

Reply to comments from Victor Brovkin

Z. Yin, S. C. Dekker, B. J. J. M. van den Hurk, H. A. Dijkstra

1. “The manuscript “Bimodality of woody cover and biomass in semi-arid regime” by Yin et al. reveals a very interesting analysis of distribution of tree cover in the precipitation space. The research follows the study by Hirota et al. (2011) but with a focus on a region with a relatively narrow range of precipitation in central Africa. The authors found that savanna and forest could co-exist for the same precipitation regime, and illustrate how vegetation structure (horizontal vs. vertical leaf extent) could affect the bistability. The study combines analysis of observations with modeling experiments, which makes the paper very informative but difficult to read (see comments below).”

A: Thanks for your interest in this work.

2. “I found the representation of the modelled tree fraction on the figures 7-9 confusing. It is difficult to understand what are the color lines on the plot. Are they trajectories of the model simulations with particular D value? What does their projection on the x/y axes mean? If it is a singular realization of the model, how does the PDF distribution done at the plots at the top? Why the end of the color lines on the density plots does not coincide with the ending of lines on the phase plane? Besides, in the color legend in the upper right corner, I missed a label ‘ D ’.”

A: Lines in the left bottom panel in Figure 7-9 are indeed trajectories of the simulated results with specific D value, which are the same as Figure 6. Here we used lines to make a clear distinction between simulation results (lines) and observations (points). Based on the trajectories in Figure 6, we can see that the density of points in a particular canopy structure varies with the growth stages, implying different growth rates. Consequently, bimodality will appear in the histograms of simulated above ground biomass (left top panel in Fig. 7-9) and woody cover (right bottom panel in Fig. 7-9) due to the different growth rates in growing ages (details in P.95, L.3-10). The right top panel is the legend of the value D .

In Section 3.2, the explanation of Fig. 7-9 will be revised as: “In Figs. 7 to 9, we compare the simulated results with observed data for three different precipitation regimes. For each figure, points in the left bottom panel are from the dataset of observations. Curves are trajectories of simulated AGB and f_c from BOSVM as displayed in Fig. 6, and each curve represents a specific canopy structure determined by D . The left top and right bottom panels display distributions of observed AGB and f_c respectively. For the chosen

values of D , the model calculated distributions of AGB and f_c are plotted as curves in the left top and right bottom panel respectively. The left top panel is the legend of D ." Figures 7-9 in the paper will be revised as Fig. R1-R3.

3. "How was landuse accounted for in the observation analysis? This is an important question, because deforestation considerably modifies the tree distribution in the climatic space."

A: In this study, we ignored the potentially disturbing effect of anthropogenic land use in the observation analysis. Firstly, we want to make a comparison with Hirota et al. [2011], who didn't filter the anthropogenic land use in the observed data. Secondly, although the anthropogenic land use indeed affects the woody cover distribution, it doesn't influence the observed bimodality in principle. To show the difference, we used the GlobalCover product from ESA (the 2009 version available in <http://due.esrin.esa.int/globcover/>) to filter anthropogenic land use from the woody cover product. Land cover types that are filtered are: Post-flooding or irrigated croplands, Rainfed croplands, Mosaic Cropland (50-70%)/Vegetation (grassland, shrubland, forest) (20-50%), water bodies, Permanent snow and ice, Artificial surfaces and associated areas (urban areas >50%) and Mosaic Vegetation (grassland, shrubland, forest) (50-70%)/Cropland (20-50%).

In each climatic grid cell (0.5 degree), there are around 12321 woody cover (500m) and 34225 land cover grid cells (300m). For each woody cover grid cell, we compare its area with the surrounding land cover grid cells. Only woody cover grid cells that don't contain anthropogenic land use are recorded and form filtered woody cover dataset. Then following Hirota et al. [2011], we randomly take 0.5% from the filtered woody cover dataset and plotted histograms of woody cover under different precipitation bands (the same as Fig. R5) in Fig. R4. From Figure R4, we can find that the observed bimodality after filtering the anthropogenic land use still exists. We notice that land use is very important. However, as the main aim of this study is to interpret the observed bimodality by different growth rates with different developmental ages, we ignore the effect of anthropogenic land use to keep the analysis as simple as possible. The effect of land use will be added as: "Another aspect that has potential effects on the observed bimodality patterns is anthropogenic land use. We analyzed histograms of f_c by using the woody cover product from which grid points affected by land use (GlobalCover 2009 version <http://due.esrin.esa.int/globcover/>) are removed. The result (not shown here) confirms that anthropogenic land use does not strongly influence the observed bimodality."

