AMAZALERT Deliverable Report

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First author	**Hans Verbeeck**
Co-authors	**Hannes De Deurwaerder and AMAZALERT WP2 modeling groups**
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Name leading Work Package Leader	**Hans Verbeeck**

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Abbreviations and acronyms

AAI	Andes-Amazon Initiative, Moore Foundation project
AGB	Above-ground biomass
CCSM	Community Climate System Model
D2.1	Deliverable report 2.1
DGVM	Dynamic Global Vegetation Model
GCM	General Circulation Model
HadCM3	Hadley Centre Coupled Model, version 3
IBIS	Integrated Biosphere Simulator
INPE	Instituto Nacional de Pesquisas Espaciais
IPSL	Institut Pierre Simon Laplace
LUC	Land Use Change
MOSES	Met Office Surface Exchange Scheme
NEE/NEP	Net Ecosystem Exchange
NPP	Net Primary Production
PCM	Parallel Climate Model
PIK	Potsdam Institute for Climate Impact Research
SRES	Special Report Emissions Scenarios
UGENT	University of Ghent
UNIVLEEDS	University of Leeds
WP2	Work Package 2

Introduction

This deliverable attempts to give a brief overview on the latest developments and insights resulting from the activities of Work Package 2 of the AMAZALERT Project. Firstly, newly gathered insights resulting from the historical DGVM runs (for more details on protocol and concepts see D2.1) will shortly be discussed within the first paragraph. Additionally, we provide a description on the model protocol for future runs, on the future climate forcings and on the participatory LUC scenarios, all necessary to generate future DGVM runs. More details on which DGVMs - Climate Forcing - LUC scenario combinations already have been accomplished, is provided in the form of a table. New advances on improved understanding on the Amazons responses to changing climate and changing land use has been explored in the penultimate chapter. Both responses will be discussed separately, starting with insights on the response to a changing climate and subsequently studying the effect of the altered LUC. A brief conclusion synthesises the most important new understandings and provides future perspectives.

Lessons learned from historical model runs

Within the framework of WP2 of the project, the historical runs (for more details on protocol and concepts see D2.1), have been applied in several analyses that resulted in new insights (i.e. on Amazon functioning, on concepts of drought and model set-ups). These new findings are planned to be published in the near future. The example shown here is an in-depth comparison of in situ observations of 167 field plots with the historical model outputs (2000-2008) of the four DGVMs (Johnson et al., in prep.). These in situ observations show that both mortality and productivity are driving the spatial variation in above ground biomass. Additionally, this study clearly reveals that the relation between stem mortality rates and AGB varies across Amazonia. We suggest that the variation in functional composition among regions might have an important influence on the AGB. When comparing these in situ results with the DGVM simulations, we ascertain a poor representation of both the spatial patterns and basin-wide mean of AGB (fig 1 & 2). Johnson et al. (in prep.) identify the incorporation of mechanistic models of mortality in the DGVMs as a priority for future research in scope of improving the AGB simulations.

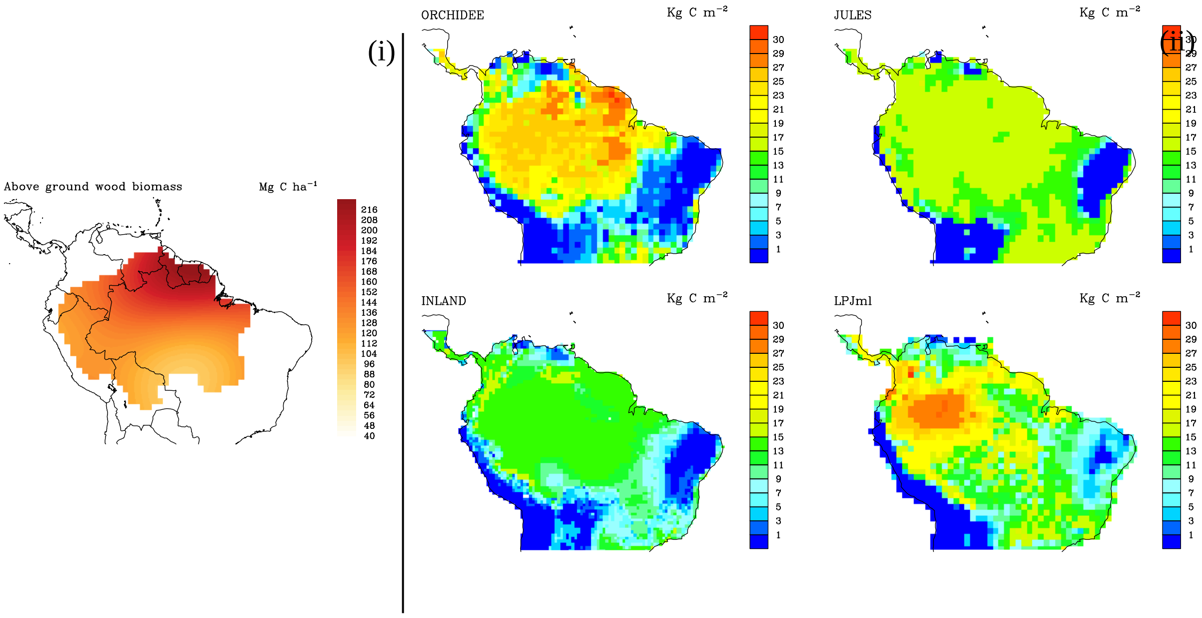


Figure 1. (i) Kriged maps of above-ground biomass derived from RAINFOR observations. (ii) Simulated mean above ground biomass for 2000 – 2008 for four DVGMs

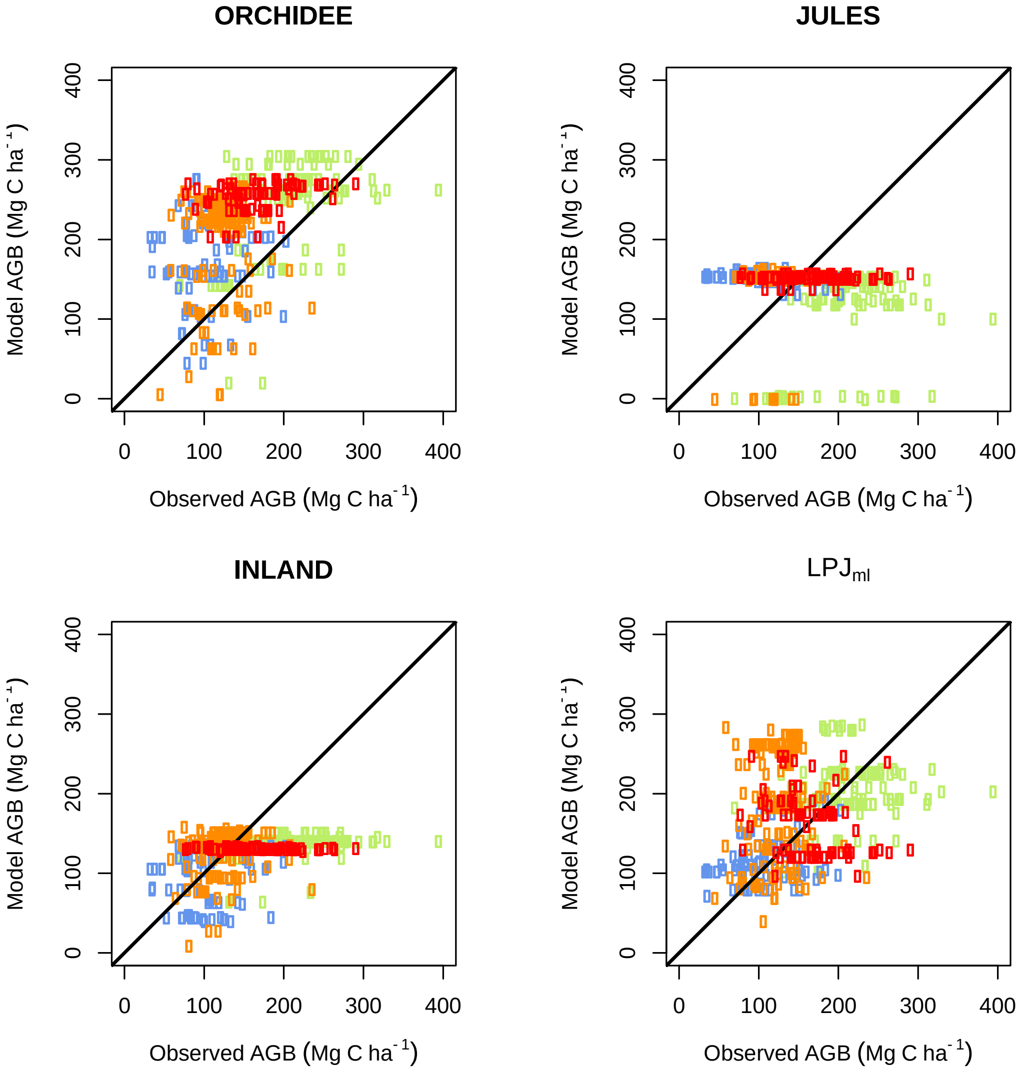


Figure 2. Modelled versus observed above ground biomass for four DVGMs. Colours indicate region, green = Guiana Shield, blue = Brazilian Shield, red = East Central Amazon and orange = Western Amazon.

