Climate Modelling User Group [CMUG]

Deliverable D2.0bv2 (5.2.2)

Interim progress report

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1.0	21 February 2025	First draft shared among partners
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Contents

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1. Aim and scope of the deliverable

The WP5.2 study aims to quantify the relationship between changes in plant phenology and land-atmosphere exchanges. This study, then, uses several Essential Climate Variables (ECVs) to assess their relations and identify the influence that they exert on plant phenology.
The present deliverable provides a progress report on the preliminary results obtained in the WP5.2 and the plan for the next steps. In particular, the list of ECVs involved in this study and the interactions with the Climate Changes Initiative (CCI) teams are provided in Section 2, the methodology and the preliminary results are described in Section 3, and next steps are highlighted in Section 4.

2. Essential Climate Variables

The first task of WP5.2 (i.e. task 5.2.1) establishes a collaboration between LAI data developers (i.e. Vegetation CCI team) and users (i.e. WP5.2 CMUG team) to provide feedback on the LAI data provided by the developers and improve understanding of data by the users. The main goals reached by this collaboration are summarized in the deliverable D2.0bv1 (5.2.1).

The main goal of the WP5.2 study requires the use of various ECVs (Table 1). Consequently, the exchange of information between users and developers (i.e. CCI teams) is needed to establish the proper version and variable to be used in each specific application of the study. Based on these preliminary interactions and the most recent version release of data, the CMUG team has been able to compile and retrieve the required variables listed in Table 1.

CCI Team	Version	Variable
Vegetation	1.0	Leaf Area Index (LAI)
Soil Moisture	9.1	Combined soil moisture, root zone soil moisture
Land Cover	2.0.8	Plant Functional Types distribution
Snow	3.1	Snow water equivalent
Water Vapour	3.2	Total column water vapour
Land surface temperature	4.0	Land surface temperature
Biomass	5.0.1	Above ground biomass

Table 1. Essential Climate Variables (ECVs), reference Climate Change Initiative (CCI) teams, and release version used in the WP5.2 CMUG study.

Each of the selected ECVs will be employed for specific needs within the study. In particular, the LAI data will be used to identify phenology phases; soil moisture, snow, land surface temperature, and water vapour will be employed in defining the land-atmosphere interactions; land cover and biomass will be used to categorize and define use cases for more detailed analysis. During the first phase of this study, a continuous exchange of information and feedback was established between the CMUG team and the Vegetation CCI team. This interaction led to the inclusion of a clumping index provided by the Vegetation CCI to be employed by the users to convert effective LAI into true LAI and the development of an aggregation tool to upscale the original LAI data towards typical land surface models' horizontal resolutions. More details are provided in the deliverable D2.0bv1 (5.2.1).

3. Methodology

Recent studies (e.g. Peano et al., 2021, 2025; Li et al., 2022) show that state-of-the-art land surface models tend to simulate a delay in the vegetative active season, with the late bias initiated at the beginning of the growing season (i.e. onset) and continuing through the timing of peak activity and the end of growing season (i.e. offset) each year. To better understand the drivers of seasonal phenology phases and provide robust datasets that can be used to evaluate modelled vegetation phenology, this study focuses on the relationships between vegetative active season and the associated land-atmosphere conditions.

This study consists of three main steps:

1. Identify the main phenology phases, with a specific focus on the onset timings;
2. Assess relationships between land-atmosphere variables and the start of the active vegetative season;
3. Generalize relationships through categories and case studies;

and each of these involve a different set of ECVs listed in Section 2.

The identification of phenology phases employs the Four Growing Season Type (4GST, Peano et al., 2019) method on the Leaf Area Index (LAI) data provided by the Vegetation CCI team. The 4GST method uses the LAI seasonal cycle to infer the timing of the growing season onset and offset. This assessment applies globally and accounts for four different phenology types: 1) evergreen; 2) single growing season peaking in summer; 3) single growing season with summer dormancy; and 4) two growing seasons. Once the phenology type is identified, 4GST employs a specific approach to identify the phenophases: 1) no phenophase is identified in evergreen areas; 2) phenophases in single growing seasons are detected based on a critical threshold upon the LAI's annual cycle; 3) the same approach is used for two growing season areas, but after separating the two vegetative active seasons. Further details are provided by Peano et al. (2019). Besides this method, the identification of the second turning point (or inflection point if there is only one turning point) in a cubic interpolation of the data is also applied to identify the timing of early onset (Figure 1).

