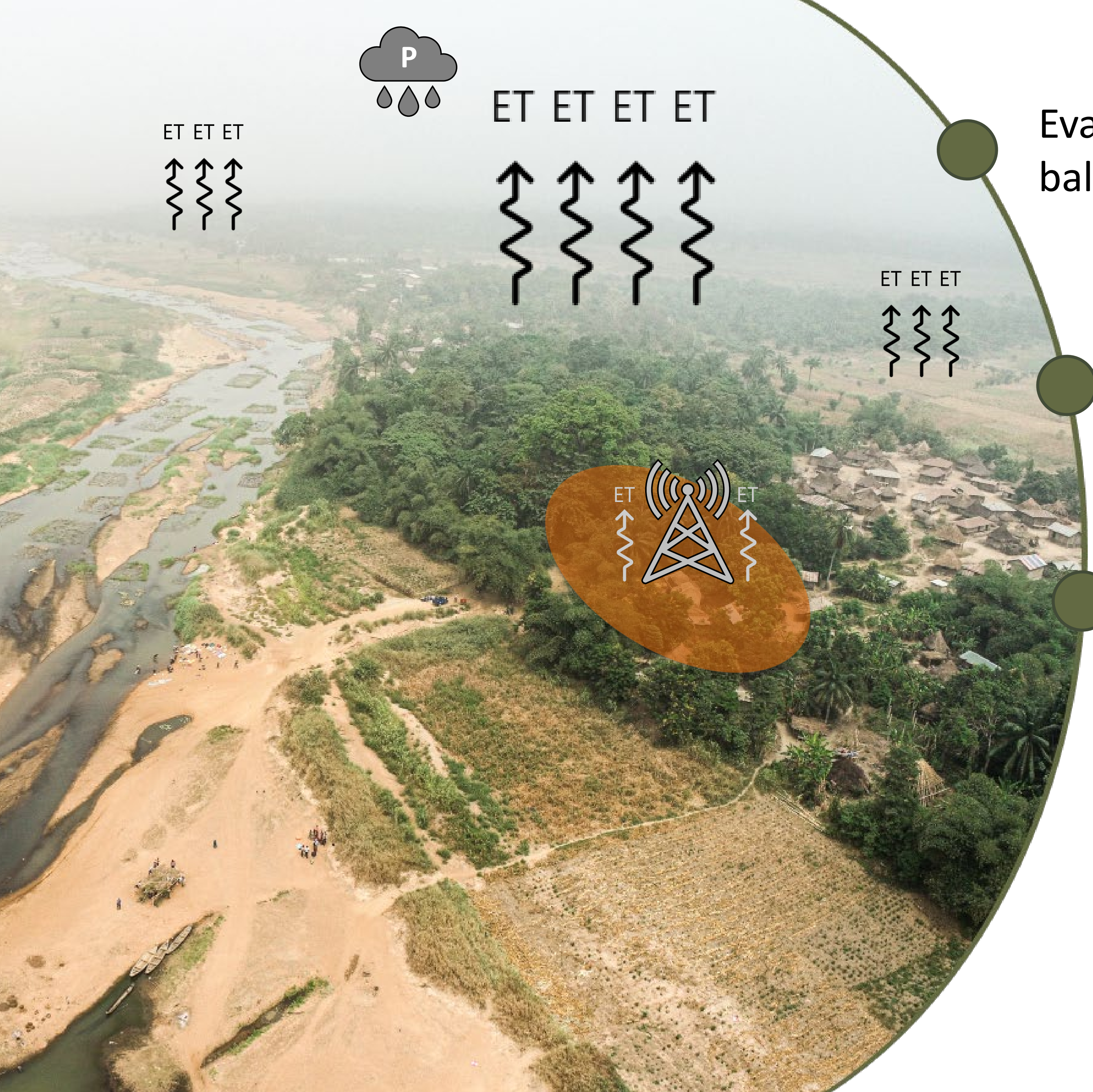


Evapotranspiration (ET) is essential water balance process in the tropics: **ET/P ≈ 70 - 80%**



Global annual-mean fluxes (10^3 km^3/yr)

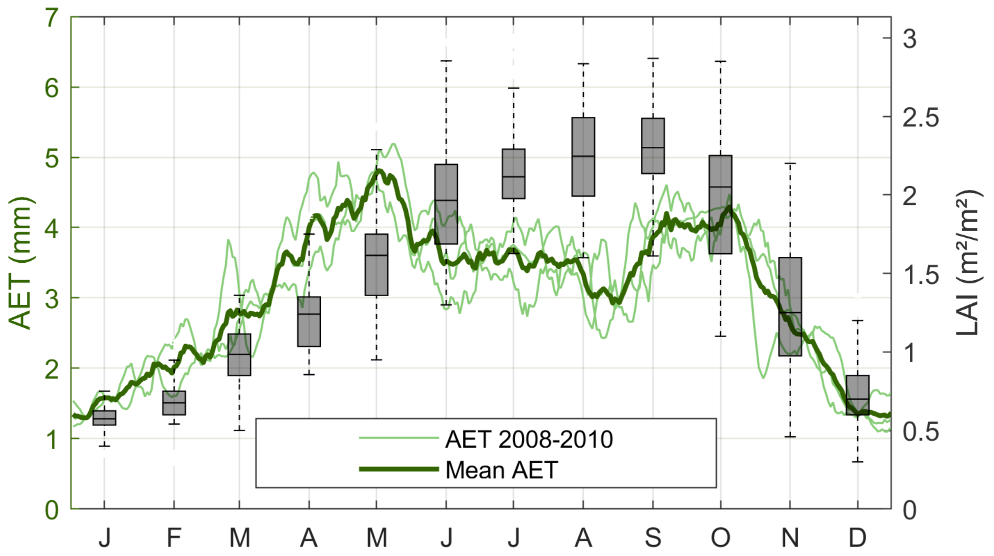
Rodell et al. (2015)

