COSMO Priority Task: Vegetation Atmosphere INTeractions (VAINT)

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Time period, FTE: 09.2020 – 08.2022, 2 FTE

Code owner: Juergen Helmert (DWD)

Main goal

Improve the current phenology of vegetation and photosynthesis in the COSMO model; prepare the work for a future implementation in the ICON model.

Motivation

It has been shown that changes in the seasonal phenological cycle due to winter or summer crops affect the local climate by changes in the biogeophysical processes in Germany (Tölle et al., 2014). Furthermore, an earlier start of the growing season of the vegetation is expected as climate change progresses due to warmer temperatures in mid-latitudes in spring. The seasonal phenology of vegetation impacts on the energy and water cycle, and can amplify extreme events (e.g. European drought in 2018) by changes of the seasonal cycle of the albedo and water availability. The frequency of extreme events increases and will increase in the near future. Hence, the need for modelling phenology will also increase.

Photosynthesis provides humidity to the environment by evapotranspiration and is important for the atmospheric boundary layer affecting weather and climate. Here, the stomatal conductance is an important regulating factor. Forecasting the phenological cycle of vegetation provides valuable information to assist with turbulent flux estimations relevant for boundary layer processes such as turbulence as well as extreme events assessments. Furthermore, knowing the evolution and magnitude of the seasonal leaf area index together with the plant coverage allows for a more realistic estimation of the surface albedo relevant for accurate weather and climate modelling. Moreover, knowledge of the current state of the vegetation

[1] Center for Environmental Systems Research, https://www.uni-kassel.de/einrichtungen/cesr/das-cesr.html

phenology is of paramount importance for numerical weather prediction (NWP) as well as climate modelling. This is especially relevant for agricultural areas when running forecast with fine horizontal resolution, where the spatial heterogeneities of the agricultural fields are large.

Currently, most NWP models, including COSMO, use simplified phenology schemes, which are in general not capable to model the complex processes depending on day length, temperature, and water availability relevant for the start of the growing season in spring, the evolution of the leaf area index and plant coverage and the senescence in autumn. The phenological cycle is based on a 6-year climatology in COSMO, which follows the same sinusoidal fitted curve between its maximum and minimum value each year while neglecting any influence, feedback on the environmental conditions. Although complex phenology and photosynthesis schemes exists in dynamic vegetation models (CARAIB, JSBACH, the Community Land Model (CLM), the Lund-Potsdam-Jena-GUESS (LPJ-GUESS) model, the ORCHIDEE), these schemes have not been implemented for production (exploitation), neither in COSMO nor in ICON yet. Schulz et al. (2015) started to implement a new leaf phenology for grassland for the land surface scheme TERRA-ML of the COSMO atmospheric model in the offline mode. Nowatzki et al. (2020) followed this approach further for grassland phenology in one-column simulations of COSMO-CLM over three experimental sites in Germany, although stomatal regulation and vegetation growth interacting with atmospheric CO2 seasonality was not accounted for. Therefore, we will implement photosynthesis and phenology of vegetation together with its growth and respiration from the model CARAIB (Warnant et al. 1994). It is an extensive validated model, which took part in the ISIMIP2a comparison study (Chang et al. 2017, Ito et al. 2017, Schewe et al. 2019) with values close to the observations. In addition, the results of CARAIB proved comparable to MODIS observations for drought events in 2003 and 2010 (François et al. 2016).

We therefore propose implementing, validating and updating – if needed – the CARAIB photosynthesis/phenology scheme in the latest version of COSMO (the one including the unified COSMO/ICON TERRA module), with the aim of reducing the forecasting errors in vegetated areas.

Remark about the model chosen as vehicle for a first implementation

As TERRA is common to COSMO and ICON, we propose to start with COSMO, as we can later on switch to the ICON model without too much effort as the phenology development does not primary depend on the model type. Evgenii Churiulin already has good knowledge of COSMO, which is advantageous for the proposed development; in the case of ICON, significant time would first have to be spent to learn about this system. In addition, this work will also directly benefit the climate CLM-community as they will still use the COSMO model for some more years. *But, at the end, the final goal is to implement the developments into ICON*; this will be done in a follow-up PT, or, if additional resources become available, the work can start earlier in parallel to this PT.

Because the timeline of this PT extends beyond the final COSMO release milestone, *the permanency of these developments* will be guaranteed by the following actions

1. define a clear code architecture which minimises the interfaces with the existing codes (as done in the SAINT project);
2. put these developments in a git branch based on the final COSMO v6.0.

Furthermore, we will keep all assumptions as *focused* and *simple* as possible. This first PT should provide a simple but robust photosynthesis/phenology scheme, laying a solid basis for possible further developments.

Additional remarks

There is no direct link with *data assimilation* (DA) in this PT. The goal is to replace the current climatology based vegetation state (PLCOV, LAI...) with a phenology model. The phenology model computes the state of the vegetation, using in particular the evolution of the weather since the start of the year. Of course, the performance of the data assimilation scheme depends on the model biases, and will change when a new physical scheme is introduced. This could be tested within the frame of this new PT, but it is beyond the scope of the PT to tune the DA scheme.

