Interactive comment on “Climate seasonality limits carbon assimilation and storage in tropical forests” by Fabien H. Wagner et al. Anonymous Referee #1

This manuscript explores the seasonal correlation of carbon assimilation (estimated using MODIS EVI), above-ground wood productivity and litter productivity. The originality of this work stems in the large dataset compilation made by the authors, which includes data from 89 tropical sites throughout the world. The drivers of the seasonal dynamics of photosynthesis and structural growth has been studied separately in the past, but their joint analysis at large scale is a major novelty of this work. I have no doubt that the focus of this study is of general interest. However, I felt that an additional effort of clarification and justification would benefit the quality of the paper.

Dear Reviewer#2, thank you very much for your review. In the new version of the paper, we have considered your comments and suggestions, and made several changes in the text. We now believe that the paper is clearer and more accurate.

General comments

The word “storage” in the title, is in my opinion confusing as it could refer to the nonstructural carbohydrate tree compartment. I suggest to consider another word (e.g., “above-ground growth”).

FW: the title was changed to “Climate seasonality limits leaf carbon assimilation and wood productivity in tropical forests”.

The authors used statistical analyses that seems overly complex. For example, in order to demonstrate that wood productivity changes are mostly related to seasonal precipitations, the authors estimated simple linear models for each variables, then performed a McNemar test on the resulting contingency tables, before performing a cluster analysis on the table of p-values of the McNemar test. My general feeling is that this complexity might be required (for example in order to deal with collinearity issues among covariates) but must be better justify and better described (see detailed comments).

FW: We have added more details on the descriptions and aims of the methodology. The paragraph was changed to “To address the first question 'Are seasonal aboveground wood productivity, litterfall productivity and photosynthetic capacity dependent on climate?', we analyzed with linear models the relationship between our variable of interest (wood productivity, litterfall productivity and photosynthetic capacity) and each climate variable at each site and at t, t-1 month and t+1 month. These lags were chosen to account for between-years variations in the climate seasonality, as we used in our analyses the average climate per site. For a given site, if the wet season have started with one month of delay the year when the tree diameter increment were measured, a lag could exist in the relation of the variable of interest with the monthly averages of climate variables used in linear models. The results were classified for each variable as a count of sites with significantly positive, negative or non-significant results. To enable between-sites comparison, when the overall link was negative, the linear model was finally run with the climate variable multiplied by -1. For a given climate variable, a site with a significant association at only one of the time lags (-1, 0 or 1) was classified as significant. This strategy enables to highlight the potential drivers of our variable of interest, which are the climate variables with a constant relation with the variable of interest in all the sites. Climate variable with no effect, or effect due to a particular correlation with a potential driver at some sites, will show changes in the sign of the relation with the variable of interest. Then, a McNemar test was run to compare the proportion of our classification (negative, positive or no relationship) between all paired combinations of climate variables accounting for dependence in the data, that is, to compare not only the proportion of positive, negative and no significant effect between two climate variables but also to detect if the sites in each of the classes were similar. In order to summarize all the relations between the climate variables, a table (similar to a correlation table) containing all paired combination p-values of the McNemar test was built. In this table a p-value < 0.05 indicate that a different association between the two climate variables and the variables of interest cannot be rejected. To determine which climate variables explain the same part of variance and to enable interpretation, a cluster analysis was performed on the table of p-values of the McNemar test using Ward distance. Climate variables in the same cluster indicate that they share a similar relation with the variable of interest."

The logical link among the last three sentences of the first paragraph is not obvious to me. Brienen et al., as well as van der Sleen et al., used annually or multi-annually resolved datasets without explicit reference to the seasonal dynamic of the carbon cycle. I agree that this seasonal dynamic may be key to understanding some of the results reported by the cited authors: e.g., the increasing trend of tree mortality found in Brienen et al. may well be explained by the seasonal dynamic of soil water stress and leaf water potential (e.g., Rowland et al., Nature, 2015), or the seasonal dynamic of nonstructural carbon reserve (e.g., Dickman et al., Plant, Cell & Env, 2015). This part of the introduction needs, in my opinion, to be rewritten in order to justify the importance of a better understanding of the seasonal drivers of the carbon cycle.

FW: This part of the introduction have been changed to "Tropical forests have a primary role in the terrestrial carbon (C) cycle, constituting 54% of the total aboveground biomass carbon of Earth's forests (Liu et al., 2015) and accounting for half (1.19 ± 0.41 PgC yr^{-1}) of the global carbon sink of established forests (Pan et al., 2011; Baccini et al., 2012). Based on annual or multi-annual measurements of forest wood productivity, changes in carbon dynamics and functioning of the tropical trees have already been observed. While tropical forests have been acting as a long-term, net carbon sink, a declining trend in carbon accumulation has been recently demonstrated for Amazonia (Brienen et al., 2015). Furthermore, a positive change in water-use efficiency of tropical trees due to the CO_2 increase over the past 150 years has also been observed (van der Sleen et al., 2015; Bonal et al., 2011). Currently, increasing evidences show that the tropical forests present a seasonality in the assimilation and storage of carbon, associated with climate seasonality (Wu et al., 2016; Doughty et al., 2014; Rowland et al., 2014b, a; Wagner et al., 2014). However, the inherent problems of these studies are that they are one-site or region-based, that renders difficult the disentangling of potential climate drivers due to collinearity between climate variables. Moreover, they sometime focus on a single part of the carbon cycle that may lead to erroneous interpretation on forest productivity due to interactions among the carbon cycle components (Doughty et al., 2014). Understanding the seasonal drivers of the carbon cycle in a pan-tropical context and as well as crossing the maximum information available on carbon storage and assimilation is therefore needed to assess the mechanisms driving changes in forest carbon use and predict tropical forest behavior under future climate changes."

More generally, I felt that this introduction needs to include a broader overview of what is already known about the seasonal dependencies of the carbon cycle to climate and internal factors. Some very interesting results have been obtained (some of them authored by the authors of the present study) regarding the determinism of the seasonal growth of the different tree compartments (wood, leaf, fine root, reserve), as well as the dependencies of photosynthesis in a tropical context. A presentation of these previous works would allow the reader to better understand the novelty and the limits of the present study.

FW: We have completed this part of the introduction to give more details on the dependencies of the carbon cycle to climate and endogenous factors. The paragraph is now "Despite long-term investigation of changes in forest aboveground biomass stock and carbon fluxes, the direct effect of climate on the seasonal carbon cycle of tropical forests remain unclear. Contrasting results have been reported depending on methods used. Studies show an increase of aboveground biomass gain in the wet season from direct measurement (biological field measurements), or, from indirect measurement, an increase of canopy photosynthetic capacity in the dry season (remote sensing, flux tower network) (Wagner *et al,* 2013}. Several hypotheses have been proposed to explain these patterns: (i) wood productivity, estimated from trunk diameter increment, is mainly controlled by rainfall and water availability and occurs preferentially during the wet season, even if carbon accumulation in the trees could be greater in the dry season than in the wet season, likely reflecting a tradeoff between maximum potential growth rate and hydraulic safety (Rowland *et al,* 2014; Rowland *et al,* 2014b; Wagner *et al,* 2014). Seasonal variation in carbon allocation to the different parts of the plant (crown, roots) also contribute to optimizing resource use and could explain the low synchronicity between wood productivity and carbon accumulation in the trees (Doughty *et al,* 2014; Doughty *et al,* 2015; Rowland *et al,* 2014). (ii) litterfall peak mainly occurs during dry periods as a combination of two potential climate drivers: seasonal changes in daily insolation leading to production of new leaves and synchronous abscission of old leaves, and high evaporative demand and low water availability that both induce leaf shedding in the dry season (Borchert *et al,* 2015; Zhang *et al,* 2014; Wright *et al,* 1990; Chave *et al,* 2010; Myneni *et al,* 2007; Jones *et al,* 2014; Bi *et al,* 2015); and (iii) photosynthesis in these tropical forested regions is mainly controlled by water limitations and is sustained during the dry season above a threshold of 2000 mm of mean annual precipitation (Restrepo-Coupe *et al,* 2013; Guan *et al,* 2015). Water limitation is not the only known control, and other climate variables and internal carbon allocation have been demonstrated to drive photosynthetic capacity in tropical forests such as irradiance, temperature and leaf dynamics. Irradiance is directly and positively linked to plant photosynthetic capacity, carbon uptake and plant growth (Graham *et al,* 2003), while temperatures above 30°C drive a reduction of photosynthetic capacity (Lloyd *et al,* 2008; Doughty *et al,* 2008; Doughty *et al,* 2011). Recently, for non-water-limited forests in Amazonia, Wu et al (2016) showed that the increase in ecosystem photosynthesis during dry period result from the synchronization of new leaf growth and litterfall, shifting canopy composition towards younger more light-use efficient leaves."

The enhanced vegetation index used by the authors in this study is claimed to be a proxy of "the canopy photosynthetic capacity". Among others, a recent study cited by the authors (Guan et al., 2015, Nature Geosc.) indeed used EVI as "a proxy for vegetation greenness and photosynthetic potential", which is supported by the strong correlation between EVI and satellite-based chlorophyll fluorescence. But EVI is also known to "include information on forest canopy structure" (Guan et al., 2015, Nature Geosc.). I felt that the complexity of the EVI signal is not emphasized enough in the present paper, as the authors refer to EVI as a "proxy of leaf production", that is, only forest canopy structure. For example, the author have to assume that some big trees at light-limited sites shed leaves because of high evaporative demand, in order to explain the decoupling between EVI and litterfall. It is indeed plausible, but the authors should provide some references to support this assumption

FW: Recently, Chavana-Bryant et al (2016) have demonstrated that EVI and more generally greenness vegetation index are age-dependent, on a cohort of 1099 leaves from 12 lowland Amazonian canopy trees in southern Peru. Across all trees, EVI and NDVI initially increased with leaf development (from youngest to mature cohorts), and then declined when leaves were at old and senescent stages. Previously, concomitant seasonal increase in leaf flushing and EVI has been reported (Brando et at., 2010, Wagner et al., 2013). These results support our assumption that increase of EVI is mainly linked to maturation of new leaves and that when EVI reached its highest, it seems to represent the moment when leaves are fully mature, the moment of the highest greenness and canopy photosynthetic capacity.
In the introduction we add the sentences: "EVI strongly correlated with chlorophyll content and photosynthetic activity (Huete et al., 2002, 2006), and we used a corrected version of the index to account for sun-angle artifact (Morton et al., 2014; Wagner et al., 2015). While positive correlation of leaf flushing and EVI has already been reported in tropical forests (Brando et at 2010; Wagner et al, 2013; Wu et al, 2016), Chavana-Bryant et al. (2016) have demonstrated that EVI increased with leaf development (from youngest to mature cohorts, and then declined when leaves were at old and senescent stages. Here, we assume that EVI represent the maturation of new leaves and that the highest value of EVI represents the highest greenness and canopy photosynthetic capacity, when leaves are fully mature."

Otherwise, they should discuss as well the possibility that – for the range of LAI explored here – EVI changes reflect actually mainly the changes in leaf photosynthesis activity (gC/m2leaf, independently of the total leaf biomass and litterfall). Could you explain why you discarded this latter possibility? I think that your dataset (EVI + litterfall at numerous sites) is very much suited to explore what is actually measured by the EVI.

FW: As we don't have field measurements of GPP, we choose to assume that EVI is the canopy photosynthetic capacity (or photosynthetic potential) based on Guan et al (2015). Furthermore, even if litterfall production is a proxy of annual leaf production in terms of annual mass balance (Aragão et al 2009), little is known on how litterfall is linked to leaf production at a seasonal scale. Wu et al (2016) indeed showed that litterfall and leaf production occur in the same time in non-water-limited forests of Amazonia (Wu et al, 2016) and they also point out that leaf dynamics give a more accurate prediction of seasonal leaf photosynthesis activity than vegetation indices do, so we prefer to refer to "a proxy of photosynthesis capacity" for EVI. However, even having acknowledged that the results of Wu et al (2016) show that EVI from MAIAC did not reproduce exactly the photosynthetic capacity as well as their dynamic models of leaves in their sites, at the scale of our study, EVI from satellite data represent currently the only manner to have an estimate of photosynthesis capacity.

In the Discussion section we change the sentence "If the increase in EVI is a proxy of leaf production, our result supports..." To "If the increase in EVI is a proxy of leaf maturation, as already observed in a tropical forest of southern Peru (Chavana et al, 2016), our results supports…". And, we add a last sentence to this paragraph: "However, more detailed data on the leaves dynamics would be necessary to confirm these assumptions."

The authors assumed that a fraction of the 89 studied sites are light-limited, based on reported higher temperatures during dry than during wet season at these sites. Although I agree that light limitation at wet sites is in line with our knowledge of photosynthesis, I felt that this assumption, that is key in this paper, deserve further justification. Indeed, the assumption that temperature actually reflects "solar energy available for the plants" is not supported by references. This is annoying, because temperature is closely link to the water evaporative demand, which is a component of drought. I have the feeling that the correlation between normalized precipitation and normalized EVI at light-limited sites may be significantly negative, which may be in line with the author's assumption (given that precipitation occurs only with a cloud cover). Would you obtain patterns similar to Fig. 5c with a variable more directly related to light availability, such as standardized cloud cover?

FW: Thank you for this comment. Indeed, the assumption that temperature actually reflects "solar energy available for the plants" is not supported by references. Our assumption was that the seasonality of maximal temperature follows the solar cycle, but with a better accuracy of the energy reaching the surface because maximal temperature integrates *de facto* the cloud cover. To test this assumption, we have explored the link between the maximal temperature from the Climate Research Unit data and the incoming radiation at the surface modelled by the CERES. Monthly incident shortwave radiation flux data were obtained from CERES SYN1deg product, version 3A, provided at 1° spatial resolution from March 2000 to Jun 2015. Shortwave (SW) radiation refers to radiant energy with wavelengths in the visible, near-ultraviolet, and near-infrared spectra. The SW radiation flux is produced using MODIS data and geostationary satellite cloud properties (Kato et al., 2011). The SYN1deg product provides datasets calculated for all-sky, clear-sky, pristine (clear-sky without aerosols), and all-sky without aerosol conditions. Here, we used only the product made for all-sky. The results are presented in Fig. 1. This result indicates that the seasonality of maximal temperature is highly correlated with the seasonality of incoming solar radiation at the surface. Seasonal maximal temperature is, hence, a reasonable proxy of the seasonal solar energy available for the plant. The spatial resolution of CERES data is 1° and the time series cover the period between 2000-2015 while the resolution of CRU is 0.5° , encompassing the period between 1901-2012.

