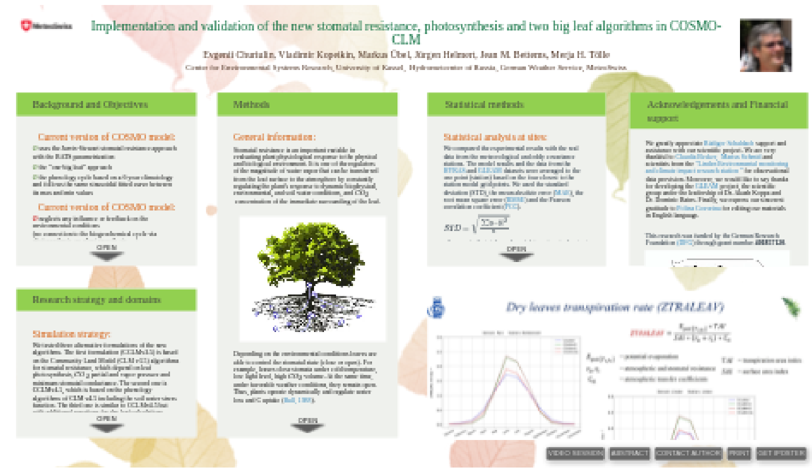
Implementation and validation of the new stomatal resistance, photosynthesis and two big leaf algorithms in COSMO-CLM



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PRESENTED AT:

BACKGROUND AND OBJECTIVES

Current version of COSMO model:

Ø uses the Jarvis-Stewart stomatal resistance approach with the BATS parametrization

Ø the "one-big leaf" approach

Ø the phenology cycle based on a 6-year climatology and follows the same sinusoidal fitted curve between its max and min values

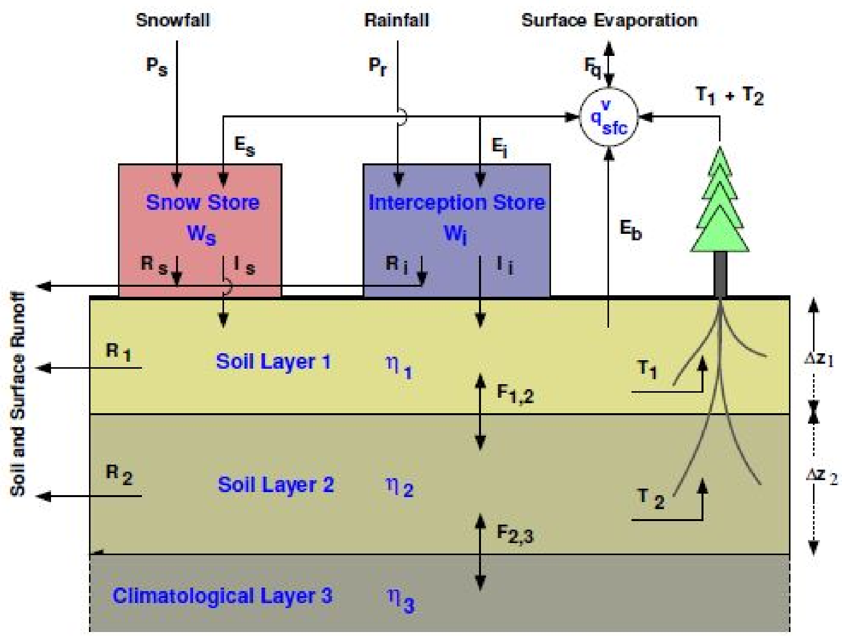
Current version of COSMO model:

Ø neglects any influence or feedback on the environmental conditions
(no connection to the biogeochemical cycle via photosynthesis, no plant growth, etc…)

Ø applies in Jarvis approach the functions which are independent of each other

Ø does not consider the influence of atmospheric CO_2 concentration

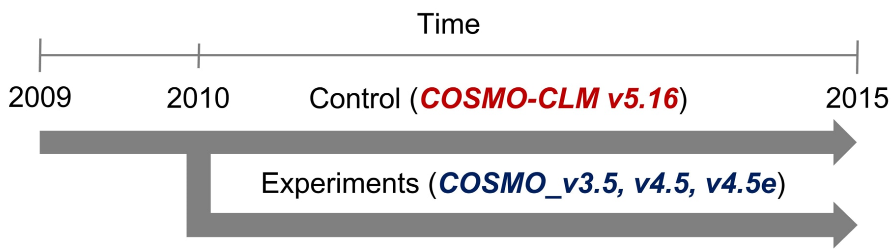
Ø applies highly simplified dependencies, for which the leaf photosynthesis and CO_2 uptake cannot be calculated



