PT VAINT

(changes and results)

Evgenii Churiulin, Merja Tölle, Vladimir Kopeykin,
Markus Übel, Juergen Helmert and Jean-Marie Bettems

Why is VAINT important?

Temperatures
evapotranspiration

- Seasonal phenological cycle of summer/winter crops
- Biogeophysical/chemical processes

Seasonal
phenology

- Energy and water cycle
- Seasonal cycle of the albedo and water availability

Extreme events

- Increase in frequency
- Increase in the need for modelling

Relevance of PT VAINT

COSMO model

Current version of COSMO model:

- uses the Jarvis-Stewart stomatal resistance approach with the BATS parametrization
- the "one-big leaf" approach
- the phenology cycle based on a 6-year climatology and follows the same sinusoidal fitted curve between its max and min values

Current version of COSMO model:

- neglects any influence or feedback on the environmental conditions (no connection to the biogeochemical cycle via photosynthesis, no plant growth, etc…)
- applies in Jarvis approach the functions which are independent of each other
- does not consider the influence of atmospheric CO_2 concentration
- applies highly simplified dependencies, for which the leaf photosynthesis and CO_2 uptake cannot be calculated

PT VAINT

SubTask1: Implementation of new photosynthesis/phenology scheme:

a) The canopy photosynthesis and stomatal regulation module (done)

b) The carbon allocation and plant growth module (testing)

c) The heterotrophic respiration and litter/soil carbon module (testing)

SubTask2: Validation of new photosynthesis/phenology scheme:

a) Run *COSMO_CLM_v5.16* with and without updates (done for SubTask 1a, in progress for Subtask 1b, 1c);

b) Run *COSMO_v5.0.8* with and without updates (in progress);

SubTask3: Validation of implementation:

a) Validation of the new implementations from the SubTask 1a (done);

b) Validation of the new implementations from the SubTask 1b and 1c (in progress);

SubTask4: Documentation:

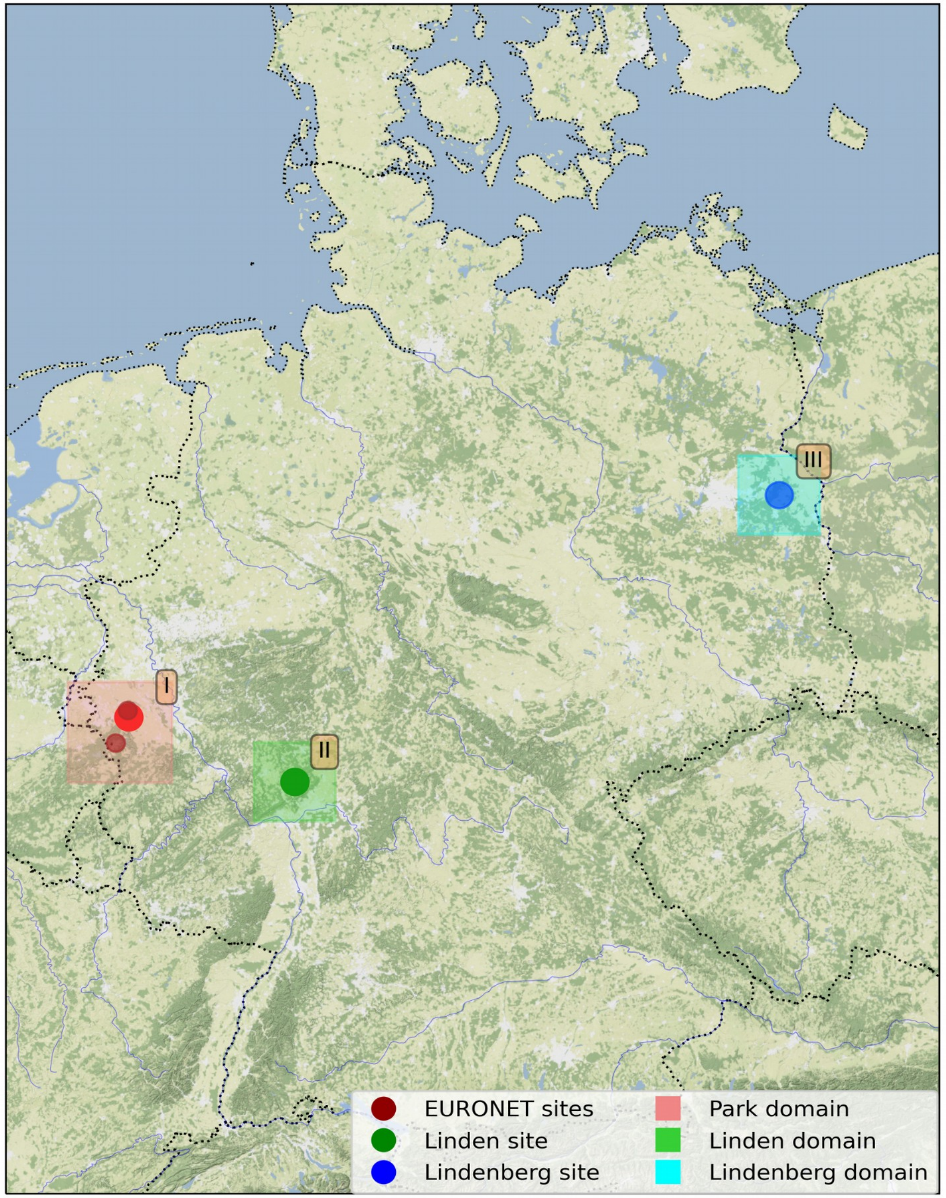
a) The first version of the documentation + block schemes for CLM 3.5 and COSMO-CLM (done);

b) The first article (in progress)