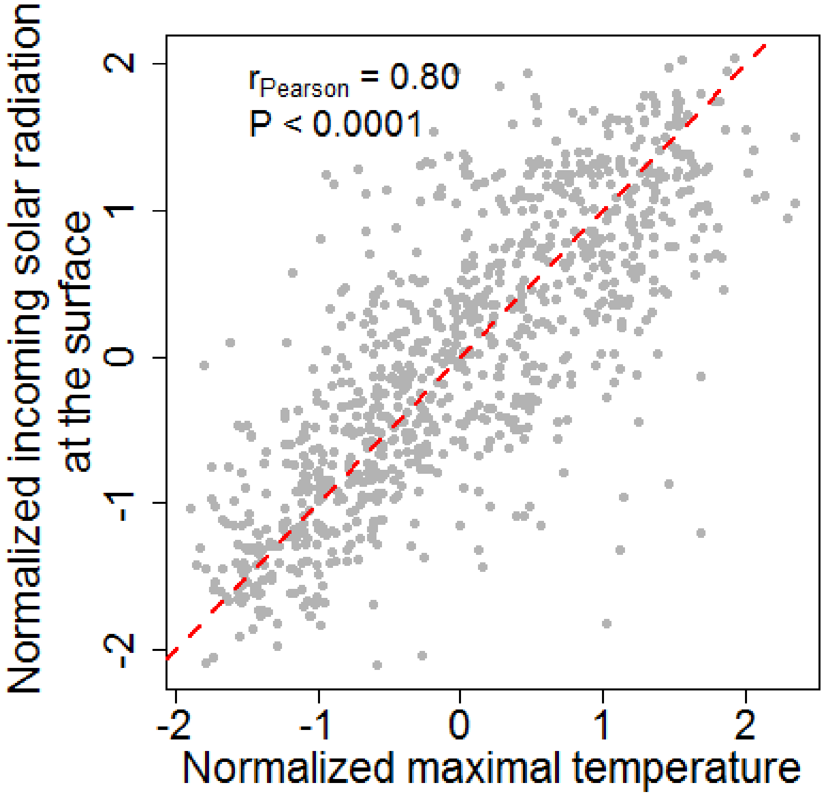

Figure 1: Association between normalized maximal temperature from Climate Research Unit and normalized incoming solar radiation at the surface from CERES.

To answer reviewer #1 question "Would you obtain patterns similar to Fig. 5c with a variable more directly related to light availability, such as standardized cloud cover?", we have reproduce Figure 5c, with maximal temperature Fig. 2 (a) and with incoming solar radiation at the surface from Ceres in Fig 2 (b).

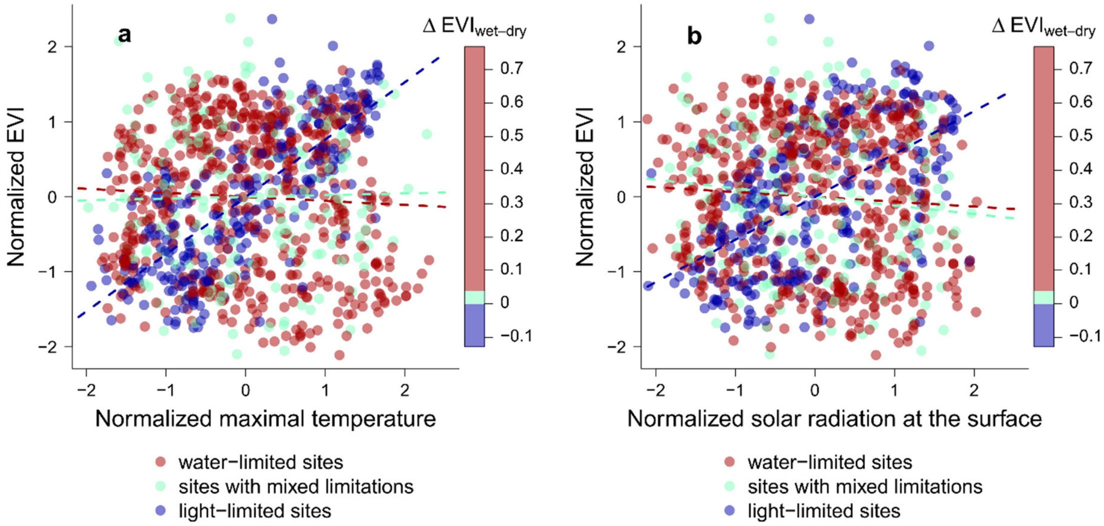

Figure 2 :

The pattern in Fig. 2a and 2b are similar. For water-limited sites and sites with mixed limitation, the linear models of EVI as a function of maximal temperature (clear blue dashed lines) or incoming solar radiation (red dashed lines) are not statistically significant. For the light limited sites, the summary of the linear regressions (blue dashed lines) are given in the Table 1. The slopes of the models in light limited sites are both positive but slightly higher for maximal temperature (slope 95% confidence interval of 0.69-0.84 for maximal temperature, and 0.47-0.67 for incoming solar radiation at the surface). The R squared of the models indicate that maximal temperature explains a larger part of the variance of EVI (R^2=0.58) than does solar radiation at the surface (R^2=0.33).

Table 1 : Summary of the linear models of normalized EVI as a function or normalized maximal temperature and incoming solar radiation at the surface

Linear models	Site limitations	parameter	Estimate	Std. Error	t value	p-value	R^2
EVI ~ temperature_{max}	Light limited	(Intercept)	-2.965e-16	3.651e-02	0.00	1	0.58
		tmx	7.643e-01	3.813e-02	20.04	<0.0001	
EVI ~ solar radiation at the surface	Light limited	(Intercept)	-1.897e-16	4.647e-02	0.00	1	0.33
		Sol surface	5.711e-01	4.854e-02	11.77	<0.0001	

These additional analyses confirm our interpretation that maximal temperature is a reasonable proxy of solar radiation at the surface. We choose to kept maximal temperature from the CRU in the analysis and not include CERES data of incoming solar radiation, as they represent similar information and because maximal temperature explain a larger part of EVI seasonality (R^2=0.58 versus 0.33). However, in Material, we added the sentence “Additionally, we used …..and monthly incoming radiation at the surface (rad_{surf}, W.m^{-2}) from CERES SYN1deg product computed for all-sky conditions, provided at 1° spatial resolution from 2000 to 2015. Monthly incoming radiation at the surface (shortwave radiation) refers to radiant energy with wavelengths in the visible, near-ultraviolet, and near-infrared spectra and is produced using MODIS data and geostationary satellite cloud properties (Kato et al., 2011).”.

Figure 1 included in the responses to reviewer#1 comments, replaced Figure 8 of the article and the legend of Fig. 8 in now: “Association between normalized maximal temperature from Climate Research Unit and normalized incoming solar radiation at the surface from CERES. Monthly incoming solar radiation at the surface (incident shortwave radiation) refers to radiant energy with wavelengths in the visible, near-ultraviolet, and near-infrared spectra and is produced using MODIS data and geostationary satellite cloud properties (Kato et al., 2011).”.

In the results, the following sentence was deleted “For these sites, while solar radiation at the top of the atmosphere is not different between the dry and wet seasons, maximal temperature is higher in the dry season, thereby reflecting solar energy available for the plants (Fig. 8).” and replaced by “For all the sites, maximal temperature is highly correlated with incoming solar radiation at the surface (rPearson =0.80, p-value < 0.0001), approximating solar energy available for the plants (Fig. 8)”

Specific comments

P.5. - L.13. “discrepancies” is confusing here, as we do not know which discrepancies the authors are referring to (temporal discrepancies, or discrepancies between biomass and photosynthesis). I suggest using another word, e.g. “patterns”.

FW: “discrepancies” was deleted and the word “patterns” is now used.

P.6. - L.11. The tables are not cited in ascending order (Table 2 is cited for the first time before Table 1). The figures are not cited in ascending order either. Please, correct this.

FW: The order of the tables and of the figures had been corrected to be cited in ascending order in the text.

P.6. - L.22:23. “For each tree. . .” This sentence is unnecessary (and in my opinion, confusing), as the whole process is explained in details in the subsequent sentences. Furthermore, please explain in which cases you deleted the increment, and in which cases you corrected it.

FW: The sentence L.22:23. “For each tree. . .” was deleted. The paragraph on the corrections was changed to “If the error was clearly identifiable, such as an abnormal increase (or decrease) in diameter values followed by a large decrease (or increase) of the same amplitude resulting from typo errors, for example 28 whereas 2.8 was expected, the typo error was corrected. When the typo error was not clearly identifiable, the value was corrected with linear approximation with the mean increment of t+1 and t-1. In some cases there was an identifiable increase of diameter values (or decrease), but not followed by a decrease (or an increase) of the same amplitude. This pattern was associated to the repositioning of the dendrometer bands (reported in the source dataset). In this case, the increment was deleted and set to zero and the new time series of cumulative diameter values were computed. As the diameter values are needed to compute biomass, this strategy was used to benefit of the full time series of diameter increment even after solving the error.”

P.7. - L.3. Please, mention here the temporal and spatial resolution of the MODIS product.

FW: the sentence “EVI for the 89 experimental sites (Fig. 1) was obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS) MCD43 product collection 5 (4 May 2002 to 30 September 2014).” was changed to “EVI for the 89 experimental sites (Fig. 1) was obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS) MCD43 product collection 5 provided every 16 days at 500m spatial resolution (from 4 May 2002 to 30 September 2014).”

P.7. Please, better justify the processing of EVI data (e.g., why did you use a square of 40km? Why did you average pixels surrounding the sites, instead of simply using the values of the pixel sites?).

FW: In tropical forest regions, few valid MCD43 observations of EVI are available for a pixel, mainly due to obstruction of visible wavelengths by cloud cover and aerosols in the atmosphere. For a given pixel, there is a high probability of missing data in the EVI time series. For resolving this problem, the adopted solution assumed that the forest around the site was homogenous and had the same EVI value of the pixel from the studied site. Then the EVI of the site at a given month was estimated as the mean of all the valid pixels of the surrounding forest. The validity of pixels was defined based on the MCD43 quality index (extracted from MCD43A2 product) from 0 (Good quality) to 3 (All magnitude inversions or 50% or less fill-values). Pixels of quality index 4 (50% or more fill-values) and 255 (Fill-values) were discarded. The pixels representing forests in the 40 km square window were selected based on the land cover map available from the product MCD12Q1 for 2001–2012 at 500 m resolution (Justice et al., 1998); and from the global forest cover loss 2000–2012 and data mask based on Landsat data (Hansen et al., 2013). Only the pixels forested in 2000, without forest losses during the studied period and with tree cover equal or above to the site tree cover were retained.

In this work, we have considered square window of 40km centered on the site to compute the mean EVI to have a reasonable amount of valid pixels to estimate the monthly value of EVI. Using this procedure, only one month at one site had only one value to estimate monthly EVI (Table 1) while 88.8% of the months have 100 or more values to estimate the monthly EVI.

Table 2: number of valid observations of EVI per months

Classes of the number of pixels used to estimate monthly values	Number of months in the classes	Frequency (%)
(1,2]	1	0.1
(2,5]	4	0.4
(5,10]	12	1.1
(10,50]	55	5.1
(50,100]	48	4.5
(100,>100[	948	88.8

In the text, we have added the sentence "This surface was selected to maximize the quantity of valid pixels to estimate monthly site's EVI, as, due to persistent cloud cover in tropical forest regions, valid observations of EVI are limited, producing incomplete time series of EVI values for a given pixel."

P.8. - L.5:6. This formulation "normalized by their site's annual mean values and standard deviation" is confusing. Please, give more details about the standardization methodology.

FW: The sentence was deleted and changed to "As at some sites, wood productivity or litterfall measurements are older than the EVI measurements (before 2002), and, for recent site measurements, climate data are not yet available (after 2012), all the datasets were monthly averaged by site. Then, in order to remove the site effect on the mean and the variance of the variables and to analyze only seasonality, all the variables were centered and scaled by site. For a given variable of a site, monthly values were subtracted by their annual mean and divided by their annual standard deviation. The obtained normalized variable had a mean of 0 and a variance of 1, but the variation in the variable time-series, that is in our case the seasonality, remained completely unchanged."

P.9. - L.17. If I am not mistaken, "the predictive model of wood productivity by precipitation" has never been presented before. Consequently, we do not know what the authors are referring to.

Please, correct this sentence, and cite the Table 4 (FW: which is now Table 3 with the new table order) in the Results section.

FW: We changed the paragraph to “To test how swelling and shrinking affect our results, we made first a linear model of wood productivity with precipitation as a single predictor with all the data, and then a similar linear model discarding the first month of the wet season (first month with precipitation > 100 mm) and the first month of the dry season (precipitation < 100 mm). Here, we assume that swelling occurs in the first month of the wet season and shrinking occurs in the first month of the dry season, as already observed. The removal of the first month of dry and wet seasons (defined respectively as the first month with precipitation > 100 mm and the first month with precipitation < 100 mm) did not affect the results of the linear model of wood productivity as a function of precipitation, that is, intercepts and slopes are not significantly different in both models (overlaps of the 95\% confidence interval of coefficients and parameters, Table 3)”. The parameter of the linear models and the R^2 were added to Table 3. As this is a preliminary analysis, we choose to only refer to Table 3 in Methods.

P.12. - L.32. “From the climatic point of view” is not proper English.

FW: “From the climatic point of view” was deleted of the sentence.

P.14. - L.16. I do not see the point to referring to the genetic loci names here. Please, explain in more details how and why this information is relevant.

FW: To clarify, the sentence referring to the genetic loci names was deleted.

P.15. - L.5:6. I do not understand this sentence. What is the difference between carbon assimilation and photosynthetic capacity seasonal pattern? Please rephrase.

FW: Sorry for this, it was an error. The sentence was changed to “Although seasonal carbon allocation to aboveground wood production is driven by water, whether the seasonality of photosynthetic capacity is driven by light or water depends on the limitations of site water availability.”

P.15. - L.7. This last sentence is confusing to me. What is a “direct limitation of canopy photosynthetic capacity” compare to “a reduction of canopy photosynthetic capacity in the dry season”. Please rephrase.

FW: The last sentence was changed to “In a drier climate, from our results we can make the following assumptions: (i) in water limited forests, the reduction of the wet period duration could lead to a time reduction of favorable conditions for carbon assimilation and allocation. (ii) In current light-limited forests with future precipitation below to the 2000 $mm.yr^{-1}$ threshold, the intensification of the dry period could suppress the canopy photosynthetic capacity increase during this high solar radiation period, reducing carbon assimilation and making these forests shift to water limited forests. However, in light-limited forests with future precipitation above the 2000 $mm.\ yr^{-1}$ threshold, as cloud cover has been shown to limits net CO_2 uptake and growth of tropical forest trees (Graham et al, 2003), it remains uncertain how reduction of cloud cover will affect the productivity.”

Figure 5. Why do the dash lines represent the relationship between climate variable and modelled EVI, rather than observed EVI, in line with the data depicted with dots? The statistic info of the different regression lines should be provided.

FW: The dash lines represent the linear relationship between climate variable and observed EVI for water-limited sites, sites with mixed limitations and light-limited sites. We have added a table with the statistics info of the regression line (Table S8). We have changed the sentence to "The dashed lines in (b) and (c) represent the linear relationship between climate variable and observed EVI for water-limited sites, sites with mixed limitations and light-limited sites. Parameters of the models are given in Supplementary Table S8.

Figure 7. Please, rewrite this caption. It does not accurately describe the figure.