RESEARCH STRATEGY AND DOMAINS

Simulation strategy:

We tested three alternative formulations of the new algorithms. The first formulation (CCLMv3.5) is based on the Community Land Model (CLM v3.5) algorithms for stomatal resistance, which depend on leaf photosynthesis, CO_2 partial and vapor pressure and minimum stomatal conductance. The second one is CCLMv4.5, which is based on the phenology algorithms of CLM v4.5 including the soil water stress function. The third one is similar to CCLMv4.5 but with additional equations for dry leaf calculations (CCLMv4.5e).



Reseach domains:

We performed single column simulations with COSMO-CLM over three observational sites with C_3 grass plants in Germany for the period from 2010 to 2015 (Parc, Linden and Lindenberg domain).

EDIT CHART

METHODS

General information:

Stomatal resistance is an important variable in evaluating plant physiological response to the physical and biological environment. It is one of the regulators of the magnitude of water vapor that can be transferred from the leaf surface to the atmosphere by constantly regulating the plant's response to dynamic biophysical, environmental, and soil water conditions, and CO_2 concentration of the immediate surrounding of the leaf.

[VIDEO] https://res.cloudinary.com/amuze-interactive/image/upload/v1637942744/agu-fm2021/42-59-33-3F-6E-DC-12-F8-6B-33-4B-F1-41-AA-8E-86/Image/bm4l4ainteractive2gif4_ehocgz.mp4

Depending on the environmental conditions leaves are able to control the stomatal state (close or open). For example, leaves close stomata under cold temperature, low light level, high CO_2 volume. At the same time, under favorable weather conditions, they remain open. Thus, plants operate dynamically and regulate water loss and C uptake (Ball, 1988 (https://www.researchgate.net/publication/36285887_An_Analysis_of_Stomatal_Conductance)).

The previos stomatal resistance algorithm:

Stomatal resistance in COSMO-CLM is calculated based on a multiplicative and simple resistance Jarvis-Stewart approach (Jarvis, 1976 (https://royalsocietypublishing.org/doi/10.1098/rstb.1976.0035); Stewart, 1988) with the BATS model parameterization (Dickinson et al., 1993 (https://opensky.ucar.edu/islandora/object/technotes:154)). This approach is phenomenological and is based on empirical dependencies between canopy resistance (and environmental variables statistical dependencies to determine the model parameters from measurements for different plant types.

$$r_s^{-1} = r_{max}^{-1} + (r_{min}^{-1} - r_{max}^{-1})[F_{rad}F_{tem}F_{wat}F_{hum}]$$

where: $r_{min}$is minimum stomatal resistance equal to 150 s/m, r_{max} is maximum stomatal resistance equal to 4000 s/m, F_{rad} is the influence of photosynthetic active radiation, F_{tem} is ambient temperature, F_{wat} is soil water content, F_{hum} is ambient specific humidity.

This approach is not capable of modelling complex processes depending on temperature, water availability and day length. Because of that we decided to update this algorithm to overcome these limitations.

The new algorithms for stomatal resistance:

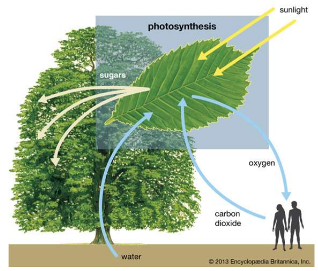
The complex phenology and photosynthesis schemes exists in dynamic vegetation models allows to overcome the limitations of Jarvis approach. For our research, we decided to use the plant physiological approaches which were implemented in the ***Community Land Model (CLM)*** version 3.5 (https://opensky.ucar.edu/islandora/object/technotes:493) and 4.5 (https://opensky.ucar.edu/islandora/object/technotes:515). We used the physically based Ball-Berry approach coupled with photosynthesis processes based on Farquhar and Collatz models for C_3 and C_4 plants and improved by (Thornton and Zimmermann, 2007 (http://journals.ametsoc.org/view/journals/clim/20/15/jcli4222.1.xml?tab_body=fulltext-display)) through the implementation of a new parametrization scheme for the maximum rate of carboxylation (V_c, max) which was the most critical problem of Collatz model.

$$g_{st} = \frac{1}{r_{st}} = m\frac{A_n}{C_s}\frac{e_s}{e_i^*}P_{atm} + b$$

where: g_{st} is stomatal resistance values from CLM3.5 and CLM4.5, A_n is the the rate of net CO_2; e_s is the water vapor pressure at the leaf surface; e_i^* is the saturation vapor pressure inside the leaf at the vegetation temperature T_v; C_s is CO_2 mole fraction of the air at the leaf surface; P_{atm} is the atmospheric pressure; b is the minimum stomatal conductance when A_n = 0; m is an empirical scaling factor of the linear dependency of the stomatal conductance on A_n and environmental variables.