Future Runs Protocol

For consistency with the historical model runs, all future runs were performed based on the protocol of the Moore Foundation Andes-Amazon Initiative (AAI) project with the supplementation of some extra outputs (mainly hydrology related) required for AMAZALERT. Each model performed 12 future runs for a time period of 91 years, covering 2009 till 2099. For initialization, the models used a fixed Land Use map taken from the year 2008 of the land use scenario’s. This represents a historical run without land use, following the Moore protocol, but using that single constant land use map run from 1970-2008. The result for 2008 was used as a starting point for the future predictions. The models use, for all subsequent years the INPE LUC maps (task 2.2) and CO_2 dataset under IPCC SRES A2 scenario.

Future Run Climate Forcing's and Scenarios

As mentioned in the previous section, all models have performed 12 future runs using 3 different climate forcings and 4 distinct future LUC scenarios. In this section we present a short summary of both the climate forcings as the future LUC scenarios used. All datasets of the climate forcings and future LUC scenarios were distributed to the modelling groups via the Amazalert-UGent webspace.

Climate Forcings:

We used 3 distinct future meteorological climate forcings resulting from the 21st century General Circulation models (GCM) projections under IPCC AR4 SRES A2 emission scenario. More specific we examined the bias corrected NCAR-PCM (*Parallel Climate Model)*, the bias corrected CCSM (*Community Climate System Model*) and the HadCM3 (*Hadley Centre Coupled Model, version 3)* climate forcings.

Future Scenarios:

Four future scenarios which are developed in the WP2, were used (Task 2.2):

· **PotVeg**:	Potential Vegetation: Natural development of vegetation without land use change.
· **SceA**:	Scenario A: Sustainable land use.
· **SceC1**:	Scenario C1: Extreme deforestation scenario without strong biofuel targets, resulting in on average 15000 km² of deforestation.
· **SceC2**:	Scenario C2: Extreme deforestation scenario with strong biofuel targets, resulting in on average 19500 km² of deforestation.

The four DGVMs

Orchidee (IPSL/UGENT)

ORCHIDEE is the land-surface scheme of the IPSL. This scheme is the result of the coupling of the SECHIBA land-surface scheme, which is dedicated to the surface energy and water balances, and the carbon and vegetation model STOMATE. More information can be found in: Krinner et al. 2005, Verbeeck et al. 2011.

Jules (UNIVLEEDS/UEDIN)

The Joint UK Land Environment Simulator (JULES) is a process-based model that simulates the fluxes of carbon, water, energy and momentum between the land surface and the atmosphere. This is developed from the Met Office Surface Exchange Scheme

(MOSES). It can be used as a stand-alone land surface model driven by observed forcing data, or coupled to an atmospheric global circulation model. More information can be found in: Best et al. 2011, Clark et al. 2011, and Powell et al., 2013.

LPJmL (PIK)

LPJmL is a dynamic global simulation model of vegetation biogeography and vegetation/soil biogeochemistry. Taking climate, soil and atmospheric information as input, it dynamically computes spatially explicit transient vegetation composition in terms of plant functional groups, and their associated carbon and water budgets. More information can be found in: Sitch et al., 2003.

Inland (INPE)

The Integrated Model of Land Surface Processes (INLAND) is the land surface package for the Brazilian Earth System Model. INLAND is based on the Integrated Biosphere Simulator (IBIS), and represents a number of land surface processes. More information can be found in: Powell et al., 2013.

Future Runs

All model outputs of completed future runs have been uploaded and shared on the Amazalert-UGent-webspace (www.amazalert.ugent.be). A quality check has been performed on the outputs to ensure correctness and usability of the outputs. The ranges of the variables were compared between the different model run outputs as well as with literature and the historical runs, to look for inequalities or nonsense data.

Table 1. This table provides an overview of the successfully completed future runs, based on a specific climate forcing and future scenario.

	PotVeg	SceA	SceC1	SceC2
HadCM3	***ORCHIDEE*** ***INLAND*** ***LPJmL*** ***JULES***	***ORCHIDEE*** ***INLAND*** ***LPJmL*** ***JULES***	***ORCHIDEE*** ***INLAND*** ***LPJmL*** ***JULES***	***ORCHIDEE*** ***INLAND*** ***LPJmL*** ***JULES***
CCSM	***ORCHIDEE*** ***INLAND*** ***LPJmL*** ***JULES***	***ORCHIDEE*** ***INLAND*** ***LPJmL*** ***JULES***	***ORCHIDEE*** ***INLAND*** ***LPJmL*** ***JULES***	***ORCHIDEE*** ***INLAND*** ***LPJmL*** ***JULES***
PCM	***ORCHIDEE*** ***INLAND*** ***LPJmL*** ***JULES***	***ORCHIDEE*** ***INLAND*** ***LPJmL*** ***JULES***	***ORCHIDEE*** ***INLAND*** ***LPJmL*** ***JULES***	***ORCHIDEE*** ***INLAND*** ***LPJmL*** ***JULES***

Analysis of future runs

Impacts of climate on future carbon fluxes and stocks

To assess the impact of the future climate, model outputs for ‘potential vegetation’ (without land use change) of the end of the century were compared with the first 10 years of the runs. In this line of thought, we created maps presenting the difference per grid cell between the average monthly mean for the periods 2009-’18 and 2090-’99 (Fig 3). The majority of the maps predict that when LUC is absent, the future climate will give cause to an increase in AGB for most regions in the Amazon basin. Suggesting that the vegetation of the Amazon basin, and especially in the north-western part, will benefit from the CO_2-fertilisation and increased radiation (coupled with lowered cloud cover), seemingly coping with gradual temperature increase. However, the runs driven by HadCM3, which simulates more sudden climate events, show larger areas with a strong decrease in AGB. These maps suggest that the vegetation could be sensitive to more sudden climatological changes and fluctuations. Further analysis should give more insight on this preliminary conclusion. Concerning the evapotranspiration of Amazon basin, we notice that the outcome of the analyses is model- and climate forcing dependent (Fig 4). All LPJmL outputs suggest that evapotranspiration will decrease throughout the period simulated. All models show a general decreasing trend in evapotranspiration when simulated with the PCM climate forcing. Also for NEP we notice some contrasting results between the models (Fig 5), showing an overall decrease in NEP for ORCHIDEE and JULES (for PCM and HadCM3), whilst the other DGVMs show an increase in NEP for the Amazon Basin. An in depth analyses of the models structure will be valuable for the clarification of this result.

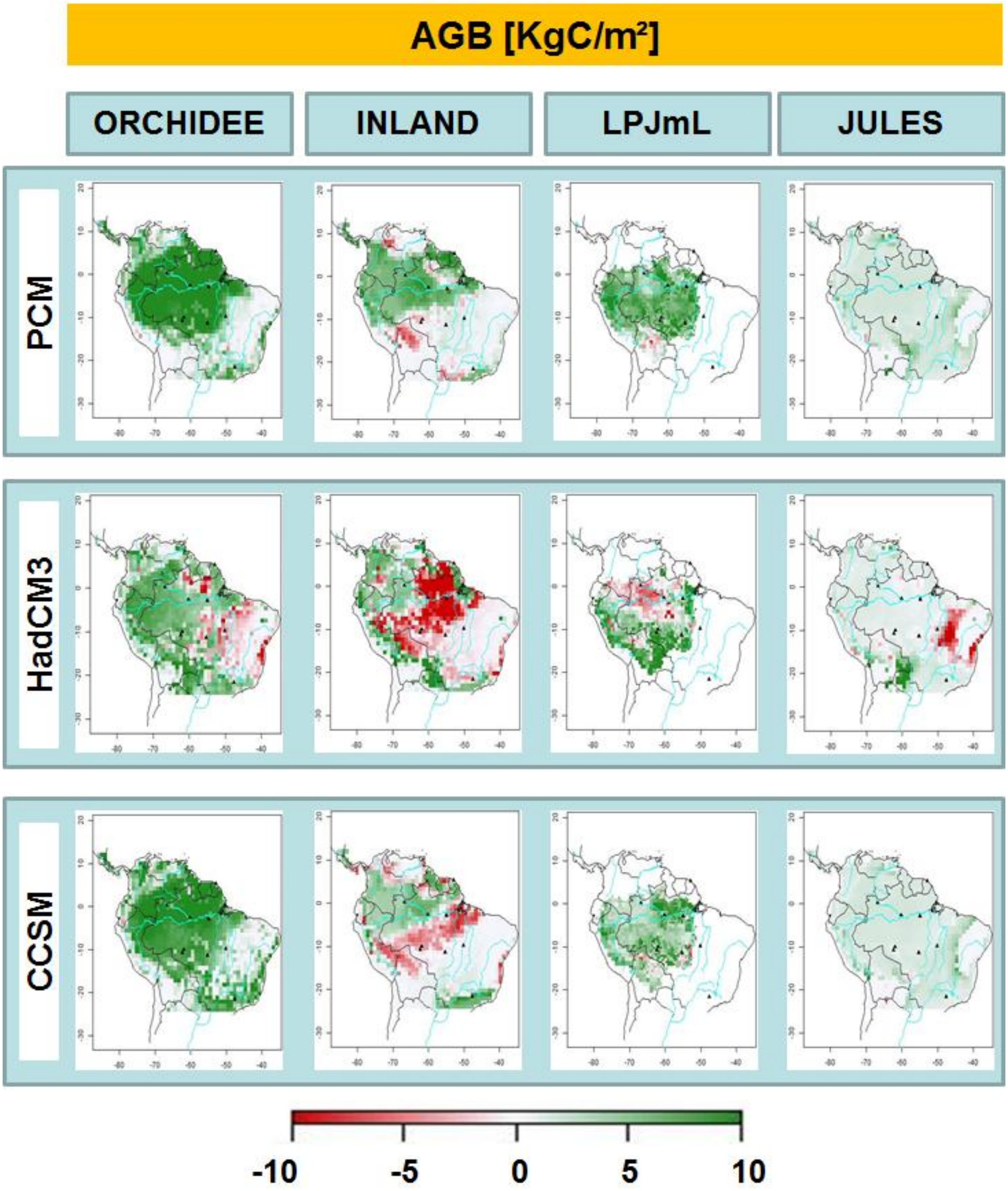


Figure 3. Map of South-America, representing per gridcel the AGB [KgC/m] difference between the average monthly mean of the PotVeg scenario for the periods 2090-'99 minus 2009-'18. ORCHIDEE, INLAND, LPJmL and JULES are the DGVMs used to generate the future runs. PCM, HadCM3 and CCSM represent the climate forcings used for the simulations.