4. "Paper title: I found the term 'semi-arid regime' confusing. What do you mean by 'regime' here? Could it be replaced by 'region'? Also, could you specify the geographical region of analysis in the title, e.g., 'central Africa', to make it clear that it is not semi-arid regions from the other continents."

A: The title will be revised as "Bimodality of woody cover and biomass across the precipitation gradient in West Africa"

5. "Paper abstract, 1.7-8: 'the simultaneous occurrences of savanna and forest

states under different precipitation forcing.’ Is it ‘different precipitation’ or ‘the same precipitation’? If it is different, what does ‘simultaneous occurrence’ mean?”

A: That is the same precipitation. Corrected.

6. “tau parameter is defined twice as a time scale of litter decomposition (p.89, line 2) and the shoot-total biomass ratio (p.89, l. 18). The later parameter should be noted by a different symbol. It leads to a confusion in Fig. 10, where a sensitivity to “tau” is presented.”

A: In P.89, L.18, we now use α instead of τ to indicate the shoot-total biomass ratio.

7. “The shoot-total biomass ratio is fixed to a value of 0.45 (p. 89, l.22). While it is a reasonable value for the shrub ecosystem, it is too low for the forest ecosystems, and it is too high for grasslands.”

A: In Yin et al. [2013], we performed a sensitivity analysis of total biomass to vegetation structure. We found that vegetation with vertical canopies can easier survive under water limited conditions. With the increase of precipitation, vegetation with a horizontal structure starts to survive. The first cluster of survived horizontal structures emerges with $\alpha = 0.45$ (Figure 9a in Yin et al. [2013]). Therefore, we decided to use $\alpha = 0.45$ as constant in this study to have a large survival threshold over the entire precipitation gradient. It is true that this value is not representative for all types of land cover. However, in this study we only have woody cover and above ground biomass data, which only allow us to retrieve canopy structures, but we cannot get a estimation of α from observations. Thus we fixed the value of α and focused on the effect of canopy structure on bimodality. In addition, α can influence the value of survival threshold and equilibrium biomass [Yin et al., 2013], it does not change the different growth rates of vegetation, which in turn has in principle no effect on the form of bimodality in the BOSVM (see Fig. R7). We will add this in the discussion section.

8. “When you are talking about the ‘vegetation continuous fraction’ (VCF) product (Hansen et al., 2003), could you please specify the version of the dataset you have used here. Also, sometimes you call it ‘tropical tree cover’ product (p. 84, l.23), sometimes “woody cover” product. Please be consistent in the terminology.”

A: The version we used is MOD44B. It will be added in the manuscript and the ‘tropical tree cover’ will be modified as ‘woody cover’.

9. “p. 96: discussion of clusters – could you please draw boundaries of these clusters on the figure to make it clear to the reader what exactly do you have in mind?”

A: A new figure (Fig. R6) will be added in manuscript to clearly illustrate the region of the four clusters that we distinguished.

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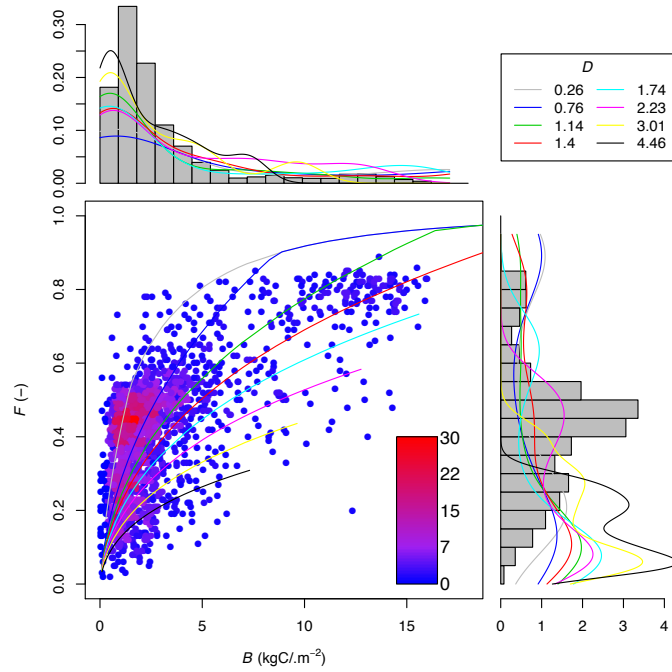