More information about project: https://github.com/users/merajtoelle/projects/

CCLM = COSMO-CLM v5.16

Research domains



COSMO-CLM parameters:

- Time increment: 25 s
- Spatial resolution: 0.0275° ~ 3 km
- Grid size: 25 * 25
- Numbers of vertical layers: 50
- Numbers of soil layers: 9

Verification parameters:

- AEVAP, $ALHFL_{PL}$, $ALHFL_{S}$, $ASHFL_{S}$, QV_{2M}, QV_{S}, T_{2m}, T_{S}, T_{max}
- T_{min}, PS, $RELHUM_{2M}$, ZTRALEAV, ZVERBO, RSTOM

Data for comparisons:

- HYRAS, E-OBS, GLEAM datasets (T_{2m}, T_{S}, T_{max}, $T_{min,}$ AEVAP, ZVERBO)
- EURONET, FLUXNET web-projects
- Linden and Lindenberg sites information (requests)

Experiments:	**Differences between experiments:**	**Research period:**
➢ CCLMref ***Terra-ML without changes***	The original code of COSMO-CLM based on v5.16 (stomatal resistance based on Jarvis approach, no leaf photosynthesis, one-big leaf approach)	from 1999 to 2017
➢ CCLMv3.5 ***Terra-ML + CLM 3.5***	The code of COSMO-CLM_v5.16 with the new implementations (stomatal resistance, leaf photosynthesis, two-big leaf approach) based on ***CLM 3.5 algorithms***	from 2010 to 2015
➢ CCLMv4.5 ***Terra-ML + CLM 4.5***	The code of COSMO-CLM_v5.16 with the new implementations (stomatal resistance, leaf photosynthesis, two-big leaf approach) based on ***CLM 4.5 algorithms***	from 2010 to 2015
➢ CCLMv4.5e ***Terra-ML + CLM 4.5 + changes in Terra-ML***	The code of COSMO-CLM_v5.16 with ***the CCLMv4.5 implementations*** + additional ***changes for dry leaf calculations*** (transpiration from dry leaves) based on CLM 4.5 algorithm	from 2010 to 2015

Differences in approach

Algorithm for “2-leaf” canopy (sunlit and shaded leaves)

- Sunlit (f_{sun}) and shaded (f_{sha}) fraction of canopy:

$$f_{sun} = 1 - \frac{e^{-KL}}{KL} \qquad f_{sha} = 1 - f_{sun}$$

- Sunlit (L^{sun}) and shaded (L^{sha}) leaf area indices:

$$L^{sun} = f_{sun} L \qquad L^{sha} = f_{sha} L$$

- Sunlit (SLA^{sun}) and shaded (SLA^{sha}) specific LAI:

$$SLA^{sun} = -\frac{cSLA_m KL + cSLA_m + cSLA_0 L - SLA_m - SLA_0 K}{K^2 L}$$

$$SLA^{sha} = \frac{L\left(SLA_0 + \frac{SLA_m L}{2}\right) - SLA^{sun} L^{sun}}{L^{sha}}$$

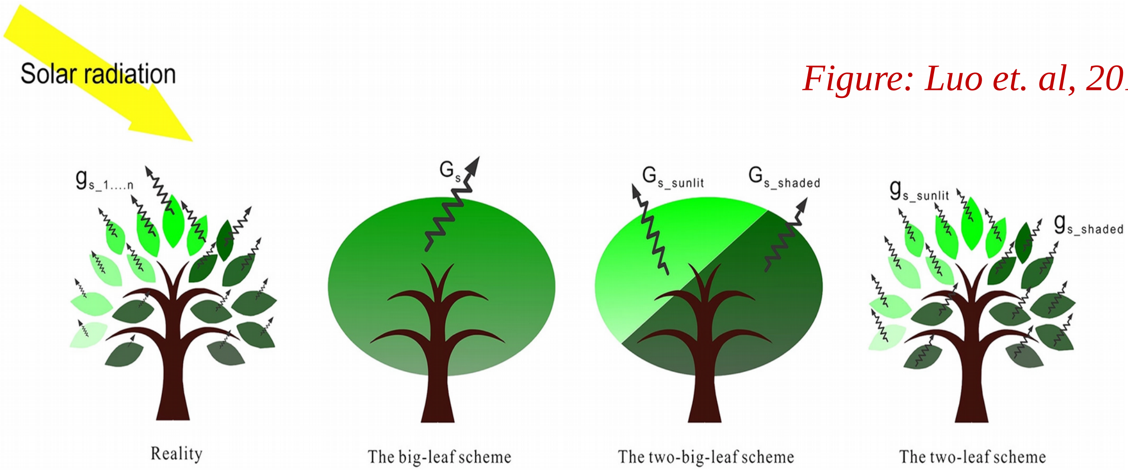


Figure: Luo et. al, 2018

where:
e^{-KL} – the fractional area of sun flecks on a horizontal plane below the leaf area index – L;
K – the light extinction coefficient;
SLA – the specific leaf area indices
L, S – the leaf and stem area indices
SLA_m – the linear slope coefficient
SLA_0 – the value for SLA at the top of the canopy

Differences in approach

Algorithm for photosynthesis (sunlit and shaded leaves)

$$A = A^{sun} L^{sun} + A^{sha} L^{sha} \qquad A^{sun,sha} = min(w_c, w_j, w_e)$$

where: A, A_{sun}, A_{sha} – the leaf photosynthesis for: canopy, sunlit and shaded leaves

$$w_c = \begin{cases} \dfrac{V_{cmax}(c_i - \Gamma_*)}{c_i + K_c\left(1 + \dfrac{O_i}{K_0}\right)} & * \\ V_{cmax} & * \end{cases}$$

$$w_j = \begin{cases} \dfrac{(c_i - \Gamma_*)\, 4.6\, \alpha\, \phi}{c_i + 2\Gamma_*} & * \\ 4.6\, \alpha\, \phi & * \end{cases}$$

$$w_e = \begin{cases} 0.5\, V_{cmax} & * \\ 4000\, V_{cmax} \dfrac{c_i}{P_{atm}} & * \end{cases}$$