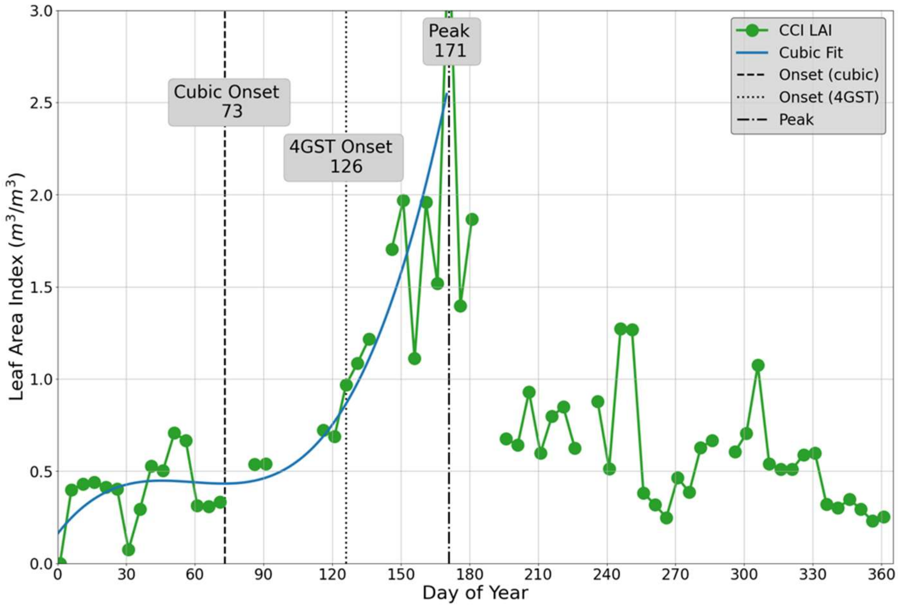

Figure 1. Start of the growing season identified using the four growing season type (4GST, Peano et al., 2019) method and a method using the second turning point of a cubic interpolation (blue line) through the CCI Leaf Area Index data for year 2010 in Chilbolton, UK.

Land surface models typically define the start of the vegetative active season through a growing-degree-day approach (e.g. White et al., 1997) accounting for temperature and soil moisture based on the main plant phenology trigger (i.e. water availability in warm year-round areas, or temperature in humid regions, or a mixture of the two).

The second step of this study uses this approach. A generic growing degree-day formula (equation 1) to help estimate the relationships between land-atmosphere conditions and vegetation phenology, providing a different onset timing.

$$GDD_{sum}^{n} = \begin{cases} GDD_{sum}^{n-1} + \alpha f_{day} & for\ var > threshold \\ GDD_{sum}^{n-1} & for\ var < threshold \end{cases} \tag{1}$$

Where, GDD_{sum} is updated on each timestep, α represents a scaling factor for the summation term (e.g. how much the variable is above the threshold), and f_{day} the daily factor to add to the summation term. The threshold for each variable may be constant or depend on species and local climate conditions.

Finally, the last step of the study focuses on evaluating specific years and case studies determined by observed climate conditions (e.g. Blunden and Boyer, 2024) or changes in vegetation derived from above-ground biomass values. Moreover, the relationship identified for specific case studies will be generalized using common categories, such as biomes or Plant Functional Types (PFTs) classifications (Figure 2).