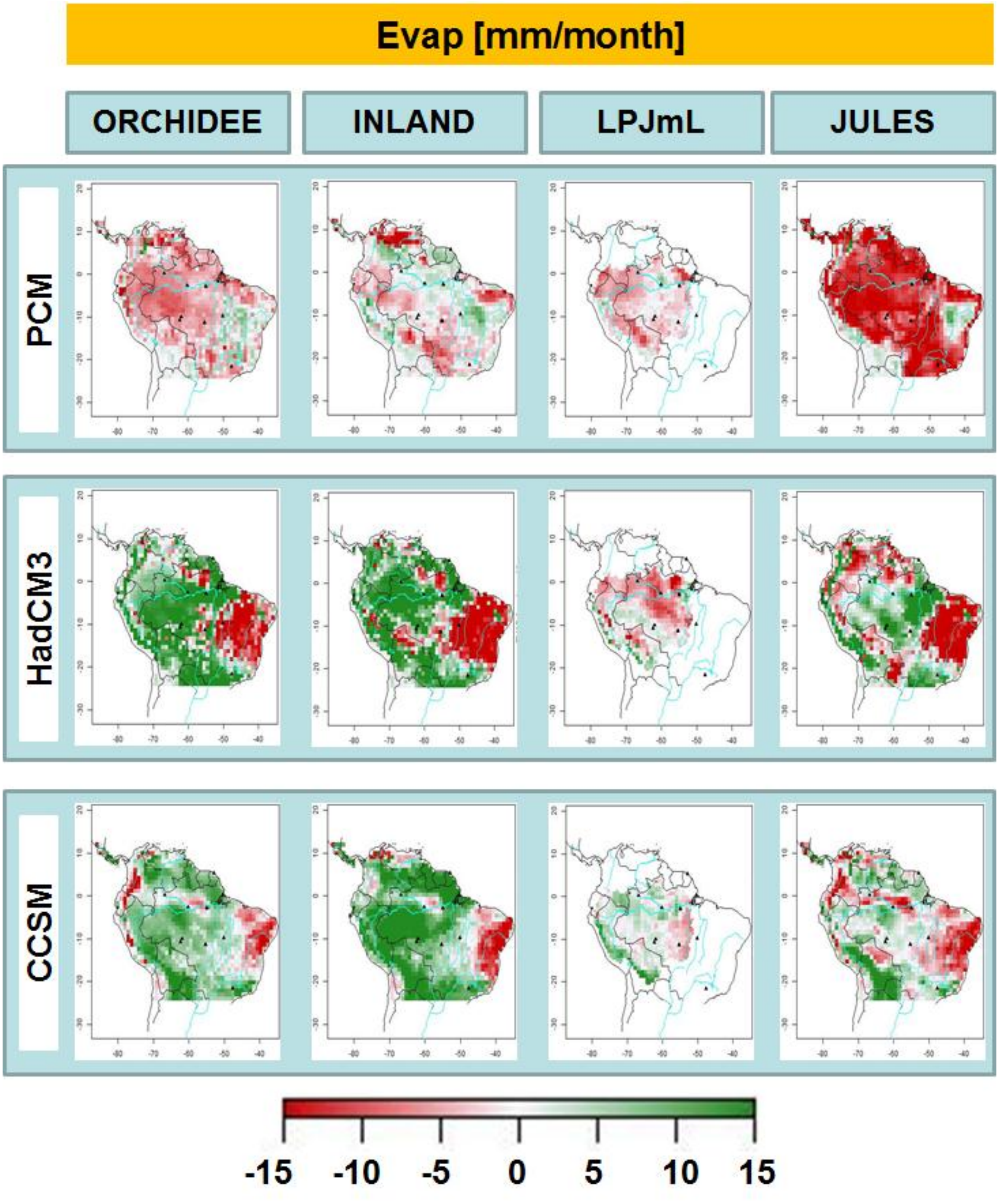
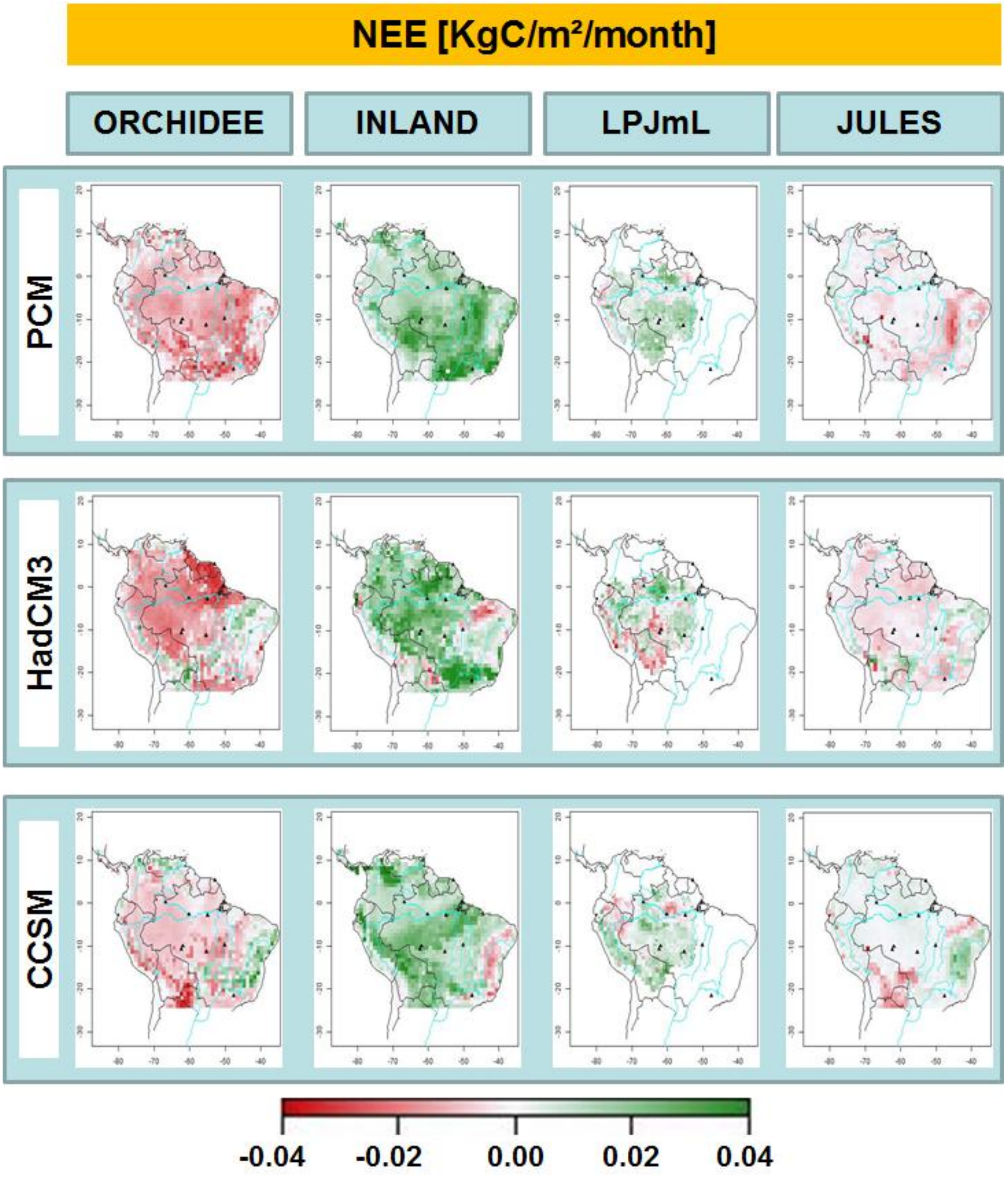


Figure 4. Map of South-America, representing per gridcel the Evapotranspiration (Evap) [mm/month] difference between the average monthly mean of the PotVeg scenario for the periods 2090-'99 minus 2009-'18. ORCHIDEE, INLAND, LPJmL and JULES are the DGVMs used to generate the future runs. PCM, HadCM3 and CCSM represent the climate forcings used for the simulations.