V_{cmax} – the maximum rate of carboxylation

K_c; K_o – the Michaelis–Menten constants for CO_2 and O_2

Γ_* – the CO_2 compensation point

c_i – the internal leaf CO_2 partial pressure

O_i – the O_2 partial pressure

α – the quantum efficiency coefficient

ϕ – the absorbed PAR

* – equations for C3 plants based on Farquhar model (1980)

* – equations for C4 plants based on Collatz model (1992)

Differences in approach

TERRA_ML vs **TERRA_ML (updated)**

TERRA_ML	TERRA_ML (updated)
Stomatal behavior represented based on empirical ***Jarvis approach*** *(Jarvis et. al., 1976)*	Stomatal conductance explicitly related to photosynthetic assimilation model using ***Ball-Berry approach*** *(Collatz et. al., 1991)*

$$g_{st}^{can} = \frac{1}{r_{max}} + \left(\frac{1}{r_{min}} - \frac{1}{r_{max}}\right)\left[F_{rad} F_{wat} F_{tem} F_{hum}\right]$$

$$g_{st}^{can} = g_{st}^{sun} L^{sun} + g_{st}^{sha} L^{sha}$$

$$g_{st}^{sun,sha} = \frac{1}{r_s^{sun,sha}} = m \frac{A^{sun,sha} e_s}{c_s e_i} P_{atm} + b F_{wat}$$

where:

COSMO-CLM v5.16:

- F_{rad} – radiation;
- F_{wat} – soil water content;
- F_{tem} – ambient temperature;
- F_{hum} – ambient specific humidity;
- r_{max} – maximal stomatal resistance;
- r_{min} – minimal stomatal resistance.

COSMO-CLM experiments:

- r_s^{sun} and r_s^{sha} – stomatal resistance for *sunlit* and *shaded* leaves;
- g_{st}^{sun} and g_{st}^{sha} – stomatal conductance for *sunlit* and *shaded* leaves
- A and b – leaf photosynthesis and the minimum g_{st};
- e_s and e_i – vapor pressure at leaf surface and inside the leaf;
- c_s – CO_2 partial pressure;
- m – PFT parameter;

Stomatal resistance (RSTOM)

TERRA_ML
(Jarvis approach – Jarvis et al., 1976)

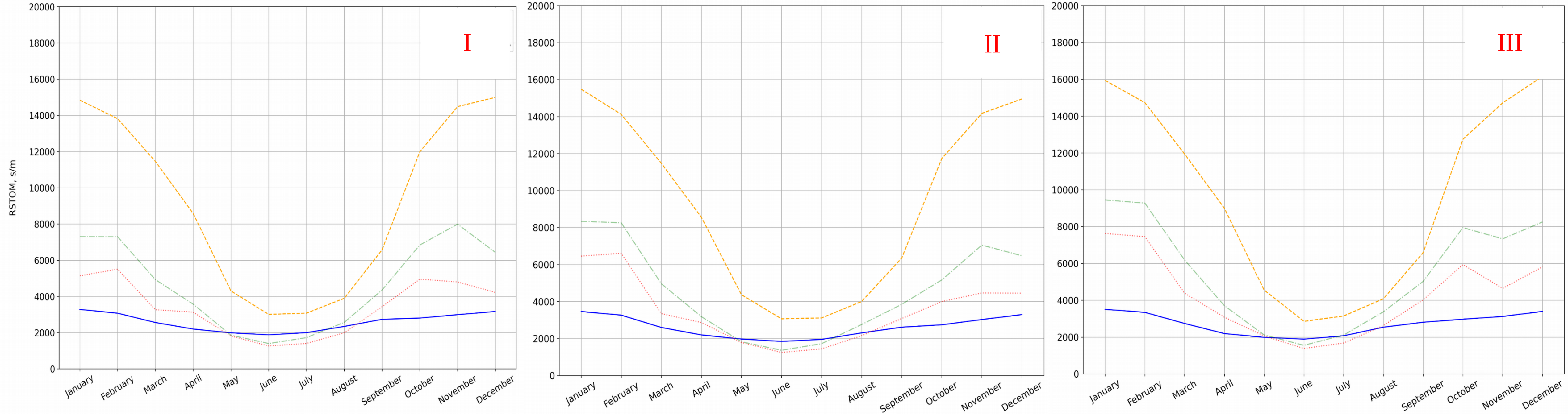
vs

TERRA_ML (updated)
(Ball-Berry approach – Collatz et al., 1991)

$$g_{st}^{can} = \frac{1}{r_{max}} + \left(\frac{1}{r_{min}} - \frac{1}{r_{max}}\right)[F_{rad} F_{wat} F_{tem} F_{hum}]$$

$$g_{st}^{can} = g_{st}^{sun} L^{sun} + g_{st}^{sha} L^{sha}$$

$$g_{st}^{sun,sha} = \frac{1}{r_s^{sun,sha}} = m \frac{A^{sun,sha} e_s}{c_s e_i} P_{atm} + b F_{wat}$$

