Predicting the response of forest ecosystems to climate extremes using MODIS data in the Regional Climate Model MAR during the 2018 drought in Belgium

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Abstract

Climate change significantly affects forest ecosystems, manifesting in ways such as droughts, wildfires, and diseases. The regional climate model MAR (Modèle Atmosphérique Régional), developed at ULiège, allows us to assess the current and future climate over Belgium at a 5km resolution. However, uncertainties persist in the model estimations.

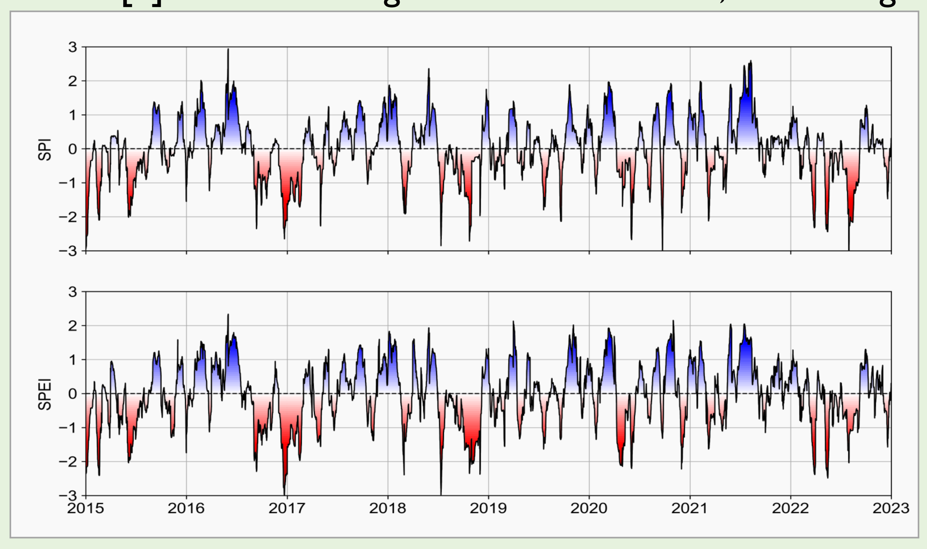
Additionally, MAR lacks a comprehensive dynamic vegetation modelling, preventing accurate near-surface estimations. This project seeks to explore the impacts of climate change on forest ecosystems by integrating a dynamic vegetation model, CARAIB, into MAR and by assimilating remote sensing data such as MODIS Leaf Area Index (LAI) to refine the model outputs.

The first results show a significant sensitivity of MAR results by enhancing the accuracy of LAI given as its vegetation input. New simulations over the period 2015-2022 indicate an increase in evaporation and transpiration across agricultural and forested areas. The increase in evapotranspiration correlates here with an increase in rain and albedo. By comparing the previous model outputs and the new ones to observations we observe a reduction in bias, but some discrepancies remain. The comparison suggests that, while MAR represents the climate accurately on average, it struggles to replicate specific events, hampering the study of extreme events.

Nevertheless, this project aims to improve our understanding of the interactions between climate and forests. By refining modelling, this research strives to support more accurate predictions and strategies for forest management under changing climatic conditions.

