Evaluation of DGVMs in tropical areas: linking patterns of vegetation, climate and fire to ecological processes

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Introduction

- Many current Dynamic Global Vegetation Models (DGVMs) display high uncertainty in predicting the forest, savanna and grassland distributions and the transitions between them in tropical areas.
- These biomes are the most productive terrestrial ecosystems, and owing to their different biogeophysical and biogeochemical characteristics, future changes in their distributions could have also impacts on climate states.
- The difficulty of the DGVMs in simulating tropical vegetation has been associated with the way they represent the ecological processes and feedbacks between biotic and abiotic conditions [1]. The inclusion of appropriate ecological mechanisms under present climatic conditions is essential for obtaining reliable future projections of vegetation and climate states.

Objectives

We analyse observed relationships of tree and grass cover with climate and fire (from satellite MODIS and TRMM), and use the current ecological understanding of the mechanisms driving the forest-savanna-grassland transition in Africa to:

- evaluate the outcomes of the LPJ-GUESS DGVM
- assess which ecological processes need to be included or improved within the model.

Main patterns and mechanisms of ecological interactions [2]

Precipitation:	Vegetation Patterns:	Main Ecological Mechanisms:
I: Low MAR[1]	Grasses are dominant, tree cover is low and fires are rare (**Fig.s 6,8,12**).	Tree and grass growth is water-limited; tree and grass compete for water, and grass has strong competitive effects on tree seedlings [3,4].
II: Intermediate MAR	Savannas and grasslands are the predominant biomes; fires are frequent (**Fig.s 6,12**).	Positive vegetation-fire feedback: grass-fuelled fires suppress grasses and savanna saplings, and low tree cover promotes fire spread since grass can regrow rapidly after fire [5]. Savanna trees are fire resistant but cannot outcompete grasses because intolerant to shade. Forest tree establishment is water-limited.
III: High MAR	Bimodality of forests and savannas in vegetation cover and tree types (**Fig.s 8,12**).	Water is enough for the development of the forest. The positive vegetation-fire feedback permits savanna-forest occurrence [5].

[1]MAR: mean annual rainfall

Methods

We compare patterns of **African** (between **35° S and 15 ° N**) observed **% Tree cover**, **% Grass Cover**, **Mean Annual Rainfall (MAR)** and **Average Fire Intervals (AFI)**, averaged in time **from 2000 to 2010** and in space to the **resolution of 0.5°** (a common DGVM resolution) with the outputs of a **DGVM (LPJ-GUESS)** run at the same resolution.

Observational data

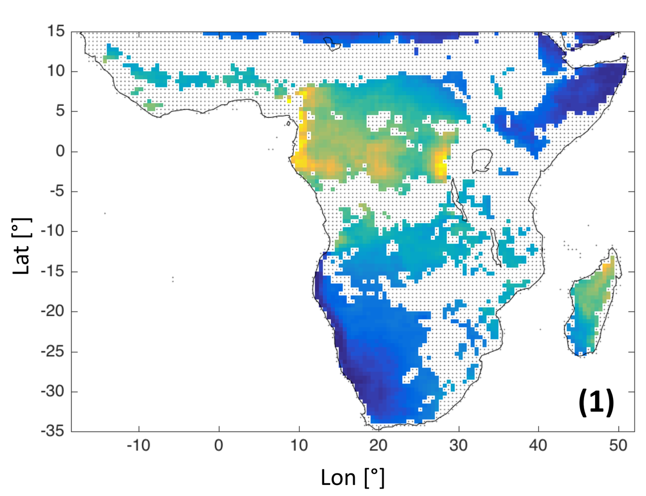


Fig. 1: African land MAR; dotted areas, excluded from the observation data analysis, are 0.5°-pixels with more than 33% (50%) of the area influenced by humans (covered by shrublands) identified using ESA CCI-LC 2010, with 300 m resolution. ESA CCI-LC is also used to identify savanna trees (identified with the deciduous class) and forest trees (identified with the **evergreen** class)

[2] Fire, tree and grass data, originally in MODIS sinusoidal projection, were re-projected and averaged on a 0.5° regular lon-lat grid.