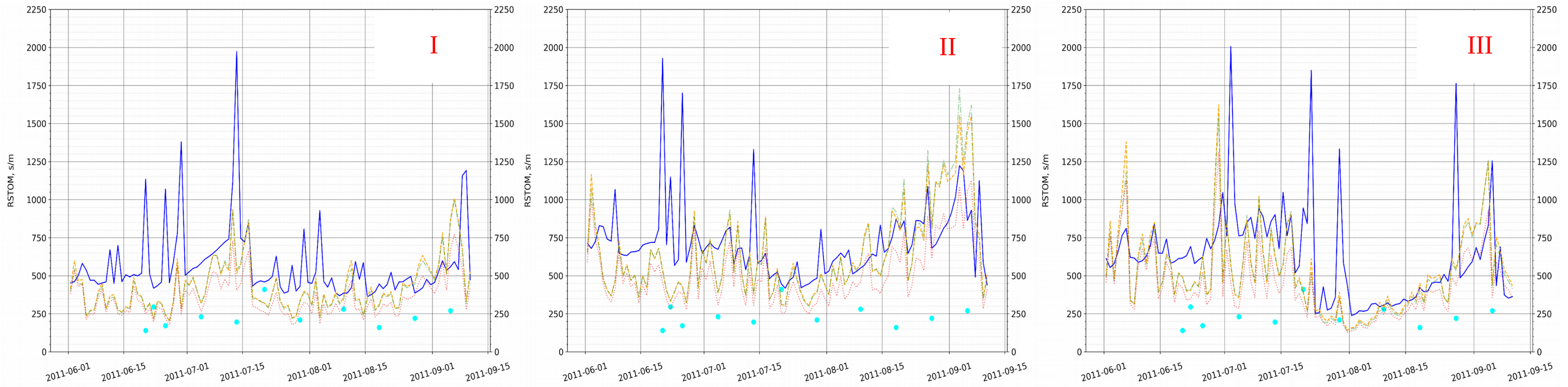


CCLMref CCLMv3.5 CCLMv4.5 CCLMv4.5e

I – Parc, II – Linden, III – Lindenberg

Stomatal resistance (RSTOM)

Time period: from 01.06.2011 to 15.09.2011



CCLMref — CCLMv3.5 — CCLMv4.5 — CCLMv4.5e — IN-SITU data — I – Parc, II – Linden, III – Lindenberg

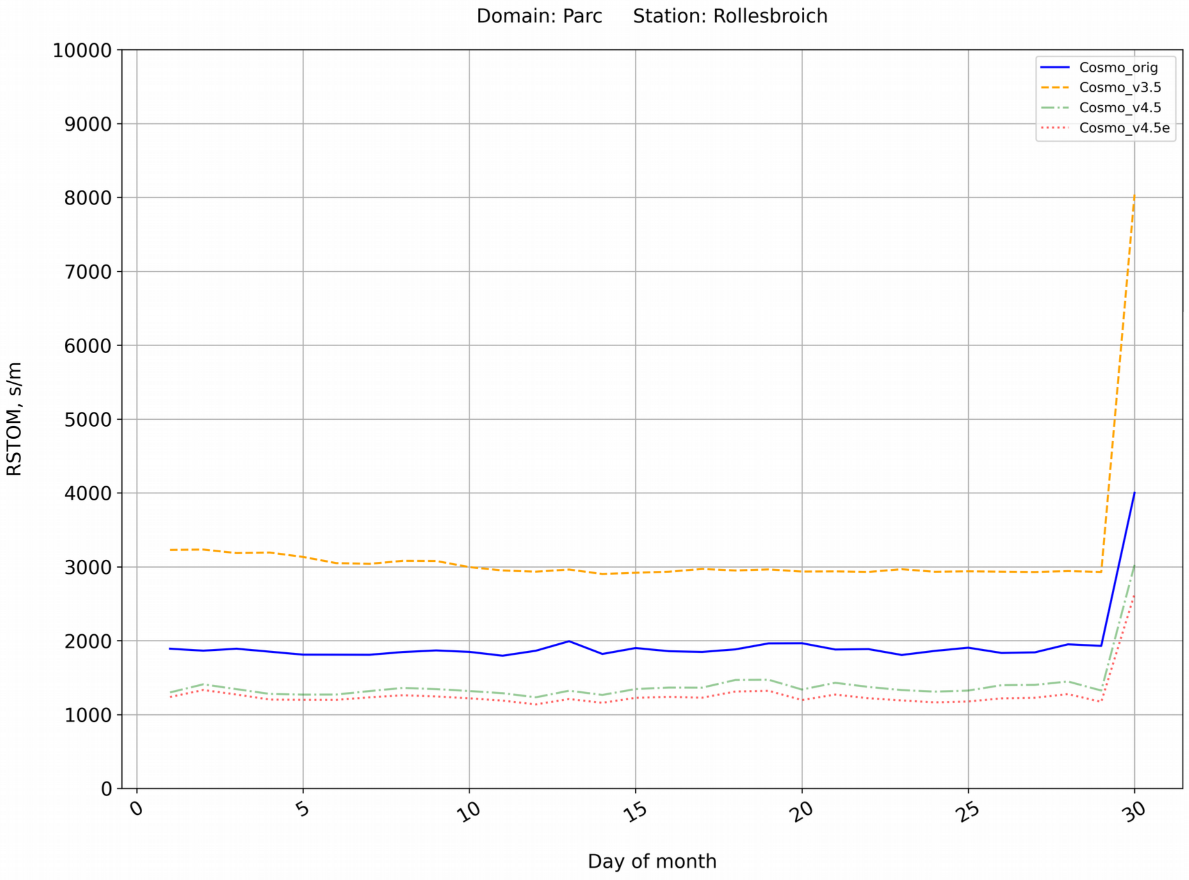
Statistical analysis of stomatal resistance data

	CCLMref	CCLMv3.5	CCLMv4.5	CCLMv4.5e
mean	713	384	384	314
std	495	183	183	133
mae	477	179	179	124
rmse	696	235	235	161
pcc	-0.426	0.103	0.103	0.08