Figuur 5. Map of South-America, representing per gridcel the NEP [KgC/m²/month] difference between the average monthly mean of the PotVeg scenario for the periods 2090-'99 minus 2009-'18. ORCHIDEE, INLAND, LPJmL and JULES are the DGVMs used to generate the future runs. PCM, HadCM3 and CCSM represent the climate forcings used for the simulations.

Impacts of land use change on future carbon fluxes and stocks

Multiple methodologies have been used to get more insight in how the land use scenarios might impact future carbon fluxes and stocks. The first type of analysis performed is the creation of maps presenting, for each land us scenario, the difference per grid between the average monthly mean for the periods 2009-’18 and 2090-’99 for different carbon related variables. These difference analyses on AGB, as an example, results on average in AGB maps following a downward AGB trend when scenarios include a stronger deforestation-impact (Fig 6, 7 & 8). Again we notice the north-western region of the Amazon mostly describing a positive trend indicating both the lower impact of deforestation and the potentially higher resilience to the future climate change. The model simulation thus indicates vulnerable regions (Southern and Eastern regions of the Amazon), threatened by the combination of anthropogenic deforestation and climate change. Note as well that for most model-climate forcing combinations the scenario of sustainable land use describes a lot less degradation of the Amazons vegetation, highlighting the importance and potential effectiveness of good management of the Amazon forest.

The effect of the different LUC scenarios on the water balance of the Amazon ecosystem was studied by making similar analyses and studying pattern changes in evapotranspiration (Fig 9). Although the magnitude and spatial distribution of evapotranspiration increase/decrease is seemingly model and climate forcing dependent, the results suggest that the water balance of the forest will be altered due to climate change and that these changes will be more severe when the scenarios getting less favorable. These alterations, although sometimes being small, can have considerable impacts, considering the high importance of the water balance for this ecosystem. Further in-depth analysis is for this reason strongly advisable.

The second analysis consists of a time series analysis. From different hydrological basins (17 in total), the annual monthly means were calculated for the total simulated period (2009-2099) and for each model-climate forcing-LUC scenario combination. Only a limited number of these result graphs are shown below and will be discussed.

In general, the highest annual fluctuations were resulting from the more intense character of the HadCM3 climate forcings, simulating more extreme and sudden climate events. CCSM forms the mildest climate forcing with mostly limited deviations of the fluctuations. PCM can, in this study, be considered as a moderate climate forcing, situation somewhere in between the two other climate forcing datasets. However, preliminary results (not shown) indicate the strongest fluctuations in evapotranspiration for the latter climate forcing. Further analyses should help to clarify why.

The study of the AGB timeline graphs (Fig 10), of which only the results for the entire Amazon basin are shown, points out the clearly different trends induced by the different LUC scenarios. With the exception of the INLAND runs using HadCM3, we notice an increase of AGB over the years for the PotVeg and SceA LUC scenarios. The scenarios including deforestation mostly show a decreasing or a seemingly constant AGB. These differences get more explicit when studying the hydraulic basins in the Southern and Easter regions of Amazonia (data not shown). Again we might conclude that HadCM3, describing more sudden and extreme climate events, results in the strongest and most unexpected variations in AGB. This indicates the importance of further in-depth research on whether or not this climate forcing is likely to occur in the future and the potential hazards of these extreme events.

Several NEP timeline graphs describing different hydrological basins in Amazonia have been enclosed to illustrate the spatial difference in carbon-flux evolutions through time (Fig 11-15). The results of these studies once more seemingly indicate that the northern and western parts of the Amazon basin are more resilient to climate change in comparison with Southern and Eastern parts of the Amazon basin. These regions show less pronounced fluctuations and trends during the simulated time. Additionally, these graphs are valuable tools in pinpointing inter-model differences. For instance, the NEP graphs shown below, describe for the INLAND runs a stronger fluctuating trend and more pronounced split up between the scenarios in comparison to the other models. We could state that the variable NEP is very sensitive for altered climate forcings within INLAND, where this variable is more stable in the other models. However, when studying for instance the GPP fluxes (not shown), the variable in seemingly sensitive in LPJmL while not in the other models. These results are a good incentive for inter-model-comparison and structure analyses with the objective of model improvement.

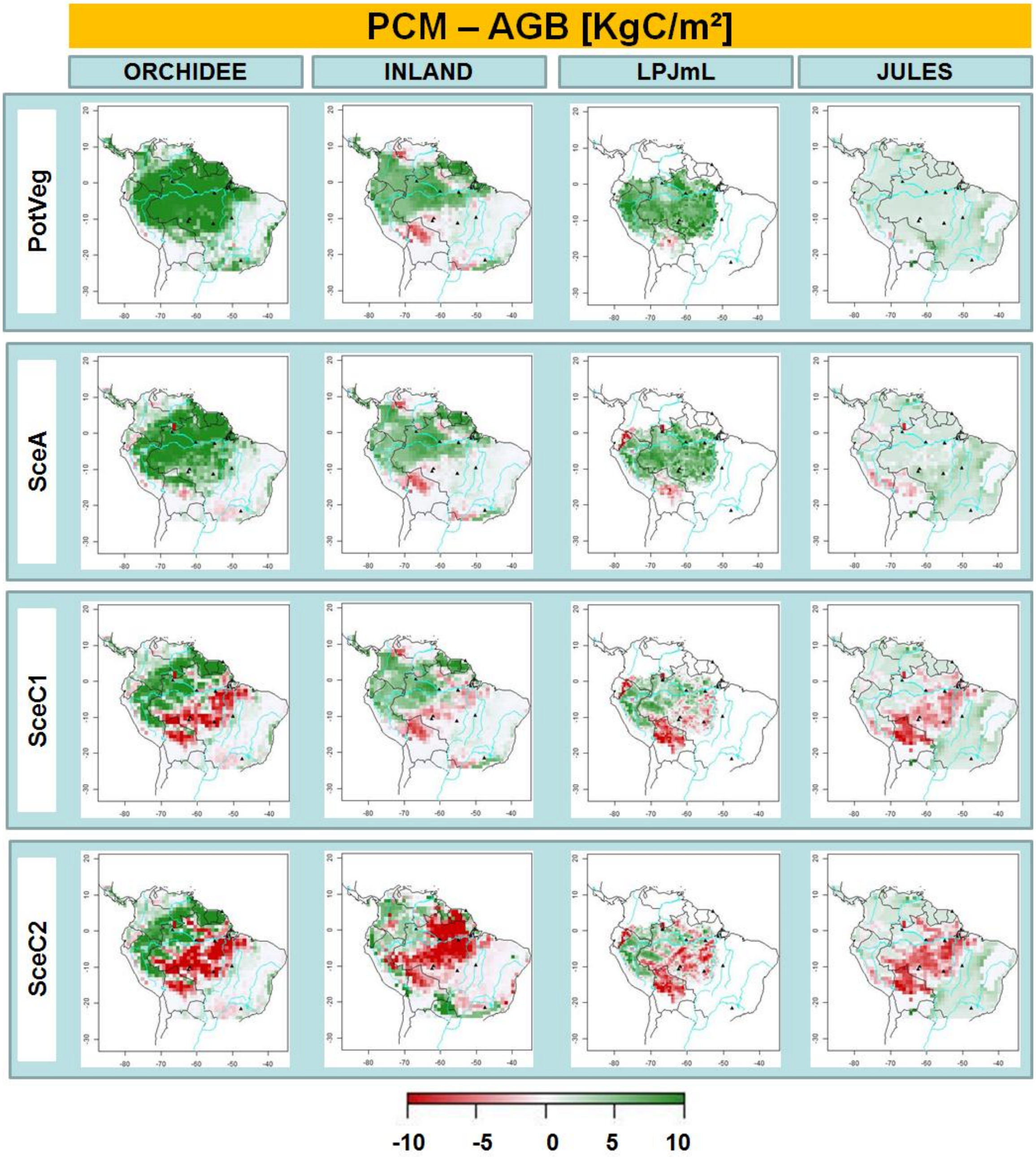


Figure 6. Map of South-America, representing per gridcel the AGB [KgC/m²] difference between the average monthly mean for the periods 2090-'99 minus 2009-'18 for all runs using the PCM climate forcing. ORCHIDEE, INLAND, LPJmL and JULES are the DGVMs used to generate the future runs and using PotVeg, SceA, SceC1 or SceC2 as LUC.