The new algorithm for leaf photosynthesis:

The leaf photosynthesis of C_3 plants is determined with a modified version of the biochemical model of Farquhar et al. (1980) (https://link.springer.com/article/10.1007/BF00386231) as integrated in the Collatz model. The leaf photosynthesis of C_4 plants is based on the model of Collatz et al. (1991) (https://www.sciencedirect.com/science/article/pii/0168192391900028). This algorithm calculates the activity of photosynthesis on the basis of enzyme kinetics of RuBisCO (https://de.wikipedia.org/wiki/RuBisCO) in the dark reaction and the regeneration of RuBP (https://de.wikipedia.org/wiki/Ribulose-1,5-bisphosphat) in the light reaction. There are different limitations to the rate of CO_2 assimilation (by photosynthesis - A_n). The model strategy is that the minimum rate resulting of one of the limitation relations controls CO_2 assimilation at the leaf level.



$$A = min(w_c, w_j, w_e)$$

where: w_c is the *RuBisCO* limitation describes the rate of CO_2 fixation in the carboxylation of *RuBP* in the Calvin cycle (https://de.wikipedia.org/wiki/Calvin-Zyklus); w_j is the light limitation rate describes the maximum rate of carboxylation allowed by the capacity to regenerate *RuBP* in the light reaction; w_e is the capacity for the export or utilization of the carbohydrates produced in the photosynthesis process for C_3 (https://de.wikipedia.org/wiki/C3-Pflanze) and C_4 (https://de.wikipedia.org/wiki/C4-Pflanze) plants [Collatz et al., 1991 (https://www.sciencedirect.com/science/article/pii/0168192391900028); Sellers et al., 1996a (https://www.researchgate.net/publication/224959772_A_revised_Land_Surface_parameterization_SiB2_for_atmospheric_GCMs_Part_I_Model_F 1996b (https://journals.ametsoc.org/view/journals/clim/9/4/1520-0442_1996_009_0706_arlspf_2_0_co_2.xml)].

$$w_c = \begin{cases} \frac{V_{cmax}(c_i - \Gamma_*)}{c_i + K_c(1 + \frac{O_i}{K_0})}, & \text{for } C_3 \text{ plants} \\ V_{cmax}, & \text{for } C_4 \text{ plants} \end{cases}$$

$$w_j = \begin{cases} \frac{(c_i - \Gamma_*)4.6\alpha PAR}{c_i + 2\Gamma_*}, & \text{for } C_3 \text{ plants} \\ 4.6\phi\alpha, & \text{for } C_4 \text{ plants} \end{cases}$$

$$w_e = \begin{cases} 0.5V_{cmax}, & \text{for } C_3 \text{ plants} \\ 4000V_{cmax}\frac{c_i}{P_{atm}}, & \text{for } C_4 \text{ plants} \end{cases}$$

where: V_c, max is the maximum rate of carboxylation and varies among plant functional types and with sunlit and shaded leaves; Γ_* is the CO_2 compensation point; c_i is the internal leaf CO_2 partial pressure; O_i is the O_2 partial pressure; K_c and K_o are the Michaelis-Menten constants for CO_2 and O_2 depending exponentially on T_v and α is the quantum efficiency (depends on PFTs (https://www.cgd.ucar.edu/tss/clm/pfts/index.html)); PAR is the absorbed photosynthetically active radiation, which is converted to photosynthetic photon flux assuming 4.6 *μmol photonos per Joule*;

Photosynthesis is calculated for sunlit and shaded leaves using average absorbed photosynthetically active radiation for sunlit and shaded leaves (PAR_{sun} and PAR_{sha}) to give sunlit and shaded stomatal resistance (r_s^{sun} and r_s^{sha}) and photosynthesis (A^{sun} and A^{sha}):

$$A_{can} = A^{sun}L^{sun} + A^{sha}L^{sha}$$

where: L^{sun} and L^{sha} are the sunlit and shaded leaf area indices. Implementation of the new photosyntesis algorithm demaned changes in the radiation module of *COSMO-CLM.* It was changed and the new algorithm for “two-big leaf” approach were added to COSMO-CLM insted of "one-big leaf" approach.