If there is an effect on the *snow characteristics*, it will be handled in cooperation with PT SAINT (or any follow-up project).

Our developments do not depend on the availability of the *canopy parameterization scheme* with the explicit treatment of radiation transfer. However, we will frequently exchange information on the status of the canopy layer developments to adapt our procedure.

We will use the *external parameters*, which are available and provided by EXTPAR. No additional external parameter data/fields are required. We will transfer the land use type in COSMO to characteristic PFTs using for example the look-up table from ICON (this step will be easier in the ICON model as there are already detailed information about the PFTs).

Preliminary work is starting now, June 2020, although the actual work will start after official review and approval in September 2020.

Expected results

It is expected to include a well validated, stable version, of an improved photosynthesis/phenology scheme in the official COSMO model code, and to prepare the work for a migration to ICON. Documentation in forms of work reports (COSMO Technical Reports, Newsletter) and/or scientific publications for peer-reviewed journals will be prepared.

Description of Individual Sub-Tasks

SubTask1: implementation of new photosynthesis/phenology scheme

Three modules describing the role of the large-scale vegetation will be implemented into the official COSMO/ICON model code. The new modules describe respectively: (1) the canopy photosynthesis and stomatal regulation; (2) carbon allocation and plant growth; (3) heterotrophic respiration and litter/soil carbon dynamics. They will be combined with the other relevant modules such as the hydrological, turbulence, and radiation module. Influences on the average soil water content in the root zone, the snow cover and all related water fluxes are expected. In addition, the seasonal varying leaf area index and plant coverage will influences the radiation. Here, CO_2 concentration will control stomatal closure in combination with photosynthesis, water stress and air relative humidity, but not the physiological acclimation of photosynthetic capacity. A simplified assumption is that carbon allocation between structural pools and fast decomposing organs is fixed and there is no coupling with nutrient cycles.

The *canopy photosynthesis and stomatal regulation module* is based on the model of Farquhar et al. (1980) for C3 and Collatz et al. (1992) for C4 plants. Here, stomatal conductance is related to the net assimilation using the parameterization developed by Ball et al. (1987). The scaling of photosynthesis from leaves to canopy will be performed using the De Pury & Farquhar (1997) scheme. This scheme integrates radiative transfer within the canopy. Therefore, photosynthesis will be calculated once for each PFT taking into account the determined LAI.

The *carbon allocation and plant growth module* (Otto et al. 2002) allocates photosynthetic products to the metabolic (leaves and fine roots) and structural (wood and coarse roots) carbon reservoirs. This module also evaluates the autotrophic respiration and litter production fluxes. In CARAIB leaf carbon is a reservoir for which a budget equation is written. It thus depends on photosynthesis (and hence, temperature, radiation, humidity, leaf C:N, etc.), allocation of carbohydrates to leaf, as well as leaf respiration. The leaf area index is then obtained from the leaf carbon reservoir by multiplying this leaf carbon biomass by the specific leaf area (SLA), which depends on the PFT. Future work will be to add SLA varying with environmental conditions within the same species to account for acclimation.

The *heterotrophic respiration and litter/soil carbon module* (Nemry et al. 1996) calculates heterotrophic respiration rates, as well as the time evolution of metabolic litter, structural litter and soil carbon reservoirs.

The new modules will be implemented in a way to minimize the additional computational time introduced by these new parameterizations.

Deliverables

Implementation of new vegetation schemes, formulation of improvements as needed.

Participating scientists

Merja Tölle (CESR) 0.1 FTE, Evgenii Churiulin (CESR) 1.29 FTE, Jean-Marie Bettems (MeteoSwiss) 0.005 FTEs, Jürgen Helmert (DWD) 0.005 FTE

SubTask2: quantification of impact on implemented parameterizations

The implementation of an improved photosynthesis/phenology scheme will influence the currently implemented parameterizations, especially for turbulence and radiation (albedo) through the new time-varying plant coverage/leaf area index/stomatal conductance. This impact on the albedo and on evapotranspiration/latent heat flux will be quantified.

Furthermore, the start from a specific date need to be accounted for NWP applications, and the necessary predictors to be written out and read in each time step.

Deliverables

Quantification of the influence to the currently used atmospheric parameterizations especially for turbulence and radiation. Adapted new COSMO input/output fields.

Participating scientists

Merja Tölle (CESR) 0.04 FTE, Evgenii Churiulin (CESR) 0.25 FTE, Jean-Marie Bettems (MeteoSwiss) 0.005 FTEs, Jürgen Helmert (DWD) 0.005 FTE

SubTask3: validation of implementation of new photosynthesis/phenology scheme

Although, the majority of the verification will be performed as the project evolves, sub-task 3 includes verification of prognostic and diagnostic parameters affected by the photosynthesis/phenology scheme. Especially, the diagnostic parameters such as the 2 m air temperature will be affected by an improved photosynthesis/phenology scheme. Adjustments to such diagnostics will be made if required.