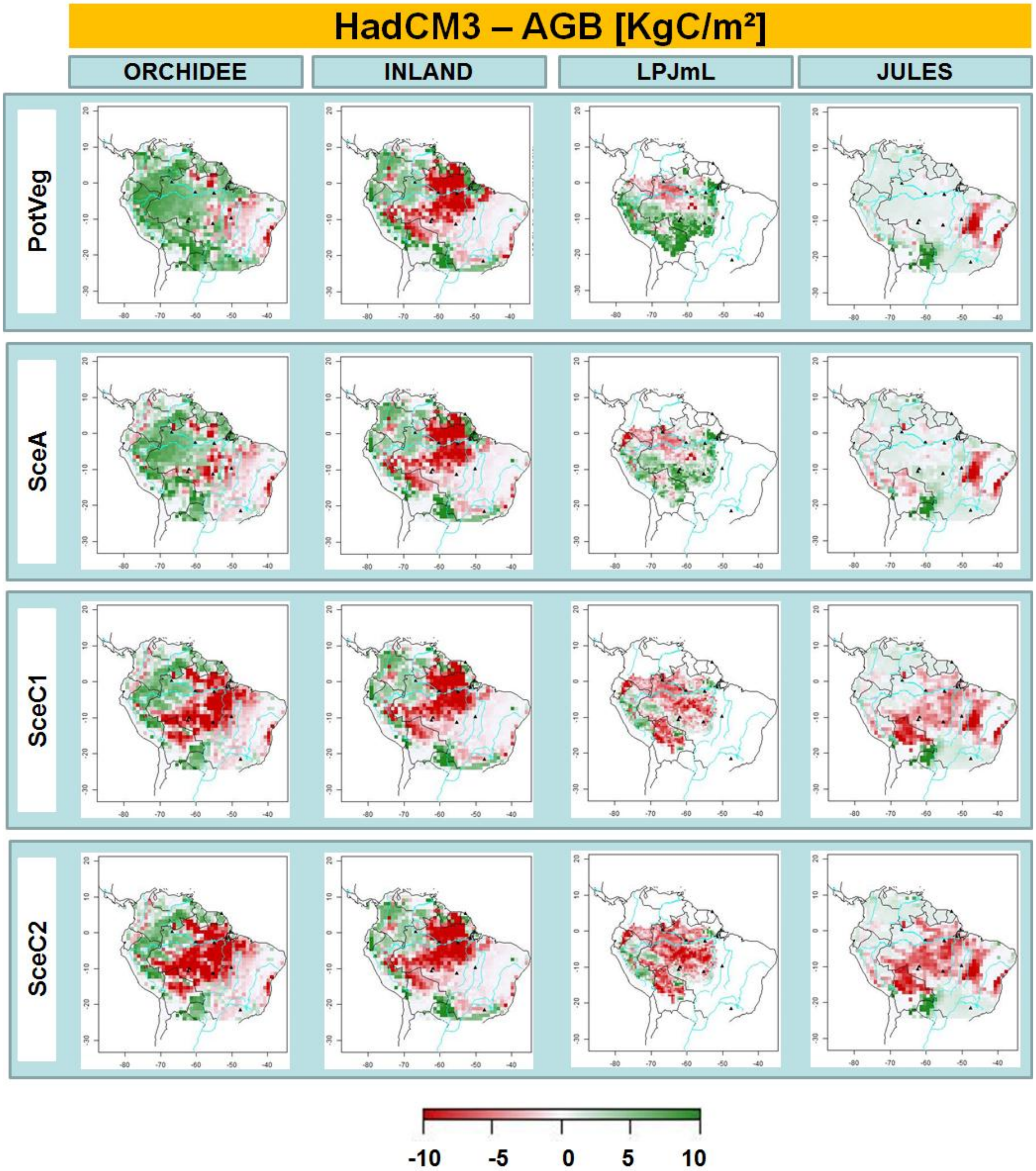


Figure 7. Map of South-America, representing per gridcel the AGB [KgC/m^2] difference between the average monthly mean for the periods 2090-'99 minus 2009-'18 for all runs using the HadCM3 climate forcing. ORCHIDEE, INLAND, LPJmL and JULESare the DGVMs used to generate the future runs and using PotVeg, SceA, SceC1 or SceC2 as LUC.

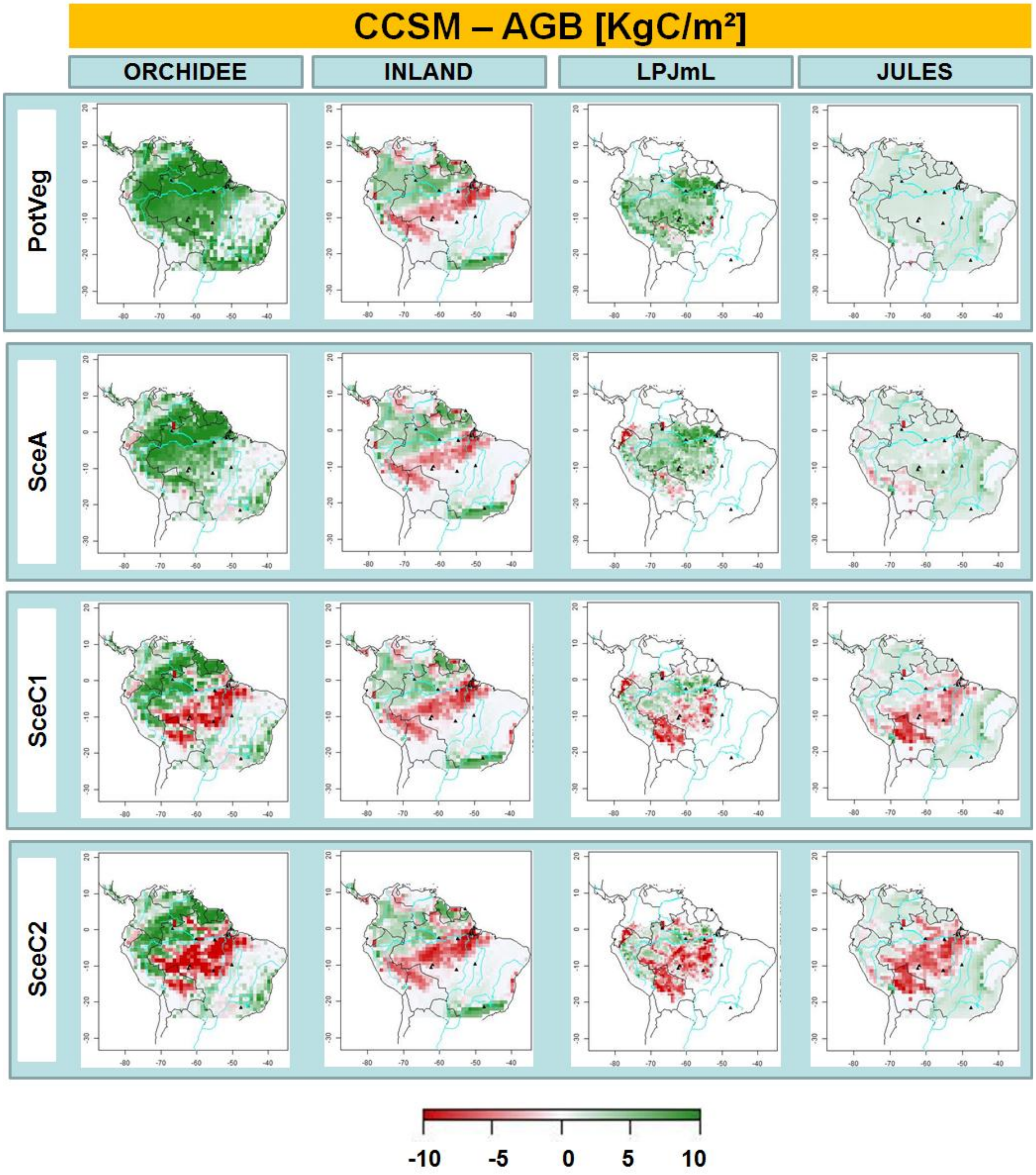


Figure 8. Map of South-America, representing per gridcel the AGB [KgC/m²] difference between the average monthly mean for the periods 2090-'99 minus 2009-'18 for all runs using the CCSM climate forcing. INLAND, ORCHIDEE and LPJmL are the DGVMs used to generate the future runs and using PotVeg, SceA, SceC1 or SceC2 as LUC.