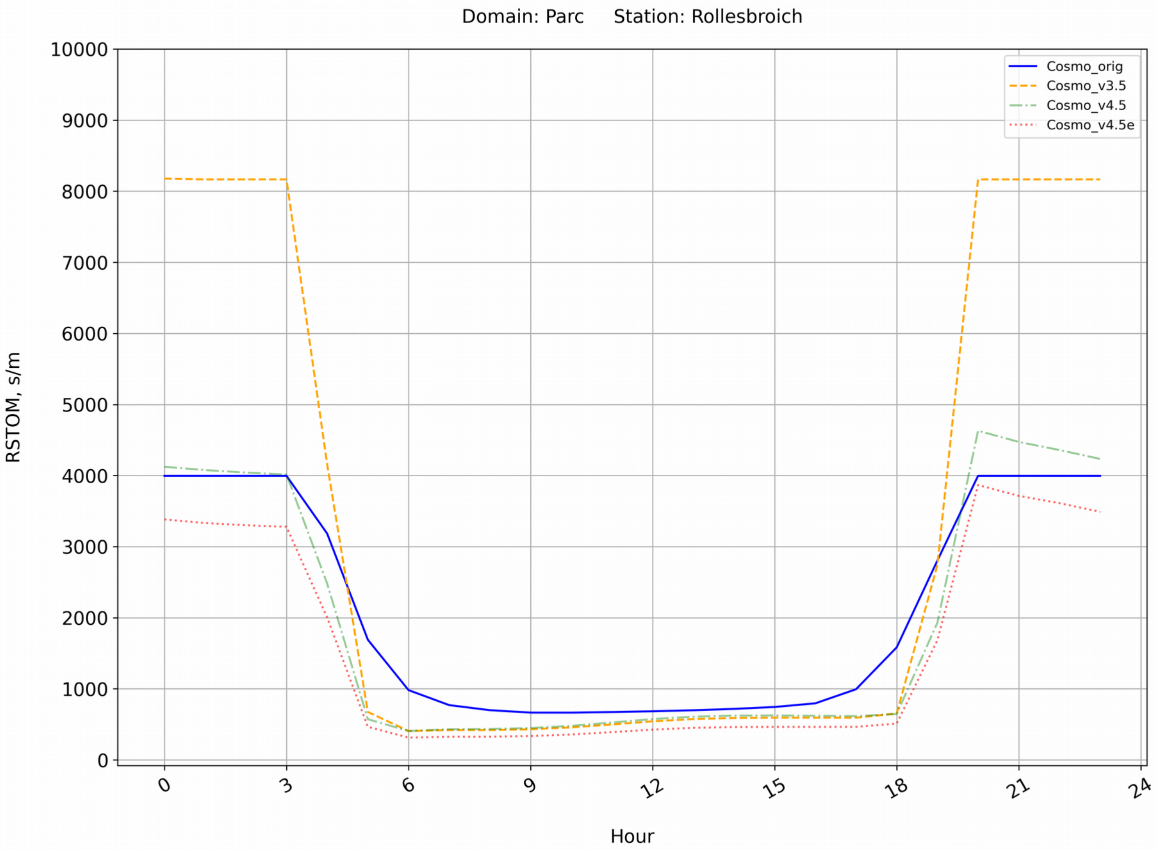
! The stomatal resistance data were measured in North America for C3 grass at 13:00 (PT)

Stomatal resistance (RSTOM)

Daily average values over 2010-2015 for June



Diurnal cycle over 2010-2015 from June to August



Model performance

At sites:

- Standard deviation (STD)
- Mean absolute error (MAE)
- Root mean square error (RMSE)
- Pearson correlation coefficient (PCC)

Grid points:

- Root mean square deviation (RMSD)
- Pearson correlation coefficient (PCC)
- Kling-Gupta Efficiency index (KGE)
- Distribution added value index (DAV)

$$KGE = 1 - \sqrt{(\rho - 1)^2 + \left(\frac{\sigma_m}{\sigma_{obs}} - 1\right)^2 + \left(\frac{\mu_m}{\mu_{obs}} - 1\right)^2}$$

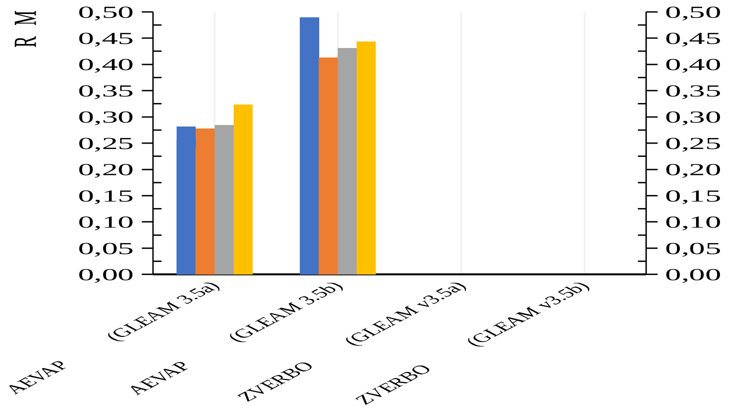
$$DAV = \frac{\sum_1^n \min(Z_{exp}, Z_{obs}) - \sum_1^n \min(Z_{ctr}, Z_{obs})}{\sum_1^n \min(Z_{ctr}, Z_{obs})}$$

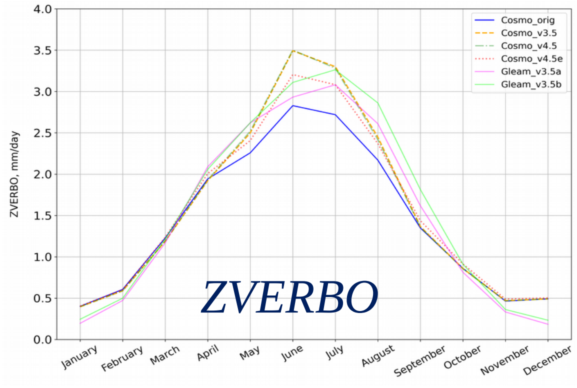
where: ρ is the Pearson correlation coefficient,
σ is standard deviation,
μ is the mean value,
Z is the frequency of values in a given bin for experiments, control run, and observations.