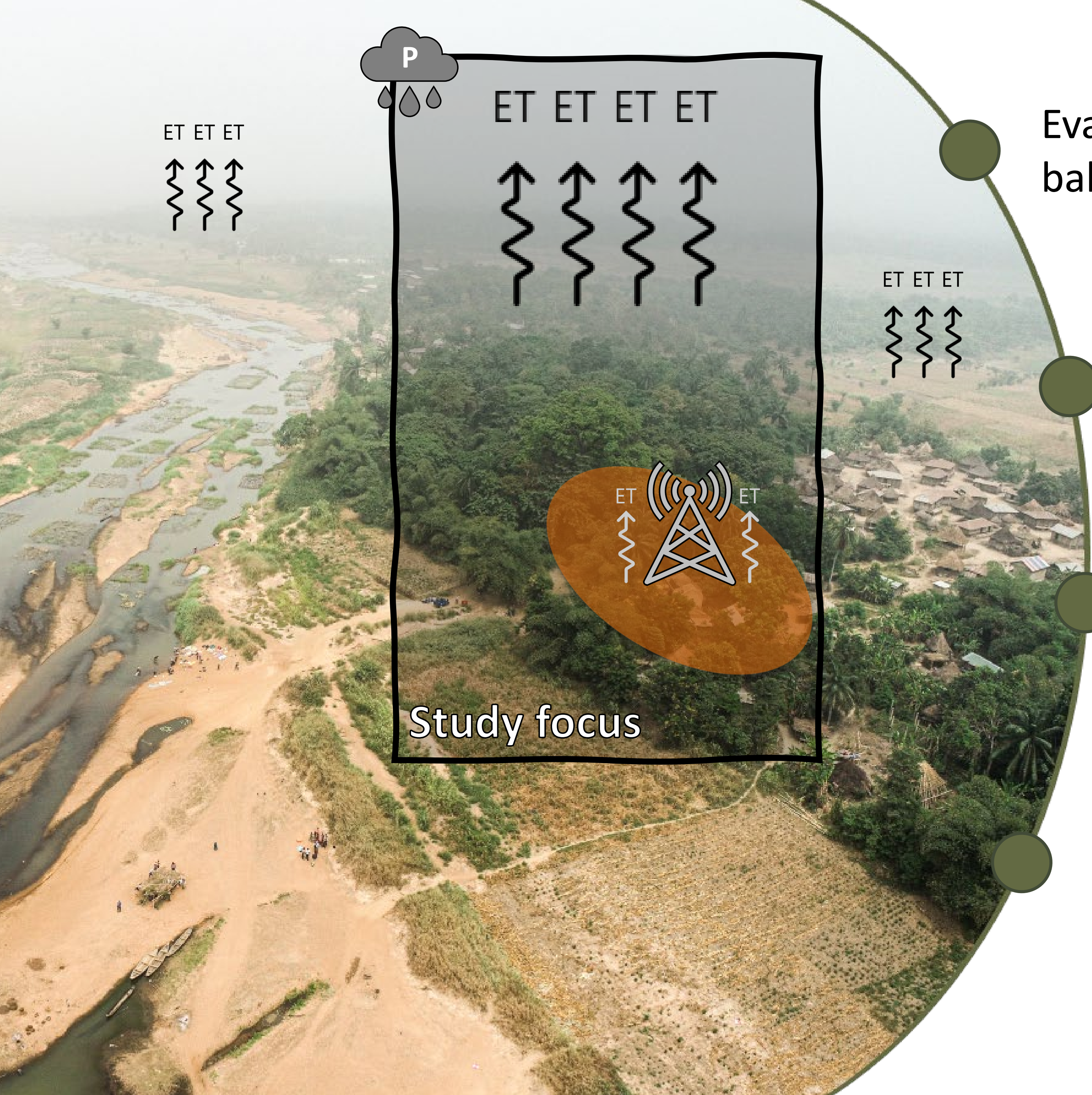


Evapotranspiration (ET) is essential water balance process in the tropics: **ET/P ≈ 70 - 80%**

ET is dynamic in space and time:
Monitored ET from e.g., **eddy flux towers**
Representative: flux footprints

ET is correlates with **plant growth (LAI)**
→ **Estimated with LAI in models**

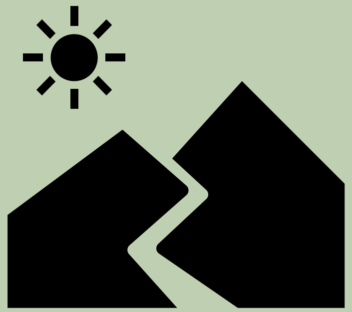




- Evapotranspiration (ET) is essential water balance process in the tropics: **ET/P ≈ 70 - 80%**
- **ET is dynamic in space and time**: Monitored ET from e.g., eddy flux towers
  Representative: flux footprints
- **ET** is correlates with **plant growth (LAI)**
  → Estimated with LAI in models
- Research objective:
  i) What is the role of LAI on AET in SWAT-T?
  ii) Can we predict AET only with LAI?

Methodology – 4 key steps

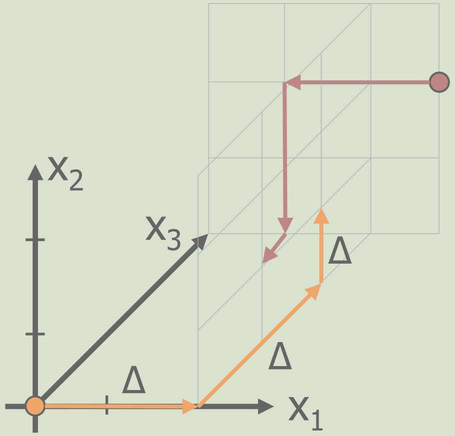
1



SWAT-T
on the footprint scale

SWAT-T by Alemayehu et al., 2017

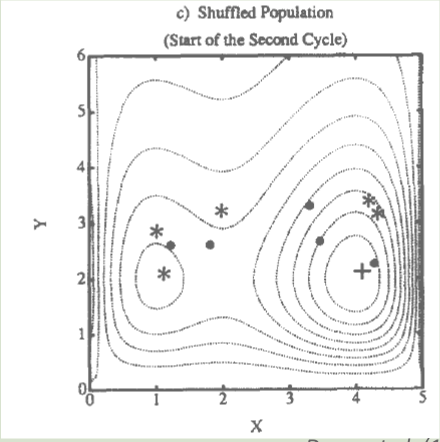
2



Global SA
with the Morris method (LAI)

27 LAI-AET parameters of SWAT-T

3

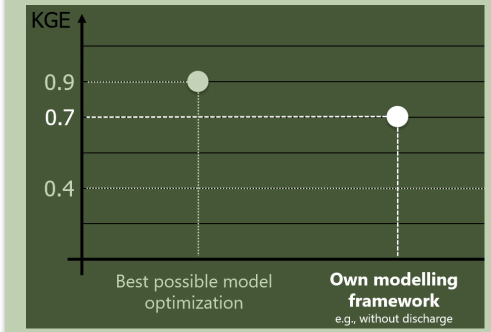


Duan et al. (1994)

Optimization
with SCE-UA algorithm

Spotpy toolbox, Hauska et al., 2015

4



Benchmark
to evaluate role of LAI on AET

Benchmark from Seibert et al., 2018

Methodology – 4 key steps

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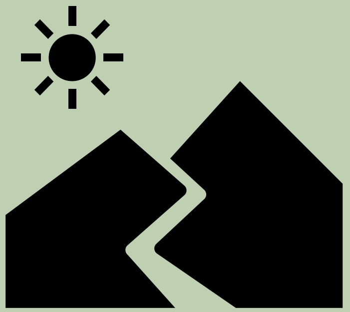