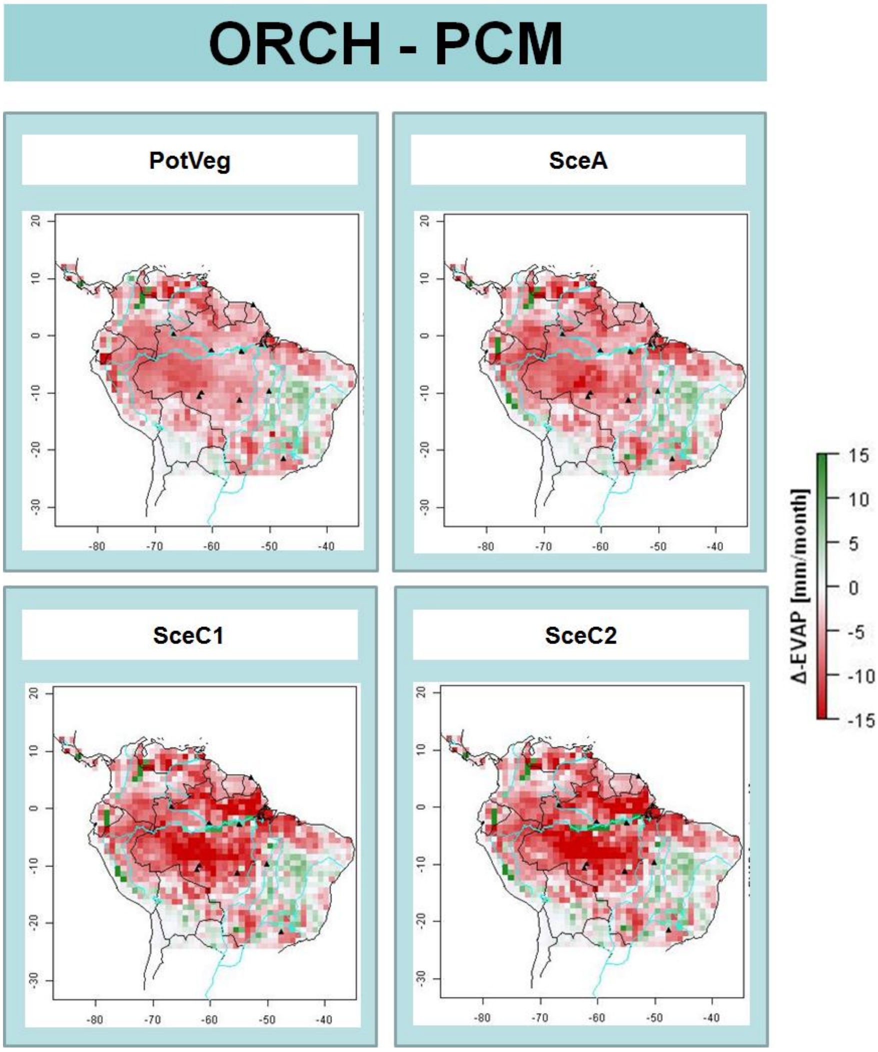


Figure 9. Evapotranspiration (Evap) [mm/month] difference between the average monthly mean for the periods 2090-'99 minus 2009-'18, calculated from ORCHIDEE simulations using PCM as climate forcing.

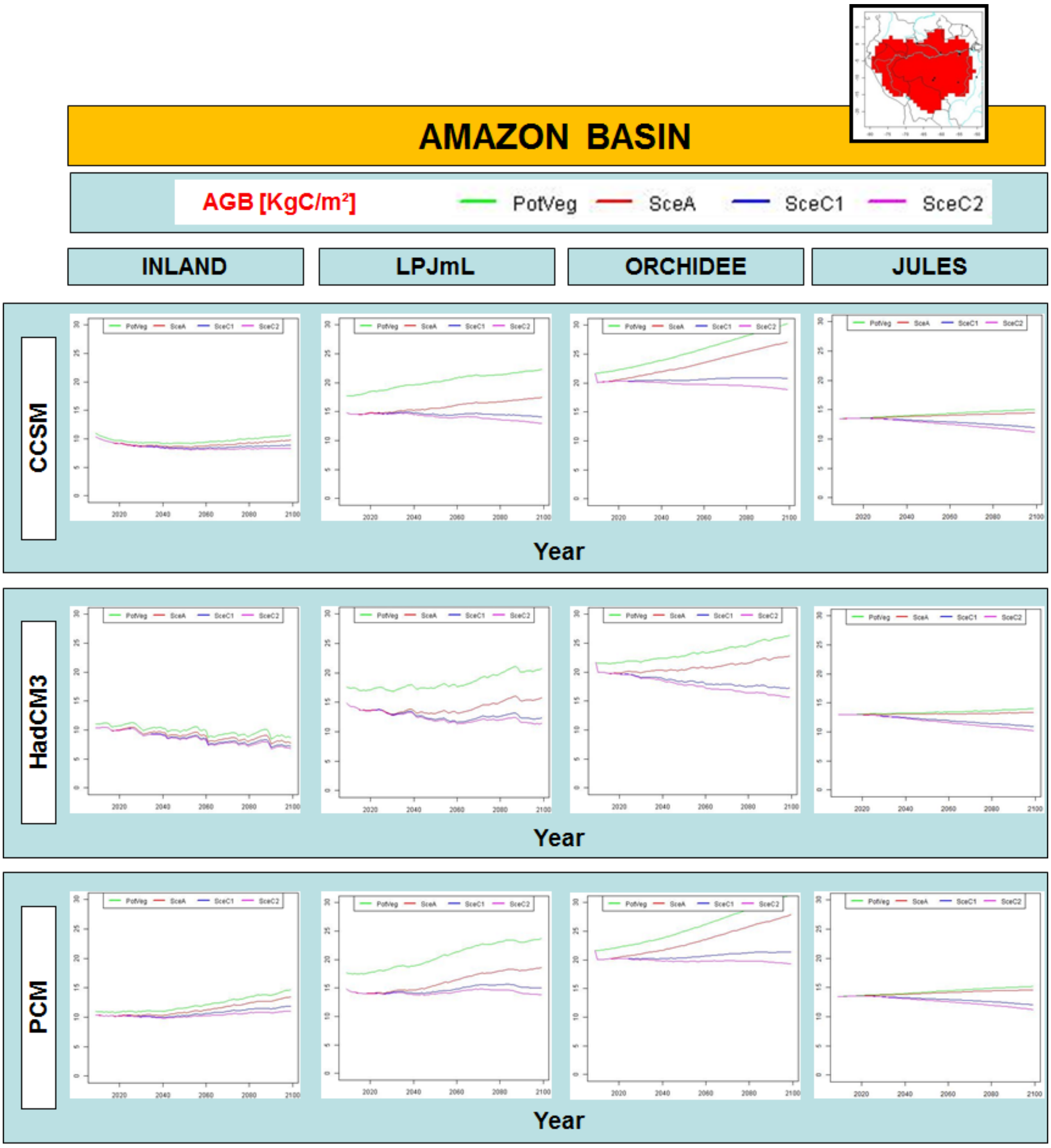


Figure 10. Timeline analyses. Graphs show the annual mean value of AGB [KgC/m²] from within the entire Amazon Basin. ORCHIDEE, INLAND, LPJmL and JULES represent the DGVMs used. PotVeg, SceA, SceC1 and SceC2 represent the LUC maps used in the simulations. CCSM, HadCM3 and PCM are the selected climate forcings applied in the future runs.

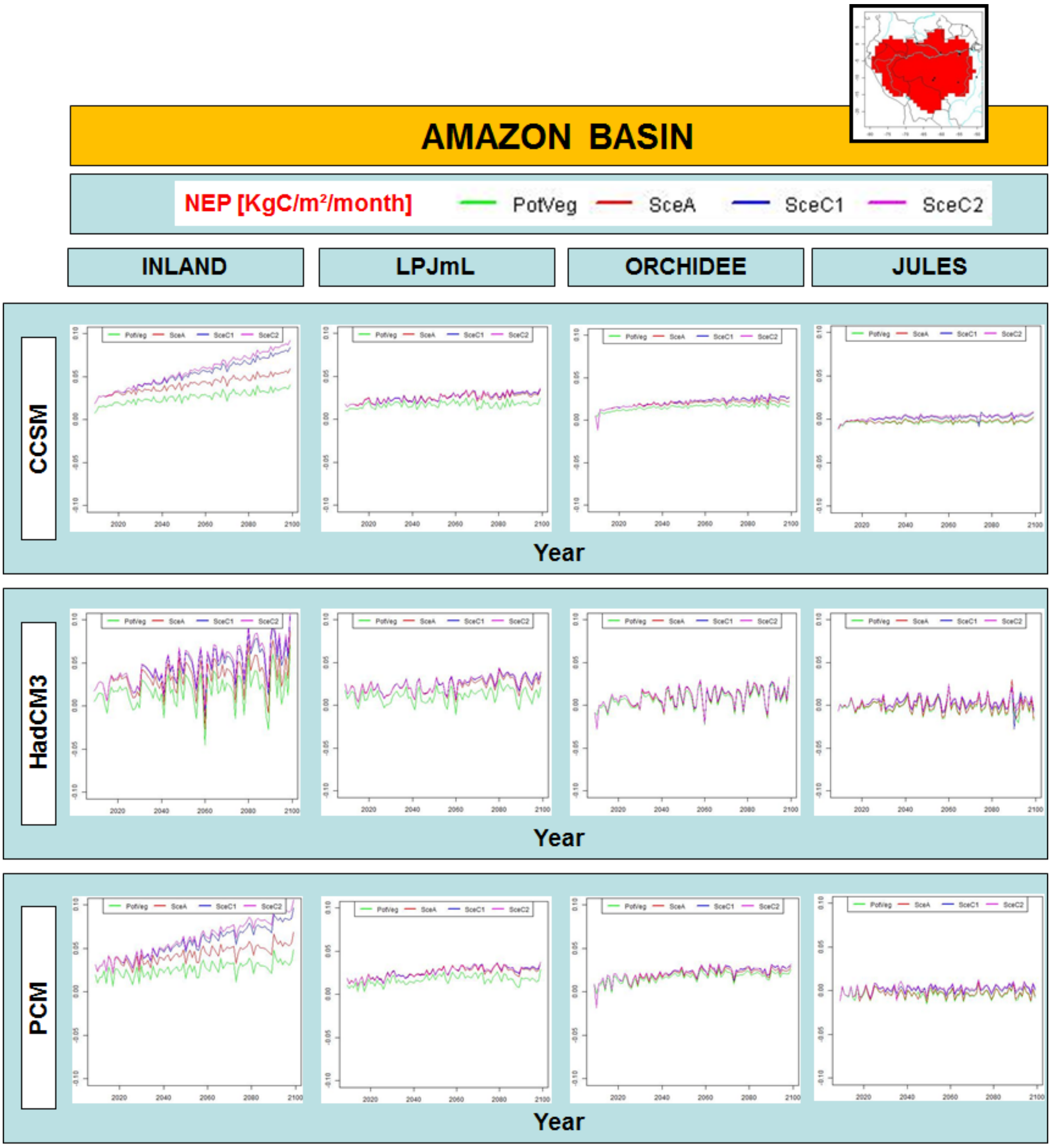


Figure 11. Timeline analyses. Graphs show the yearly mean value of NEP [KgC/m²/month] from within the entire Amazon Basin. ORCHIDEE, INLAND, LPJmL and JULES represent the DGVMs used. PotVeg, SceA, SceC1 and SceC2 represent the LUC maps used in the simulations. CCSM, HadCM3 and PCM are the selected climate forcings applied in the future runs.