Deliverables

Verification (skill scores) of COSMO performance, validation of diagnostics.

Participating scientists

Merja Tölle (CESR) 0.01 FTE, Evgenii Churiulin (CESR) 0.18 FTE, Jean-Marie Bettems (MeteoSwiss) 0.005 FTE, Jürgen Helmert (DWD) 0.005 FTE

SubTask4: documentation of new photosynthesis/phenology scheme

In the final phase 4 required documentations in forms of internal work reports (COSMO consortium) as well as scientific publications for peer-reviewed journals will be prepared.

Deliverables

Results of the proposed work will be summarized in form of COSMO Technical report and/or peer-reviewed paper, and/or COSMO Newsletter including a documentation of the scheme in terms of usage, i.e. namelists options, changes of default values etc.

Participating scientists

Merja Tölle (CESR) 0.02 FTE, Evgenii Churiulin (CESR) 0.07 FTE, Jean-Marie Bettems (MeteoSwiss) 0.005 FTE, Jürgen Helmert (DWD) 0.005 FTE

Advising and collaborations

Since the implementation of a photosynthesis/phenology scheme will have an expected large effect on surface processes/exchange we will also coordinate our work with M. Raschendorfer (DWD) leader of working group WG3a, Physical Aspects, Upper Air. In addition, J. Helmert (DWD), TERRA SCA, agreed to support this work by giving advices about goals, strategy, plans, and developments steps, and by ensuring compatibility of this work with other developments taking place at DWD. Finally, a proposal will be submitted to the DKRZ to acquire computational resources.

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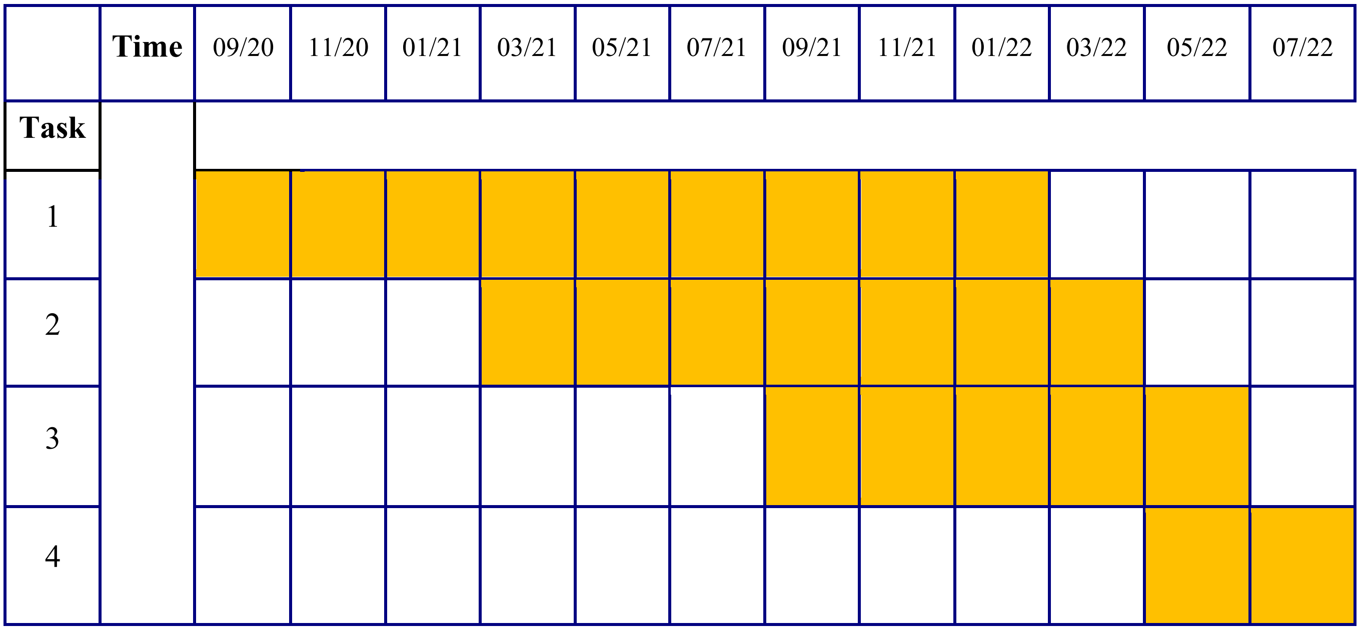
Gantt chart



FTEs summary

	Institution	CESR	MeteoSwiss	DWD
Task				
1		1.39	0.005	0.005
2		0.29	0.005	0.005
3		0.19	0.005	0.005
4		0.09	0.005	0.005
Total FTEs		1.96	0.02	0.02

Total of 2 FTEs over 2 years