The role of rainfall intermittency for tropical vegetation

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Introduction

- Savannas occupy about a fifth of the global land surface and store approximately 15% of the terrestrial carbon. They also encompass about 85% of the global land area burnt annually. Taken together, grassland and savannas are defined as **Tropical Grassy Biomes (TGBs)**.
- Future projections of global climate models suggest an increased likelihood of high intensity rainfall events and higher prevalence of dry periods, with these changes not necessarily associated with corresponding changes to average annual rainfall quantities. This may have implications for savanna structure.
- Previous work on the importance of rainfall intermittency to vegetation structure has been assessed in small scale ecological studies [1], dynamic vegetation modelling studies [2] and continental analyses focused on total tree cover only [3], with sometimes conflicting findings.
- Recent work anyalysing continental scale MODIS data on tree and grass cover in relation to precipitation and fire, has shown that the relative dominance of trees and grasses show clear changes in the dependence on mean annual rainfall (**Fig. 1**) [4]. Three distinct ranges were defined, where biome emergence was controlled by different water-fire dynamics:
  - I Low MAR: 0 – 630 mm y^{-1}
  - II Intermediate MAR: 630 – 1200 mm y^{-1}
  - III High MAR: 1200 – 2500 mm y^{-1}

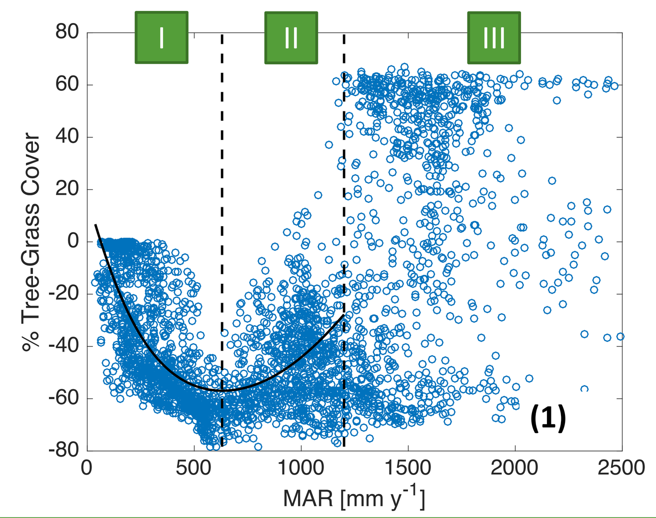

Fig.1 Relative tree-grass dominance (Tree cover-Grass cover from MODIS data at 0.5° res.) as a function of mean annual rainfall (MAR. Continuous line: best GLM fit, whose min. marks limit of first MAR range. Adapted from [4]

Objectives

Based on the approach followed by [4] in assessing continental scale data at MAR ranges, we assess the **importance of rainfall intermittency for** determining the emergence of the **TGBs in sub-Saharan Africa using** both **tree and grass cover data**

Methods

Observational data

We analyse the relationships between **African** (between **35° S and 15 ° N**) observed **% Tree cover and % Grass Cover of TGBs** with **rainfall** and **fire intervals** data averaged in time from **2000 to 2010** and in space to the **resolution of 0.5°**. Tree cover and grass cover information was obtained from the annual Terra MODIS Vegetation Continuous Fields product (MOD44B, V051), with 250 m resolution.

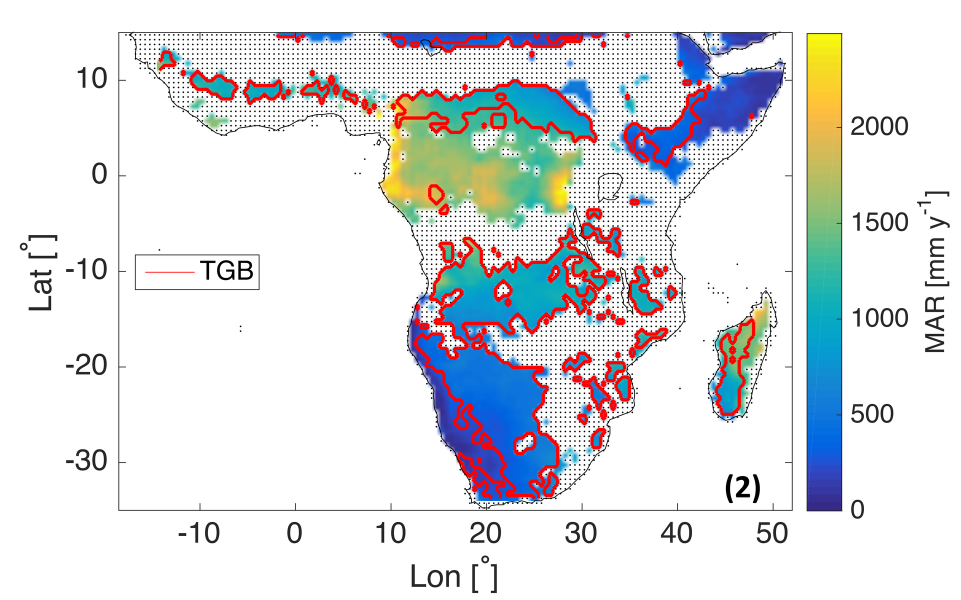

Fig.2. Mean annual rainfall of Africa. Based on ESA CCI-LC 2010, areas with greater than 33% area influenced by humans and greater than 50% covered by shrublands were excluded.