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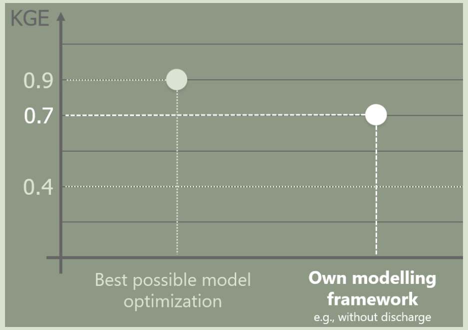

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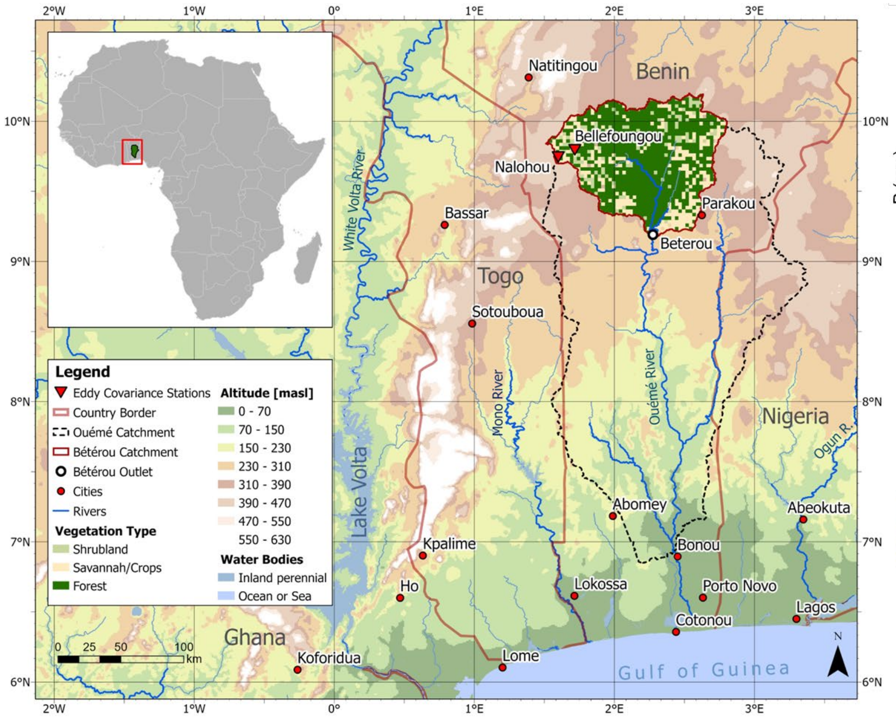
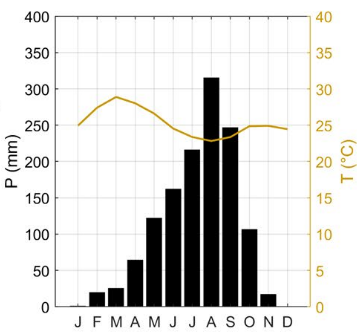
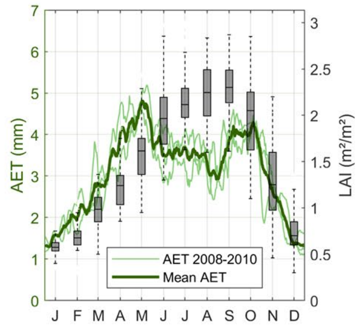
Benchmark from Seibert et al., 2018

Study sites: EC systems in the Bétérou catchment







Distinct wet/dry seasonality

Sub-humid climate

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Methodology – 4 key steps

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SWAT-T
on the footprint scale

SWAT-T by Alemayehu et al., 2017

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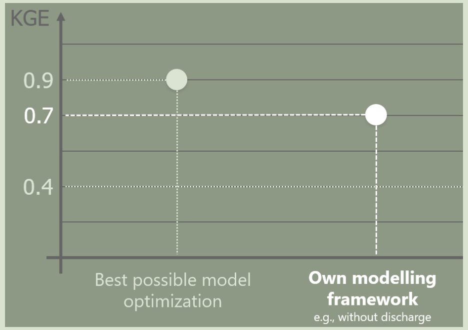

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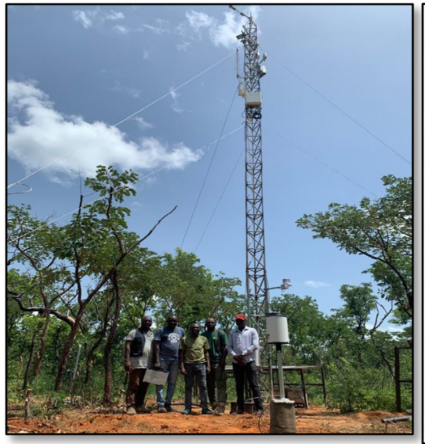
Micro-scale SWAT-T model setup:



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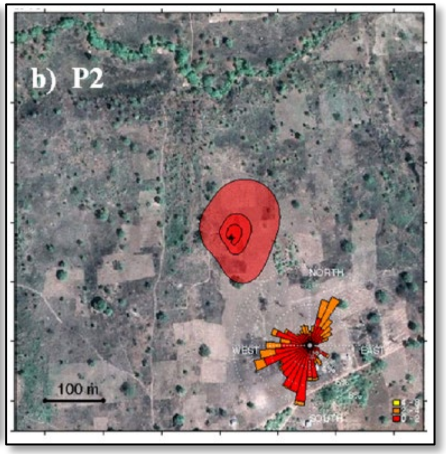

Example from Mamadou et al. (2014)

Reliability = *footprint*
Chu et al. (2021): AET is representative for radii <250 m

Micro SWAT-T

1 land use
1 soil type
1 HRU

Forest and grassland

Methodology – 4 key steps

Micro-scale SWAT-T model setup:

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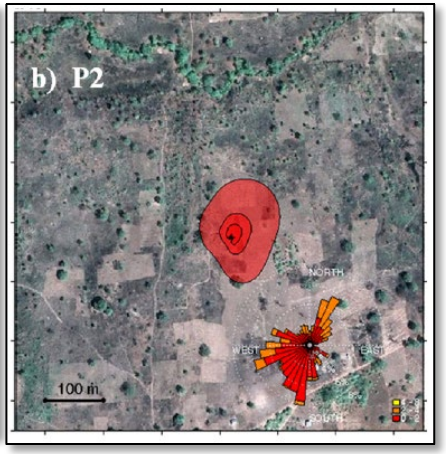

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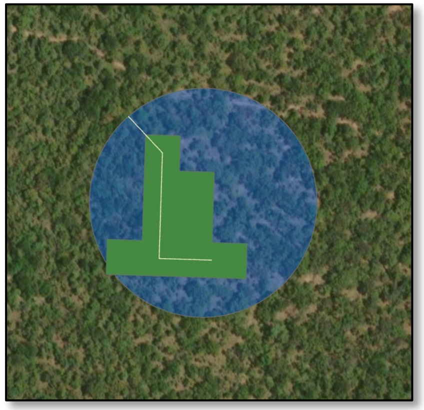