FW: Following the General comment 5 of reviewer 1, the figure was deleted and replace by the figure 1 of the response of reviewer. The title is now "Association between normalized maximal temperature from Climate Research Unit and normalized incoming solar radiation at the surface from CERES. Monthly incoming solar radiation at the surface (incident shortwave radiation) refers to radiant energy with wavelengths in the visible, near-ultraviolet, and near-infrared spectra and is produced using MODIS data and geostationary satellite cloud properties (Kato & al, 2011). The red dashed line is the identity line y = x."

In my opinion the cross correlation plot, especially Figure 10, do a poor job in illustrating the author's results. For example, I do not understand how Fig. 10a shows that "EVI seasonality is well associated with aboveground wood production for water-limited forests". If I assumed that the Y-axis is actually the "number of sites with a significant correlation", which is not mentioned by the authors, I could evaluate this statement by comparing the number of significant sites against the total number of sites. . .which is not straightforward. The direct information given by these plots is whether of not the light and water-limited sites have a similar time-lags in their correlation. This information is however not discussed by the authors.

FW: The sentence "EVI seasonality is well associated with aboveground wood production for water-limited forests" was changed to "In water-limited forests, the seasonality EVI and aboveground wood production are synchronous for the majority of the sites (Fig. 10a), as a consequence of their relationship with precipitation." The title of the figure 10 was changed to "Cross-correlation between monthly EVI and wood productivity (a), EVI and litter productivity (b) and wood and litter productivity (c) for water- and light-limited sites. The x-axis indicates the time-lag to get the maximum correlation between the variables. When no observations were available for wood and litter productivity, predictions from the climatic model were used (Table 4). To facilitate graphical representation, cross-correlation (a) is positive, (b) and (c) are negative. A positive cross-correlation at lag one month indicates a similar seasonal pattern in the time series with a time lag of one month, while a negative cross-correlation at lag one month indicates an opposite seasonal pattern with a time lag of one month. All the water-limited and light-limited sites were represented (respectively 50 and 24 sites) as only 4 water-limited sites in (a) and 3 in (b), and only 2 light-limited sites in (c) have no statistically significant cross-correlation."

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Climate seasonality limits leaf[FW] carbon assimilation and ~~storage~~wood productivity[FW] in tropical forests.

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Abstract. The seasonal climate drivers of the carbon cycle in tropical forests remain poorly known, although these forests account for more carbon assimilation and storage than any other terrestrial ecosystem. Based on a unique combination of seasonal pan-tropical data sets from 89 experimental sites (68 include aboveground wood productivity measurements and 35 litter productivity measurements), their associate canopy photosynthetic capacity (enhanced vegetation index, EVI) and climate, we ask how carbon assimilation and aboveground allocation are related to climate seasonality in tropical forests and how they interact in the seasonal carbon cycle. We found that canopy photosynthetic capacity seasonality responds positively to precipitation when rainfall is < 2000 mm.yr^{-1} (water-limited forests) and to radiation otherwise (light-limited forests); on the other hand, independent of climate limitations, wood productivity and litterfall are driven by seasonal variation in precipitation and evapotranspiration respectively. Consequently, light-limited forests present an asynchronism between canopy photosynthetic capacity and wood productivity. ~~Precipitation first-order control indicates an overall decrease in tropical forest productivity in a drier climate.~~Precipitation first-order control indicates a decrease in tropical forest productivity in a drier climate in water limited forest, and in current light-limited forest with future rainfall < 2000 mm.yr^{-1}.^{FW}

1 Introduction

Tropical forests have a primary role in the terrestrial carbon (C) cycle, constituting 54% of the total aboveground biomass carbon of Earth's forests (Liu et al., 2015) and accounting for half (1.19 ± 0.41 PgC yr^{-1}) of the global carbon sink of established forests (Pan et al., 2011; Baccini et al., 2012). Based on annual or multi-annual measurements of forest wood productivity, changes in carbon dynamics and functioning of the tropical trees have already been observed.$^{\mathrm{FW}}$ While tropical forests have been acting as a long-term, net carbon sink, a declining trend in carbon accumulation has been recently demonstrated for Amazonia (Brienen et al., 2015). Furthermore, a positive change in water-use efficiency of tropical trees due to the CO_2 increase over the past 150 years$^{\mathrm{FW}}$ has also been observed (van der Sleen et al., 2015; Bonal et al., 2011). Currently, increasing evidences show that the tropical forests present a seasonality in the assimilation and storage of carbon, associated with climate seasonality (Wu et al., 2016; Doughty et al., 2014; Rowland et al., 2014b, a, 2015; Wagner et al., 2014). However, the inherent problems of these studies are that they are one-site or region-based, that renders difficult the disentangling of potential climate drivers due to collinearity between climate variables. Moreover, they sometime focus on a single part of the carbon cycle that may lead to erroneous interpretation on forest productivity due to interactions among the carbon cycle components (Doughty et al., 2014).$^{\mathrm{FW}}$ Understanding the seasonal drivers of the carbon cycle in a pan-tropical context and as well as crossing the maximum information available on carbon storage and assimilation$^{\mathrm{FW}}$ is therefore$^{\mathrm{FW}}$ needed to assess the mechanisms driving changes in forest carbon use and predict tropical forest behavior under future climate changes.

Despite long-term investigation of changes in forest aboveground biomass stock and carbon fluxes, the direct effect of climate on the seasonal carbon cycle of tropical forests remain unclear. Contrasting results have been reported depending on methods used. Studies show an increase of aboveground biomass gain in the wet season from direct measurement (biological field measurements), or, from indirect measurement, an increase of canopy photosynthetic capacity in the dry season (remote sensing, flux tower network) (Wagner et al., 2013). Several hypotheses have been proposed to explain these patterns$^{\mathrm{FW}}$~~discrepancies~~: (i) wood productivity, estimated from trunk diameter increment, is mainly controlled by rainfall and$^{\mathrm{FW}}$ water availability and occurs preferentially during the wet season$^{\mathrm{FW}}$~~(Wagner et al., 2014)~~, even if carbon accumulation in the trees could be greater in the dry season than in the wet season, likely reflecting a tradeoff between maximum potential growth rate and hydraulic safety (Rowland et al., 2014b, a; Wagner et al., 2014).$^{\mathrm{FW}}$~~, but s~~ S$^{\mathrm{FW}}$easonal variation in carbon allocation to the different parts of the plant (crown, roots) also contribute to optimizing resource use and could explain the low synchronicity between wood productivity and carbon accumulation in the trees $^{\mathrm{FW}}$(Doughty et al., 2014, 2015; Rowland et al., 2014b)~~;~~.$^{\mathrm{FW}}$ (ii) litterfall peak mainly occurs during dry periods as a combination of two potential climate drivers: seasonal changes in daily insolation leading to production of new leaves and synchronous abscission of old leaves, and high evaporative demand and low water availability that both induce leaf shedding in the dry season (Borchert et al., 2015; Zhang et al., 2014; Wright and Cornejo, 1990; Chave et al., 2010; Myneni et al., 2007; Jones et al., 2014; Bi et al., 2015); and (iii) photosynthesis ~~on a global scale~~in these tropical forested regions$^{\mathrm{FW}}$ is mainly controlled by water limitations and is sustained during the dry season above a threshold of 2000 mm of mean annual precipitation (Restrepo-Coupe et al., 2013; Guan et al., 2015). Water limitation is not the only known control, and other climate variables and internal carbon allocation have been demonstrated to drive photosynthetic capacity in tropical forests such as irradiance, temperature and leaf dynamics. Irradiance is directly and positively linked to plant photosynthetic capacity, carbon uptake and plant growth (Graham et al., 2003), while temperatures above 30°C drive a reduction of photosynthetic capacity (Lloyd and Farquhar, 2008; Doughty and Goulden, 2008; Doughty, 2011). Recently, for non-water-limited forests in Amazonia, (Wu et al., 2016) showed, that the increase in ecosystem photosynthesis during dry period result from the synchronization of new leaf growth and litterfall, shifting canopy composition towards younger more light-use efficient leaves.$^{\mathrm{FW}}$

Here, we determine the dependence of seasonal aboveground wood productivity, litterfall and canopy photosynthetic capacity (using the MODIS Enhanced Vegetation Index – EVI as a proxy) on climate across the tropics, and assess their interconnections in the seasonal carbon cycle. EVI strongly correlated with chlorophyll content and photosynthetic activity (Huete et al., 2002, 2006), and we used a corrected version of the index to account for sun-angle artifact (Morton et al., 2014; Wagner et al., 2015). While positive correlation of leaf flushing and EVI has already been reported in tropical forests (Brando et al., 2010; Wagner et al., 2013; Wu et al., 2016), Chavana-Bryant et al. (2016) have demonstrated in a tropical forest that EVI increased with leaf development (from youngest to mature cohorts), and then declined when leaves were at old and senescent stages. Here we assume that EVI represent the maturation of new leaves and that the highest value of EVI represents the highest greenness and canopy photosynthetic capacity canopy photosynthetic capacity, when leaves are fully mature$^{\mathrm{FW}}$. We use a unique satellite and ground-based combination of monthly data sets from 89 pan-tropical experimental sites (68 include aboveground wood productivity and 35 litter productivity measurements), their associate canopy photosynthetic capacity and climate to address the following questions: (i) Are seasonal aboveground wood productivity, litterfall productivity and photosynthetic capacity dependent on climate? (ii) Does a coherent pan-tropical rhythm exist among these three key components of forest carbon fluxes? (iii) if so, is this rhythm primarily controlled by exogenous (climate) or endogenous (ecosystem) processes?

We found that aboveground wood productivity and litterfall are directly related to climate seasonality and particularly to variations in precipitation and evaporation demand. Patterns of photosynthetic capacity are more complex as they respond positively to precipitation when mean annual precipitation is < 2000 mm.yr^{-1} (water-limited sites) and to radiation otherwise (light-limited sites). Consequently, photosynthetic capacity and aboveground wood productivity have similar seasonal patterns in water-limited sites. In contrast, in light-limited forests, we observed decoupled seasonal patterns between aboveground wood productivity and photosynthetic capacity, likely indicating an asynchrony in the use of photosynthesis products for aboveground wood productivity. Precipitation exerts a first-order control on the seasonality of canopy photosynthetic capacity and wood productivity. With reduction in mean annual precipitation, we found that the drivers of seasonality in canopy photosynthetic activity shifted from radiation to precipitation. Because of water scarcity in the dry season, water-limited forests are unable to maintain maximum canopy photosynthetic throughout times of high solar radiation. ~~This likely indicates an overall decrease in tropical forest productivity in a drier climate.~~ This likely indicates a decrease in tropical forest productivity in a drier climate in water limited forest, and in current light-limited forest with future rainfall < 2000 mm.yr^{-1}.$^{\mathrm{FW}}$

2 Methods

2.1 Datasets

We compiled the literature of publications reporting seasonal wood productivity of tropical forests. Seasonal tree growth measurements in 68 pantropical forest sites, 14481 individuals, were obtained from published sources when available or directly from the authors (Table 1, Figures 1). The data set consists of repeated seasonal measurements of tree diameter mostly with dendrometer bands (94.1%), electronic point surveys (4.4%) or graduated tapes (1.5%). The names of all recorded species were checked using the Taxonomic Name Resolution Service and corrected as necessary (Boyle et al., 2013; Chamberlain and Szocs, 2013). Botanical identifications were made at the species-level for 11967 trees, at the genus-level for 1613 trees, family-level for 171 trees and unidentified for 730 trees. Wood density values were taken from the Global Wood Density Database (Chave et al., 2009; Zanne et al., 2009) or from the authors when measured on the sample (Table 1). Direct determination for 455 trees and species mean was assumed for an additional 8671 trees. For the remaining 5355 trees, we assumed genus mean (4639), family mean (136) or site mean (580) of wood density values as computed from the global database (Zanne et al., 2009). Palms, lianas and species from mangrove environments were excluded from the analysis. Diameter changes were converted to biomass estimates using a tropical forest biomass allometric equation – which uses tree height (estimated in the allometric equation if not available), tree diameter and wood density (Chave et al., 2014) – and then the mean monthly increment of the sample was computed for each sample. Recently, Cuny et al. (2015) showed that stem woody biomass production lags behind stem-girth increase by over one month in temperate coniferous, but here we assume that stem-girth increase represent woody biomass production as no such information are yet available for tropical forest trees.^{FW} ~~For each tree, unusual increments were identified and corrected when it was possible by replacing them with the mean increment of t+1 and t-1, or deleted.~~ To detect the errors of overestimated or underestimated growth, increment histogram of each sites was plotted. For each suspect error, increment trajectory of trees were then visually assessed to confirm the error. ~~If the increment was identified as an error, it was corrected with linear approximation.~~ If the error was clearly identifiable, such as an abnormal increase (or decrease) in diameter values followed by a large decrease (or increase) of the same amplitude resulting from typo errors, for example 28 whereas 2.8 was expected, the typo error was corrected. When the typo error was not clearly identifiable, the value was corrected with linear approximation with the mean increment of t+1 and t-1. In some cases there was an identifiable increase of diameter values (or decrease), but not followed by a decrease (or an increase) of the same amplitude. This pattern was associated to the repositioning of the dendrometer bands (reported in the source dataset). In this case, the increment was deleted and set to zero and the new time series of cumulative diameter values were computed. As the diameter values are needed to compute biomass, this strategy was used to benefit of the full time series of diameter increment even after solving the error.^{FW}

Seasonal litterfall productivity measurements from a previously published meta-analysis were used for South America (Chave et al., 2010) (description in Table 1 of (Chave et al., 2010)). In this dataset, we used only data with monthly measurements from old-growth forests, as some sites have plots of both secondary and old-growth forests; flooded forests were excluded. Additionally to these 23 sites, we compiled the seasonal leaf/litterfall data of 12 sites where we already had tree growth measurements (Fig. 1 and Table 2). For these 35 sites, 26 had monthly leaf-fall and 9 had monthly litterfall data (leaf-fall, twigs usually less than 2 cm in diameter, flowers and fruits). The Pearson correlation coefficient between leaf-fall and litterfall for the 20 sites where both data are available is 0.945 (Pearson test, t = 42.7597, df = 218, p-value < 0.001). Consequently, we assumed that the seasonal pattern of litterfall is not different from seasonal pattern of leaf-fall.