The new algorithm for "two-big leaf" canopy (sunlit and shaded leaves):

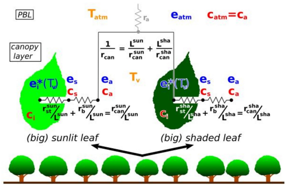


Figure: Übel et. al, 2015

The "two-big leaf" approach (Thornton and Zimmermann, 2007 (https://journals.ametsoc.org/view/journals/clim/20/15/jcli4222.1.xml?tab_body=fulltext-display)) allows to calculate the LAI separately for sunlit and shaded leaves, which is necessary for leaf photosynthesis and stomatal resistance calculations.

$$L^{sun} = f_{sun}L$$

$$L^{sha} = f_{sha}L$$

where: L is leaf area index, and $f_{sun,sha}$ are sunlit and shaded leaves fraction. Sunlit leaves receive (absorb) beam direct and diffuse solar radiation, while shaded leaves get only scattered diffuse solar radiation.

Adaptation of CLM v3.5

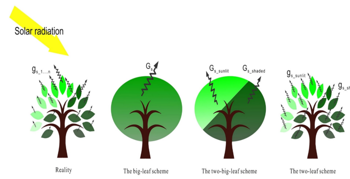


Figure: Luo et. al, 2018

(https://www.cesm.ucar.edu/models/cesm1.2/cesm/cesmBbrowser/html_code/clm/) "two-big leaf" approach in COSMO-CLM model structure also required modernization in the radiation parameterization scheme of COSMO-CLM. In particular, the direct component (ϕ^{μ}_{dir}), diffuse downward component (ϕ^{μ}_{dif}) , and diffuse upward component (ϕ_{dif}) of photosynthetic active radiation at the ground were updated and improved. We used these parameters for calculating for separate calculations of PAR flux for sulit and shaded leaves. for extracting

$$\phi^{sun} = \frac{(\phi^{\mu}_{dir} + \phi^{\mu}_{dif} f sun + \phi_{dif} f sun) * (\frac{L}{L+S})}{L^{sun}}$$

$$\phi^{sha} = \frac{(\phi^{\mu}_{dif} f_{sha} + \phi_{dif} f_{sha} (\frac{L}{L+S})}{L^{sha}}$$

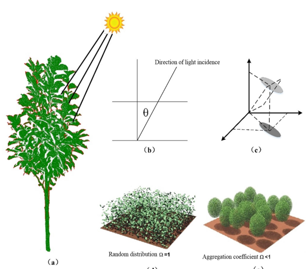


Figure: Chen et. al, 1991

Furthermore, the implementation of the "two-big leaf" approach demanded creation of the new algorithms for calculating the specific leaf area (SLA) indexes for sunlit and shaded leaves, which can be used to estimate the reproductive strategy of a particular plant based upon light and moisture (humidity) levels, among other factors.

$$SLA^{sun} = \frac{-(cn_v KL + cn_v + cSLA_0 K - n_v - SLA_0 K)}{K^2 L^{sun}}$$

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

where: K - is the light extinction coefficient; L - is leaf area index; $c = exp(-KL)$ - is the coefficient; Because $K, L^{sun,sha}$ vary with solar zenith angle, SLA^{sun} and SLA^{sha} vary over the course of a day and throught the year.

STATISTICAL METHODS

Statistical analysis at sites:

We compared the experimental results with the real data from the meteorological and eddy covariance stations. The model results and the data from the HYRAS and GLEAM datasets were averaged to the one point (station) based on the four closest to the station model grid points. We used the standard deviation (STD), the mean absolute error (MAE (https://medium.com/human-in-a-machine-world/mae-and-rmse-which-metric-is-better-e60ac3bde13d)), the root mean square error (RMSE (https://medium.com/human-in-a-machine-world/mae-and-rmse-which-metric-is-better-e60ac3bde13d)) and the Pearson correlation coefficient (PCC (https://www.investopedia.com/terms/c/correlationcoefficient.asp)).

$$STD = \sqrt{\frac{\sum |y-\bar{y}|^2}{n}}$$

where: n is the total number of data, x is actual output value, $\bar{x}$ is mean value

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|y_i - \hat{y}_i|$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}$$

$$PCC = \frac{C_{ov}(exp,obs)}{\sigma_{exp}\sigma_{obs}}$$

where: $C_{ov}(exp, obs)$ is covariance of model and observational variables (subscripts – *exp* and *obs*); σ_{exp} is standard deviation of model data; $\sigma_{obs}$is standard deviation of in-situ data.