Micro SWAT-T

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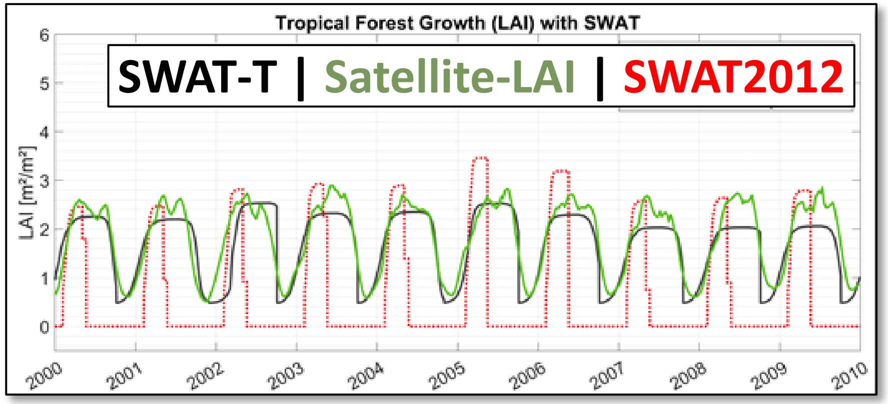
Forest and grassland

SWAT-T by Alemayehu et al., 2017:
→ Improved modelling of LAI in the tropics



Key Modelling Features

12 LAI and 15 ET parameters selected

3 PET methods, 2 land cover types

Observed AET and LAI data

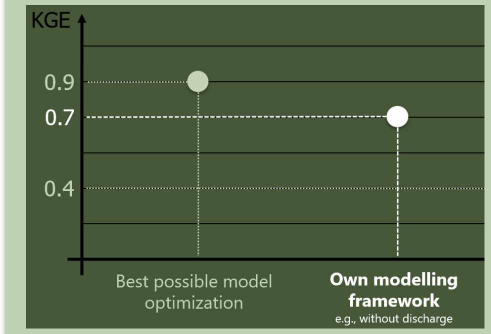
Methodology – 4 key steps

1

SWAT-T
on the footprint scale

SWAT-T by Alemayehu et al., 2017

4

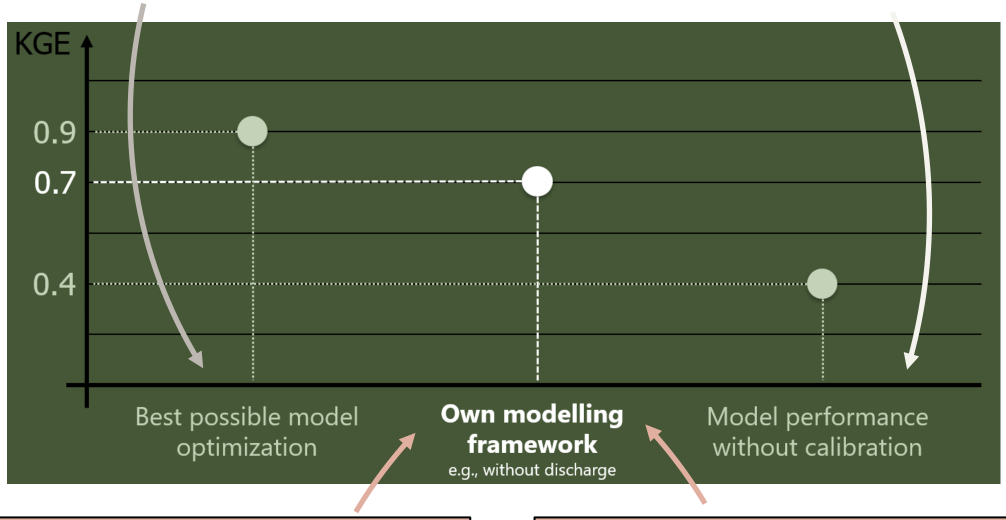


Benchmark
to evaluate role of LAI on AET

Benchmark from Seibert et al., 2018

Upper Benchmark:
Optimization of AET with observed AET and LAI

Lower Benchmark:
Random sampling, median run (N=1000)



Framework 1:
Optimization of AET with observed LAI only

Framework 2:
Optimization of AET with satellite-LAI (LAI-GLASS)

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Methodology – 4 key steps

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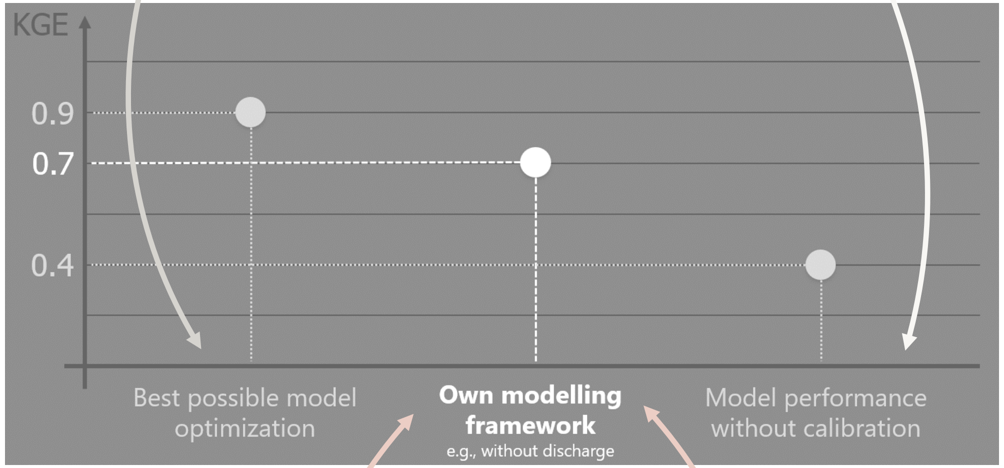