Enhanced Vegetation Index (EVI) was used as a proxy for canopy photosynthetic capacity in tropical forest regions (Huete et al., 2006; Guan et al., 2015). EVI for the 89 experimental sites (Fig. 1) was obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS) MCD43 product collection 5 provided every 16 days at 500m spatial resolution$^{\mathrm{FW}}$ (from 4 May 2002 to 30 September 2014). Before computing the mean monthly EVI per site, we did a pixel selection in five steps: (i) selection of all the pixels in a square of side 40 km, centered on the pixel containing each site (6561 pixels per site). This surface was selected to maximize the quantity of valid pixels to estimate monthly site's EVI, as, due to persistent cloud cover in tropical forest regions, valid observations of EVI are limited, producing incomplete time series of EVI values for a given pixel$^{\mathrm{FW}}$. (ii) in this area, the pixels containing the same or at least 90% of the site land cover pixel were selected, based on MCD12Q1 for 2001–2012 at 500 m resolution (Justice et al., 1998); (iii) thereafter, only the pixels forested in 2000 and without loss of forest and with tree cover above or equal to the site tree cover were retained using using Global forest cover loss 2000–2012 and Data mask based on Landsat data (Hansen et al., 2013); (iv) only pixels with a range of ± 200 m the site altitude were retained, using NASA Shuttle Radar Topographic Mission (SRTM) data, reprocessed to fill in the original no-data holes (Jarvis et al., 2008); (v) for corrected reflectance computation we used quality index from 0 (Good quality) to 3 (All magnitude inversions or 50% or less fill-values) extracted from MCD43A2. When required, data sets used to make the selection were aggregated to the spatial resolution of MCD43 product (500 m) and reprojected in the MODIS sinusoidal projection. The reflectance factors of red (0.620 - 0.670 μm, MODIS band 1), NIR (0.841 - 0.876 μm, MODIS band 2) and blue bands (0.459 - 0.479 μm, MODIS band 3) of the retained pixels were modeled with the RossThick-LiSparse-Reciprocal model parameters contained in the MCD43A1 product with view angle θ_v fixed at 0°, sun zenith angle θ_s at 30° and relative azimuth angle Φ at 0° and EVI was computed as shown in Equation 1:

$$EVI = 2.5 \times \frac{NIR - red}{NIR + 6 \times red - 7.5 \times blue + 1} \tag{1}$$

To filter the time series, EVI above or below the 95% confidence interval of the site's EVI values were excluded. Then, the 16-days time series were interpolated to a monthly time step. Finally, the interannual monthly mean of EVI for each site was computed. Further, the ΔEVI$_{wet-dry}$ index was computed for each site, that is, the differences of wet- and dry-season EVI normalized by the mean EVI, where dry season is defined as months with potential evapotranspiration above precipitation (Guan et al., 2015). For the sites where evapotranspiration is never above precipitation, dry season was defined as months with normalized potential evapotranspiration above normalized precipitation. In this study $\Delta EVI_{wet-dry}$ computed from MODIS MCD43A1 is correlated with MOD13C1 (Amazonian sites: $\rho_{Spearman}$=0.90; pan-tropical sites: $\rho_{Spearman}$=0.86) and MAIAC (Amazonian sites: $\rho_{Spearman}$=0.89) products (Supplementary Fig. S4).

To extract the monthly climate time series for the 89 experimental sites (Fig. 1), we used climate datasets from three sources: the Climate Research Unit (CRU) at the University of East Anglia (Mitchell and Jones, 2005), the Consortium for Spatial Information website (CGIAR-CSI, http://www.cgiar-csi.org) and from NASA (Loeb et al., 2009). From the CRU, we used variables from the CRU-TS3.21 monthly climate global dataset available at 0.5° resolution from 1901–2012: cloud cover (cld, unit: $\%$); precipitation (pre, mm); daily mean, minimal and maximal temperatures (respectively tmp, tmn and tmx, ° C); temperature amplitude (dtr, ° C); vapour pressure (vap, hPa); and potential evapotranspiration (pet, mm). The maximum climatological water deficit (CWD) is computed with CRU data by summing the difference between monthly precipitation and monthly evapotranspiration only when this difference is negative (water deficit) (Chave et al., 2014). From the CGIAR-CSI, we used the Global Soil-Water Balance, soil water content (swc, $\%$) (Zomer et al., 2008). Additionally, we used monthly incoming radiation at the top of the atmosphere (rad, W.m^{-2}) covering the period from 2000 to 2015 at 1° spatial resolution from the CERES instruments on the NASA Terra and Aqua satellites (Loeb et al., 2009)~~.~~and monthly incoming radiation at the surface (rad_{surf},W.m^{-2}) from CERES SYN1deg product computed for all-sky conditions, provided at 1° spatial resolution from 2000 to 2015. Monthly incoming radiation at the surface (shortwave radiation) refers to radiant energy with wavelengths in the visible, near-ultraviolet, and near-infrared spectra and is produced using MODIS data and geostationary satellite cloud properties (Kato et al., 2011).$^{\mathrm{FW}}$ Additional to the temporal series of climate variables, we extracted the Global Ecological Zones (GEZ) of the sites. These GEZ are defined by the Food and Agriculture Organization of the United Nations (FAO) and relies on a combination of climate and (potential) vegetation (FAO, 2012).

~~To analyze only seasonality, the site effect was removed in all the datasets, that is, the monthly values were normalized by their site's annual mean values and standard deviation.~~ As at some sites, wood productivity or litterfall measurements are older than the EVI measurements (before 2002), and, for recent site measurements, climate data are not yet available (after 2012), all the datasets were monthly averaged by site. Then, in order to remove the site effect on the mean and the variance of the variables and to analyze only seasonality, all the variables were centered and scaled by site. For a given variable of a site, monthly values were subtracted by their annual mean and divided by their annual standard deviation. The obtained normalized variable had a mean of 0 and a variance of 1, but the time variation in the variable time-series, that is in our case the seasonality, remained completely unchanged.$^{\mathrm{FW}}$

The 89 sites represent a large sample of tropical forests under different tropical and subtropical climates corresponding to six global ecological tropical zones (FAO, 2012): Tropical rain forest (TAr, 41 sites), Tropical moist deciduous forest (TAwa, 23 sites), Tropical dry forest (TAwb, 14 sites), Tropical mountain systems (TM, 7 sites), Tropical shrubland (TBSh, 1 site) and Subtropical humid forest (SCf, 3 sites).

2.2 Data analysis

2.3 Effect of stem hydration on wood productivity

Changes in tree circumference with dendrometers are commonly used to characterize seasonal wood productivity. However, accelerated changes in circumference increments during the onset of the wet season can be caused by bark swelling as they become hydrated (Stahl et al., 2010). Similarly, bark shrinking during dry periods can mask any secondary growth and even lead to negative growth increments (Stahl et al., 2010; Baker et al., 2002). Stem shrinkage during dry periods may be an important limitation of this work (Sheil, 2003; Stahl et al., 2010), as negative monthly growth values exist at almost all the study sites.

Since the measurements are stem radius or circumference changes rather than wood formation, it is difficult to distinguish between true wood formation and hydrological swelling and shrinking. Direct measurements of cambial growth like pinning and microcoring currently represent the most reliable techniques for monitoring seasonal wood formation; however, all these methods are highly time-consuming, which severely restricts their applicability for collecting large data sets (Makinen et al., 2008; Trouet et al., 2012). Nevertheless, some observations already exist to compare growth from dendrometers and cambial growth at a seasonal scale for the same trees. In a tropical forest in Ethiopia experiencing a strong seasonality, high-resolution electronic dendrometers have been combined with wood anatomy investigation to describe cambial growth dynamics (Krepkowski et al., 2011). These authors concluded that water scarcity during the long dry season induced cambial dormancy (Krepkowski et al., 2011). Furthermore, after the onset of the rainy season, (i) bark swelling started synchronously among trees, (ii) bark swelling was maximum after few rainy days, and (iii) evergreen trees were able to quickly initiate wood formation. In a laboratory experiment of trunk section desiccation, Stahl et al. (2010) have showed a decrease in the diameter of the trunk sections ranging from 0.08% to 1.73% of the initial diameter and significantly correlated with the difference in water content in the bark, but not with the difference in water content in sapwood. The variation in the diameter of the trunk sections were observed when manipulating the chamber relative air humidity from 90% to 40%. However, these values are not representative of the *in situ* French Guiana climatic conditions, which is where the trunk sections have been collected and where relative humidity never falls below 70%. Negative increments were reported for one-quarter of their sample with dendrometers measurements in the field. Recently, at the same site, some authors showed that biomass increments were highly correlated between the first and last quantiles of trunk bark thickness and between the first and the last quantile of trunk bark density, thereby suggesting that secondary growth is driven by cambial activity (Wagner et al., 2013) and not by water content in bark. At Paracou, a recent study showed a decrease or stop in the cambial growth for some species during the dry season, based on analysis of tree rings (Morel et al., 2015).

In a temperate forest, Makinen et al. (2008) simultaneously using dendrometer pinning and microcoring on Norway spruce and Scots pine, (see Fig. 3 and Fig. 5 in (Makinen et al., 2008)) showed that a lag of two weeks exists between the growth measured by dendrometers, but the general pattern of growth is highly correlated. Furthermore, a substantial rainfall event occurring after the end of the cambial growth season did not induce xylem initiation or false ring formation Trouet et al. (2012); Wagner et al. (2012). In La Selva (Costa Rica) where there is no month with precipitation below 100 mm, a seasonal variation is reported, thereby suggesting a seasonality only driven by cambial growth. In conclusion, swelling and shrinking exist and could result from different biotic and abiotic causes, cell size, diameter, bark thickness and relative air humidity (Stahl et al., 2010; Baker et al., 2002). To test how swelling and shrinking affect our results, we made first a linear model of wood productivity with precipitation as a single predictor^{FW}~~the analysis~~ with all the data, and then a similar linear model^{FW}~~a second analysis~~ discarding the first month of the wet season (first month with precipitation $>$ 100 mm) and the first month of the dry season (precipitation $<$ 100 mm). Here, we assume that swelling occurs in the first month of the wet season and shrinking occurs in the first month of the dry season, as already observed. The removal of the first month of dry and wet seasons (defined respectively as the first month with precipitation $>$ 100 mm and the first month with precipitation $<$ 100 mm) did not affect the results of the linear^{FW} ~~predictive~~ model of wood productivity as a function of precipitation, that is, intercepts and slopes are not significantly different in both models (overlaps of the 95% confidence interval of coefficients and parameters, Table 3).

2.4 Seasonality analysis

To address the first question 'Are seasonal aboveground wood productivity, litterfall productivity and photosynthetic capacity dependent on climate?', we analyzed with linear models the relationship between our variable of interest (wood productivity, litterfall productivity and photosynthetic capacity)^{FW} and each climate variable at each site and at t, t-1 month and t+1 month. These lags were chosen to account ~~artificially~~ for between-years^{FW} variations in the climate seasonality, as we used in our analyses the average climate per site.^{FW} For a given site, if the wet season have started with one month of delay the year when the tree diameter increment were measured, a lag could exist in the relation of the variable of interest with the monthly averages of climate variables used in linear models^{FW}. The results were classified for each variable as a count of sites with significantly positive, negative or ~~not~~ non-^{FW}significant results. To enable between-sites^{FW} comparison, ~~if the overall effect of the climate variable~~when the overall link^{FW} was negative, the linear model ~~for each site~~ was finally^{FW} run with the climate variable multiplied by -1. For a given climate variable, a site with a significant association at only one of the time lags (-1, 0 or 1) was classified as significant. This strategy enables to highlight the potential drivers of our variable of interest, which are the climate variables with a constant relation with the variable of interest in all the sites. Climate variable with no effect, or effect due to a particular correlation with a potential driver at some sites, will show changes in the sign of the^{FW} relation with the variable of interest.^{FW} Then, a McNemar test was run to compare the proportion of our classification (negative, positive or no relationship) between all paired combinations of climate variables accounting for dependence in the data, that is, to compare not only the proportion of positive, negative and no significant effect between two climate variables and the variable of interest^{FW} but also to detect if the sites in each of the classes (positive, negative and no significant effect)^{FW} were similar. In order to summarize all the relations between the climate variables, a table (similar to a correlation table) containing all paired combination p-values of the McNemar test was built. In this table a $p\text{-value} < 0.05$ indicate that a different association between the two climate variables and the variables of interest cannot be rejected.^{FW} To determine which climate variables explain the same part of variance and to enable interpretation, a cluster analysis was performed on the table of p-values of the McNemar test using Ward distance. Climate variables in the same cluster indicate that they share a similar relation with the variable of interest.^{FW}

When the climate variable with direct effect was identified, we built a linear model to predict wood and litter productivity seasonality with climate in all sites. For EVI, two climate variables were identified and their influence was dependent on the site values of $\Delta\text{EVI}_{wet-dry}$. To find the $\Delta\text{EVI}_{wet-dry}$ threshold of main influence of each variable, the R^2 of the linear relationship EVI as a function of the climate variable for different values of $\Delta\text{EVI}_{wet-dry}$ threshold were computed. R^2 was computed for the sample above or below $\Delta\text{EVI}_{wet-dry}$ depending on the relationship of each variable to the threshold. The optimal threshold of $\Delta\text{EVI}_{wet-dry}$ for climate variable influence on normalized EVI was defined by a break in the decrease of R^2 values. Optimal thresholds were then used to define the range of $\Delta\text{EVI}_{wet-dry}$ where EVI is influenced by one of the climate variables, the other and by both. To find the best linear combination of variables that contains the maximum information to predict EVI, we ran an exhaustive screening of the candidate models with the identified climate variables and their interactions with the ΔEVI$_{wet-dry}$ classes using a stepwise procedure based on the Bayesian information criterion, BIC (Schwarz, 1978).

To address the second question 'Does a coherent pan-tropical rhythm exist among these three key components of the forest carbon fluxes?', we analyzed the linear relationship between wood, litter productivity and canopy photosynthetic capacity. The non-parametric Mann-Whitney test was used to determine the association between wood/litter productivity and photosynthesis rhythmicity depending on site limitations.

To address the third question 'Is the rhythm among these three key components of the forest carbon controlled by exogenous (climate) or endogenous (ecosystem) processes?', we analyzed the linear relationship between ΔEVI$_{wet-dry}$ and mean annual precipitation, as well as the relationship between ΔEVI$_{wet-dry}$, Δwood productivity$_{wet-dry}$ and Δlitter productivity$_{wet-dry}$ and maximum climatological water deficit (CWD). ΔEVI$_{wet-dry}$, Δwood productivity$_{wet-dry}$ and Δlitter productivity$_{wet-dry}$ indices are the differences of wet- and dry-season variable values normalized by the mean of the variable, where the dry season is defined as months with potential evapotranspiration above precipitation.

To avoid over-representation of sites with the 'same climate' (that is, to account for spatial and temporal autocorrelation in the climate data) cross correlation (positive and negative) were computed within sites for the monthly climate variables rad, pre, pet, dtr, tmn and tmx. The site's annual values of the same climates variable were added in the table. After scaling and centering the table, the Euclidian distance between each site and the mean table of all other sites (baricenter) was computed. We defined the weight of each site as the distance to the other divided by the maximum distance to the other. This distance was used as a weight in the linear models.

All analysis were performed in R (Team, 2014).

3 Results

3.1 Climate footprint in seasonal carbon assimilation and storage

A direct and dominant signal of precipitation seasonality was found in seasonality of wood productivity for 59 out of the 68 sites (86.8%) where wood productivity data were available (cluster of variables in Fig. 2a with temperature amplitude (dtr), cloud cover (cld), precipitation (pre) and soil water content (swc), Methods 2.2 and Supplementary Table S1). All the variables in this cluster are wet season indicators: low temperature amplitude, high precipitation, high soil water content and high cloud cover. Two other clusters of climate variables are apparently associated with wood productivity. However, the climate variables that better explained wood productivity in these two clusters, vapor pressure (vap) and mean temperature (tmp), respectively, are highly correlated with precipitation in the clusters (Fig. 2a and Supplementary Table S3-S4). In spite of this dominant signal, these are outliers in our data, that exhibit no relationship or a negative relationship with precipitation (Appendix A1). Four of the five sites that have no dry season (months with precipitation below 100 mm) were amongst these outliers.