Figure R1: Observed and simulated above ground biomass (B) and woody cover (F) for mean annual precipitation $P = 1000 \pm 50$ mm. In left bottom panel, observed samples are plotted as points. The color represents the density of samples. Lines are trajectories of simulated results. Each line represents one type of canopy structure. The values of canopy structure parameter D are listed in the right top panel. Grey bars in left top and bottom right panels are histograms of observed B and F , respectively. Lines in those two panels are histograms of simulated results corresponding to the same color lines in the left bottom panel. The value of fire return interval (I) is 30 years.

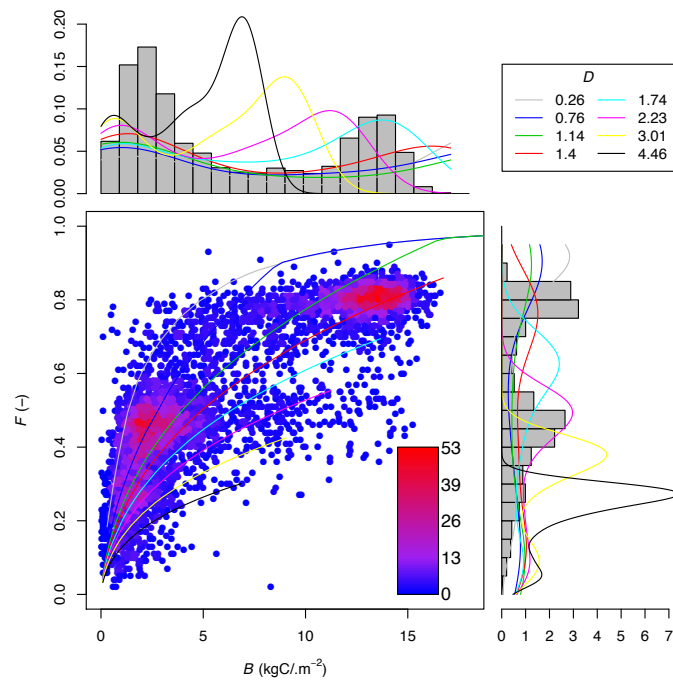


Figure R2: Observed and simulated B and F when $P=1200\pm 50$ mm yr $^{-1}$ while $I = 70$ yr.

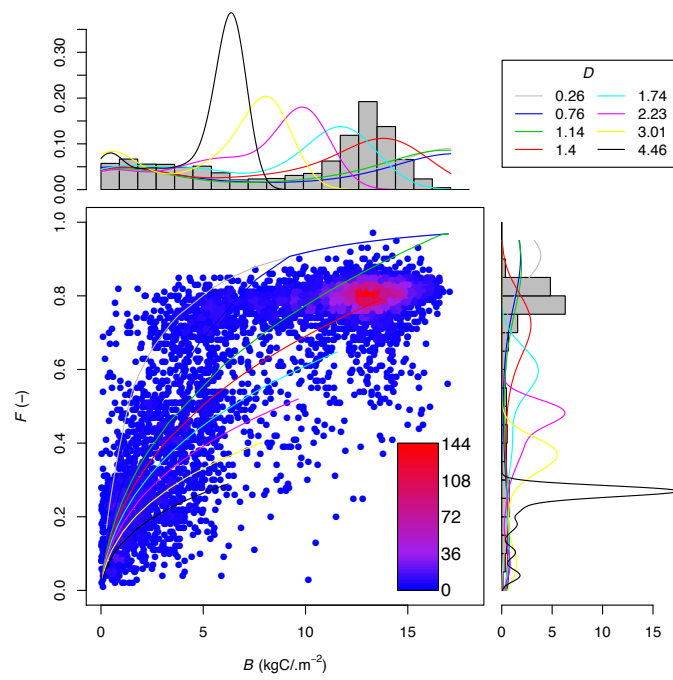


Figure R3: Observed and simulated B and F when $P=1500\pm 50$ mm yr⁻¹ while $I = 100$ yr.