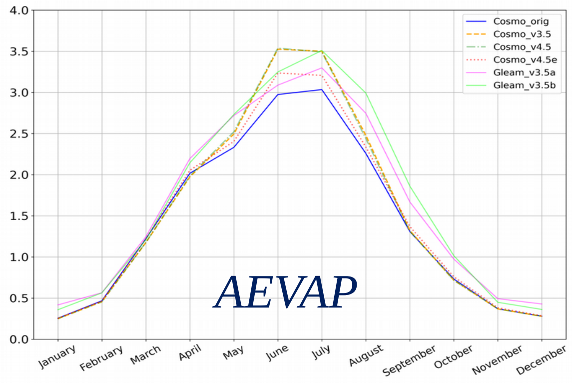
Total evapotranspiration (ZVERBO) and evaporation (AEVAP)

Stations (parc domain)

(a)

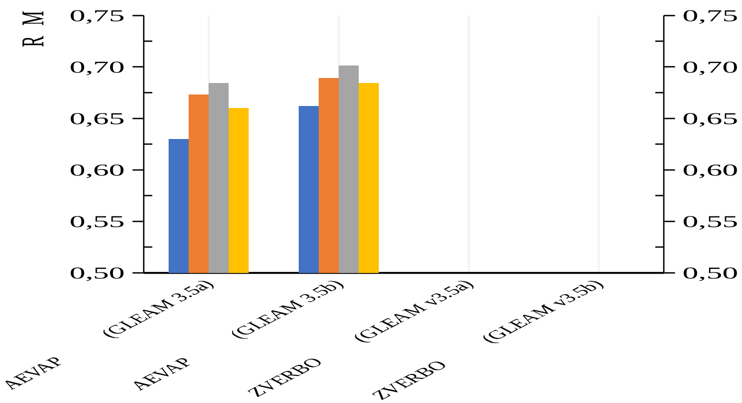




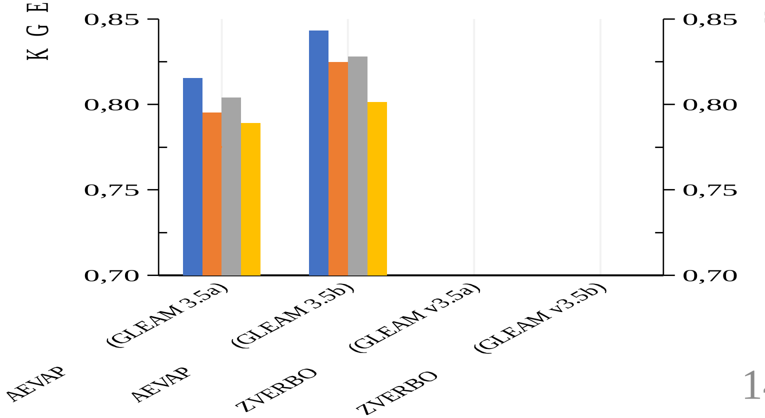


Grid points (parc domain)

(b)



(c)