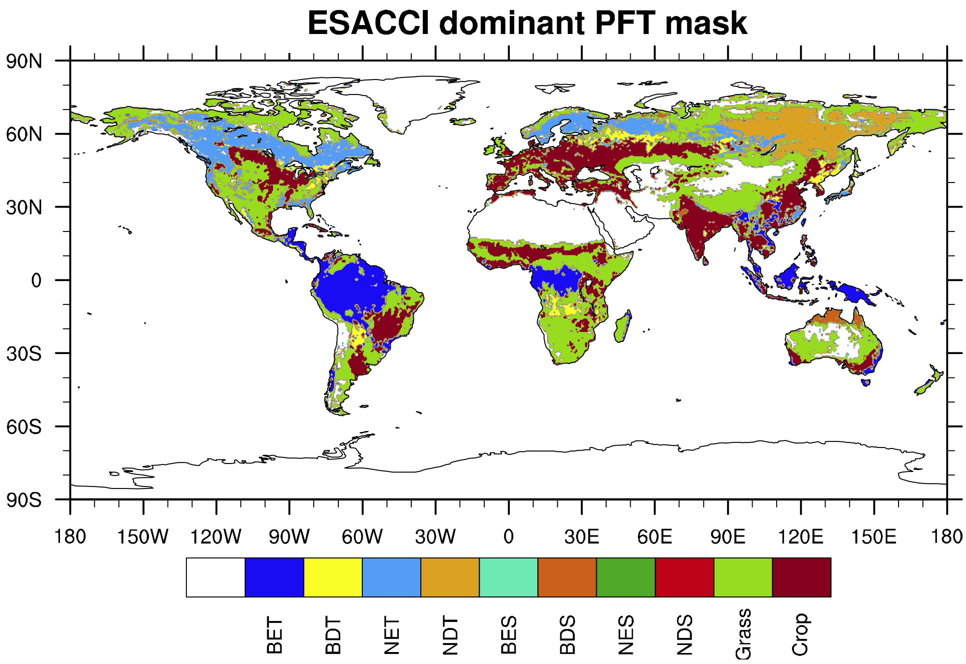

Figure 2. Example of categorization of dominant PFT map based on ESA-CCI land cover data (Li et al., 2018) as used in Peano et al. (2021, 2025).

4. Outlook

The methodology presented in section 3 will be applied to a set of biomes and PFT-dominated regions that span from shrubs and grasses to deciduous and evergreen forests and from tropical and Mediterranean to boreal biomes. The selection of use cases is limited by the LAI data availability, which covers a transect from Scandinavia to South Africa (Figure 3).

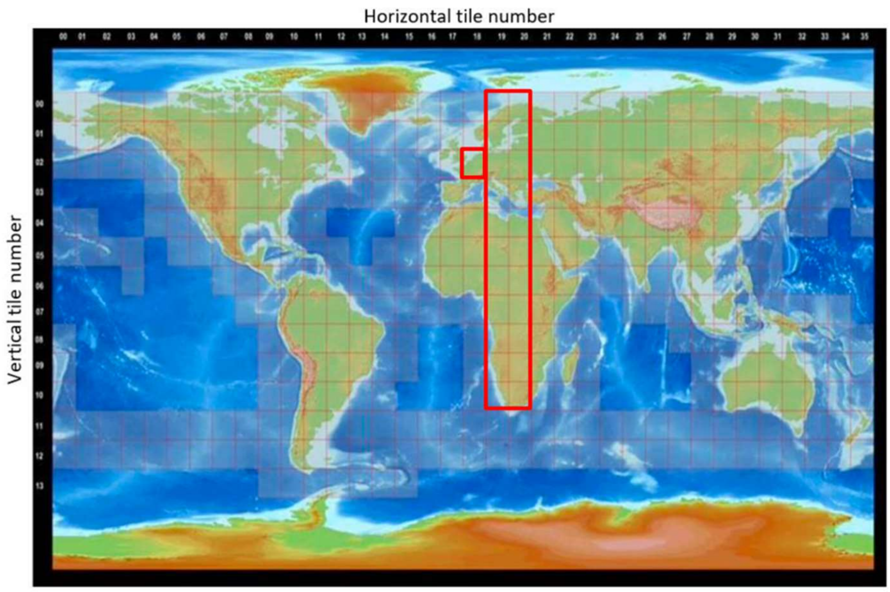

Figure 3. The red outlined area indicated the tiles that are provided in the first LAI data release. The tiling is based on Wolters et al. (2023). Figure taken from Swinnen et al. (2023).

The detection of the start of growing season (onset) will be obtained by applying the methodology of step 1 to the CCI LAI data and also on other satellite LAI datasets, such as the Copernicus Global Land Service database (Baret et al., 2013). Moreover, estimates of onset timing from *in situ* observations, such as the PhenoCam data (Richardson, 2023), will also be considered.

Differently from previous LAI products, the LAI dataset produced by the Vegetation CCI team provides a 5-day temporal coverage with no smoothing, making this product suitable for a wide variety of applications. On the other hand, these choices may supply a "noisy" product. For this reason, the phenology timings estimated from this product will be compared to results obtained from other satellite products (e.g. Copernicus Global Land Service database) and against in-situ observation to evaluate the potential enhancement supplied by the features of the novel LAI dataset produced by the Vegetation CCI group.