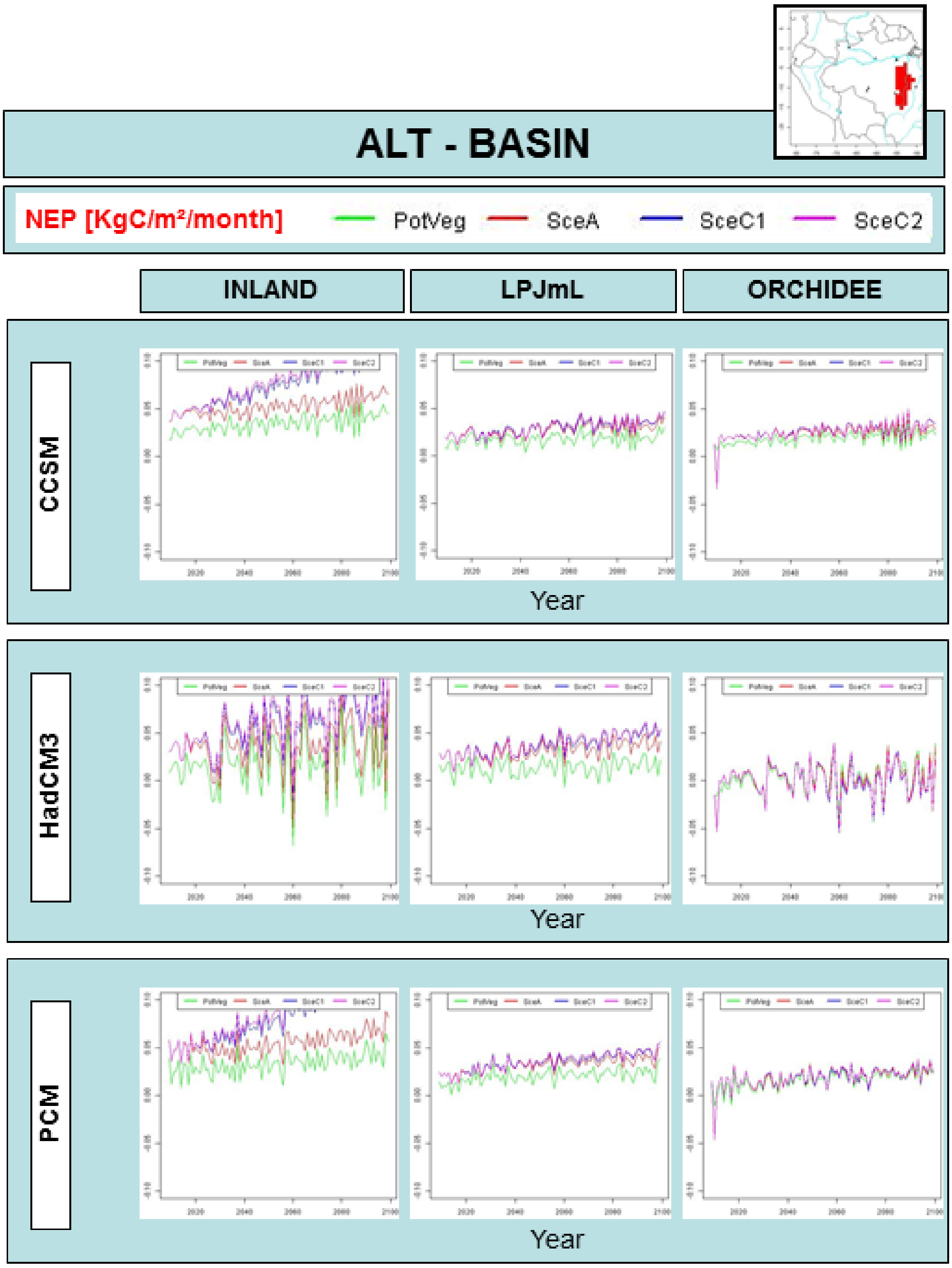


Figure 11. Timeline analyses. Graphs show the yearly mean value of NEP [KgC/m²/month] from within the Xingu basin, confined by the Altamira station (ALT) . ORCHIDEE, INLAND and LPJmL represent the DGVMs used. PotVeg, SceA, SceC1 and SceC2 represent the LUC maps used in the simulations. CCSM, HadCM3 and PCM are the selected climate forcings applied in the future runs.

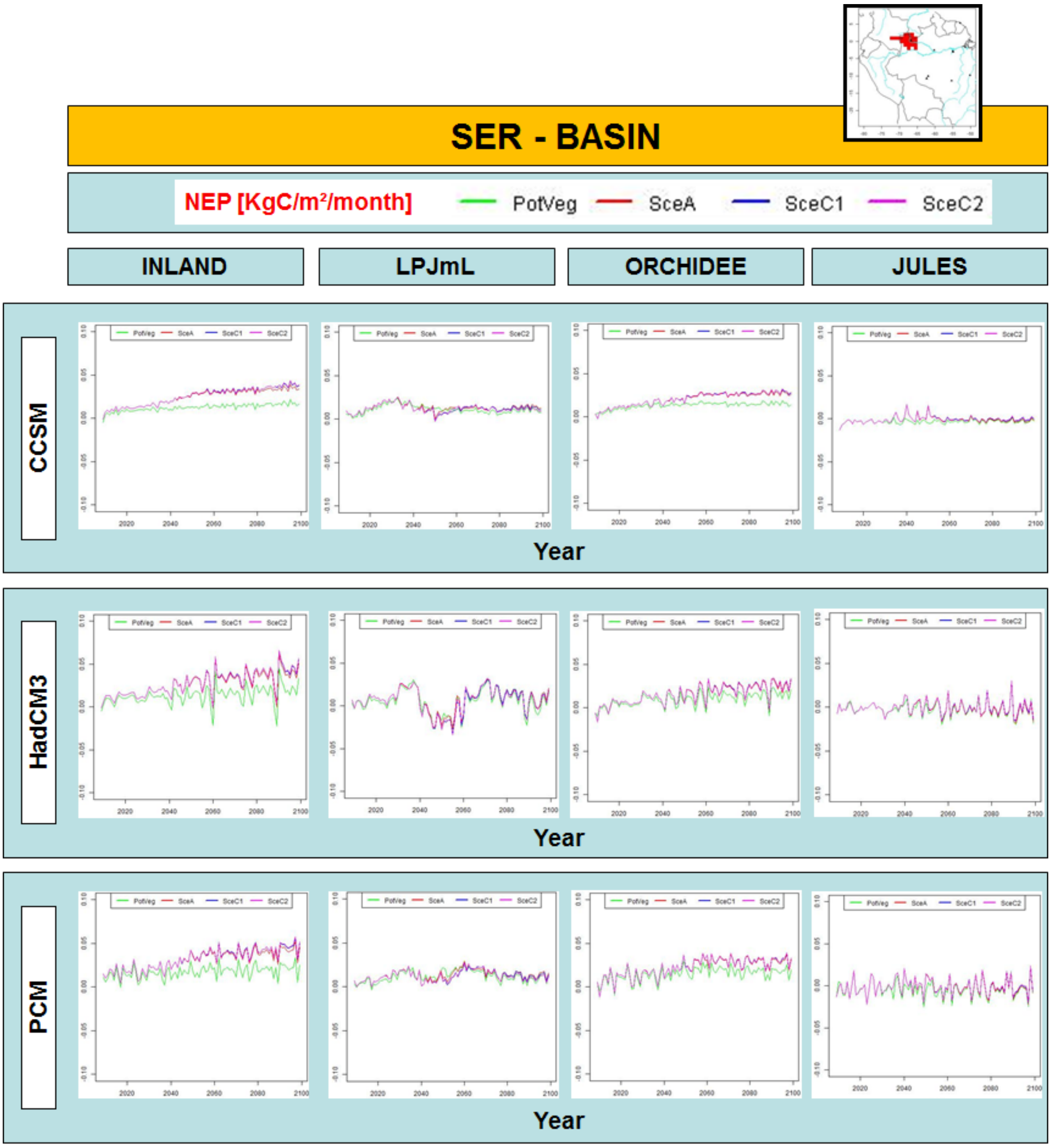


Figure 12. Timeline analyses. Graphs show the yearly mean value of NEP [KgC/m²/month] from within the Negro basin, confined by the Serrinha station (SER). ORCHIDEE, INLAND, LPJmL and JULES represent the DGVMs used. PotVeg, SceA, SceC1 and SceC2 represent the LUC maps used in the simulations. CCSM, HadCM3 and PCM are the selected climate forcings applied in the future runs.