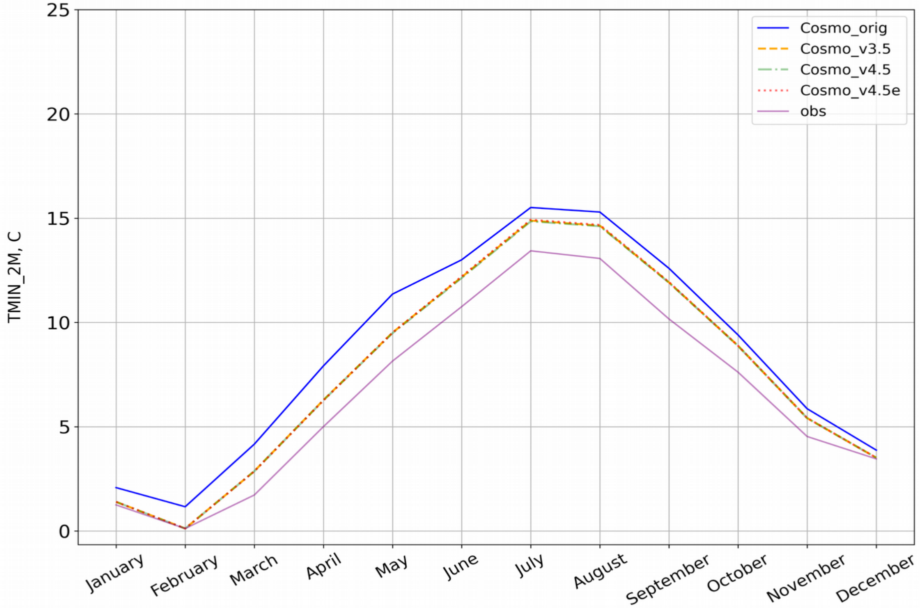
CCLMref

CCLMv3.5

CCLMv4.5

CCLMv4.5e

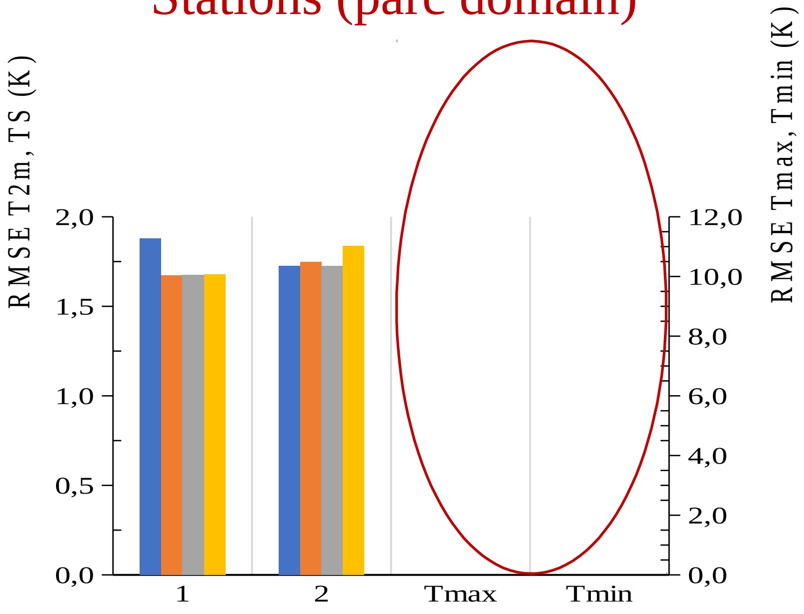
Surface (T_S), maximum (T_{max}) and minimum (T_{min}) temperatures



CCLMref
CCLMv3.5
CCLMv4.5
CCLMv4.5e
IN-SITU data

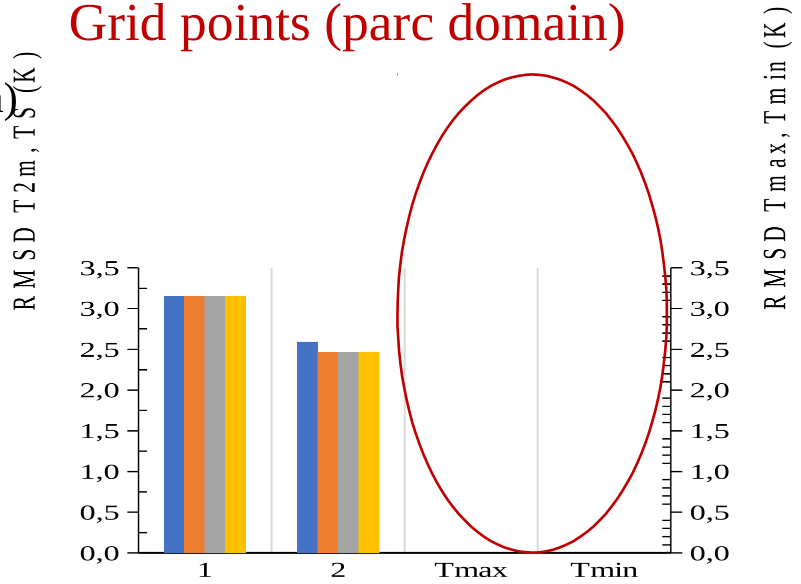
CCLMref
CCLMv3.5
CCLMv4.5
CCLMv4.5e

Stations (parc domain)

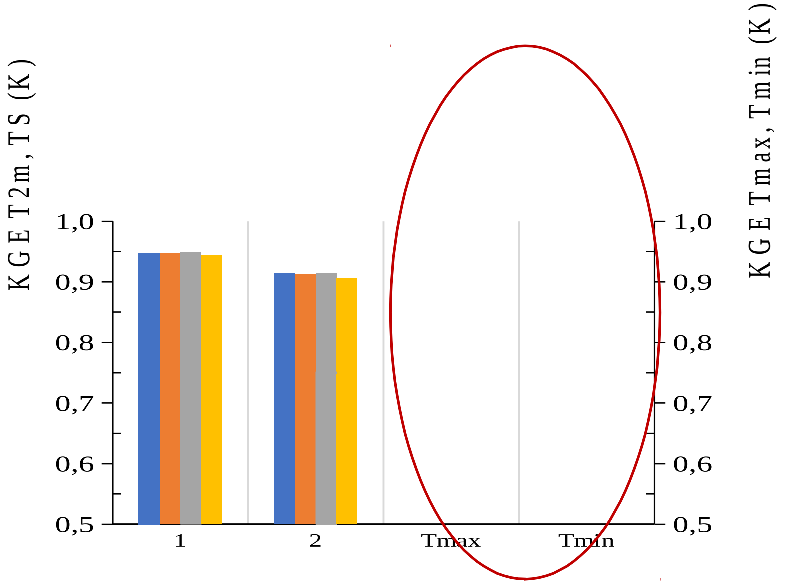


Grid points (parc domain)

(a)



(b)



Conclusions

The new versions (*CCLMv3.5, CCLMv4.5, CCLMv4.5e*):

- consider the difference of the physiological properties between sunlit and shaded leaves
- use the modern physically based approach for stomatal resistance.
- apply the prognostic environmental parameters for calculations of stomatal resistance, which are connected to each other by leaf photosynthesis.
- use stomatal resistance values, which are influenced by atmospheric CO_2 concentration
- allow to calculate the leaf photosynthesis and CO_2 uptake

Didn't change in (*CCLMv3.5, CCLMv4.5, CCLMv4.5e*):

- the phenological cycle of COSMO-CLM (yet), which is still based on a 6-year climatology and follows the same sinusoidal fitted curve between its maximum and minimum value each year neglecting any influence or feedback on the environmental conditions.