We identify TGB pixels as cells with more then 50% of their area is flagged on the ESA CCI-LC map as deciduous trees and grasslands

Explanatory variables	Data source and description
Mean Annual Rainfall (**MAR**) (**mm y^{-1}**)	• From Tropical Rainfall Measuring Mission (TRMM 3B42), with 0.25° resolution.
Rainfall Seasonality Index (**SI**)	• SI describes the rainfall regimes as the contrast of monthly rainfall amount during the year [5].
Average Wet Season Rainfall Intensity (**α_w**) (**mm d^{-1}**) Average Wet Season Rainfall Frequency (**λ_w**) (**d^{-1}**)	• α_w and λ_w are calculated from the length and MAR of the wet season (MAR_w and L_w), such as $MAR_w = \alpha_w \cdot \lambda_w \cdot L_w$, where L_w is computed as the sum of the days of the months in which precipitation is greater than the 50% of annual precipitation divided by 12.
Average Fire Frequency (**AFI**) (**y**)	• From monthly MODIS MCD45A1 burnt area product, with 500 m resolution. AFI=1/BA, where BA is the annual burnt area. We use $\log_{10}$(AFI).

Analysis

We analyse the relationships between TGB vegetation cover and explanatory variables, in the three different MAR ranges, using Generalized Linear Models (GLMs) in a stepwise process using the Akaike Information Criterion. Models including both α_w and λ_w were excluded from consideration.

Results and Discussion

MAR range	Best model predictors (direction of dependence)	Discussion
I Low rainfall range		
Fig. 3	**Grass cover**: SI (-) and λ_w (+) (R^2 = 0.58)	• Grass cover increases with rainfall frequency (**Fig. 3**). • This is analogous to experimental research showing grass being favoured by decreasing precipitation intensity α (and thus indirectly by increasing λ) due root niche partitioning [1]. Grasses are better equipped then trees to extract shallow soil water, and have an advantage when rainfall is more frequent [6]
	Tree cover: MAR (+) (R^2 = 0.2)	• However, it is important to note that a model with SI alone explains a large variance of grass cover (R^2 = 0.54) • Tree growth is limited by water availability
III High rainfall range		
Fig. 4	**Grass cover:** None	• In general, in this range the interaction between seasonality and fire determines tropical forest-TGB occurrence [2,7]
	Tree cover: α_w (-) (R^2 = 0.33).	• Within TGBs, no models describe grass cover with any significance and tree cover can be described by only α_w (**Fig. 4**) • The role of α_w in influencing tree cover in TGBs at this range is difficult to interpret

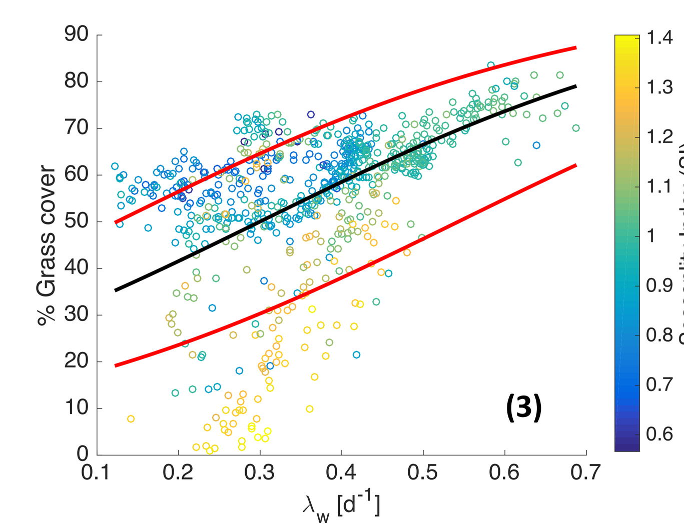

Fig.3. % Grass cover as a function of rainfall frequency (λ_w). Continuous lines are the best model fit for grass, computed with the median value of SI (black line), the 95th and 5th percentiles of SI (red lines). The colour bar shows the range of values for SI

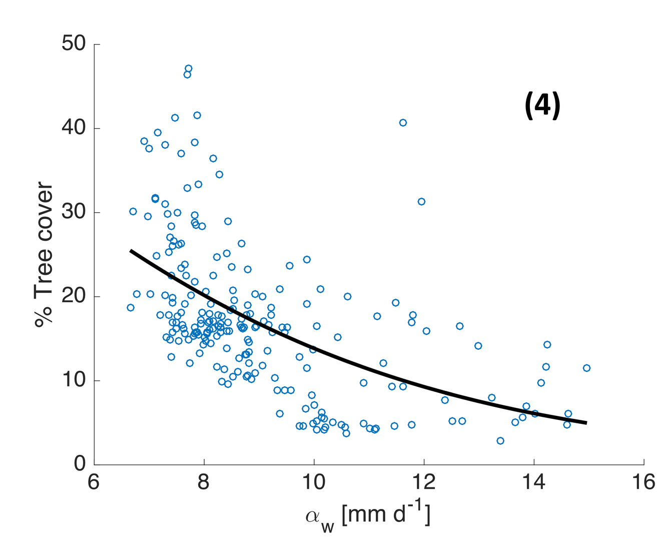

Fig. 4. % Tree cover as a function of rainfall intensity (α_w). Continuous lines is the best model fit