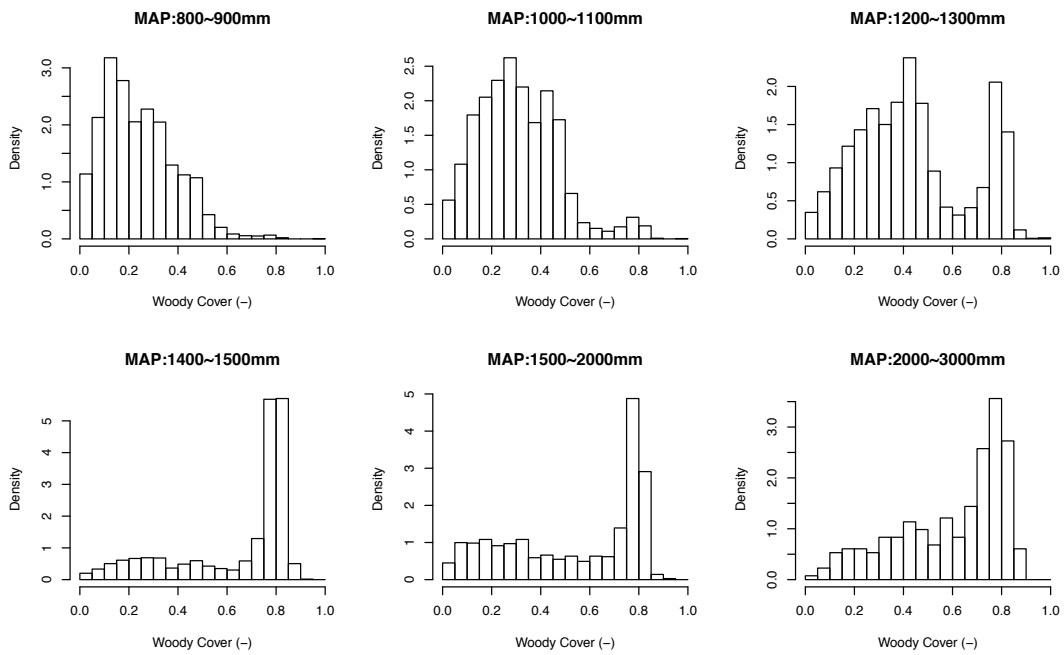


Figure R4: Histograms of observed woody cover under different precipitation regimes. The samples used here are from the observed woody cover dataset [Hansen et al., 2003] after filtering land use change by the GlobalCover dataset from ESA (<http://due.esrin.esa.int/globcover/>).