Our contacts:

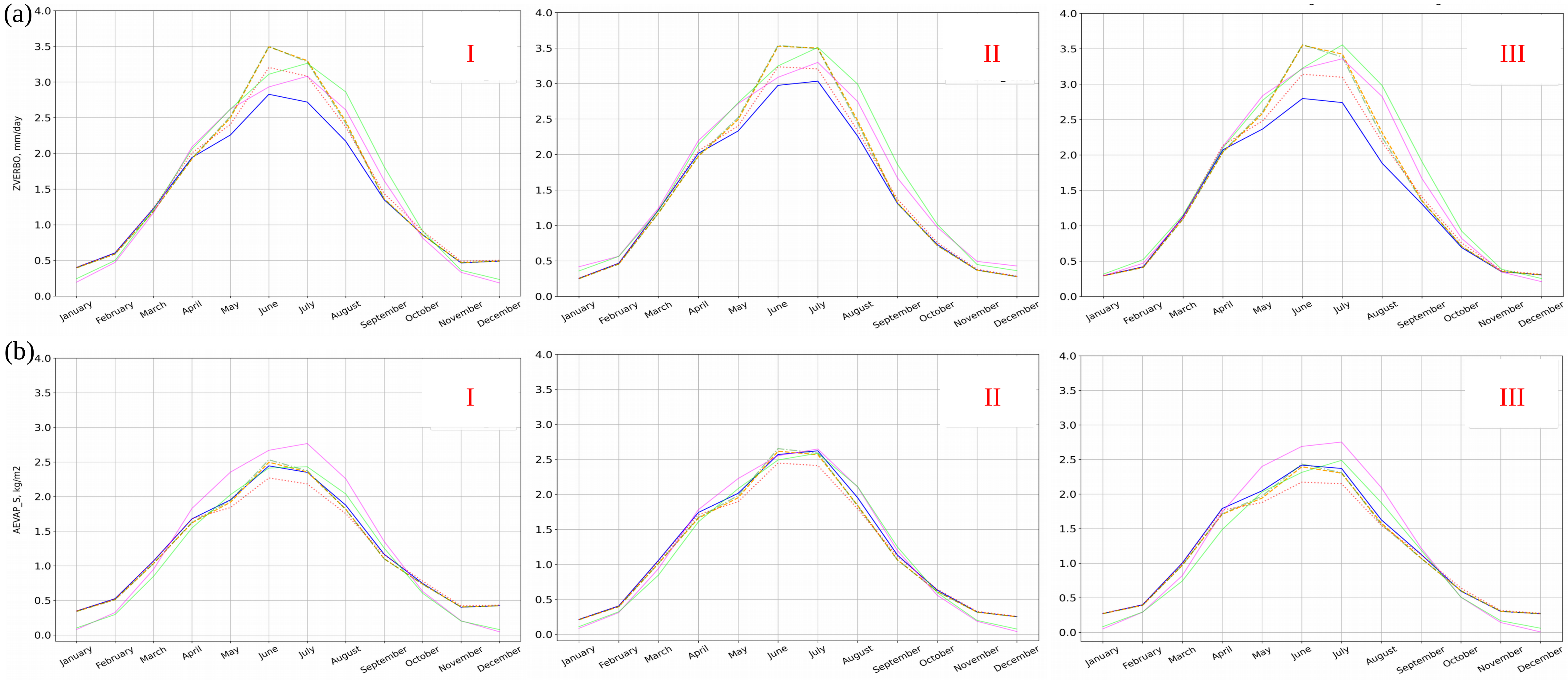
GitHub page: https://github.com/users/merajtoelle/projects/1

Address: Universität Kassel - CESR

Wilhelmshöher Allee 47, 34117 Kassel

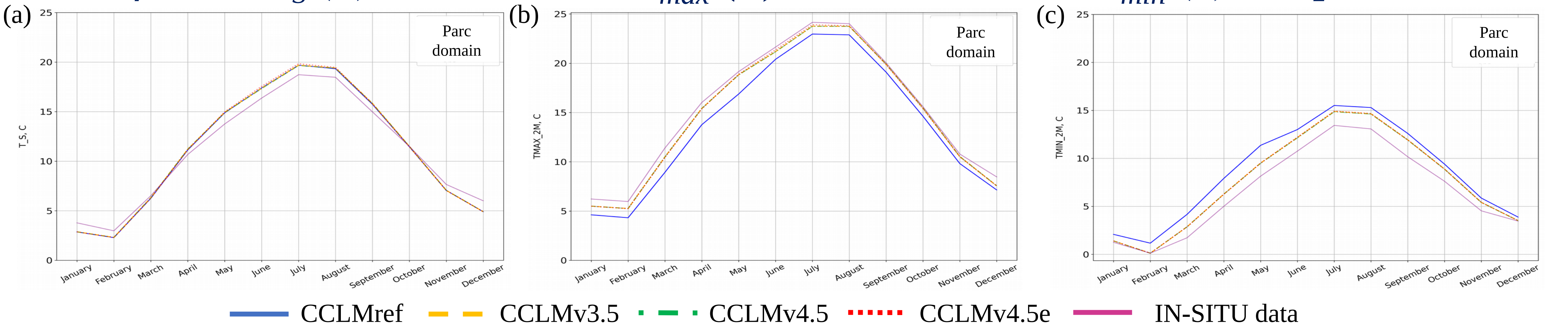
Email: evgenychur@uni-kassel.de

Total evapotranspiration – ZVERBO (a) and evaporation – AEVAP (b)



CCLMref CCLMv3.5 CCLMv4.5 CCLMv4.5e Gleam_v3.5a Gleam_v3.5b I – Parc, II – Linden, III – Lindenberg

Surface – T_S (a), maximum –T_{max} (b) and minimum–T_{min} (c) temperatures



Model performance:

❖ RMSE (d) from the differences taken at sites

❖ RMSD (e) and KGE (f) at COSMO-CLM grid points over the time period 2010 – 2015