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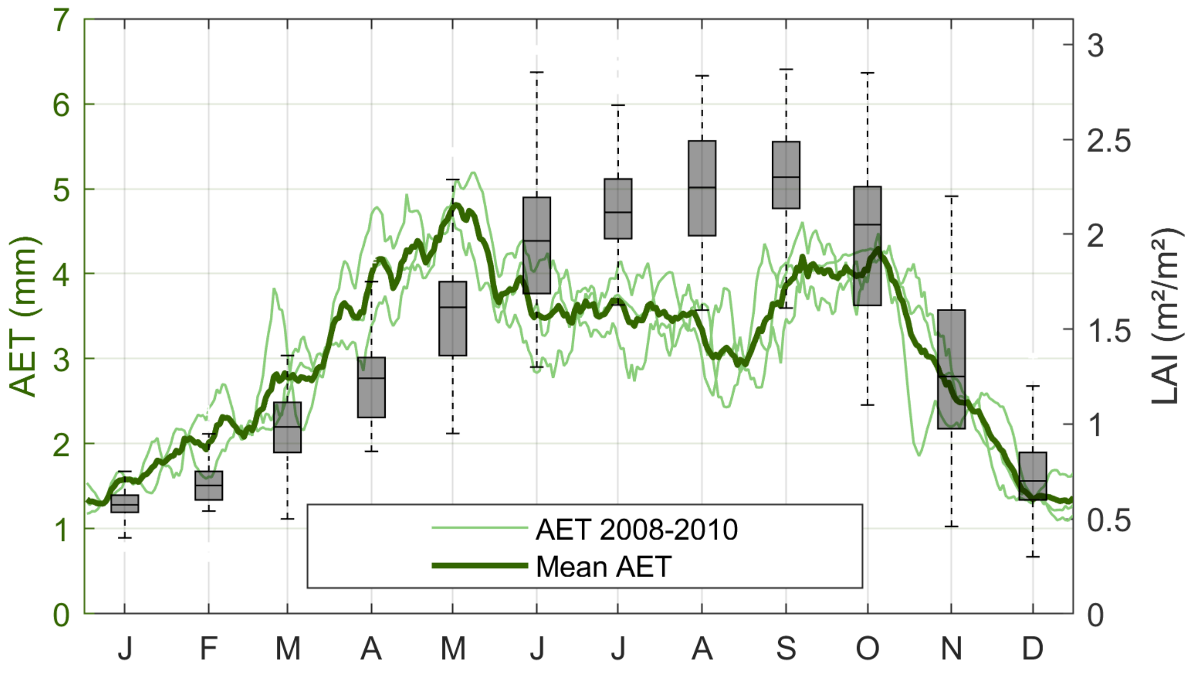

Understand the LAI-AET interaction and if we disregard AET, can we still predict AET based on LAI?

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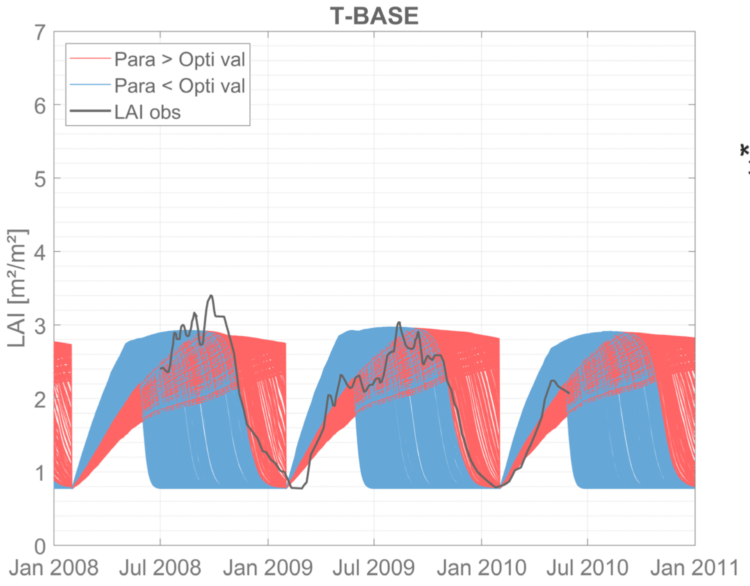
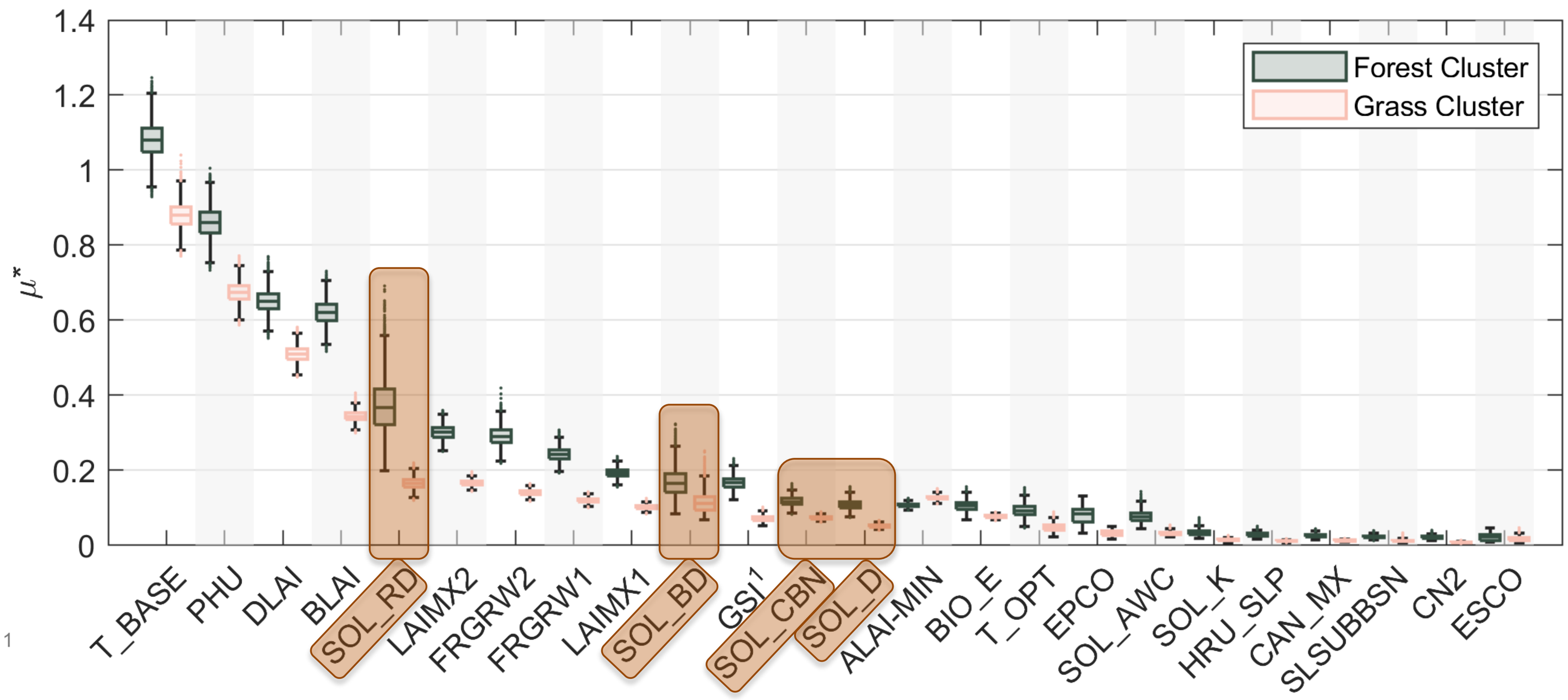
Global Sensitivity Analysis – Morris Method with observed LAI

Example:
Variations of LAI for T_BASE





- Modelling importance (T_BASE, PHU, DLAI)
- Ranking independent of PET and land cover
- **Not only LAI, but soil parameters are important, too**