5. Summary

The novel LAI dataset produced by the Vegetation CCI team will be used to identify the timings of vegetation phenology phases, particularly the start of the growing season, using different approaches including those defined in the literature (e.g. Peano et al., 2019). It also enables the onset timings derived from land and atmosphere conditions to be estimated through a growing degree-day approach, in a similar way to that used by state-of-the-art land surface and earth system models (e.g. Lawrence et al., 2019), which will be used to identify missing or underrepresented linkages between land-atmosphere conditions and could be used in the future for model evaluation. A set of use cases will be identified that cover various biomes and climate conditions to assess the responses of different vegetation types under the variable conditions, including extremes such as cold or dry springs.

6. References

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7. Glossary

Terms	
Data assimilation	Observations directly influence the model initial state considering their error characteristics during every cycle of a model. This is used for reanalysis, NWP, which includes seasonal and decadal forecasting.
Model validation	Observations are compared with equivalent model fields to assess the accuracy of the model. This can be on short time scales for process studies or long-time scales for climate trends.
Climate monitoring	This describes the use of a satellite only dataset to monitor a particular atmospheric or surface variable over a period > 15yrs to investigate whether there is a trend due to climate change.

Initialisation	To initialise prognostic quantities of the model with reasonable values at the beginning of the simulation but do not continuously update.
Prescribe boundary conditions	Prescribe boundary conditions for a model run for variables that are not prognostic (e.g. land cover, ice caps etc).
Accuracy	Accuracy is the measure of the non-random, systematic error, or bias, that defines the offset between the measured value and the true value that constitutes the SI absolute standard.
Stability	Stability is a term often invoked with respect to long-term records when no absolute standard is available to quantitatively establish the systematic error – the bias defining the time-dependent (or instrument-dependent) difference between the observed quantity and the true value.
Precision	Precision is the measure of reproducibility or repeatability of the measurement without reference to an international standard so that precision is a measure of the random and not the systematic error. Suitable averaging of the random error can improve the precision of the measurement but does not establish the systematic error of the observation.
Effective Leaf Area Index (LAI_{eff})	The effective LAI (LAI_{eff}) is defined as the LAI value that would produce the same indirect ground measurement as that observed, assuming a simple random foliage distribution.
Canopy clumping index	Canopy clumping index describes the non-randomness of the leaf foliage distribution.
Onset	The beginning of the growing season.
Offset	The end of the growing season.
Acronyms	
4GST	Four Growing Season Types
(A)ATSR	(Advanced) Along Track Scanning Radiometer on ERS -1&2 and ENVISAT
AVHRR	Advanced Very High-Resolution Radiometer
BADC	British Atmospheric Data Centre
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite
CCI	Climate Change Initiative
CCMVAL	Chemistry-Climate Model Validation Activity
CDR	Climate Data Record
CMC	Climate Modelling Community
CMIP5	Climate Model Intercomparison Project-5
CMUG	Climate Modelling Users Group
COSP	CMIP5 Observation Simulator Package
CSAB	Climate Scientific Advisory Board
DAAC	Distributed Active Archive Centres
ECV	Essential Climate Variable
EGU	European Geophysical Union
ENSO	El Nino- Southern Oscillation
ERA	ECMWF Reanalysis

ERBS	Earth Radiation Budget Satellite
ERRMERG	Error of merged dataset
FAPAR	Fraction of Absorbed Photosynthetically Active Radiation
FCDR	Fundamental Climate Data Record
FOAM	The Fast Ocean Atmosphere Model
GCOS	Global Climate Observing System
GDD	Growing Degree Day
GPS	Global Positioning System
GSICS	GCOS Satellite Inter-Calibration System
HIRS	High resolution Infrared Radiation Sounder
IGOS	Integrated Global Observing Strategy
IPCC	International Panel for Climate Change
ISCCP	International Satellite Cloud Climatology Project
LAI	Leaf Area Index
MACC	Monitoring Atmospheric Composition and Climate
METAFOR	Common Metadata for Climate Modelling Digital Repositories
NAO	North Atlantic Oscillation
NWP	Numerical Weather Prediction
OSTIA	Operational Sea Surface Temperature and Sea Ice Analysis
PCMDI	Program for Climate Model Diagnosis and Intercomparison
PDO	Pacific Decadal Oscillation
SAGE	Stratospheric Aerosol and Gas Experiment
SSAOB	Single sensor accuracy for each observation
SSEOB	Single sensor error for each observation
SSM/I	Special Sensor Microwave Imager
SST	Sea Surface Temperature
TCDR	Thematic Climate Data Record
UMARF	Unified Meteorological Archive and Retrieval Facility