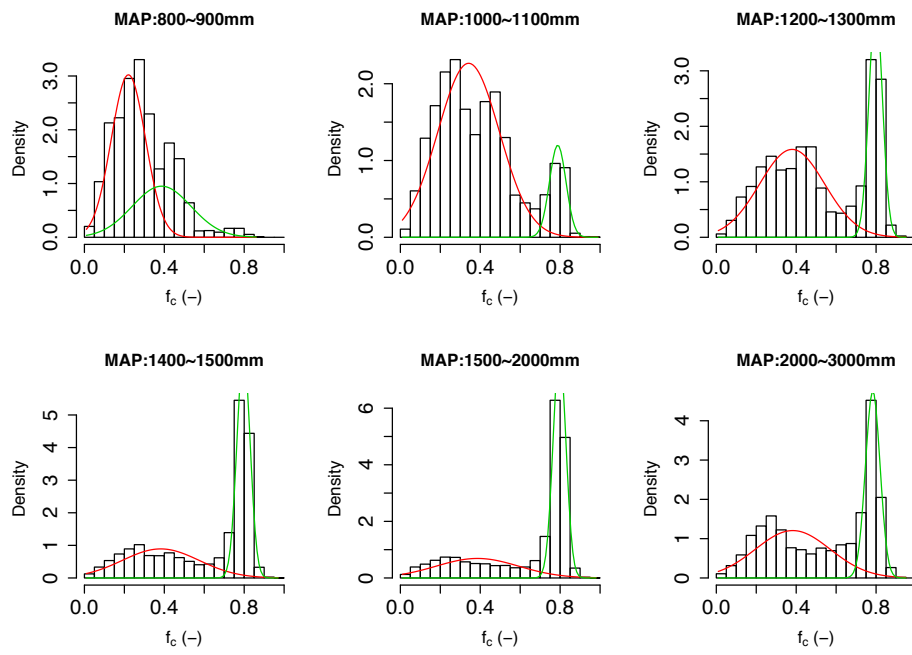


Figure R5: Figure 2 in the ESDD paper

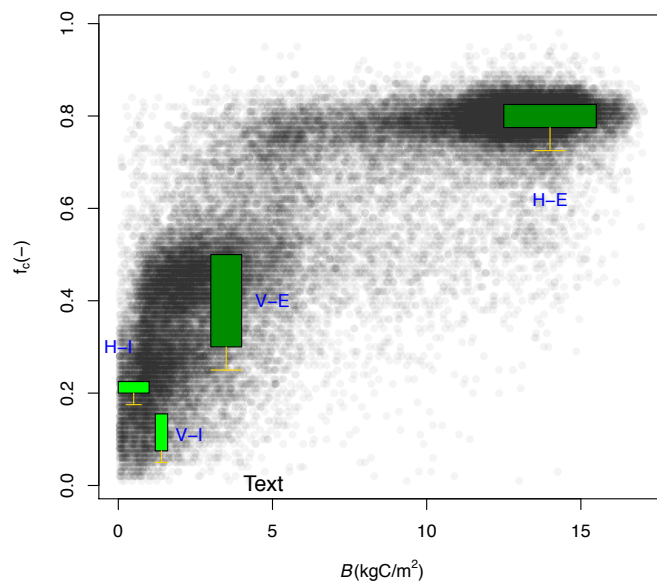


Figure R6: Regions of the four clusters of woody plants. Grey circles are observed samples of B and f_c . Each tree represents a specific clusters. Dark and light green indicates woody plants near its equilibrium and initial states, respectively.