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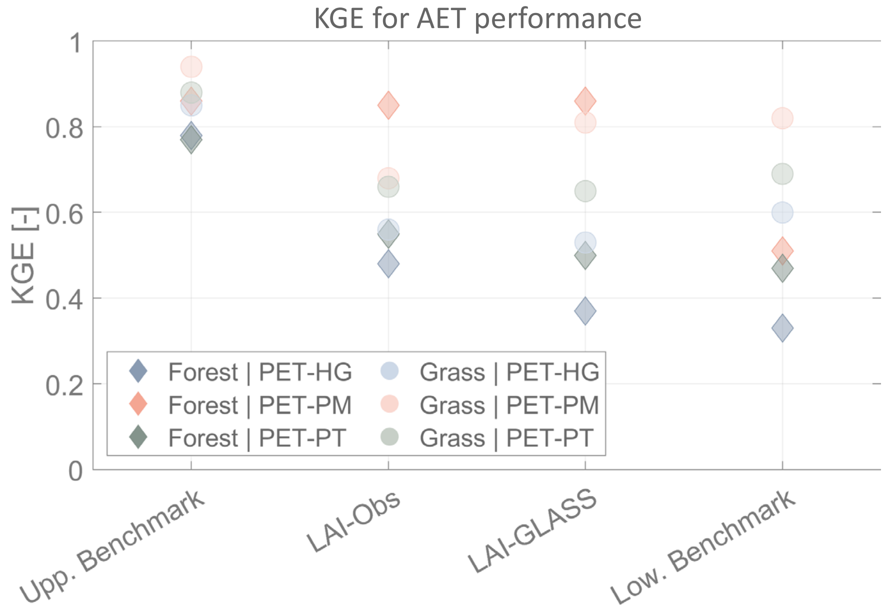
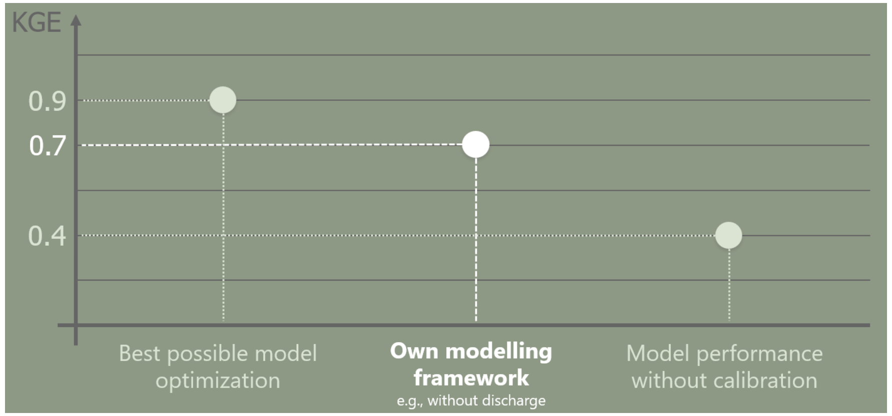
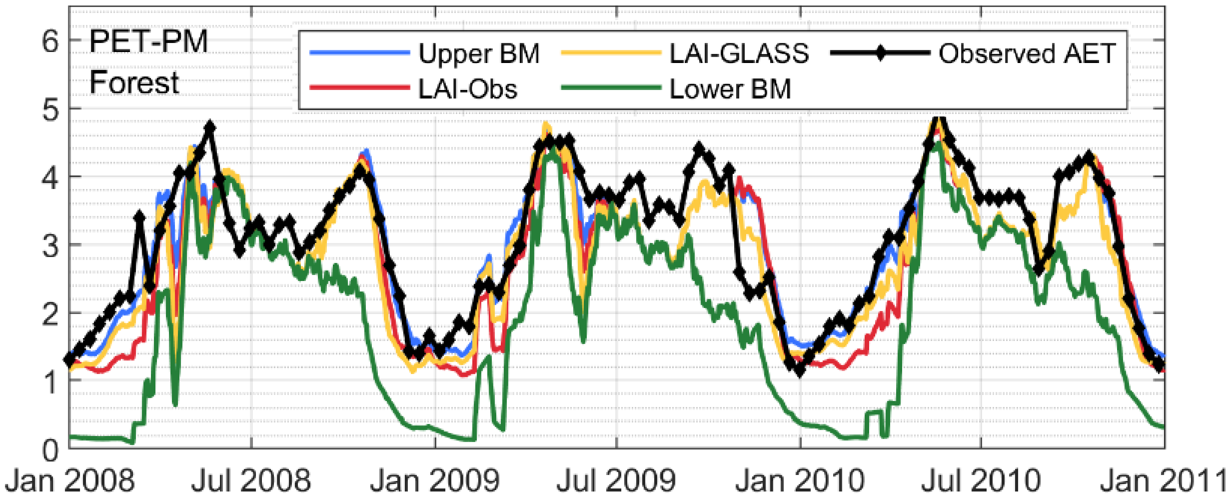
Optimization and Benchmarking



- SWAT-T can predict LAI/AET accurately on the footprint (→ PET-PM)
- LAI optimization (no AET!) yields acceptable AET predictions
- Lower benchmark can outperform AET for LAI optimization
- **LAI modelling in forest is more significant than in grassland**





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Conclusion

The present work evaluates the LAI-AET interaction for characteristic Sub-Saharan land covers.