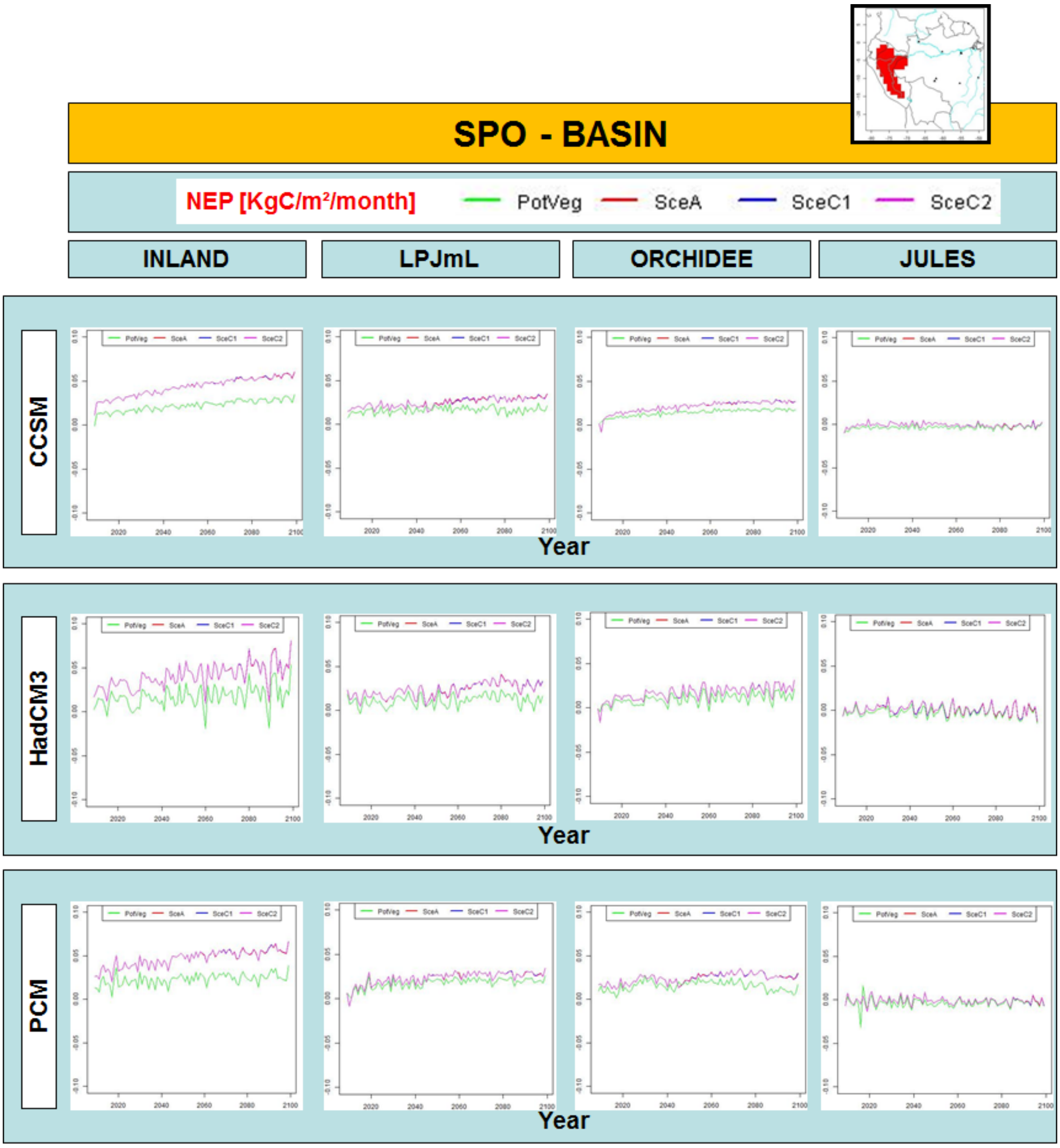


Figure 13. Timeline analyses. Graphs show the yearly mean value of NEP [KgC/m²/month] from within the Solimoes basin, confined by the Sao Paulo de Olivença station (SPO). ORCHIDEE, INLAND, LPJmL and JULES represent the DGVMs used. PotVeg, SceA, SceC1 and SceC2 represent the LUC maps used in the simulations. CCSM, HadCM3 and PCM are the selected climate forcings applied in the future runs.

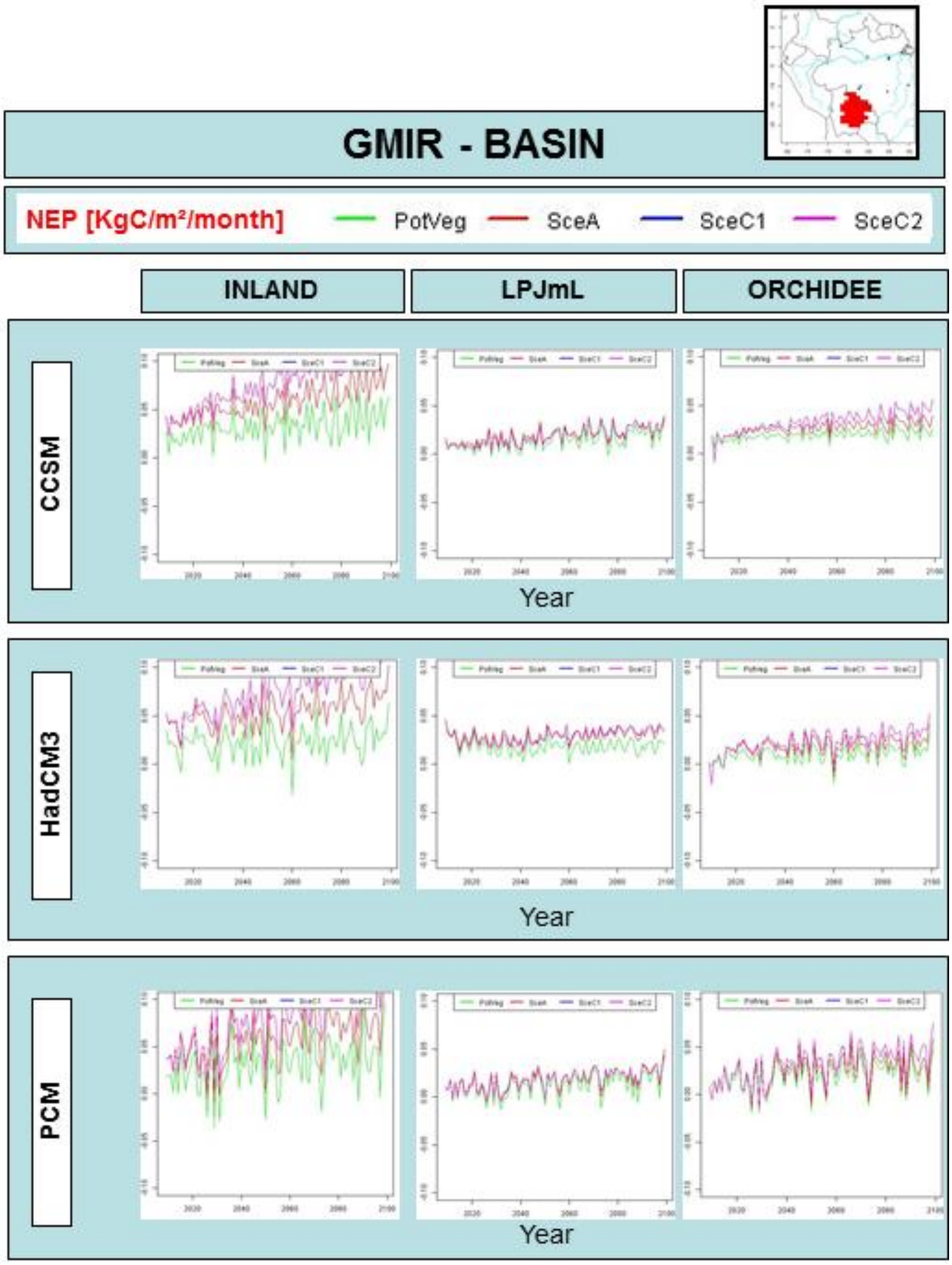


Figure 14. Timeline analyses. Graphs show the yearly mean value of NEP [KgC/m^2/month] from within the Mamoré basin, confined by the Guajara-Mirim station (GMIR). ORCHIDEE, INLAND and LPJmL represent the DGVMs used. PotVeg, SceA, SceC1 and SceC2 represent the LUC maps used in the simulations. CCSM, HadCM3 and PCM are the selected climate forcings applied in the future runs.

Conclusions

One noticeable finding is that the generated maps and timeline analyses suggest a potential biomass growth in the western and northern regions of the Amazon, while even in intact forests, a decline might be expected in the more vulnerable southern and eastern ecosystems, independent from - however strengthened by - more intense land use practices. Secondly, findings indicate a potentially alteration of the water cycling, enhanced by deforestation. Additionally, resulting from the HadCM3 future forcings, we can conclude that carbon fluxes and stocks seem sensitive to sudden, unpredictable and intense climate extremes and variability, which strengthens the importance of studying the vegetation responses to these hazardous events. So although some regions of the Amazon appear quite resilient to gradual climate change, potential dieback due to more unpredictable climate patterns is still conceivable. Finally, insights resulting from both the historical and future runs strongly encourage future research on inter-model differences, model set-up improvement (i.e. by including mechanistic models on mortality) and vegetation dynamics on climate extremes.

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