Evaluation of DGVMs in tropical Africa: linking vegetation-climate-fire relationships to key ecological processes

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1. Abstract

INTRODUCTION: Many current Dynamic Global Vegetation Models (DGVMs) display high uncertainty in predicting the distribution of tropical biomes and the transitions between them. This difficulty has been associated with the way they represent the ecological processes and feedbacks [1]. The inclusion of appropriate ecological mechanisms under present climatic conditions is essential for obtaining reliable future projections of vegetation and climate states.

AIM: We compare the observed-modeled relationships of tree and grass cover with precipitation and fire and the pattern of tropical grassy biomes (TGB) and forests (TF), and use the current ecological understanding of the mechanisms driving the TGB-TF transition to:

- evaluate and compare the outcomes of state-of-the–art DGVMs
- assess which key ecological processes need to be included or improved within the models

2. 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 (**Figs 2,7,12**).	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	TGBs are the predominant biomes; fires are frequent (**Figs 7,12**).	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]. TGB trees are fire resistant but cannot outcompete grasses because intolerant to shade. Forest tree establishment is water-limited.
III: High MAR	Bimodality of TGBs and TFs in vegetation cover and tree types (**Figs 2,12**).	Water is enough for the development of the forest. The positive vegetation-fire feedback permits TGB-TF occurrence [5].

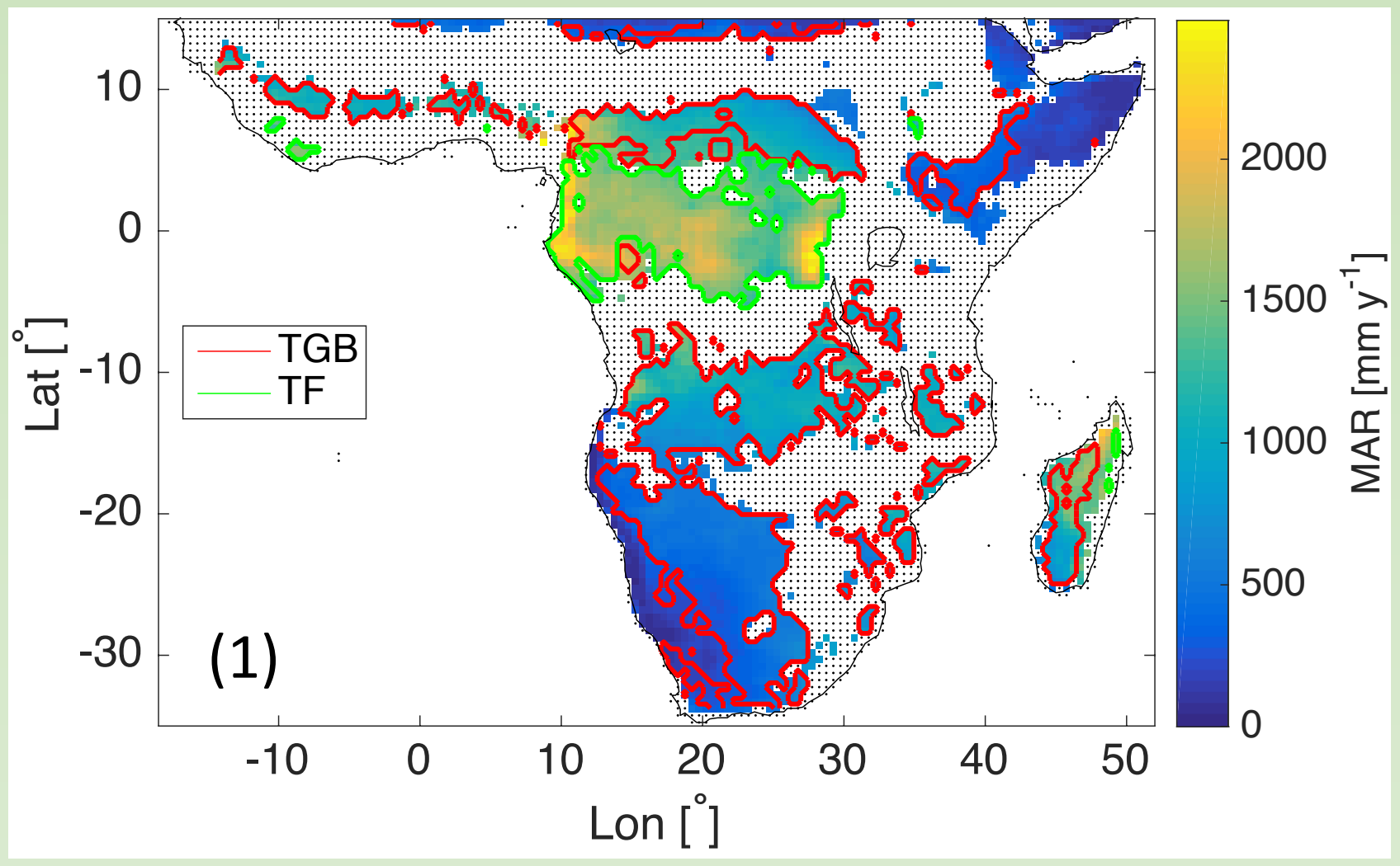
More details on a complete observation analysis in [2] and http://sansone.to.isac.cnr.it/diss/egu2017/donofrio1_egu2017.pdf

[1] MAR= mean annual rainfall

3. Materials and 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 LPJ-GUESS (0.5°) and of JSBACH (1.875°)** with the outputs of **LPJ-GUESS, JSBACH and JSBACH-SPITFIRE**.