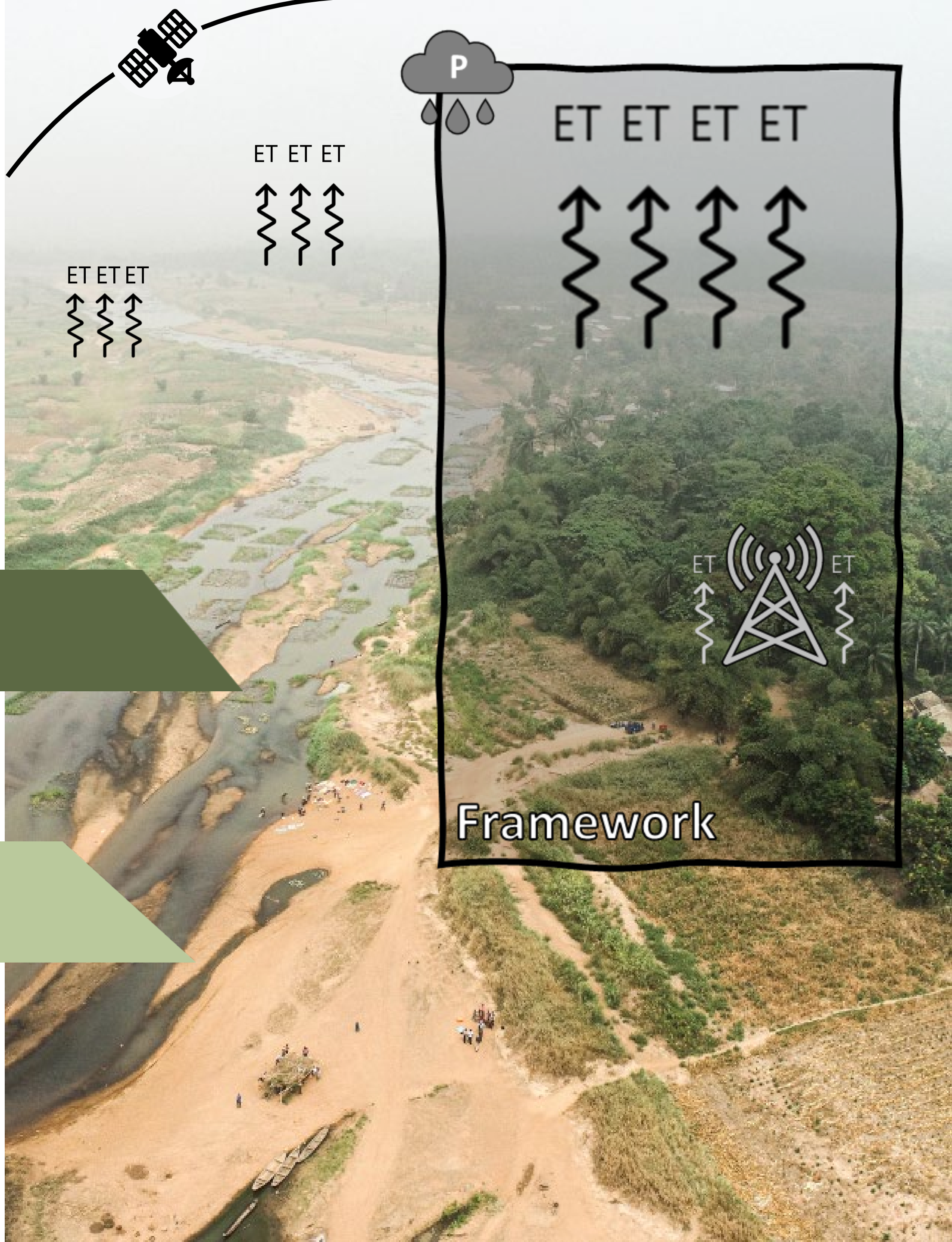
Different data sets are used for evaluation
→ Observed AET & LAI, remotely-sensed LAI

Parameter ranking with the elementary effects method

SWAT-T accurate for LAI and AET
Independent of PET → PET-PM performs best

Benchmark test spotlights the significance of LAI for forest
Grassland: good AET results, less importance of LAI

Data-scarcity: GLASS-LAI yields adequate AET
Also applicable for other vegetation and scales



Thank you for your attention!

Paper pre-print in HESS:

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Federal Ministry of Education and Research

FONA
Research for Sustainability

Backup

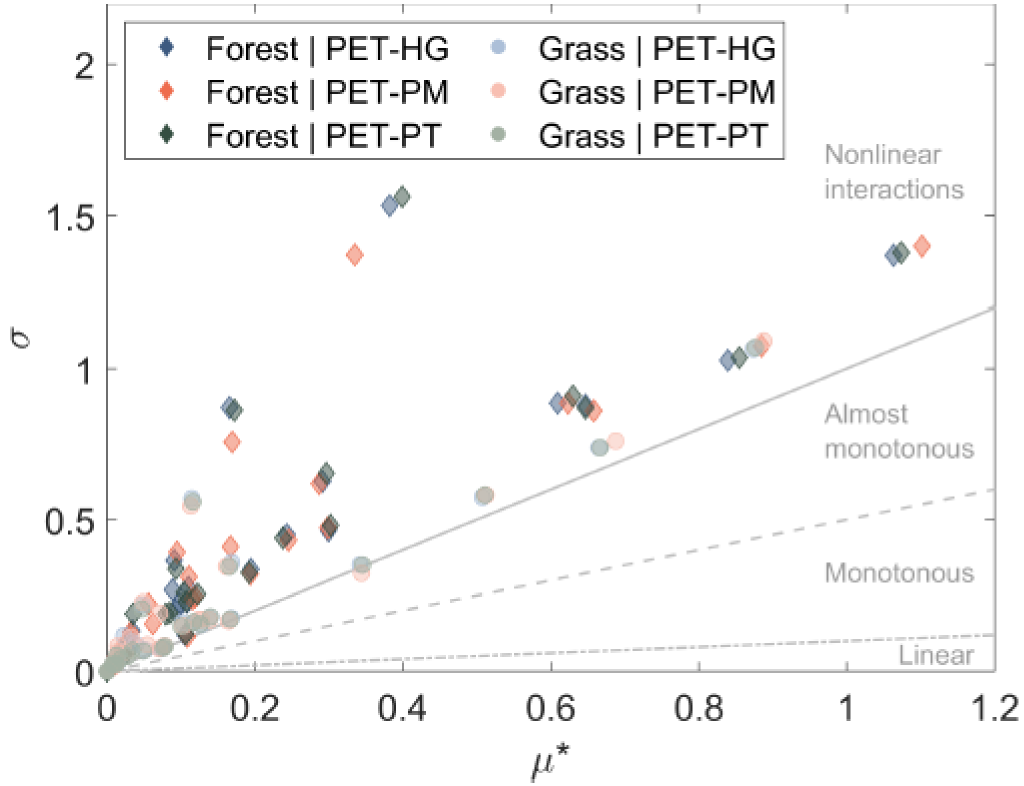
Table 1. Approaches to compute potential evapotranspiration E_0 and potential transpiration T_{plant} provided in SWAT-T.

PET method	Equation for E_0	Equation for T_{plant}
PET-HG	$E_0 = \frac{0.0023 \cdot H_0}{\lambda} \cdot \sqrt{T_{mx} - T_{mn}} \cdot (T_{av} + 17.8)$	$T_{plant} = \begin{cases} LAI \cdot \frac{E_0}{3.0}, & \text{if } LAI \leq 3.0 \\ E_0, & \text{if } LAI > 3.0 \end{cases}$
PET-PT	$E_0 = \frac{\alpha_{pet} \cdot \Delta}{\lambda \cdot (\Delta + \gamma)} \cdot (H_{net} - G)$	$T_{plant} = \begin{cases} LAI \cdot \frac{E_0}{3.0}, & \text{if } LAI \leq 3.0 \\ E_0, & \text{if } LAI > 3.0 \end{cases}$
PET-PM	$E_0 = \frac{\Delta \cdot (H_{net} - G) + \rho_{air} \cdot c_p \cdot (e_z^0 - e_z)/r_a}{\lambda \cdot (\Delta + \gamma \cdot (1 + r_c/r_a))}$, with r_c, r_a from alfalfa crop reference	$T_{plant} = \frac{\Delta \cdot (H_{net} - G) + \rho_{air} \cdot c_p \cdot (e_z^0 - e_z)/r_a}{\lambda \cdot (\Delta + \gamma \cdot (1 + r_c/r_a))}$, with r_c, r_a from actual plant (canopy height and LAI)