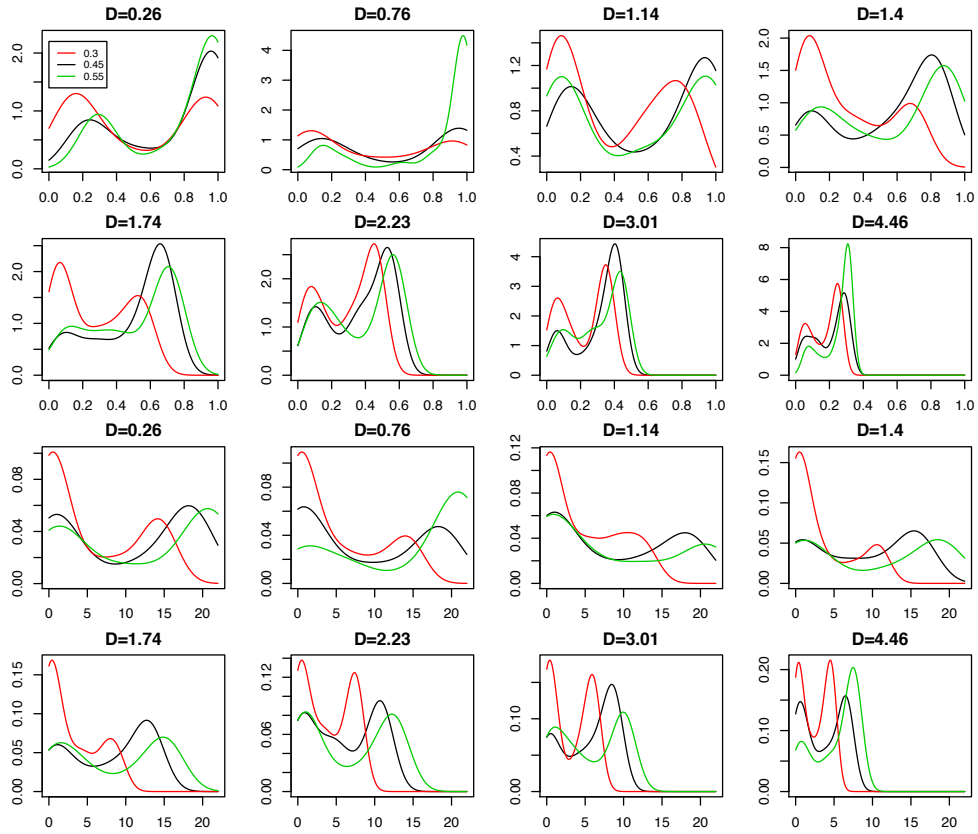


Figure R7: Simulated bimodality of f_c (top two rows) and B (bottom two rows) under $P = \pm 1200\text{mm}$ with $\tau = 30\text{yr}$, $I = 70\text{yr}$. For each value of D (each sub plot), three lines represents simulated density distribution of f_c (or B) with different shoot-to-total biomass (α).

Reply to comments from Referee #2

Z. Yin, S. C. Dekker, B. J. J. M. van den Hurk, H. A. Dijkstra

1. **“This paper is interesting and it addresses the well-known, and widely studied, problem of savanna dynamics and tree-grass coexistence. It is very interesting the distinction between horizontal and vertical structure.”**

A: Thanks for your interest and positive comments on our work.

2. **“On the other hand, other works (eg, Baudena et al 2009) find bimodality (in that case, associated with bistability) without the need for disturbances, and introducing the distinction between adult trees and seedlings, taking into account the differences in competition with grass. How do these results relate to the other mechanisms which have been proposed? How can one distinguish between the different mechanisms?”**

A: Indeed it is true that there is a large body of ecological literature explaining coexistence and bistability in savanna systems. However, we provide several new aspects to understand the modeled bistability and observed bimodality. New aspects are first that we analyze and model both woody cover and biomass. Second, we discuss the need and effect of disturbances by fire to understand bimodality and third we focus on the different approaches of age class modeling.

In the Discussion Section, we will add: “A large number of experimental and modelling studies have focused on the tree-grass co-existence from an ecological perspective (eg. Higgins et al. [2000], Baudena et al. [2010] and Sankaran et al. [2005]) thereby mainly focusing on cover and far less on biomass. In our paper we have demonstrated bimodality in both observed woody cover and biomass. It is interesting to see that for high cover fractions both high and low above ground biomass occurs. With our coupled energy-water-biomass model that distinguishes horizontal and vertical structures of woody vegetation we are for the first time able to fit observed bimodality in woody cover and biomass (Fig. 11).

Modelling bimodalities in tree cover is generally done with a fire-vegetation feedback mechanism, in which fire limits tree establishment and induces tree mortality (e.g. Staver and Levin [2012]). As it is also thought that the majority of the fuel for the fire is provided by the grass biomass (e.g. Higgins et al. [2000]), the outcome is that fire frequency is reduced by an increase in tree cover. In general, without disturbance the models will simulate full tree cover due to the competitive exclusion mechanism [Tilman, 1982], also in the wet regimes, where our analysis is focused owing to the availability of above ground biomass observations in these regions.

Our approach of age class modeling, in which the vegetation increases its biomass, while

keeping the same structure is similar to models using tree seedlings and adult trees (e.g. Baudena et al. [2010], Scheiter and Higgins [2009]). Baudena et al. [2010] found that tree seedlings compete for the same water as grasses, while adult trees can outcompete grass as it has deeper roots. A similar mechanism is found in our model: young species compete against bare soil processes, while more adult trees have higher root depths having more water resources.”

We will thank Mara Baudena for her contribution to this discussion in the acknowledgement.

3. “Finally, the paper is plagued with a continued use of too many acronyms which make it very difficult to read. Streamlining the presentation and reducing the jargon/acronyms would help.”

A: We have defined a group of mathematical symbols instead of acronyms (e.g. B for AGB, P for MAP, etc).

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