3a. Observational data



- **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.

[2] Fire, tree and grass data, originally in MODIS sinusoidal projection, were re-projected and averaged on a 0.5° and 1.875° regular lon-lat grid.

Fig. 1: African land MAR (0.5° res.); dotted areas, excluded from the observation data analysis (areas human influenced/covered by shrubland from ESA CCI-LC 2010). Coloured lines: TGB areas identified with deciduous trees and grasslands classes; TF areas identified with evergreen and flooded trees classes from ESA CCI-LC 2010.

3b. DGVMs: main characteristics, experimental setup and outputs

LPJ-GUESS [6]

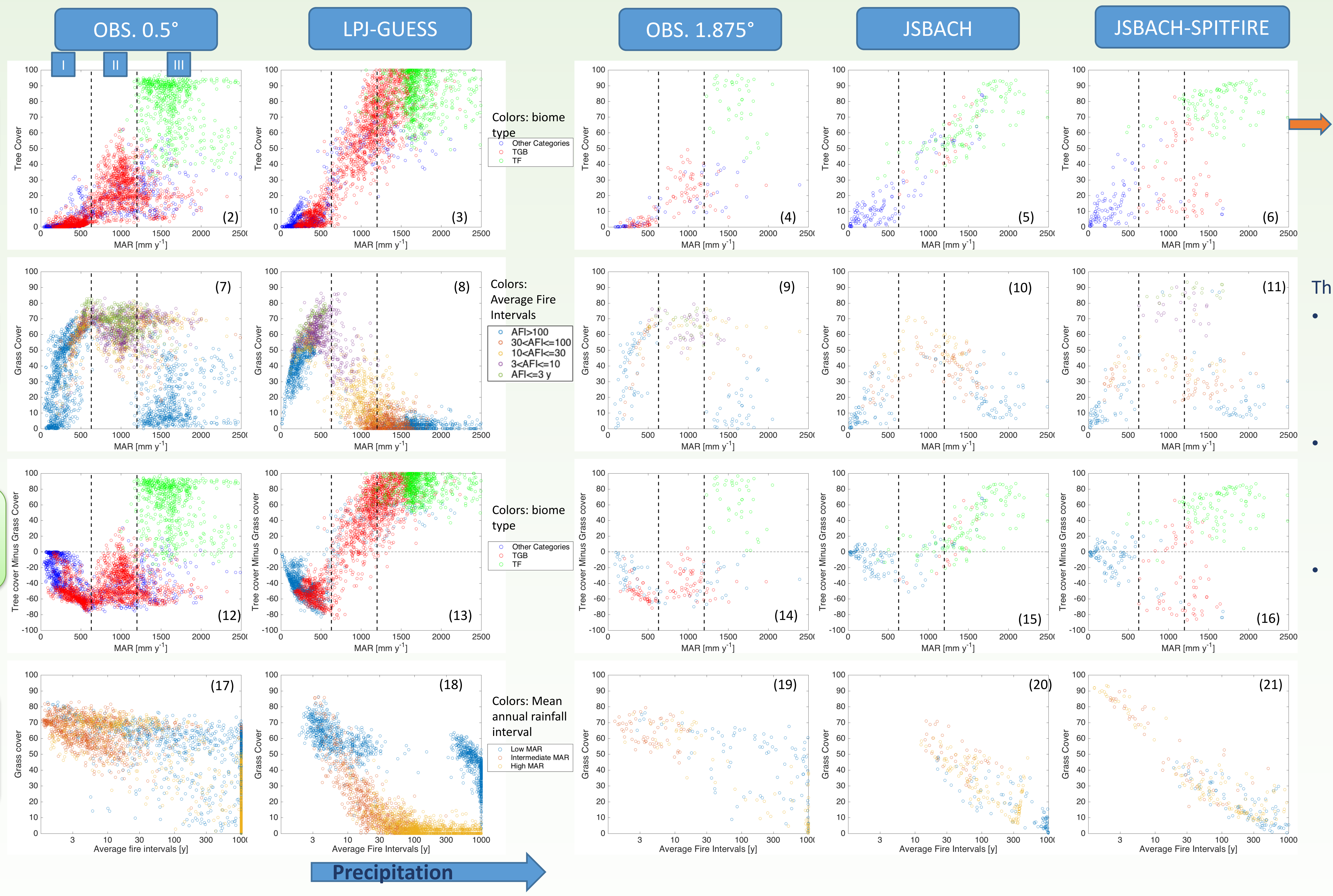
- Individual-processes-based DGVM, included in the ESM EC-Earth, here used offline.
- Spatial resolution: 0.5°
- Simple empirical fire algorithm
- Input data: CRU data (1901-2006)
- For each independent grid cell, it simulates a number of replicate patches (5 in our experiment)