Backup

Parameter	Description [unit]
Parameters associated with plant growth (LAI) in the plant data base of SWAT	
BIO_E	Radiation-use efficiency [(kg/ha)/(MJ/m^2)]
BLAI	Maximum potential leaf area index [m^2/m^2]
$FRGRW_1$	Fraction of PHU corresponding to the first point on the optimal leaf area development curve [-]
$LAIMX_1$	Fraction of BLAI corresponding to the first point on the optimal leaf area development curve [-]
$FRGRW_2$	Fraction of PHU corresponding to the second point on the optimal leaf area development curve [-]
$LAIMX_2$	Fraction of BLAI corresponding to the second point on the optimal leaf area development curve [-]
DLAI	Fraction of total PHU when leaf area begins to decline [-]
T_OPT	Optimal temperature for plant growth [°C]
T_BASE	Minimum temperature for plant growth [°C]
ALAI_MIN	Minimum leaf area index for plant during dormant period [m^2/m^2]
PHU	Total number of heat units needed to bring plant to maturity [-]
GSI	Maximum stomatal conductance [m/s]
Parameters associated with AET estimation	
CAN_MX	Maximum canopy storage [mm]
ESCO	Soil evaporation compensation factor [-]
EPCO	Plant uptake compensation factor [-]
HRU_SLP	Average slope steepness [m/m]
SLSUBBSN	Average slope length [m]
CN2	Initial SCS runoff curve number [-]
SOL_AWC	Available water capacity of the soil layer [mm]
SOL_BD	Moist bulk density [g/cm^3]
SOL_CBN	Organic carbon content [% soil weight]
SOL_K	Saturated hydraulic conductivity [mm/hr]
SOL_RD	Maximum rooting depth of soil profile [mm]
SOL_D[a]	Soil layer depth [mm]
GW_REVAP	Groundwater re-evaporation coefficient [-]
RCHRG_DP	Deep aquifer percolation fraction [-]
REVAPMN	Threshold depth of water for re-evaporation to occur [mm]

Backup

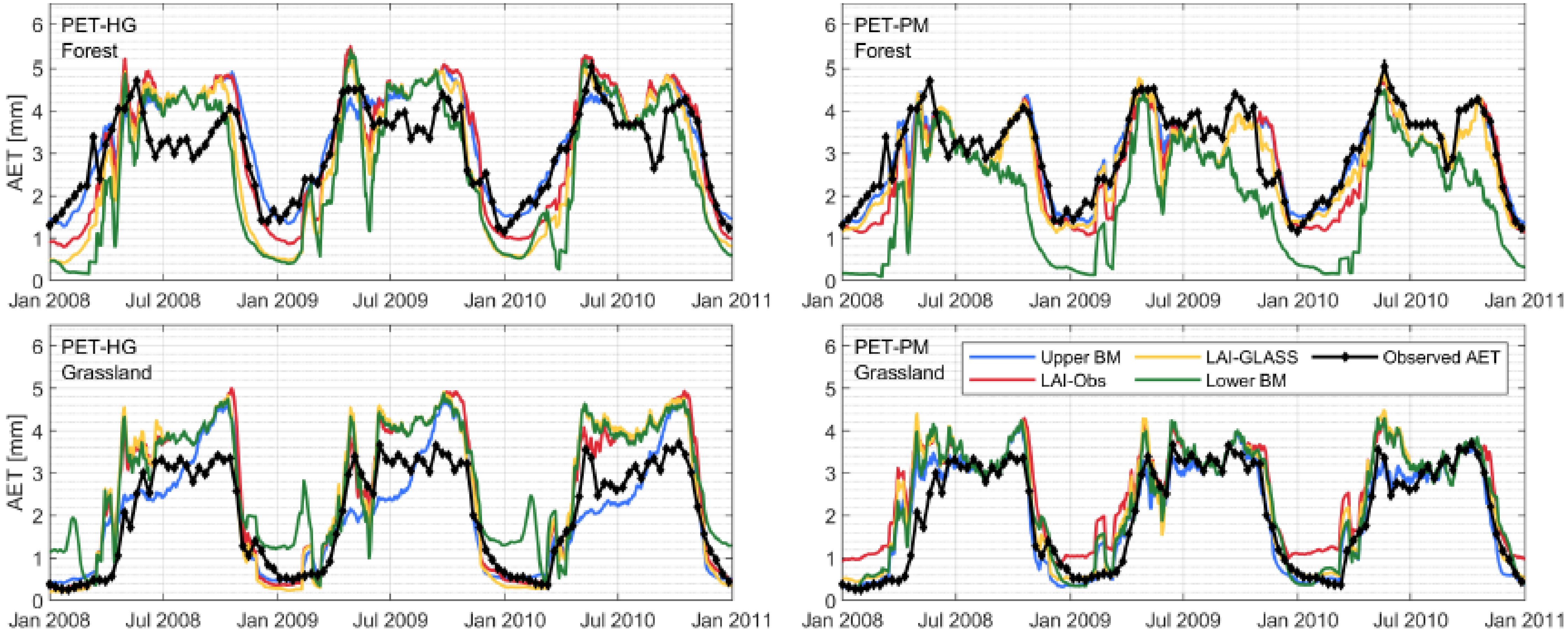


Forest | PET-HG
Forest | PET-PM
Forest | PET-PT
Grass | PET-HG
Grass | PET-PM
Grass | PET-PT
Nonlinear interactions
Almost monotonous
Monotonous
Linear
σ
μ*
0
0.5
1
1.5
2
0
0.2
0.4
0.6
0.8
1
1.2

Backup

PET method	Upper benchmark		LAI-Obs		LAI-GLASS		Lower benchmark	
	Forest	Grassland	Forest	Grassland	Forest	Grassland	Forest	Grassland
Final KGE values regarding AET performance								
PET-HG	0.78	0.85	0.48	0.56	0.37	0.53	0.33	0.60
PET-PM	0.86	0.94	0.85	0.68	0.86	0.81	0.51	0.82
PET-PT	0.77	0.88	0.55	0.66	0.50	0.65	0.47	0.69
Final KGE values regarding LAI performance								
PET-HG	0.94	0.86	0.94	0.91	0.96	0.94	0.20	-0.65
PET-PM	0.94	0.89	0.94	0.91	0.96	0.94	-0.26	0.20
PET-PT	0.90	0.87	0.94	0.91	0.96	0.94	-0.36	-0.76

Backup



PET-HG
Forest
PET-PM
Forest
PET-HG
Grassland
PET-PM
Grassland
AET [mm]
Upper BM
LAI-Obs
LAI-GLASS
Lower BM
Observed AET
0
1
2
3
4
5
6
Jan 2008
Jul 2008
Jan 2009
Jul 2009
Jan 2010
Jul 2010
Jan 2011