- **MAR (mm y^{-1})** : obtained from Tropical Rainfall Measuring Mission (TRMM 3B42), with 0.25° resolution
- **% Tree and Grass cover** [2]: obtained from annual Terra MODIS Vegetation Continuous Fields product (MOD44B, V051), with 250 m resolution
- **AFI (y)** [2]: derived from the 0.5° area - annual burnt area obtained from the monthly MODIS MCD45A1 burnt area product, with 500 m resolution.

LPJ-GUESS Model [6], Experimental Setup and Outputs

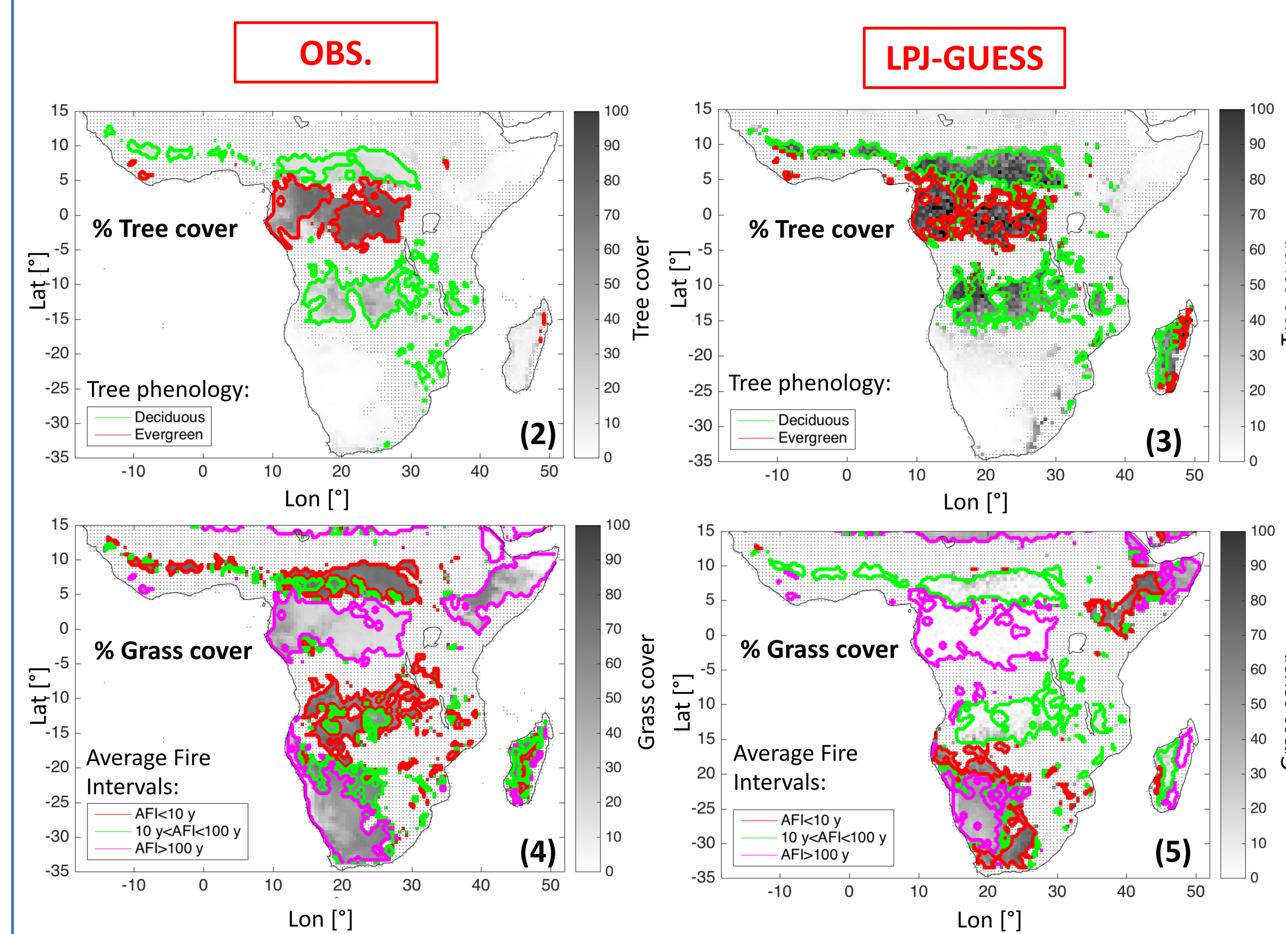
Main characteristics and Experimental Setup:

- Individual-processes-based DGVM, included in the Earth System Model EC-Earth, here used offline
- It simulates the age-structured dynamics of several interacting Plant Functional Types (PFTs) (e.g. C3, C4 grasses, tropical trees, temperate trees) as the outcome of growth and competition for light, space and soil resources, including fire responses
- Input data of climatic, atmospheric CO2 and soil conditions (CRU data from 1901 to 2006, with 0.5° resolution in our exp.)
- For each independent grid cell, it simulates a number of replicate patches (5 in our experiment)

Model Outputs: % Tree and grass cover, average fire intervals and main PFT averaged over the last 10 years of simulation

RESULTS AND DISCUSSION

First Comparison: Maps of Tree and Grass Cover



Maps of % Tree Cover (**Fig.s 2-3**) and % Grass Cover (**Fig.s 4-5**)

LPJ-GUESS overestimates tree cover and underestimates grass cover in many areas, especially where it underestimates the average fire intervals (color lines in **Fig.s 4-5**)

Distribution of PFTs deciduous (savanna trees) and evergreen (forest trees)[3] are in agreement with observed distributions (color lines in **Fig.s 2-3**)

Second Comparison: relations between precipitation-fire-vegetation

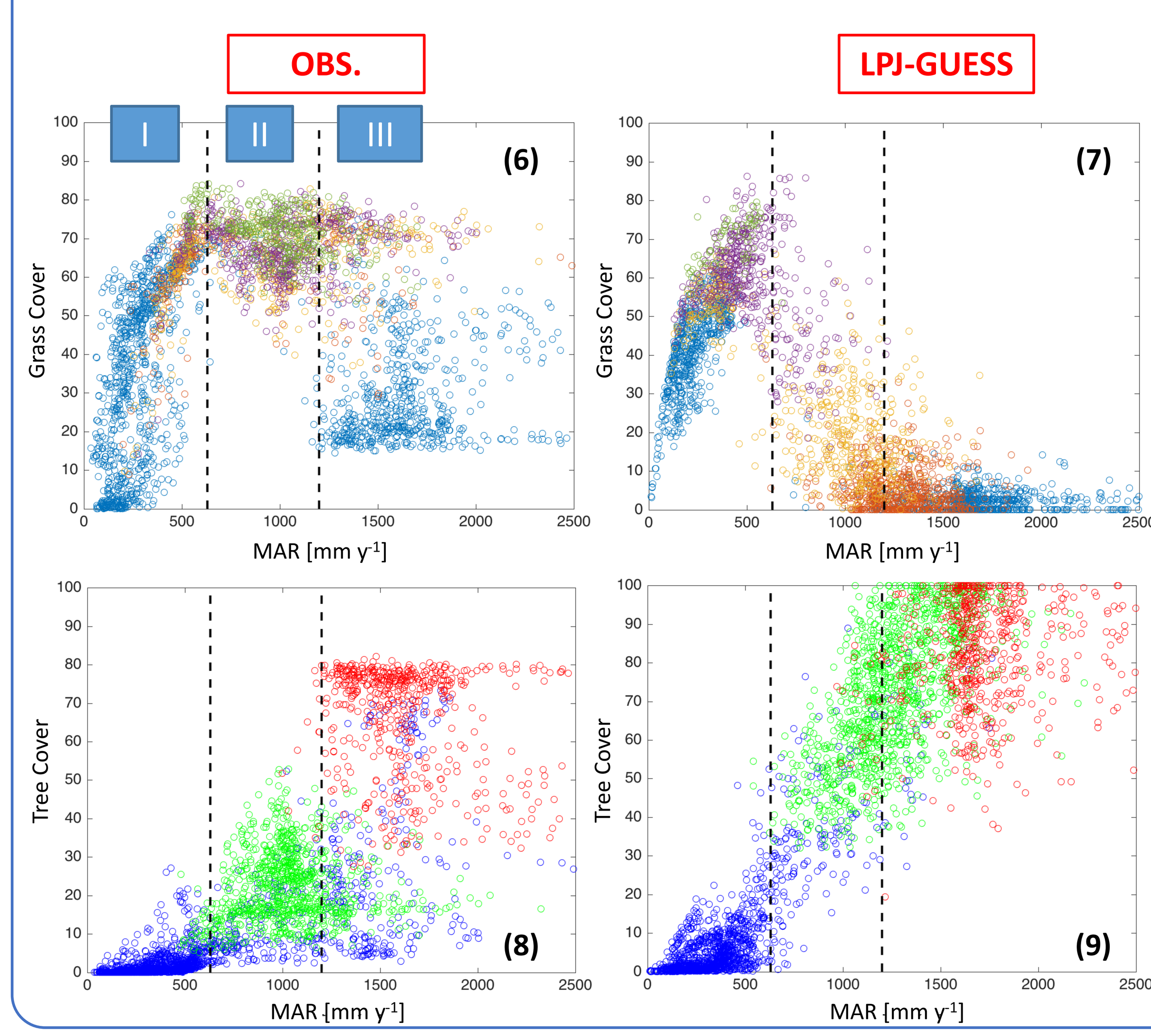


Fig.s 6-7: % Grass Cover vs. MAR

Symbols: average fire intervals (AFI)
- AFI>100
- 30<AFI<100
- 10<AFI<30
- 3<AFI<=10
- AFI<=3 y

Fig.s 8-9: % Tree Cover vs. MAR

Symbols: tree type
- Other Categories
- Deciduous
- Evergreen

[3]Deciduous (savanna) trees: fire-tolerant, shade-intolerant
Evergreen (forest) trees: fire-intolerant, shade-tolerant