Droughts in Belgium

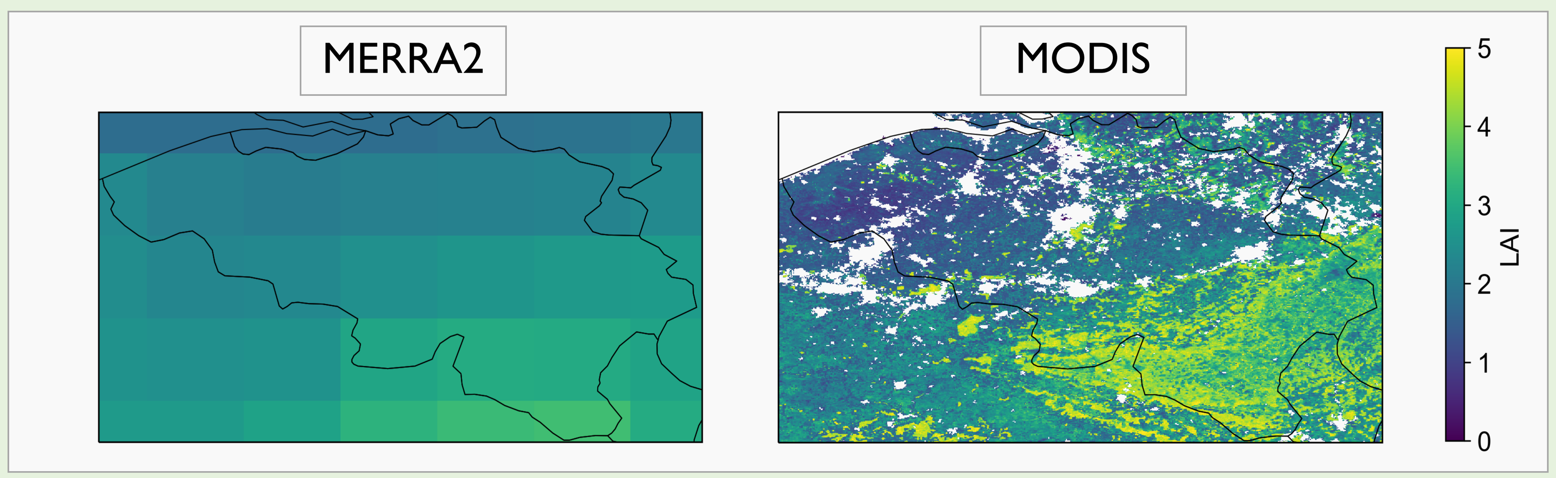
With climate change, Belgium is experiencing more and more hot days. What was considered heatwaves 50 years ago can / will become standard summer in a few years. This implies that the definition of an "extreme" or drought can change over time. Here to consider a period as a drought, we use the Standardized Precipitation Index (SPI) and Standardized Precipitation Evapotranspiration Index (SPEI). Whereas SPI relies solely on precipitation, SPEI considers both precipitation and potential evapotranspiration (PET) to assess drought conditions [1]. The more negative the indexes are, the stronger the drought. Here, we can see that in spring 2018 Belgium experienced one of its strongest droughts these recent years which was followed by a dry summer.



Nonetheless, both the MERRA2 and MODIS LAI used in MAR are climatology (average) computed on multiple years of data. Thus, the change in LAI caused by the stress on the vegetation is not included in the data provided to MAR. Further experiments could include simulations using observed LAI rather than climatology.

MODIS LAI in MAR

LAI 50km ⟶ 500m
Monthly ⟶ 8-days

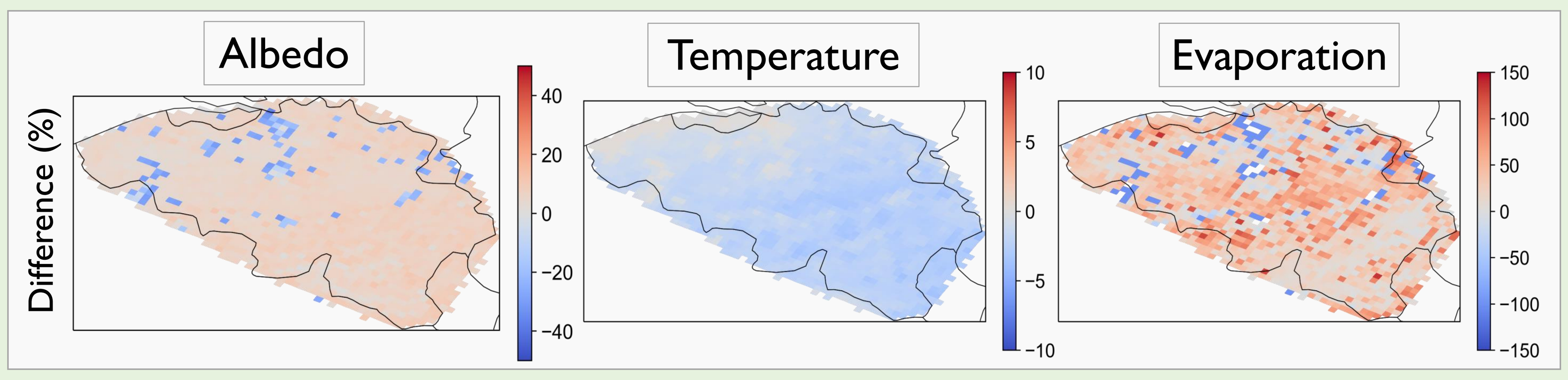


MODIS is included into MAR by replacing its Leaf Area Index (LAI) input. MAR was previously using the monthly MERRA2 LAI database [2]. This database has been replaced by a climatology based on MODIS 8-day LAI at 500m from 2011 to 2020 [3]. The images hereabove represent the LAI given by MERRA2 (left) and MODIS (right) climatology for the 30th of May.