Statistical analysis at COSMO-CLM grid points:

The model results are presented on the COSMO-CLM model grid (http://chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/viewer.html?pdfurl=https%3A%2F%2Fwww.hereon.de%2Fimperia%2Fmd%2Fassets%2Fclm%2F2018_cosmo_tutorial_2018.pdf&clen=2167072&chunk=true (spatial resolution is equal to 2.2 km), because of that we decided to apply additional datasets which are also presented on the personal dataset grids. For this purpose, we used the HYRAS (https://www.dwd.de/DE/leistungen/hyras/hyras.html)and GLEAM (https://www.gleam.eu/) datasets. At first, we converted the data to a standard COSMO-CLM format (rotated grid with 2.2 km), after which we extracted data for the similar research domains and period (2010 – 2015). As a result, we prepared the six couples of model variables (four air temperature: two meter – **T2m**, surface – **TS**, maximum – Tmax and minimum – Tmin, the total evapotranspiration – **ZVERBO** and the amount of water evaporation – **AEVAP**) which were used for statistical analysis at COSMO-CLM grid points. For this analysis, we calculated the **PCC** which reflects the quality and the spatial consistency of the simulations and observations. Moreover, we applied the Kling-Gupta Efficiency index (**KGE**), the distribution added value index (**DAV**), and the root-mean-square deviation (**RMSD**) (Raffa et al., 2021 (https://www.mdpi.com/2073-4433/12/2/260)).

The KGE is a statistical index applied as an indicator of a goodness-of-fit measure for runoff model performance. The index was developed by Gupta et al. (2009) (https://www.sciencedirect.com/science/article/pii/S0022169409004843?via%3Dihub) to provide a diagnostically interesting decomposition of the Nash-Sutcliffe efficiency (and hence MSE), which facilitates the analysis of the relative importance of its different components (correlation, bias and variability) in the context of hydrological modelling. Raffa et al., 2021 (https://www.mdpi.com/2073-4433/12/2/260) adapted this index for climatological purposes.

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

where: **ρ** is the Pearson correlation coefficient, **σ** is standard deviation, **μ** is the mean value, subscripts – m and – obs mean the model and the observational time-series. KGE = 1 attests to the fact that there is a perfect mapping between the experiment and the control data. The KGE values lower than -0.41 correspond to an underperformance with respect to the mean of the control (observational) data (Tölle and Churiulin, 2021 (https://www.frontiersin.org/articles/10.3389/feart.2021.722244/full)).

The DAV is is another statistical index applied for determining the benefit of applying the alternative experiment versions over the original version of COSMO-CLM when compared to observations. Moreover, the DAV index allows to estimate the Perkins skill scores (S) between the experiment based on one of the alternative versions (subscript – exp), the control simulation based on the reference version of COSMO-CLM (subscript – ref) and the observations (subscript – obs).

$$DAV = \frac{\sum_{i=1}^{n} min(Z_{exp}, Z_{obs}) - \sum_{i=1}^{n} min(Z_{ref}, Z_{obs})}{\sum_{i=1}^{n} min(Z_{ref}, Z_{obs})}$$

where: Z is the frequency of values in a given bin for experiments, control run, and observations. The DAV = 0 indicates that no gain is found, DAV < 0 there is a loss in performance for the alternative version, DAV > 0 attests to the fact that there is a beneficial impact in using the alternative experiment version compared to the reference with respect to the observations.