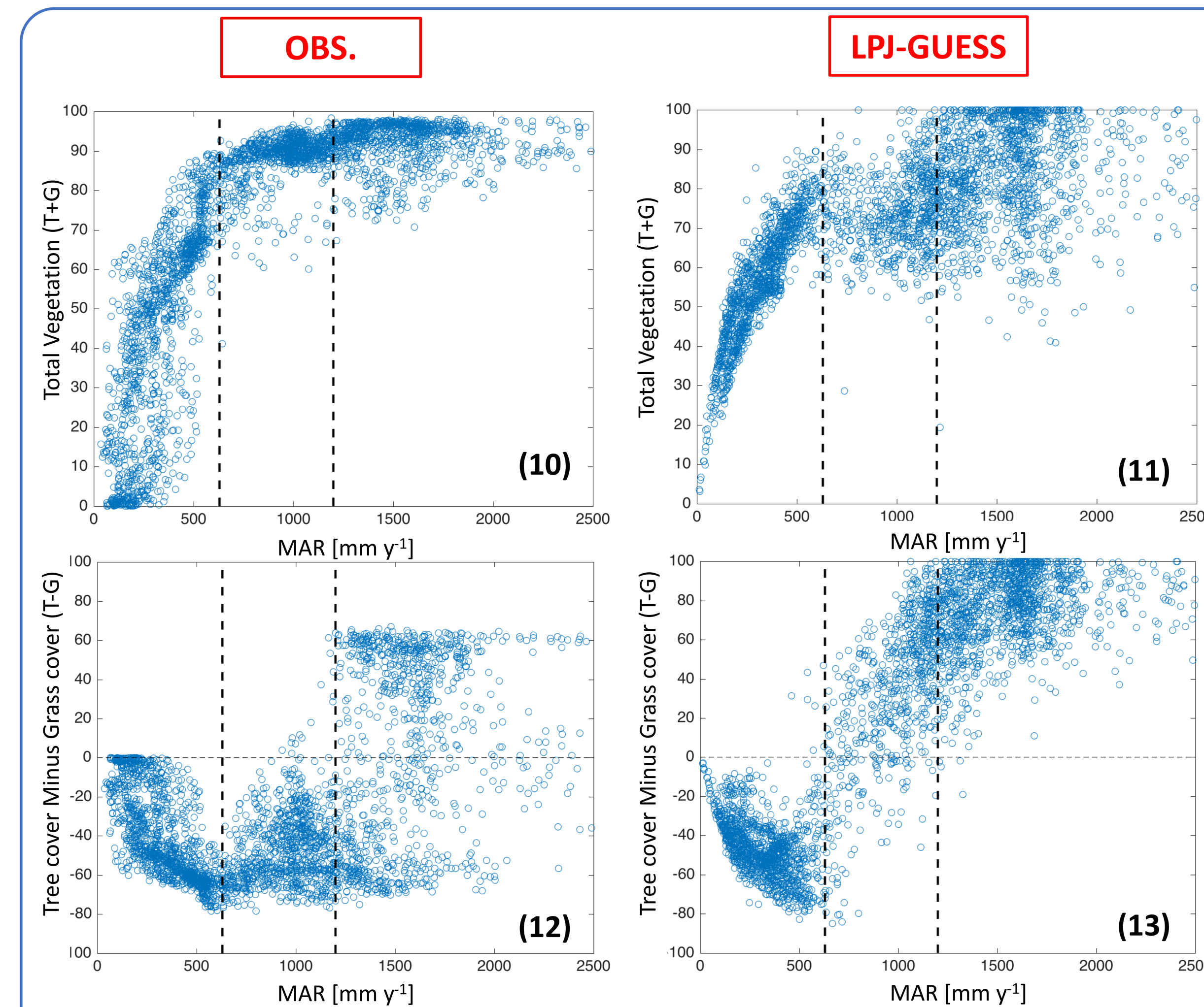


Fig.s 10-11: % Total vegetation vs MAR

Fig.s 12-13: % Tree cover minus Grass Cover (relative tree-grass dominance) vs. MAR

Overall, with respect observations, LPJ-GUESS mean tree (grass) cover is higher (lower) for all the MAR values and LPJ-GUESS has few pixels with fire average intervals smaller than 3 years.

Precipitation →	I: Low MAR	II: Intermediate MAR	III: High MAR
LPJ-GUESS vs. Obs.:	General good agreement (Fig.s 12-13) but - steeper increase of trees (Fig.s 8-9) - fires are overestimated (Fig.s 6-7)	- Steeper increases of trees (Fig.s 8-9) - Larger dominance of trees (Fig.s 12-13) - Grasses decrease with MAR, but in observations this does not occur (Fig.s 6-7) - Fires are underestimated (Fig.s 6-7)	Coexistence of savanna trees and forest trees (Fig. 9) but - No bimodality in tree cover: only closed canopy (Fig.s 8,9,12,13) - Fires are rare (Fig.s 6-7)
Possible ecological deductions:	- Trees outcompete grasses too much (water competition) - Tree water uptake too strong - The open canopies maintained by water limitation promote too frequent fires. In the real world fires are limited by fuel continuity	- Tree competition for water too strong - The closed canopies (>50%) do not permit the start of the fire-vegetation feedback which maintains open canopies in observations	The weak shade intolerance of savanna trees (deciduous) and the absence of frequent fires lead the model to produce only closed canopy and not the observed savanna
Suggestions:	Improving/adding: - tree-grass competition for water - relation of fire spread to fuel continuity	Preventing the tree dominance and favouring fire spread improving: - tree-grass competition for water - savanna tree characteristic of shade intolerance	Improving the responses of savanna trees and forest trees to shade and fire, for preventing closed forest formation and allowing the vegetation-fire feedback to start

Conclusions

The comparative analysis suggests possible improvements in the model representations of tree-grass competition for water, of the vegetation-fire interaction, as well as of savanna and forest trees responses to shade and fire.

The proposed comparative analysis could be useful for evaluating DGVMs in tropical areas, especially in the phase of model set-up, before the coupling with Earth System Models. Improving the simulations of ecological processes and consequently of land-climate interactions is of fundamental importance when using such models for predictions.

References

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