MAR range	Best model predictors (direction of dependence)	Discussion
II Intermediate rainfall range		
Fig. 5	**Grass cover:** AFI (-) and λ_w (-) (R^2 = 0.37)	• For grasses, there is a negative relationship between both AFI and λ_w (**Fig. 5**). A model that includes λ_w alone explains R^2 = 0.27 of grass cover however • Tree cover is favoured by increasing rainfall frequency (**Fig. 6**) • At this intermediate MAR, there is overlap between roots of grasses and trees at shallow depths [6], differently than in I
Fig. 6	**Tree cover:** λ_w (+, parabolic dependence) (R^2 = 0.39)	• This change in root depth between I and II [6] could explain our observation that rainfall frequency favours trees above grasses at this range (and in line with earlier observational findings [3]). • In turn, this highlights the importance of the vegetation-fire feedback in limiting woody encroachment [e.g. 7; 8]; indeed AFI and λ_w are negatively correlated in this MAR range (r = - 0.33), suggesting a more frequent rainfall pattern reduces the prevalence of fire

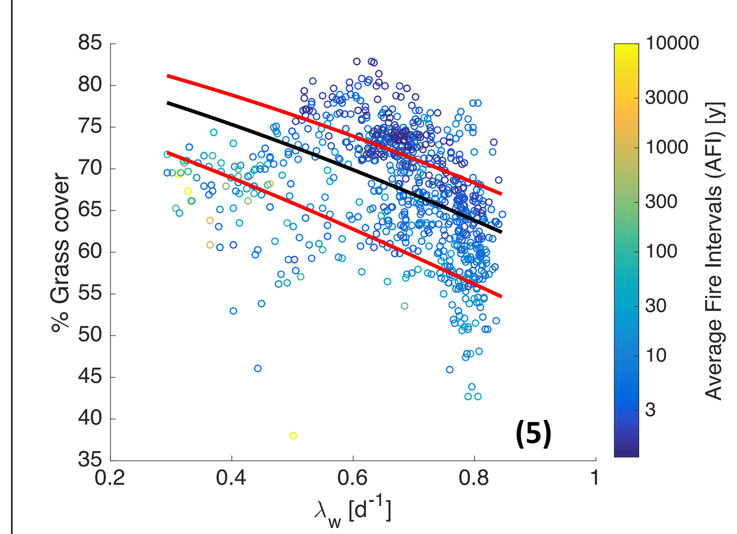

Fig.5. % Grass cover as a function of rainfall frequency (λ_w). Continuous lines are the best model fit for grass, computed with the median value of AFI (black line), the 95th and 5th percentiles of AFI (red lines). The colour bar shows the range of values for AFI

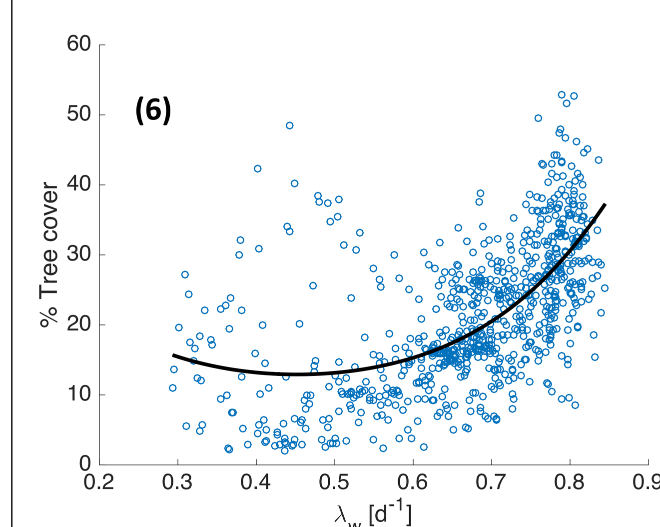

Fig.6. % Tree cover as a function of rainfall frequency (λ_w). Continuous lines is the best model fit

Conclusions

- Our analysis confirms that rainfall intermittency appears to have a role in determining tree and grass vegetation cover of tropical grassy biomes in sub-Saharan Africa.
- At different MAR ranges, these impacts vary, with, for example, grass cover positively associated with rainfall frequency at low MAR locations but negatively in intermediate MAR areas.
- These contrasting findings could possibly be related to variable grass and tree root depths at different MAR values, and may help explain contrasting findings from previous studies in relation to rainfall intermittency.

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