Impact on MAR estimates over Belgium

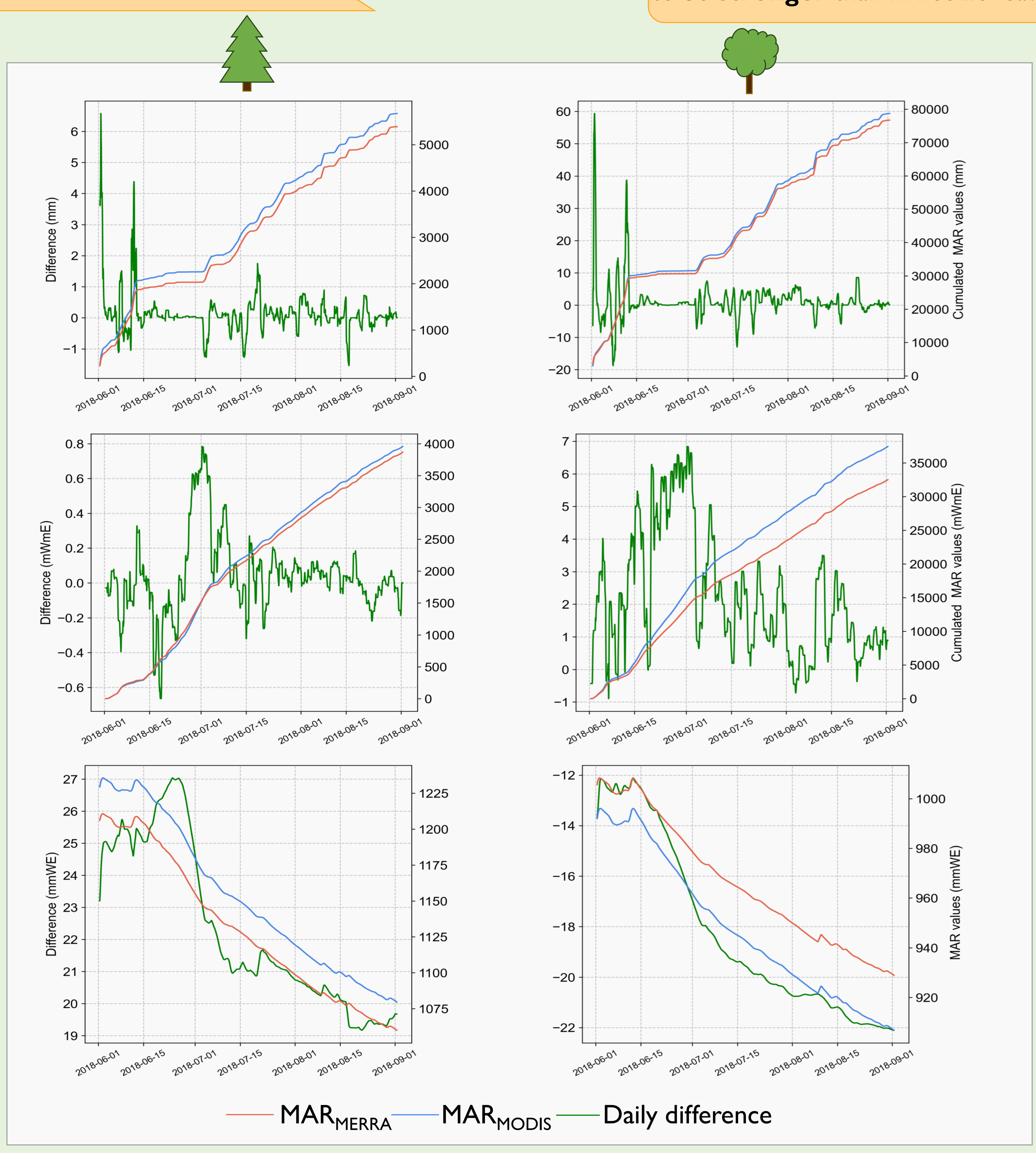
Evaporation ↑
Albedo ↑
Temperature ↓

Most of the Belgium territory and variables modelled are impacted by the change in LAI. While the change causes an overall decrease in temperature by a few percent (~0.5°C), the evolution of surface-related variables depends on the land cover. Here we can see that agricultural regions experience an increase in albedo and evaporation when built-up areas show a decrease, and forested regions tend to remain unchanged.