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[VIDEO] https://res.cloudinary.com/amuze-interactive/image/upload/v1637335740/agu-fm2021/42-59-33-3F-6E-DC-12-F8-6B-33-4B-F1-41-AA-8E-86/Image/thank-you-thanks_fk1hhy.mp4

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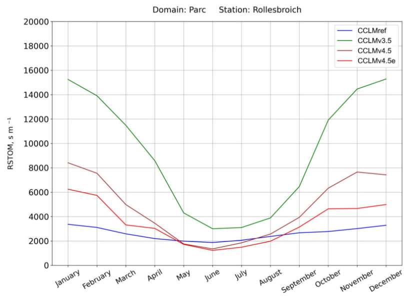
Results and Conclusions of *RESEARCH*

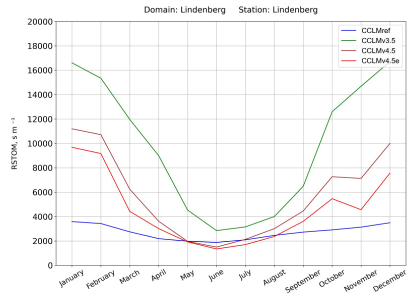
COSMO-CLM v5.16 → CCLM   *Community Land Model → CLM 3.5, CLM 4.5*

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

2

Monthly values of stomatal resistance (RSTOM) from 2010 to 2015





CCLMref – the control experiment based on **COSMO-CLM v5.16** (Jarvis-Stewart approach + BATS model parameterization scheme)

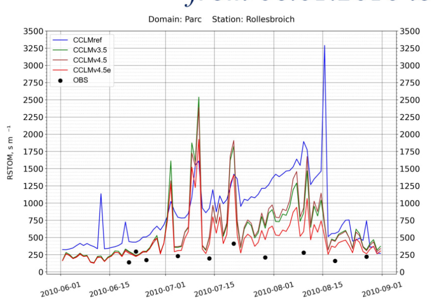
CCLMv3.5 – the experiment based on COSMO-CLM v5.16 with updated phenology algorithms based on CLM 3.5

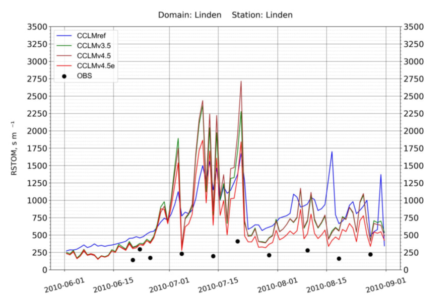
CCLMv4.5 – the experiment based on COSMO-CLM v5.16 with updated phenology algorithms based on CLM 4.5

CCLMv4.5e – the experiment based on COSMO-CLM v5.16 with updated phenology algorithms based on CLM 4.5 and additional corrections of COSMO-CLM algorithm for transpiration from dry leaf

3

Daily values of stomatal resistance from 06.01.2010 to 15.09.2010 at 13.00





CCLMref **CCLMv3.5**

CCLMv4.5 **CCLMv4.5e**

IN-SITU data[1, 2, 3]

$RSTOM \rightarrow ZTRALEAV \rightarrow ZVERBO \rightarrow AEVAP \rightarrow ALHFL \rightarrow ASHFL \rightarrow Ts \rightarrow Tmax \rightarrow Tmin$

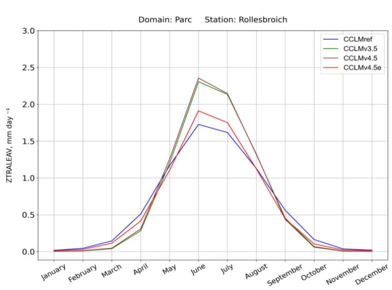
[1] We found the in-situ stomatal resistance values in the articles of *Alfieri et al., 2008*; Irmak and Mutiibwa, 2009;

[2] Data is available for the research domain with C3 grass which is located in the North America region

[3] If you know more about the real stomatal resistance data, please write us to get into details of partnership. We will be happy to compare our model results with your data.

4

Dry leaves transpiration rate (ZTRALEAV)



$$ZTRALEAV = \frac{E_{pot(T_{sfc})} * TAI}{SAI * (r_a + r_s) * C_A}$$

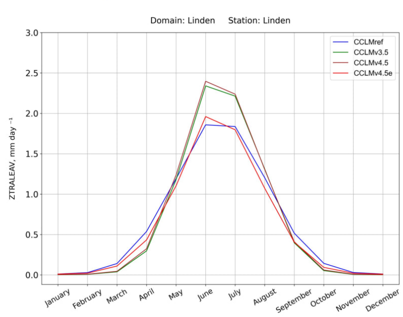
$E_{pot(T_{sfc})}$ – potential evaporation

r_a, r_s – atmospheric and stomatal resistance

C_A – atmospheric transfer coefficients

TAI – transpiration area index

SAI – surface area index



CCLMref **CCLMv4.5**

CCLMv3.5 **CCLMv4.5e**

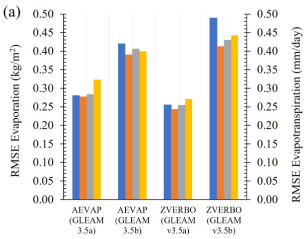
Considered parameters:

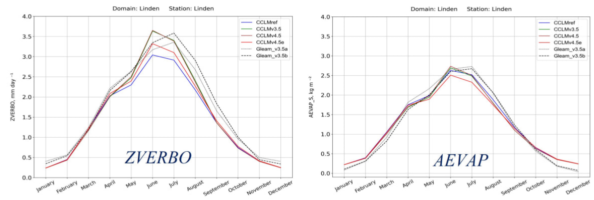
$RSTOM \rightarrow ZTRALEAV \rightarrow ZVERBO \rightarrow AEVAP \rightarrow ALHFL \rightarrow ASHFL \rightarrow Ts \rightarrow Tmax \rightarrow Tmin$

5

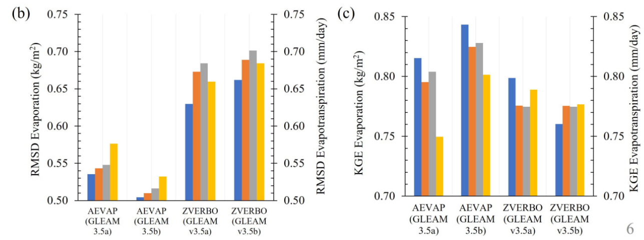
Total evapotranspiration (ZVERBO) and evaporation (AEVAP)

Stations (parc domain)





Grid points (parc domain)



CCLMref

CCLMv3.5

CCLMv4.5

CCLMv4.5e

Considered parameters:
RSTOM → ZTRALEAV → ZVERBO → AEVAP → ALHFL → ASHFL → Ts → Tmax → Tmin

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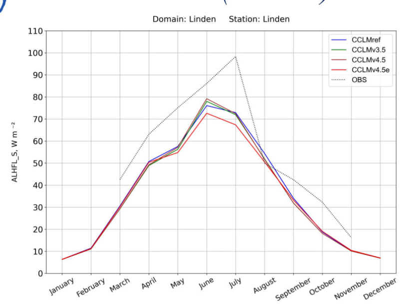
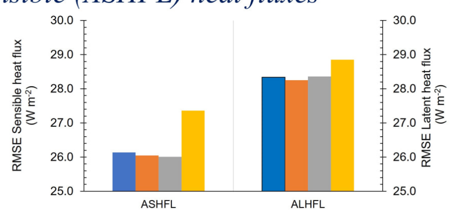
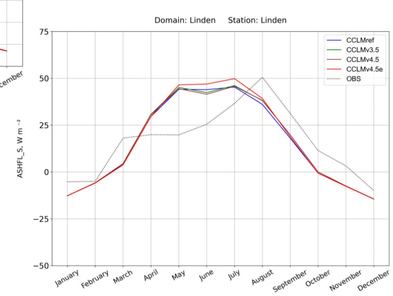
Latent (ALHFL) and Sensible (ASHFL) heat fluxes







CCLMref **CCLMv4.5**

CCLMv3.5 **CCLMv4.5e**

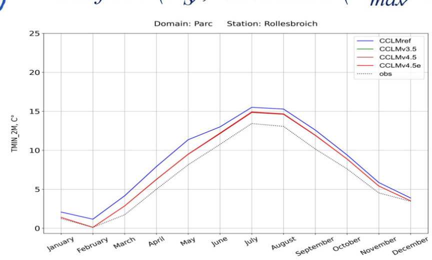
OBS*

* The FLUXNET and EURONET dataset were used for analysis of the experiments. The data from EURONET and FLUXNET are actual for sites, while the experiments data were calculated on the model grid with 2.2 km step

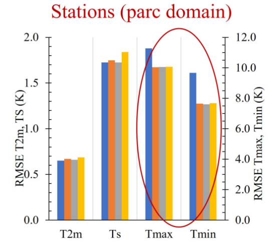
Considered parameters:
RSTOM → ZTRALEAV → ZVERBO → AEVAP → ALHFL → ASHFL → Ts → Tmax → Tmin

7

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



Stations (parc domain)