It is interesting to note that 48.0% of the monthly wood productivity is explained by the single variable 'precipitation' (model m_{WP} in Table 4). The linear model with monthly precipitation only (m_{WP}) was able to reproduce the seasonality of the majority of the sites analyzed (Fig. 3a). No monthly lag between predicted and observed seasonality was observed for 35 sites. For 63 sites, a lag between -2 and +2 months was observed (Fig. 4a).

Canopy photosynthetic capacity, as estimated by EVI, for the 89 experimental sites, displayed an intriguing pattern with monthly precipitation, apparently related to the difference of $\Delta EVI_{wet-dry}$ (Fig. 5a), an indicator of the dry season evergreen state maintenance (Guan et al., 2015), computed as the difference between the mean EVI of the wet season ($pre \geq pet$) and of the dry season ($pre < pet$) (Methods 2.1). This pattern can be explained by a change in the climate parameters that mainly control photosynthesis, from precipitation in water-limited sites ($\Delta EVI_{wet-dry} > 0.0378$, Fig. 5b) to maximal temperature in light-limited site ($\Delta EVI_{wet-dry} < -0.0014$, Fig. 5c and Supplementary Fig. S1). Sites with mixed influence of precipitation and temperature are found between the range of $\Delta EVI_{wet-dry}$ [-0.0014;0.0378] (Fig. 6 for the definition of the thresholds). In our sample, the shift in climate control depends on the annual water availability. That is, sites are not water-limited above 2000 mm.yr^{-1} of mean annual precipitation (Fig. 5d), as previously observed (Guan et al., 2015), but then they are light-limited as shown by the relationship between photosynthetic capacity and maximal temperature (Fig. 5c). Light-limited sites are located in Amazonia, in the south of Brazil and in Southeast Asia (Fig. 7). ~~For these sites, while solar radiation at the top of the atmosphere is not different between the dry and wet seasons, maximal temperature is higher in the dry season, thereby reflecting solar energy available for the plants (Fig. 8)~~ For all the sites, maximal temperature is highly correlated with incoming solar radiation at the surface ($r_{Pearson}$=0.80, p-value < 0.0001), approximating solar energy available for the plants (Fig. 8)[FW]. With the model mBIC$_{EVI}$ (Table 4), precipitation, maximal temperatures and their thresholds explained 54.8% of the seasonality of photosynthetic capacity (Fig. 3c). For 39 sites, no seasonal lag between predicted and observed seasonality of canopy photosynthetic capacity was observed using the model mBIC$_{EVI}$. However, a majority of the sites (82 sites) appeared to have a lag between -2 and +2 months (Fig. 4c). The model failed to reproduce the seasonality for seven sites (one water-limited, one light-limited and five mixed sites).

For 27 out of the 35 sites (77.1%) where litter data were available, litter productivity was associated with dry season indicators (lack of precipitation, high evaporation, low soil water content and high temperature amplitude, Fig. 2b). Surprisingly, we found that cloud cover (cld), an indirect variable, was the best single predictor of litterfall seasonality (Table 4). Direct effects are observed only for potential evapotranspiration (pet) and temperature amplitude (dtr) (Fig. 2b and Supplementary Table S5). A second cluster of climate variables is associated with litter productivity but a key variable in this subgroup, minimal temperature (tmn), is correlated with cloud cover (Supplementary Table S7). Despite this dominant signal, outliers showing no relationship with cld exist in our data (Appendix A2). The predictive model with cloud cover as a single variable (Table 4) explains 31.7% of the variability and performs well to reproduce the seasonality of litterfall productivity (Fig. 3b and 4b).

At a pan-tropical scale, 48% of the variability of monthly aboveground wood productivity (Fig. 3a and Table 4) and 31.7% of the monthly litterfall seasonality can be linearly explained with a single climate variable (Fig. 3b). The relationship between photosynthetic capacity (EVI) and climate is more complex; however, 54.8% of the monthly EVI variability can be linearly explained with only two climate variables, precipitation and maximal temperature (Fig. 3c).

3.2 Decoupling wood productivity, litter productivity and canopy photosynthetic capacity seasonality

In sites where both measurements were available, we observed a negative relationship between wood productivity and litterfall (Fig. 9, supported by linear analysis, Supplementary Fig. S2). This relationship is consistent across the tropics and constant for all our sites (Fig. 10c), independently of the site water or light limitations (Mann-Whitney test, U = 746, p-value = 0.0839). Wood productivity and litterfall are mainly driven by only one climate driver in our results, precipitation and cloud cover respectively. The seasonality of these climate drivers are coupled for all the sites, where maximum precipitation occurs in the wet season while minimum cloud cover occurs in the dry season.

In water-limited forests, the seasonality EVI and aboveground wood production are synchronous for the majority of the sites (Fig. 10a)$^{\mathrm{FW}}$~~EVI seasonality is well associated with aboveground wood production for water-limited forests~~, as a consequence of their relationship with precipitation. However, aboveground wood production is better explained by precipitation than EVI (R^2 of 0.503 and 0.451 respectively).

Conversely, in light-limited sites and forests with mixed limitations (mixed forests), EVI is weakly coupled with the seasonality of wood productivity (respectively p-value = 0.0633, R^2 = 0.017 and p-value = 0.0124, R^2 = 0.055). Therefore, we conclude that the relationship between EVI and wood productivity depends on site limitations (Mann-Whitney test, U = 874.5, p-value = 0.0012).

The relationship between EVI and litter production is not constant (Fig. 10b), and also depends on site limitations (Mann-Whitney test, U = 1016.5, p-value < 0.001). EVI is consistently negatively associated with litterfall production for water-limited forests ($p < 0.001$, R^2 = 0.510), reflecting forest 'brown-down' when litterfall is maximal. Litter production is slightly better explained by cloud cover than EVI (R^2 of 0.533 and 0.510 respectively) and they predict the same effect for the same site (McNemar test, p-value = 0.999). No significant associations are found between EVI and litter in forests with mixed limitations (p-value = 0.8531, $R^2 < 0.0001$) and in light-limited forests (p-value = 0.4309, $R^2 < 0.0001$).

ΔEVI$_{wet-dry}$ and Δwood productivity$_{wet-dry}$ are dependent on annual water availability (Fig. 11a-b and Fig. 5d). Δwood productivity$_{wet-dry}$ is close to zero and could be negative for light-limited sites; the amplitude of the seasonality is driven by the annual water availability. The values for Δwood productivity$_{wet-dry}$ in South East Asia are all negative. This is consistent with the negative or null associations of wood productivity and precipitation at these sites (Appendix A1). Δlitter productivity$_{wet-dry}$ is poorly correlated with maximum climatological water deficit (CWD).

4 Discussion

We have found a remarkably strong climate signal in the seasonal carbon cycle components studied across tropical forests. While wood and litterfall production appear to be dependent on a single major climate driver across the tropics (water availability), the control of photosynthetic capacity varies according to the increase in annual water availability, shifting from water-only to light-only drivers.

Minimum aboveground wood production tends to occur in the dry season. This result is not new (Wagner et al., 2014), but here we confirm this pattern. ~~From the climatic point of view, months~~Months$^{\mathrm{FW}}$ with the lowest water availability are less favourable for cell expansion, as water stress is known to inhibit this process, as observed in dry tropical sites (Borchert, 1999; Krepkowski et al., 2011). This pattern is found in water-limited, mixed and light-limited sites. At the very end of the water availability gradient (wettest ones), some sites have no relationship or a negative relationship with monthly precipitation, as observed in Lambir, Malaysia (Kho et al., 2013). These sites, three in South East Asia and one in South Brazil, have no marked dry season, defined as months with precipitation below 100 mm. These relationships with monthly precipitation could reflect cambial dormancy induced by soil water saturation, as observed in Amazonian floodplain forests (Schöngart et al., 2002), and/or be related to limited light availability due to persistent cloud cover. However, for these ultra wet sites, the lack of field data limits the analysis of the effects of climate on the seasonality of aboveground wood production.

Maximum litterfall, for most of our sites, occurs during the months of minimum cloud cover during the dry season. It is known that the gradient from deciduous to evergreen forests is related to water availability, with the evergreen state sustained during the dry season above a mean annual precipitation threshold of approximately 2000 mm.yr^{-1} (Guan et al., 2015). The litterfall peak occurs when evaporative demand is highest. The maintenance of litterfall seasonality in the light-limited sites could be driven mostly by a few large/tall canopy trees shedding leaves, mainly in response to high evaporative demand. This can explain why litterfall occurs in the dry season and is decoupled from EVI, a parameter that integrates the entire canopy (Fig. 10b). On the other hand, in water-limited sites, most of the trees shed their leaves, thereby resulting in a litterfall signal coupled with EVI 'brown-down' (Fig. 10b).

Canopy photosynthetic capacity has different climate controls depending on water limitations (Fig. 5). As already observed, in sites with mean annual precipitation below 2000 mm.yr^{-1} (Fig. 5d), photosynthetic capacity is highly associated with water availability (Guan et al., 2015) and highly dependent on monthly precipitation (Fig. 5b). This seems to confirm that longer or more intense dry seasons can lead to a dry-season reduction in photosynthetic rates (Guan et al., 2015). In addition to the control by water availability (Guan et al., 2015; Bowman and Prior, 2005; Hilker et al., 2014), we demonstrated that for sites where water is not limiting, photosynthetic capacity depends on maximal temperatures, which reflects available solar energy or daily insolation at the forest floor (Fig. 8). For these sites, the EVI peak occurs at the same time as the maximal temperature peak, which supports the hypothesis of the detection of a leaf flushing signal induced by a preceding increase of daily insolation (Borchert et al., 2015). This result is also consistent with flux-tower-based GPP estimates in neotropical forests (Restrepo-Coupe et al., 2013; Guan et al., 2015; Bonal et al., 2008). If the increase in EVI is a proxy of leaf ~~production~~maturation, as already observed in a tropical forest of southern Peru (Chavana-Bryant et al., 2016), our result supports the satellite-based hypothesis that temporal adjustment of net leaf flush occurs to maximize water and radiation use while reducing drought susceptibility (Myneni et al., 2007; Jones et al., 2014; Bi et al., 2015). However, more detailed data on the leaves dynamics would be necessary to confirm these assumptions^{FW}.

We demonstrated that the seasonality of aboveground wood production and litterfall are coupled while photosynthetic capacity seasonality can be decoupled from wood and litterfall production seasonality depending on the local water availability (Fig. 10).

Further, our results show that carbon allocation to wood is prioritized in the wet season, independently of the site conditions (water- or light-limited). This priority has also been shown in forests impacted by droughts, where trees prioritized wood production by reducing autotrophic respiration even when photosynthesis was reduced as a consequence of water shortage (Doughty et al., 2015). However, there is still a lack of information on a wider scale regarding how trees prioritize the use of non-structural carbohydrates. The potential decoupling of carbon assimilation and carbon allocation found here seems to indicate a complex and indirect mechanism driving carbon fluxes in the trees. Some experimental results showed that endogenous and phenological rhythms can define the prioritization in carbon allocation and may be more important drivers of the carbon cycle seasonality than climate in tropical forests (Malhi et al., 2014; Doughty et al., 2014; Morel et al., 2015). This corroborates other results that indicate that growth is not limited by carbon supply in tropical forests (Körner, 2003; van der Sleen et al., 2015; Wurth et al., 2005). However, even if these results are in accordance with our results for light-limited sites, it must be noted that they cannot be generalized to water-limited sites, where climate constrains both photosynthetic capacity and wood productivity.

Canopy photosynthetic capacity and aboveground wood production appear to be predominantly driven by climate at seasonal and annual scales, thereby suggesting exogeneous drivers (Fig. 5 and Fig. 11). However, if litterfall was driven by climate only, its pattern would be more predictable, with a linear relationship between annual water availability (CWD) and Δlitter productivity$_{wet-dry}$ such as for wood production (Fig. 11b-c), which would translate into a massive peak in the dry season. Even with the litterfall peak occurring mainly in the dry season, another part of the variation seems to be related to endogeneous drivers. Such endogeneous effects have already been observed in tropical forests, for example, seasonality of root production prioritized over leaf production in a dry site in Bolivia or leaf production occurrence during wet months in French Guiana (Doughty et al., 2014; Morel et al., 2015). ~~If the molecular mechanisms of photoperiodic control of tree development are the same in temperate and tropical trees (Borchert et al., 2015), tropical tree phenology could depend on the following genetic loci: FLOWERING LOCUS T1 (FT1), FLOWERING LOCUS T2 (FT2) and EARLY BUD-BREAK 1 (EBB1), respectively for reproductive onset, vegetative growth and inhibition of bud set, and release from seasonal dormancy and bud break initiation (Yordanov et al., 2014; Yordanov et al., 2011; Yordanov et al., 2012).~~ The lag between peak of litterfall in dry season and minimum photosynthetic capacity of the canopy we observe for light-limited sites (Fig. 10b) could reflect a mixture of bud sets and bud breaks with a relative weak synchronism due to the high diversity of species involved and the weakness of the seasonal signal of solar insolation. Our results are consistent with a seasonal cycle timed to the seasonality of solar insolation, but with an additional noise due to leaf renewal and/or net leaf abscission during the entire year unrelated to climate variations (Borchert et al., 2015; Myneni et al., 2007; Jones et al., 2014; Bi et al., 2015). ~~While photosynthetic capacity and wood productivity appear mostly exogenously driven, litterfall is the result of both exogenous and endogenous processes.~~While photosynthetic capacity and wood productivity appear mostly exogenously driven, litterfall association with climate at seasonal and annual scales suggest both exogenous and endogenous processes. It remains that the unexplained variability of photosynthetic capacity and wood productivity seasonality could be link to endogenous drivers but more investigations are needed to demonstrate it$^{\mathrm{FW}}$.

In this study, we use EVI as an index of seasonality of canopy photosynthetic capacity based on the previously demonstrated correlation between canopy photosynthetic capacity from the MODIS sensor and solar-induced chlorophyll fluorescence (SIF) at a pan-tropical scale (Guan et al., 2015) and from the correlation between $\Delta EVI_{wet-dry}$ from MODIS MOD13C1, MCD43A1 and MAIAC products (Supplementary Fig. S4). Here, we show how satellite and field data can be used to infer characteristics of tropical forests carbon cycle in a consistent framework. To go further, it is necessary to determine the real amount of photosynthetic products in order to describe quantitatively the seasonal carbon cycle in tropical forests.