Impact over forests

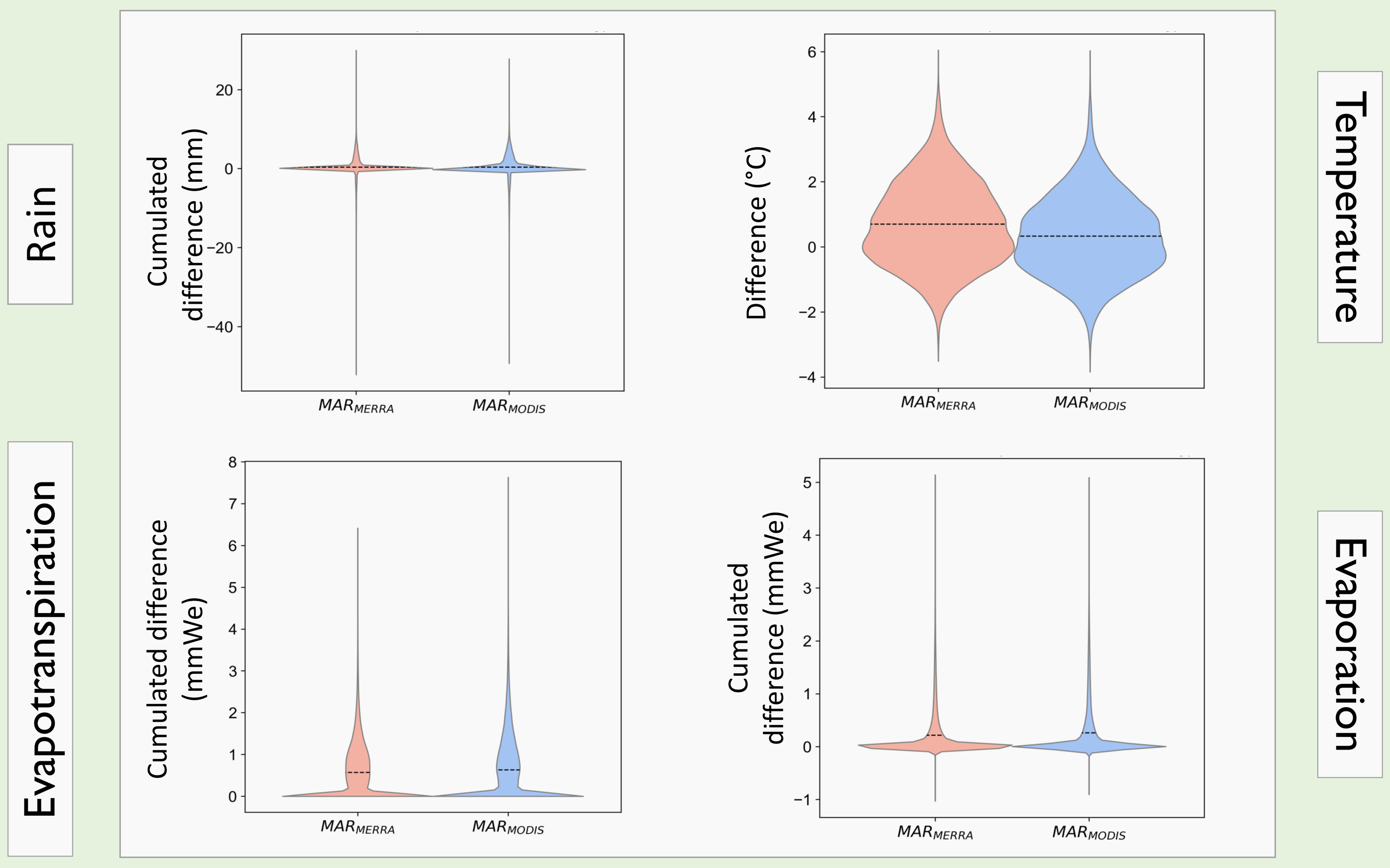
In **broadleaved** forests, **changes** tend to be **stronger** than in needle-leaved



With comparison maps, it is clear that the effect of changing LAI is different given the land use. Even more, this effect is also different depending on the vegetation type. Here we compare three variables in needleleaf forests and broadleaf forests. The pixels were considered as one of the two forest types if its surface is at least covered at 50% by one of these two forest types.