* The HYRAS dataset was applied for verification of the experiments

CCLMref

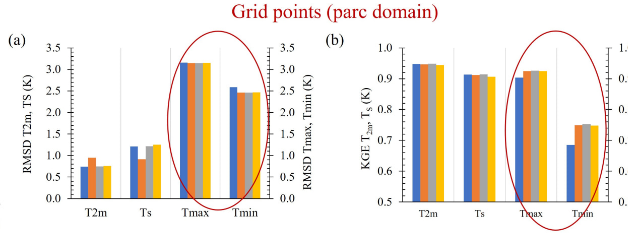
CCLMv3.5

CCLMv4.5

CCLMv4.5e

OBS*

Grid points (parc domain)



Considered parameters:
RSTOM → ZTRALEAV → ZVERBO → AEVAP → ALHFL → ASHFL → Ts → Tmax → Tmin

8

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.

ABSTRACT

Climatic changes with warmer temperatures in mid-latitudes require the need to improve the simplified vegetation scheme of the regional climate model COSMO-CLM, which is not capable of modelling complex processes depending on temperature, water availability and day length. Thus, we have implemented the physically based Ball-Berry approach coupled with photosynthesis processes based on Farquhar and Collatz models for C_3 and C_4 plants in COSMO-CLM (v 5.16). The implementation of the new algorithms includes the replacement of the “one-big leaf” by a “two-big leaf” approach. We performed single column simulations with COSMO-CLM over three observational sites with C_3 grass plants in Germany for the period from 1999 to 2015 (Parc, Linden and Lindenberg domain, Fig.1). Hereby, we tested three alternative formulations of the new algorithms. The first formulation (COSMO_v3.5) is based on the Community Land Model (CLM v3.5) algorithms for stomatal resistance, which depend on leaf photosynthesis, CO_2 partial and vapor pressure and minimum stomatal conductance. The second one is COSMO_v4.5, which is based on the phenology algorithms of CLM v4.5 including the soil water stress function. The third one is similar to COSMO_v4.5 but with additional equations for dry leaf calculations (COSMO_v4.5e). The results revealed major differences in the annual cycle of stomatal resistance compared to the control simulation (COSMO_orig) with the original algorithm (Fig. 1). The biggest changes are from October to April when stomata are closed. The summer values of experiments are closer to measured values, than COSMO_orig. Further, changes in the stomatal resistance algorithms improve the accuracy of calculated transpiration rate and total evapotranspiration. The results indicate that changes in stomatal resistance and photosynthesis algorithms can improve the accuracy of other parameters of the COSMO-CLM model by comparing them with FLUXNET data and meteorological observations at the sites, and GLEAM datasets.

Figure 1: The stomatal resistance based on COSMO-CLM experiments (a - annual cycle; b - daily values from 01.06.2011 to 15.09.2011) for: I – Parc domain, II – Linden domain, III – Lindenberg domain.

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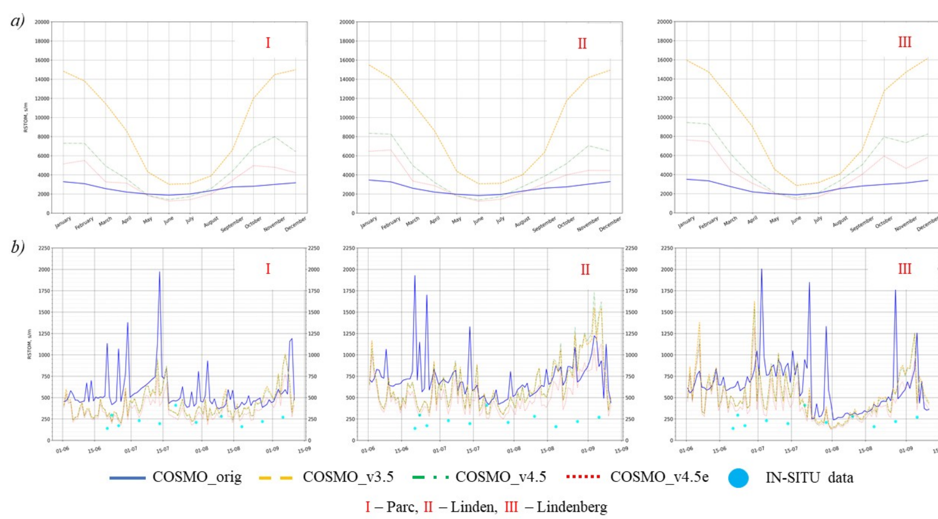

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