5 Conclusions

In summary, the seasonality of carbon assimilation and allocation through photosynthetic capacity and aboveground wood production is consistently and directly related to climate in tropical forested regions. Notably, we found that regions without annual water limitations exhibit a decoupled carbon assimilation and storage cycle, which highlight the complexity of carbon allocation seasonality in the tropical trees. Although seasonal$^{\mathrm{FW}}$ carbon allocation to aboveground wood production$^{\mathrm{FW}}$~~assimilation~~ is driven by water, whether the seasonality of$^{\mathrm{FW}}$ photosynthetic capacity ~~seasonal pattern~~ is driven by light or water depends on the limitations of site water availability. ~~The first-order precipitation control likely indicates a decline in tropical forest productivity in a drier climate, by a direct limitation of canopy photosynthetic capacity in water-limited forests and, in light-limited forests, by a reduction of canopy photosynthetic capacity in the dry season.~~

In a drier climate, from our results we can make the following assumptions : (i) in water limited forests, the reduction of the wet period duration could lead to a time reduction of favorable conditions for carbon assimilation and allocation. (ii) In current light-limited forests with future precipitation below to the 2000 mm.yr^{-1} threshold, the intensification of the dry period could suppress the canopy photosynthetic capacity increase during this high solar radiation period, reducing carbon assimilation and making these forests shift to water limited forests. However, in light-limited forests with future precipitation above the 2000 mm.yr^{-1} threshold, as cloud cover has been shown to limits net CO_2 uptake and growth of tropical forest trees (Graham et al., 2003), it remains uncertain how reduction of cloud cover will affect the productivity.$^{\mathrm{FW}}$

Appendix A: Description of outliers

A1 Wood productivity outliers

Although this dominant signal, outliers exist in our data showing negative (3 sites) or no relationship (6 sites) with precipitation. Due to the correlation of climate variables at the site scale, it is difficult to interpret each site alone; however, some groups arose in these outlier sites. The first group, the two sites Itatinga and Pinkwae, contains only saplings measurements. The second group, the sites with no month with precipitation below 100 mm, includes Lambir (Malaysia), Muara Bungo (Indonesia), Pasoh (Malaysia), Flona SFP (Brazil). The third group includes two mountain sites, Tulua and Munessa. For Munessa, there is evidence of cambial growth related to precipitation Krepkowski et al. (2011); however, the sample we used comprises two species known to have different sensitivity to rainfall. The monthly mean of the sites' wood productivity could be responsible for the lack of rainfall-related pattern. Finally, for Caracarai (Brazil), there was a lack of six-month data encompassing the beginning and middle of the wet season, which has been linearly interpolated to the month; however, due to the important sampling effort, we initially chose to keep this dataset.

A2 Litterfall productivity outliers

Only one site, BDFFP, showed no apparent relationship between litter productivity and cloud cover (Supplementary Fig. S3). This site is in a fragmented forest where fragmentation is known to affect litterfall (Vasconcelos and Luizão, 2004). For the other outlier, they all have a peak of litterfall correlated with pet or cld (Supplementary Fig. S3). Three different groups can be observed: (i) sites which have another peak of litterfall during the year (Cueiras, La Selva, Gran Sabana), (ii) sites with very skew litterfall peaks followed by an important decrease in litterfall, while the climate conditions are optimal for litterfall productivity from the viewpoint of the linear model (Capitao Paco, Rio Juruena and RBSF) and (iii) sites which have two peaks of pet, but litterfall occurs only during one of them (Apiau Roraima, Gran Sabana).

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Table 1. Description of the study sites. For each site, continent (Africa – Af, America – Am, Asia – As and Australia – Aus), country, full site name and geographical coordinates (long.-lat., in degrees) are reported. The next column reports annual litterfall measurement of wood productivity and litterfall (WP+LT) or only wood productivity (WP), the time scale of the measurements, the number of trees, the number of species,the reference for the wood densities, the period of the measurements, the mean diameter (mm) of the sample and the mean wood productivity in kg.tree^{-1}.year^{-1}.

reference	cont	country	site	Lat	Lon	type	method	time_scale	N_tree	N_sp	wsg	duration	diam	dagb±SE
Detienne and A. (1976)	Af	Cameroon	MBalmayo	3.515	11.501	WP	DB	bi-weekly	1	1	Zanne et al. (2009)	1/1966-12/1970	491.8 (491.8-491.8)	41.24±4.698
Detienne and A. (1976)	Af	CAR	MBaiki	3.812	17.881	WP	DB	bi-weekly	1	1	Zanne et al. (2009)	2/1969-11/1970	282.9 (282.9-282.9)	9.51±1.651
Detienne and A. (1976)	Af	CAR	Mokinda	3.650	18.350	WP	DB	bi-weekly	1	1	Zanne et al. (2009)	2/1969-12/1970	391.1 (391.1-391.1)	11.52±2.771
Couralet et al. (2010)	Af	DRC	Luki forest	-5.583	13.183	WP	DB	monthly	40	4	Zanne et al. (2009)	4/2006-8/2007	243.2 (121.4-456.9)	12.23±1.646
Krepkowski et al. (2011)	Af	Ethiopia	Munessa	7.433	38.867	WP	EPD	30-min	9	2	Zanne et al. (2009); Aerts (2008)	3/2008-1/2012	327 (168.3-582.1)	11.5±1.309
Baker et al. (2003)	Af	Ghana	Bonsa River	5.333	-1.850	WP	DB	monthly	36	2	Zanne et al. (2009)	8/1997-12/1999	380.7 (107.2-824.3)	20.18±0.976
Swaine et al. (1990)	Af	Ghana	GPR	5.908	0.061	WP	DB	monthly	12	7	Zanne et al. (2009)	1/1978-4/1979	112.4 (45.7-186.6)	1.05±0.655
Lieberman (1982)	Af	Ghana	Pinkwae	5.750	-0.133	WP	DB	monthly	7	2	Zanne et al. (2009)	3/1978-4/1979	51.7 (34.8-91.7)	0.21±0.188
Baker et al. (2003); Owusu-Sekyere et al. (2006)	Af	Ghana	Tinte Bepo	7.067	-2.100	WP+LP	DB	monthly	40	3	Zanne et al. (2009)	7/1997-1/1999	346.6 (172.9-780.5)	20.71±1.498
Devineau (1991)	Af	Ivory Coast	Lamto	6.217	-5.033	WP	DB	monthly	23	13	Zanne et al. (2009)	7/1972-12/1981	168.6 (74.3-322.5)	3.74±0.231
Detienne and A. (1976)	Af	Ivory Coast	Oume	6.383	-5.416	WP	DB	bi-weekly	1	1	Zanne et al. (2009)	4/1966-12/1970	550.4 (550.4-550.4)	25.12±3.806
Gliniars et al. (2013)	Af	Kenya	Kakamega	0.258	34.883	WP	DB	monthly	766	52	Zanne et al. (2009); Becker et al. (2012)	6/2003-12/2009	355 (98.3-1624.7)	11.99±0.108
Elifuraha et al. (2008)	Af	Tanzania	Kitulangalo	-6.667	37.973	WP	DB	monthly	53	10	Zanne et al. (2009)	2/2007-8/2008	237.1 (71-632.3)	4.27±1.239
Gliniars et al. (2013)	Af	Uganda	Budongo	1.750	31.500	WP	DB	monthly	312	64	Zanne et al. (2009); Becker et al. (2012)	1/2005-12/2009	230.7 (93.7-1163.8)	4.22±0.115
Chidumayo (2005)	Af	Zambia	Makeni	-15.467	28.183	WP	DB	monthly	45	4	Zanne et al. (2009)	12/1996-6/2003	69.7 (28.2-167.7)	13.68±0.633
Chidumayo (2005)	Af	Zambia	UNZA	-15.392	28.333	WP	DB	monthly	51	2	Zanne et al. (2009)	1/1997-5/2002	68.6 (30.7-340)	6.88±0.329
Mendivelso et al. (2013)	Am	Bolivia	Inpa	-16.117	-61.717	WP	DB	monthly	43	5	Mendivelso et al. (2013)	8/2010-9/2011	162.5 (107.7-290.7)	3.67±0.58
Dünisch et al. (2002)	Am	Brazil	Aripuana	-10.150	-59.433	WP	DB	monthly	60	2	Zanne et al. (2009)	10/1998-10/2001	413.3 (138.3-1120.4)	45.43±1.442
Chagas et al. (2004)	Am	Brazil	Caetetus	-22.400	-49.700	WP	DB	monthly	70	7	Zanne et al. (2009)	2/1996-7/1997	203.2 (50.9-651)	5.91±0.89
Castilho et al. (2012)	Am	Brazil	Caracarai	1.476	-61.019	WP+LP	DB	3-monthly	2396	202	Zanne et al. (2009); Boanerges (2012)	1/2013-3/2014	198.6 (34.3-1049.6)	4.55±0.105
Melgaço (2014)	Am	Brazil	Ducke	-2.952	-59.944	WP+LP	DB	bi-monthly	1972	540	Zanne et al. (2009)	2/2013-2/2014	266.1 (97.3-1367.9)	11.67±0.266
Lisi et al. (2008); Ferreira-Fedele et al. (2004)	Am	Brazil	Duratex	-22.417	-48.833	WP	DB	monthly	54	11	Zanne et al. (2009)	1/1999-4/2006	231.7 (89.7-521.9)	15.37±0.548
Vieira et al. (2004)	Am	Brazil	FEC	-10.074	-67.627	WP	DB	monthly	313	76	Zanne et al. (2009)	11/2000-6/2008	433.9 (102.7-1388.2)	36.97±0.558
Zanon and Finger (2010)	Am	Brazil	Flona SFP	-29.417	-50.404	WP	DB	monthly	96	1	Zanne et al. (2009)	2/2004-6/2006	413.1 (235.3-551)	37.48±0.847
Carvalho (2009)	Am	Brazil	Iaciara	-14.065	-46.487	WP	DB	monthly	171	6	Zanne et al. (2009)	5/2007-11/2008	270.9 (39.3-1815.3)	18.37±2.965
Rossatto et al. (2009)	Am	Brazil	IBGE	-15.945	-47.885	WP	DB	monthly	116	24	Zanne et al. (2009)	6/2006-5/2008	79.1 (35.7-261.5)	3.24±0.156
Lisi et al. (2008); Ferreira-Fedele et al. (2004)	Am	Brazil	Ibicatu	-22.783	-47.717	WP	DB	monthly	32	5	Zanne et al. (2009)	12/1998-5/2006	264.2 (109.1-462.1)	22.44±0.882
Kohler et al. (2008)	Am	Brazil	Irati	-25.374	-50.575	WP	DB	3-monthly	199	20	Zanne et al. (2009)	7/2002-6/2008	341.6 (100.5-983.1)	10.52±0.179
de Castro (2014)	Am	Brazil	Itatinga	-23.043	-48.631	WP	DB	weekly	9	1	Zanne et al. (2009)	11/2012-12/2013	52 (45.7-62.9)	4.02±0.178
Toledo et al. (2012); Paula and Lemos Filho (2001)	Am	Brazil	Lagoa Santa	-19.543	-43.927	WP+LP	DB	monthly	28	1	Toledo et al. (2012)	10/2009-5/2011	322.8 (139.2-711.9)	9.63±0.991
Grogan and Schulze (2012); Free et al. (2014)	Am	Brazil	Marajoara	-7.833	-50.267	WP+LP	DB	monthly	72	3	Zanne et al. (2009)	12/1996-11/2001	476.3 (137.1-1468.5)	66.5±1.769
Lisi et al. (2008); Ferreira-Fedele et al. (2004)	Am	Brazil	Porto Ferreira	-21.833	-47.467	WP	DB	monthly	56	12	Zanne et al. (2009)	12/1998-5/2006	314.8 (87.6-883.8)	20.83±0.893
Kanieski et al. (2012, 2013)	Am	Brazil	REPAR	-25.587	-49.346	WP	DB	monthly	87	4	Zanne et al. (2009)	7/2009-10/2012	190.8 (81.7-325.1)	5.27±0.168