Most of the differences occur during the late spring, where an increase in rain during the first days of June is followed by an increase in evapotranspiration during the last days of the month in both forest types. Nonetheless, needleleaf forests are experiencing an increase in soil humidity while it is the opposite for broadleaf forests. This difference can be imputed to the stronger increase in evapotranspiration that is modelled for them.

MAR vs in-situ observations



To validate the model results, the outputs are compared to in-situ observation. The observations were collected from weather stations and gridded over Belgium using kriging [4]. They are then interpolated onto the MAR grid using linear interpolation.

For the 4 variables presented here, the difference between the MAR datasets and the observations are not significantly different except for temperature. For rain and temperature, there is a small reduction of the bias (the average difference is closer to 0), but for evaporation and evapotranspiration, the bias is slightly increased.

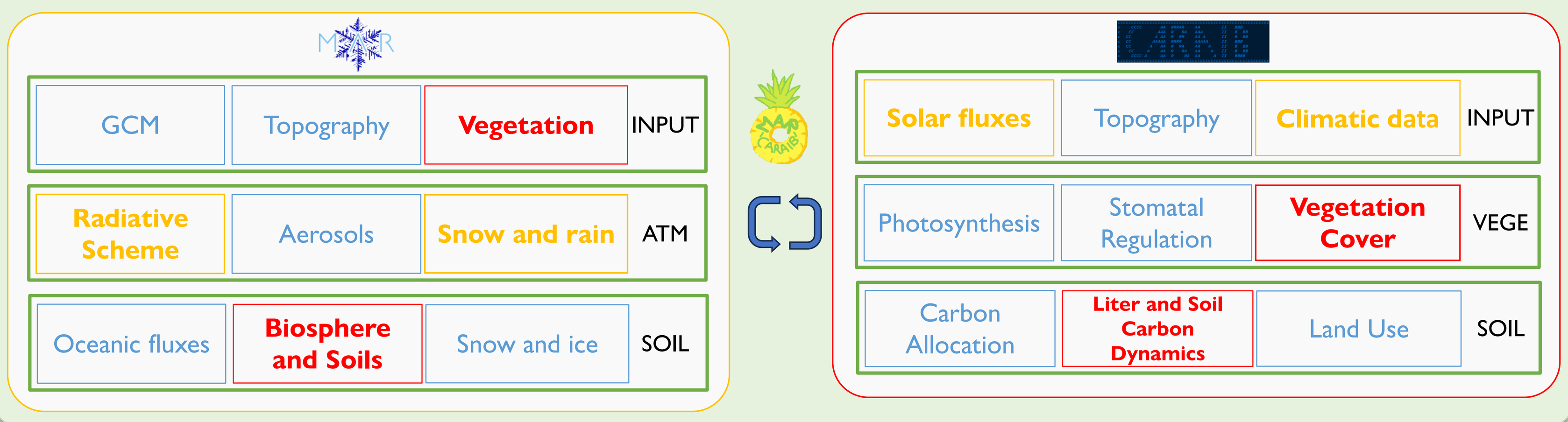
The difference between the observation and the model for the vegetation-related variables can be explained by the use of an LAI climatology instead of the observations.

On-going work: vegetation modelling

As demonstrated by this work, MAR represents correctly the climate when averaged over time and/or places but can still misrepresent it for a given place/time partially because of its sensitivity to vegetation. The decrease of this sensitivity, and consequently a decrease in the uncertainties in the vegetation-climate interaction, can be reached by implementing a dynamical vegetation module into MAR.

The new implementation is achieved by coupling MAR with an existing dynamical vegetation model, the CARbon Assimilation In the Biosphere (CARAIB) model [5]. By running concurrently, the two models can provide each other with the variables they require as inputs or replace the outputs of the other model. In this case, MAR would provide CARAIB with all the climatic data (precipitation, temperature, …) and CARAIB would provide MAR with the LAI required as input.

By refining the model projections, this project aims to support new strategies for forest management under changing climatic conditions, especially during extreme events we will undergo in the future.



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