JSBACH, JSBACH-SPITFIRE [7]

- Processes-based DGVM, part of the MPI Earth system model (MPI-ESM), here used offline
- Spatial resolution: 1.875°
- Simulations with two alternative fire algorithms: a simple empirical model and the process-based SPITFIRE model
- Input data: climate data from MPI-ESM 1.1 (1850-2005). SPITFIRE uses a population density dataset and monthly lightning climatology

Model Outputs: % Tree and grass cover, average fire intervals and main PFTs averaged over the last 10 years of simulation. In **LPJ-GUESS:** TGB: deciduous trees and C4 grass; TF: evergreen trees. In **JSBACH**: TGB: deciduous trees and shrub and C4 grass; TF: evergreen trees;

4. RESULTS: relations between precipitation-fire-vegetation



Tree cover Vs MAR

Note: Observed vegetation cover data were rescaled to represent crown cover as in models

Grass cover Vs MAR

(Tree cover – Grass cover) Vs MAR

Grass cover Vs Average Fire interval

Overall, with respect to observation, in all models grass cover decreases more steeply with average fire intervals and displays narrower spread (Figs 17-21).

5. Conclusions

The comparative analysis:

- suggests possible improvements in the model representation of tree-grass competition for water in both models, especially in arid and humid areas, and PFT responses to fire and shading.
- highlights the improvements of the inclusion of a complex fire module (SPITFIRE) in simulating TGB-TF transition, although grasses/TGB tree responses to fire should be revised.
- This type of analysis allows to compare DGVMs in tropical areas, helping to understand their ability in representing key ecological processes and to improve ESMs simulations.

6. References

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	I: Low MAR	II: Intermediate MAR	III: High MAR
DGVMS vs. Obs.:	**LPJ-GUESS:** General good agreement **(Figs 12-13)** but slightly steeper increase of trees **(Figs 2-3)** and fires are overestimated **(Figs 7-8);** **JSBACH (both):** Steeper increase of trees **(Figs 4-6)**, underestimation of grasses **(Figs 9-10,14-16);** Absence of TGBs and presence of TF **(Figs 4-6,14-16).** Good agreement in fire occurrence **(Figs 9-11,19-21)**	**LPJ-GUESS:** Steeper increase of trees **(Figs 2-3);** larger dominance of trees **(Figs 12-13);** grasses decrease with MAR **(Figs 7-8);** fires are underestimated **(Figs 7-8,17-18); JSBACH:** steeper increases of trees **(Figs 4-5**; slight underestimation of grasses **(Figs 9-10,14-15)**; underest. of TGBs, presence of TF **(Figs 4-5,14-15)**, underestimation of fire occurrence **(Figs 9-10,19-20);** **JSBACH-SPITFIRE:** larger spread in vegetation cover; overestimation of grass and underestimation of trees when fires are frequent and viceversa (bimodality in grass cover), presence of TF **(Figs 4,6,9,11,14,16)**;	**LPJ-GUESS:** Coexistence of TGBs and TFs but no bimodality in tree cover: only closed canopy **(Figs 2-3,12,13)** and fires are rare **(Figs 7-8,17-18); JSBACH:** quite similar to LPJ-GUESS; **JSBACH-SPITFIRE:** General good agreement but grasses are overestimated when fires are also overestimated **(Figs 4,6,9,11,14,16,19,21)**
Possible ecological deductions:	**ALL:** Trees outcompete grasses too much (water competition); Tree water uptake is too strong; **LPJ-GUESS:** The open canopies maintained by water limitation promote too frequent fires. In the real world fires are limited by fuel continuity.	**ALL:** Tree competition for water too strong; grasses have too much advantage compared to trees when fires are frequent and viceversa (**SPITFIRE**). The closed canopies (>50%) do not permit the start of the fire-vegetation feedback which maintains open canopies and TGBs presence in observations	**LPJ-GUESS/JSBACH:** The absence of frequent fires leads the model to produce only closed canopies and not the observed savanna; **SPITFIRE:** as in the Intermediate MAR range, grasses have too much advantage compared to trees in presence of fire.
Suggestions:	Improving/adding: **ALL**: tree-grass competition for water; **LPJ-GUESS**: relation of fire spread to fuel continuity; **JSBACH (both)**: TF PFT responses to water.	**ALL:** Preventing the tree dominance and favouring fire spread improving: tree-grass competition for water, TGB tree characteristics of shade intolerance and fire-tolerance and diminishing the advantage of grasses compared to trees in presence of fire (**SPITFIRE).**	**LPJ-GUESS/JSBACH:** Improving the responses of TGB trees and TF trees to shade and fire, in order to 1) prevent closed forest formation, allowing the vegetation-fire feedback to start, and, 2) prevent too open canopies (**SPITFIRE**).