Table 1: Continued

reference	cont	country	site	Lat	Lon	type	method	time_scale	N_tree	N_sp	wsg	duration	diam	dagb±SE
Silveira et al.; Vieira et al. (2004)	Am	Brazil	RHF	-9.754	-67.664	WP	DB	monthly	253	89	Zanne et al. (2009)	1/2005-6/2008	326.9 (103.3-1410.4)	32.83±1.297
Cardoso et al. (2012)	Am	Brazil	Rio Cachoeira	-25.314	-48.690	WP	DB	monthly	121	2	Zanne et al. (2009)	9/2007-10/2008	135.5 (63.1-205.4)	16.25±0.69
Lisi et al. (2008); Ferreira-Fedele et al. (2004)	Am	Brazil	Santa Genebra	-22.746	-47.109	WP	DB	monthly	22	9	Zanne et al. (2009)	9/2000-5/2006	260.5 (99-554.1)	11.5±0.75
Lisi et al. (2008); Ferreira-Fedele et al. (2004)	Am	Brazil	SRPQ	-21.667	-47.500	WP	DB	monthly	48	8	Zanne et al. (2009)	2/2000-12/2006	275.4 (199.8-376.9)	18.66±0.523
Vieira et al. (2004); Nepstad and Moutinho (2013)	Am	Brazil	Tapajos km67	-2.853	-54.955	WP	DB	monthly	1369	263	Zanne et al. (2009)	6/1999-3/2006	326.2 (99-1997.6)	18.49±0.35
Figueira et al. (2011); Nepstad and Moutinho (2013)	Am	Brazil	Tapajos km83	-3.017	-54.971	WP+LP	DB	weekly	734	127	Zanne et al. (2009)	11/2000-12/2004	345.6 (101.3-1135.2)	32.34±0.412
Lisi et al. (2008); Ferreira-Fedele et al. (2004)	Am	Brazil	Tupi	-22.723	-47.530	WP	DB	monthly	32	6	Zanne et al. (2009)	12/1998-5/2006	224.9 (123.3-483.3)	16.04±0.824
Chambers et al. (2013)	Am	Brazil	ZF-2	-2.967	-60.183	WP	DB	monthly	174	73	Zanne et al. (2009)	7/2000-12/2001	222.6 (101.9-644.6)	5.74±0.245
Mendivelso et al. (2013)	Am	Colombia	Tulua	4.083	-76.200	WP	DB	monthly	39	4	Mendivelso et al. (2013)	7/2010-8/2011	208.3 (129.4-338.4)	15.2±0.858
O'Brien et al. (2008); Clark et al. (2010, 2009)	Am	Costa Rica	La Selva	10.431	-84.004	WP+LP	DB	monthly	205	49	Zanne et al. (2009)	4/1997-5/2012	321.1 (100.3-743.1)	37.38±0.768
Homeier (2012)	Am	Costa Rica	RBAB	10.215	-84.597	WP	DB	monthly	403	74	Zanne et al. (2009)	12/1999-4/2003	250.5 (103.3-1000.2)	5.79±0.101
Homeier et al. (2010, 2012); Roderstein et al. (2005); Brauning et al. (2009)	Am	Ecuador	RBSF	-3.978	-79.077	WP+LP	DB,EPD	monthly and 30-min	694	92	Zanne et al. (2009)	7/1999-12/2011	182.3 (81.8-681.7)	3.22±0.059
Wagner et al. (2013); Stahl et al. (2010); Bonal et al. (2008)	Am	French Guiana	Paracou	5.279	-52.924	WP+LP	DB	bi-weekly	256	74	Rutishauser et al. (2010); Stahl et al. (2010); Baraloto et al. (2010)	4/2007-6/2010	337.8 (95.4-1001.6)	19.21±0.389
Lopez-Ayala et al. (2006)	Am	Mexico	El Palmar	19.133	-104.467	WP	DB	bi-monthly	23	2	Zanne et al. (2009)	6/2002-8/2003	212.5 (81.3-500.5)	6.02±0.981
Lopez-Ayala et al. (2006)	Am	Mexico	La Barcinera	19.150	-104.425	WP	DB	bi-monthly	14	1	Zanne et al. (2009)	6/2002-8/2003	198.3 (96-416.4)	2.94±0.808
Rowland et al. (2014b)	Am	Peru	Tambopata	-12.835	-69.285	WP+LP	DB	3-monthly	1167	287	Rowland et al. (2014b); Zanne et al. (2009)	10/2005-4/2011	221.5 (91.3-1966.3)	17.37±0.22
Ross et al. (2003)	Am	USA	Big Pine Key	24.671	-81.354	WP	DB	monthly	15	7	Zanne et al. (2009)	4/1990-11/1993	180.1 (112.8-299.3)	1.48±0.166
Ross et al. (2003)	Am	USA	Key Largo	25.267	-80.324	WP	DB	monthly	36	15	Zanne et al. (2009)	12/1989-11/1993	175.4 (103.2-338.4)	2.52±0.221
Ross et al. (2003)	Am	USA	Lignumvitae Key	24.903	-80.698	WP	DB	monthly	27	11	Zanne et al. (2009)	6/1990-11/1993	162.3 (99.9-376.6)	1.45±0.279
Ross et al. (2003)	Am	USA	Sugarloaf Key	24.625	-81.543	WP	DB	monthly	47	12	Zanne et al. (2009)	1/1990-11/1993	144.5 (101.7-226.6)	1.35±0.074
Worbes (1999)	Am	Venezuela	RFC	7.500	-71.083	WP	DB	monthly	25	7	Zanne et al. (2009)	4/1978-5/1982	256.9 (117.2-391.8)	21.04±1.029
Pelissier and Pascal (2000); Pascal (1984)	As	India	Attapadi	11.083	76.450	WP+LP	DB	monthly	101	23	Zanne et al. (2009)	3/1980-11/1983	172.7 (32-1250.9)	6.21±0.655
Vincent (2012)	As	Indonesia	Muara Bungo	-1.523	102.273	WP	M	monthly	40	3	Zanne et al. (2009)	4/2004-5/2006	135 (53.3-175.5)	14.18±0.608
Kho et al. (2013)	As	Malaysia	Lambir	4.200	114.033	WP+LP	DB	monthly	1048	334	Kho et al. (2013)	6/2009-9/2010	224.9 (22-1367.1)	10.2±0.314
Toma (2012)	As	Malaysia	Pasoh	2.983	102.300	WP	DB	weekly	195	41	Zanne et al. (2009)	8/1991-10/1994	232.7 (99-688.5)	14.76±0.506
Ohashi et al. (2009); Bunyavejchewin (1997)	As	Thailand	SERS	14.500	101.933	WP+LP	DB	monthly	35	7	Zanne et al. (2009)	3/2004-10/2006	386.7 (161.2-1075.6)	4.38±0.28
Prior et al. (2004)	Au	Australia	Berry Springs	-12.700	131.000	WP	DB	monthly	28	6	Zanne et al. (2009)	11/2000-5/2002	122.9 (24.2-287.9)	2.44±0.328
Drew et al. (2011)	Au	Australia	CSIRO	-12.411	130.920	WP	EPD	daily	8	1	Cause et al. (1989)	2/2009-5/2011	83 (61-109.7)	4.78±0.34
Koenig and Griffiths (2012)	Au	Australia	Gunn Point1	-12.194	131.147	WP	DB	monthly	6	1	Zanne et al. (2009)	4/2003-4/2005	105.3 (65.4-138.7)	1.03±0.247
Koenig and Griffiths (2012)	Au	Australia	Gunn Point1B	-12.151	131.035	WP	DB	monthly	6	1	Zanne et al. (2009)	4/2003-4/2005	205.7 (87.2-324)	1.82±0.823
Koenig and Griffiths (2012)	Au	Australia	Gunn Point2B	-12.226	131.030	WP	DB	monthly	6	1	Zanne et al. (2009)	4/2003-4/2005	206.9 (64.7-336.2)	1.56±1.061
Koenig and Griffiths (2012)	Au	Australia	Gunn Point3	-12.184	131.028	WP	DB	monthly	6	1	Zanne et al. (2009)	4/2003-4/2005	107.4 (74.6-141.5)	1.44±0.297
Brodribb et al. (2013)	Au	Australia	Indian Island	-12.641	130.507	WP	DB	3-monthly	20	1	Zanne et al. (2009)	6/2008-10/2010	233.9 (107.7-411.8)	3.72±0.45
Prior et al. (2004)	Au	Australia	Leanyer	-12.404	130.898	WP	DB	monthly	12	3	Zanne et al. (2009)	2/2001-5/2002	85 (21.1-189)	2.46±0.604
Brodribb et al. (2013); Stocker et al. (1995)	Au	Australia	Mt Baldy	-17.269	145.423	WP+LP	DB	3-monthly	20	1	Zanne et al. (2009)	5/2008-8/2010	306.3 (171.9-598.4)	4.37±0.516

Table 2. Description of the study sites for litterfall measurements,adapted from Chave et al. (2010). For each site, reference of the article, continent, country, full site name and geographical coordinates (long.-lat., in degrees) are reported. The next column reports annual litterfall measurement of wood productivity and litterfall (WP+LP) or only Litterfall (LP), leaf fall (YES) or total litterfall (NO), the number of traps, the trap size, the total area sampled, the mean litterfall productivity in Mg.ha^{-1}.year^{-1} and the duration.

reference	cont	country	site	Lat	Lon	type	typ data	trap nb	trap size	tot size	Mean ± SE	duration
Baker et al. (2003); Owusu-Sekyere et al. (2006)	Af	Ghana	Tinte Bepo	7.067	-2.100	WP+LP	YES	9	1	9	8.59±1.123	1998/2000
Chave et al. (2010)	Am	Brazil	Apiau Roraima	2.567	-61.300	LP	NO	6	1	6	8.91±0.564	1988/1989
Chave et al. (2010)	Am	Brazil	BDFFP Reserve	-2.500	-60.000	LP	NO	18	1	18	6.59±0.675	1999/2002
Chave et al. (2010)	Am	Brazil	Capitao Paco Para	-1.733	-47.150	LP	NO	16	1	16	7.97±0.6	1979/1980
Castilho et al. (2012)	Am	Brazil	Caracarai	1.476	-61.019	WP+LP	YES	75	0.25	18.75	5.36±0.19	2012/2013
Chave et al. (2010)	Am	Brazil	Caxiuana	-1.785	-51.466	LP	YES	25	0.25	6.25	6.17±0.738	2005/2006
Chave et al. (2010)	Am	Brazil	Cuieiras Reserve Manaus	-2.567	-60.117	LP	NO	15	0.5	7.5	8.03±0.564	1979/1982
Chave et al. (2010)	Am	Brazil	Curua-Una Reserve	-2.000	-54.000	LP	YES	45	1	45	6.62±0.799	1994/1995
Melgaço (2014); Chave et al. (2010)	Am	Brazil	Ducke	-2.952	-59.944	WP+LP	YES	10	0.25	2.5	3.97±0.197	1976/1977
Chave et al. (2010)	Am	Brazil	Jari Para	-1.000	-52.000	LP	YES	100	0.25	25	7.63±0.896	2004/2005
Toledo et al. (2012); Paula and Lemos Filho (2001)	Am	Brazil	Lagoa Santa	-19.543	-43.927	WP+LP	YES	20	0.2	4	4.12±0.331	1997/1998
Chave et al. (2010)	Am	Brazil	Manaus	-3.133	-59.867	LP	NO	20	0.25	5	7.24±0.607	1997/1999
Grogan and Schulze (2012); Free et al. (2014)	Am	Brazil	Marajoara	-7.833	-50.267	WP+LP	NO	50	1	50	3.53±0.416	1998/2001
Chave et al. (2010)	Am	Brazil	Mata de Piedade Pernanbuco	-7.833	-34.917	LP	YES	10	0.25	2.5	11.05±1.427	2003/2004
Chave et al. (2010)	Am	Brazil	Nova Xavantina	-14.685	-52.335	LP	YES	10	1	10	0.45±0.091	2002/2003
Chave et al. (2010)	Am	Brazil	Rio Juruena	-10.417	-58.767	LP	YES	16	1	16	5.21±1.514	2003/2004
Chave et al. (2010)	Am	Brazil	Sinop	-11.412	-55.325	LP	YES	20	1	20	5.27±1.116	2002/2003
Figueira et al. (2011); Nepstad and Moutinho (2013)	Am	Brazil	Tapajos km83	-3.017	-54.971	WP+LP	YES	30	1	30	5.54±0.533	2000/2003
Chave et al. (2010)	Am	Colombia	Amacayacu	-3.717	-70.300	LP	YES	25	0.5	12.5	6±0.31	2004/2006
Chave et al. (2010)	Am	Colombia	Chiribiquete	0.067	-72.433	LP	YES	24	0.5	12	5.62±0.528	1999/2002
Chave et al. (2010)	Am	Colombia	Cordillera Central	4.833	-75.525	LP	YES	30	0.25	7.5	3.36±0.211	1986/1987
Chave et al. (2010)	Am	Colombia	Gran Sabana Guayana	5.117	-60.933	LP	NO	8	0.5	4	5.23±0.449	1999/2000
Chave et al. (2010)	Am	Colombia	Zafire	-3.996	-69.904	LP	YES	25	0.5	12.5	5.2±0.383	2004/2006
O'Brien et al. (2008); Clark et al. (2010, 2009)	Am	Costa Rica	La Selva	10.431	-84.004	WP+LP	YES	162	0.25	40.5	6.73±0.314	1997/2011
Homeier et al. (2010, 2012); Roderstein et al. (2005); Brauning et al. (2009)	Am	Ecuador	RBSF	-3.978	-79.077	WP+LP	YES	12	0.16	1.92	4.35±0.21	2001/2002
Chave et al. (2010)	Am	French Guiana	Nouragues	4.084	-52.680	LP	YES	40	0.5	20	5.88±0.64	2001/2008
Wagner et al. (2013); Stahl et al. (2010); Bonal et al. (2008)	Am	French Guiana	Paracou	5.279	-52.924	WP+LP	YES	40	0.45	18	4.77±0.311	2003/2011
Chave et al. (2010)	Am	French Guiana	Piste de Saint Elie	5.333	-53.033	LP	YES	60	1	60	5.04±0.608	1978/1981
Wieder and J.S. (1995)	Am	Panama	BCI Plateau	9.154	-79.846	LP	NO	40	0.25	10	12.88±0.941	1986/1990
Rowland et al. (2014b); Chave et al. (2010)	Am	Peru	Tambopata	-12.835	-69.285	WP+LP	YES	25	0.25	6.25	7.16±0.607	2005/2006
Chave et al. (2010)	Am	Venezuela	San Ignacio de Yuruani	5.000	-61.017	LP	NO	10	1	10	5.23±0.562	1990/1991
Pelissier and Pascal (2000); Pascal (1984)	As	India	Attapadi	11.083	76.450	WP+LP	YES	100	0.5	50	6.08±0.937	1980/1982
Kho et al. (2013)	As	Malaysia	Lambir	4.200	114.033	WP+LP	YES	50	0.25	12.5	7.07±0.555	2008/2010
Ohashi et al. (2009); Bunyavejchewin (1997)	As	Thailand	SERS	14.500	101.933	WP+LP	YES	25	1	25	4.81±0.534	1985/1989
Brodribb et al. (2013); Stocker et al. (1995)	Au	Australia	Mt Baldy	-17.269	145.423	WP+LP	YES	60	0.65	39	5.93±0.48	1980/1985

Table 3. coefficient of the linear model of wood productivity with the precipitation; with all data m_{WP} or after removing the first month of the dry season and wet season (defined respectively as the first month with precipitation $>$ 100 mm and the first month with precipitation $<$ 100 mm), $m_{WP,-init}$. ^{a}: confidence intervals of the model parameters.

model	parameter	value	2.5% CI^a	97.5% CI^a	p-value	R^2
m_{WP}	(Intercept)	-0.001	-0.05	0.05	0.982	0.433
	precipitation	0.66	0.64	0.74	<0.0001	
$m_{WP,-init}$	(Intercept)	-0.03	-0.08	0.02	0.284	0.466
	precipitation	0.67	0.61	0.72	<0.0001	

Table 4. Intercepts and slopes of the fitted linear models for seasonal wood production (m$_{WP}$), litterfall (m$_{lit}$) and EVI (mBIC$_{EVI}$); with the seasonal climate variables: precipitation (pre), cloud cover (cld) and maximal temperature (tmx). Light-, water- and mixed limitation indicate the limitation of the sites and are defined with the value of $\Delta EVI_{wet-dry}$ (Fig. 6 for the definition of the thresholds).

Model	Components	Coefficient (std. error)	t value	p-value	R^2
Wood production (m$_{WP}$)	Intercept	0.0005 (0.0249)	0.02	0.9833	0.480
	Precipitation	0.6869 (0.0260)	26.40	<0.0001	
Litterfall (m$_{lit}$)	Intercept	0.0000 (0.0389)	0.00	0.9999	0.317
	Cloud cover	-0.5685 (0.0407)	-13.98	<0.0001	
EVI (mBIC$_{EVI}$)	Intercept	0.0000 (0.0197)	0.00	0.9999	0.548
	Maximal temperature in light-limited sites	0.7643 (0.0396)	19.28	<0.0001	
	Maximal temperature in sites with mixed limitations	0.1683 (0.0545)	3.09	0.0020	
	Maximal temperature in water-limited sites	-0.1100 (0.0275)	-4.00	<0.0001	
	Precipitation in sites with mixed limitation	0.3697 (0.0545)	6.78	<0.0001	
	Precipitation in water-limited sites	0.8149 (0.0275)	29.60	<0.0001	

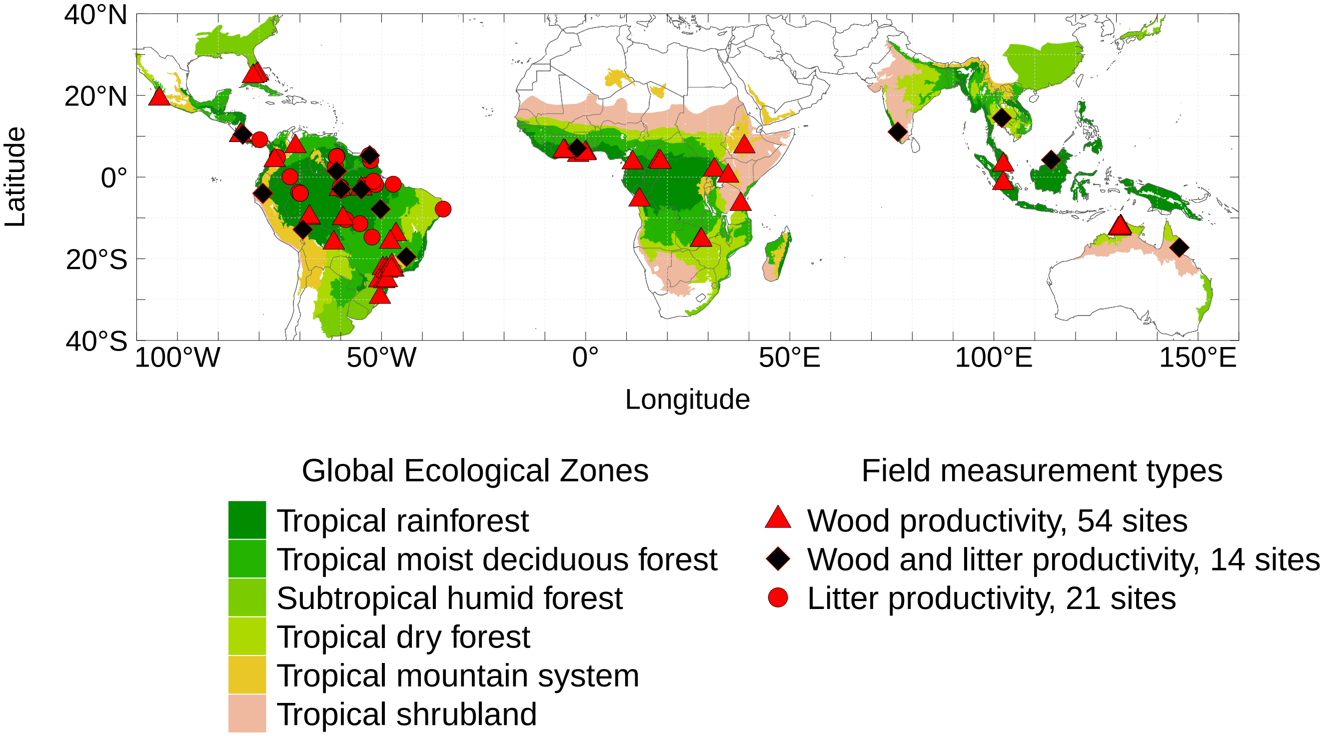

Figure 1. Geographical locations of the 89 observation sites with the field measurement types (wood productivity and/or litter productivity) and Global Ecological Zones FAO (2012). Wood productivity is available for 68 sites (54+14), litter productivity for 35 sites (21+14), and EVI and climate for all the 89 studied sites (54+21+14).

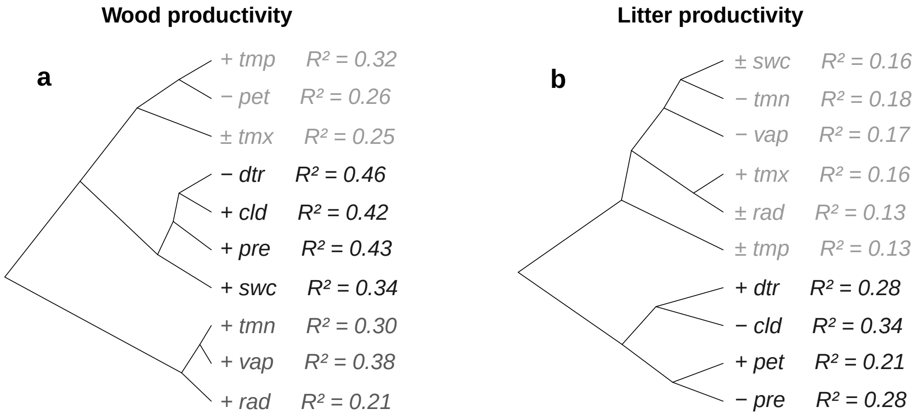

Figure 2. Dendrogram of the climate seasonality associations with the seasonality of wood productivity (a) and litterfall (b). The global sign and R^2 of the linear relationship between wood and litter productivity and the following climate variable is given. $+$ indicates a positive correlation between the climate variable and wood or litter productivity in all the sites, $-$ a negative correlation in all the sites, while $\pm$ indicates positive correlation for a portion of the sites while negative for the other. Climate variables in the same cluster are highly correlated, that is, they produce the same prediction in terms of values and effects for the same sites. Different shades of grey indicate the relative strength of associations for each cluster with seasonality of wood or litter productivity, black indicates the strongest association. cld: cloud cover; pre: precipitation; rad: solar radiation at the top of the atmosphere; tmp, tmn and tmx are respectively the daily mean, minimal and maximal temperatures; dtr: temperature amplitude; vap: vapour pressure; pet: potential evapotranspiration; and swc: relative soil water content.

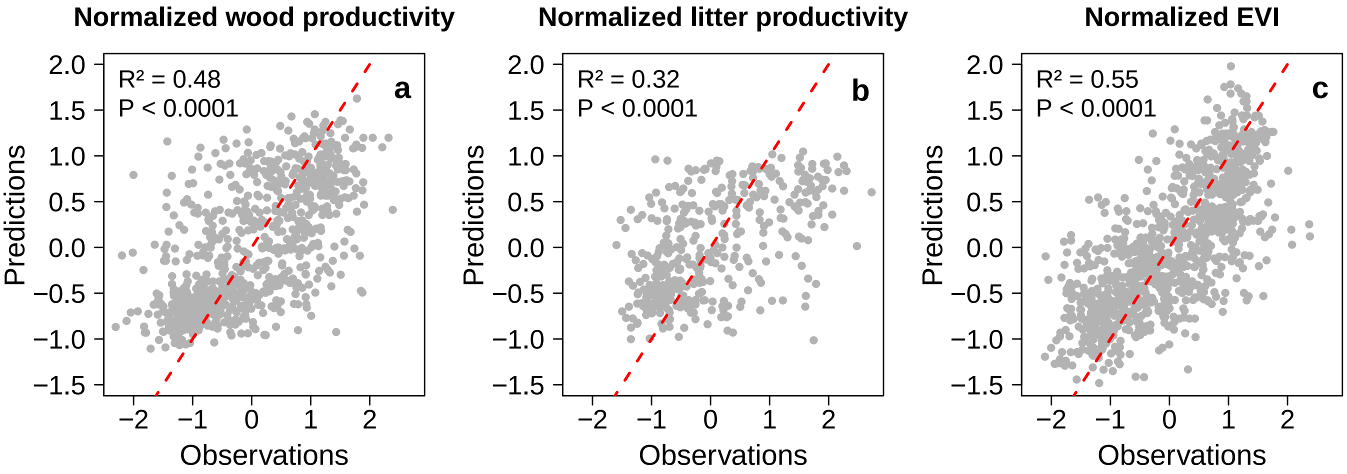

Figure 3. Observed versus predicted monthly wood productivity under the model only with precipitation, m_{WP} (a); litterfall productivity under the model only with cloud cover , m_{lit} (b); and EVI the model only with precipitation, maximal temperature and site limitations, $mBIC_{EVI}$ (c). The red dashed line is the identity line y = x. Parameters of the models are given in Table 4.

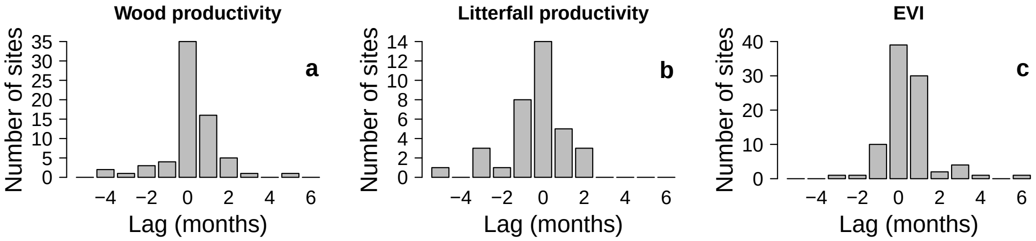

Figure 4. Cross correlation between observations and predictions of wood production (a), litterfall (b) and EVI (c) with the linear models parameters (Table 4). A cross correlation of zero month indicates a similar seasonal pattern in the time series of observations and predictions.^{FW}

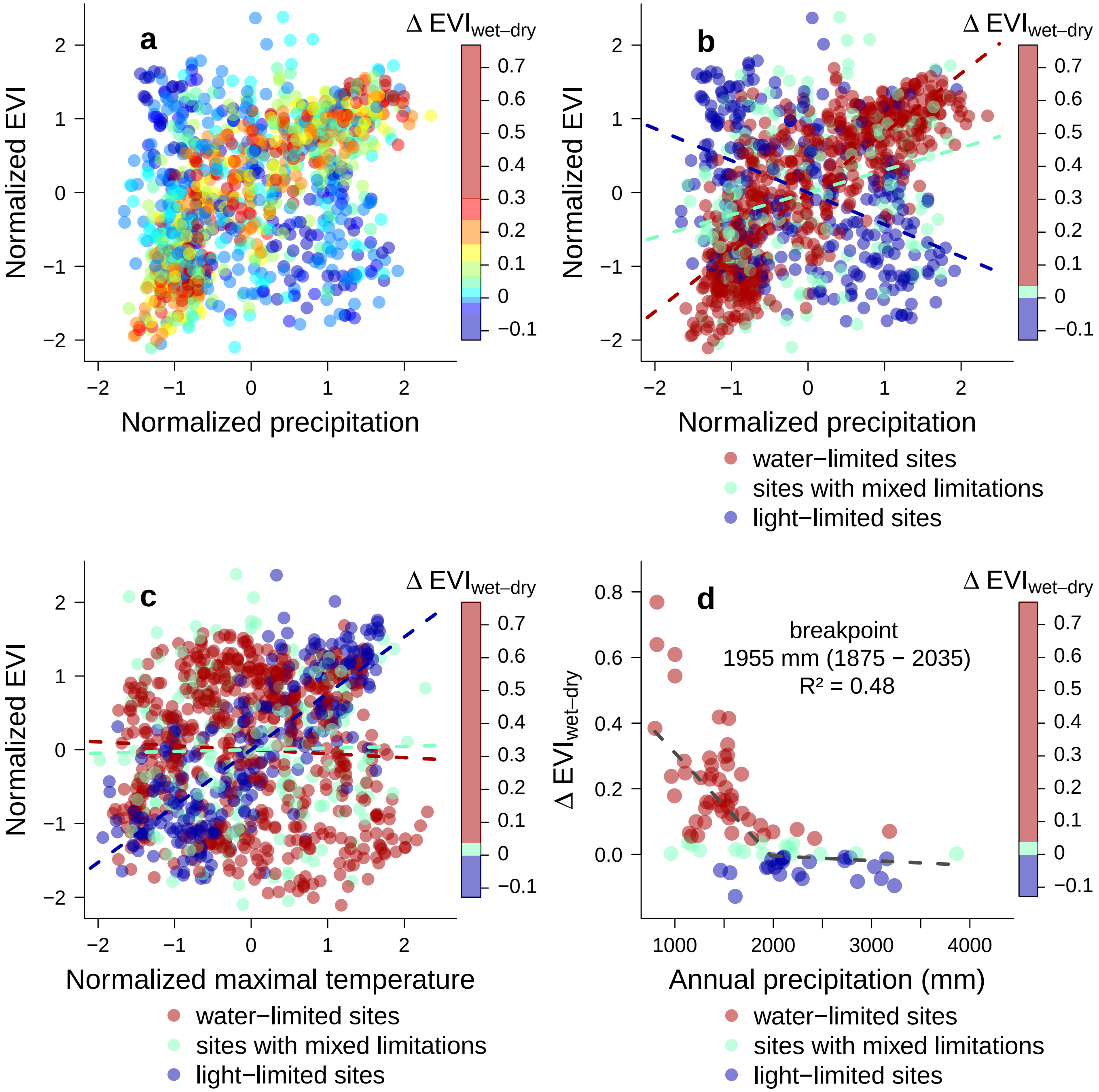

Figure 5. Monthly associations of EVI with precipitation (a and b), maximal temperatures (c), and association of $\Delta EVI_{wet-dry}$ with mean annual precipitation (d). In (a) colors represent the value of $\Delta EVI_{wet-dry}$ while in (b), (c) and (d) colors represent $\Delta EVI_{wet-dry}$ grouped by the following classes : water-limited sites ($\Delta EVI_{wet-dry} > 0.0378$), sites with mixed limitations ($\Delta EVI_{wet-dry}$ [-0.0014;0.0378]) and light-limited sites ($\Delta EVI_{wet-dry} < -0.0014$). The dashed lines in (b) and (c) represent the linear relationship between climate variable and observed EVI for water-limited sites, sites with mixed limitations and light-limited sites. Parameters of the models are given in Supplementary Table S8.^{FW}~~The dashed lines represent the linear relation between the climate variable of the x-axis and EVI obtained with the model mBIC$_{EVI}$ for water-limited sites, sites with mixed limitations and light-limited sites~~. The dashed lines in (d) represents the best regression model with a breakpoint between $\Delta EVI_{wet-dry}$ and mean annual precipitation.

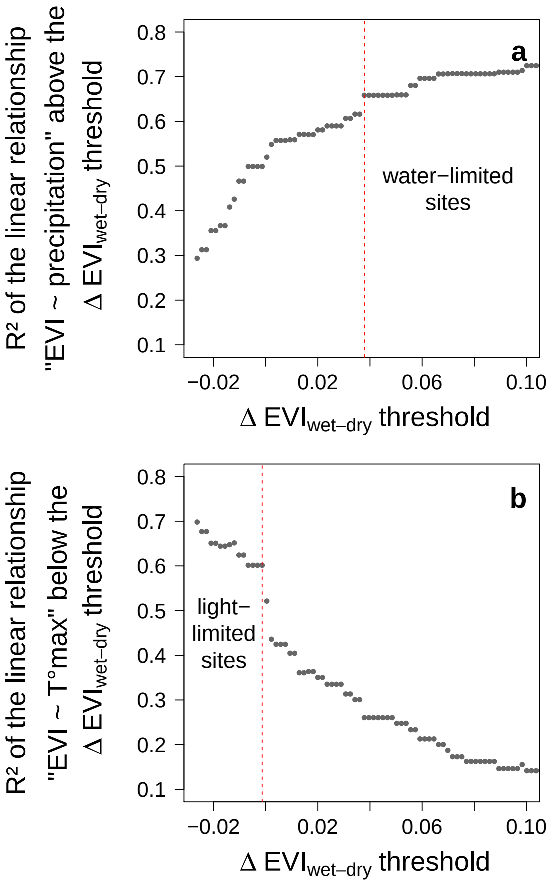

Figure 6. Threshold of $\Delta\mathrm{EVI}_{wet-dry}$ used to define 'water-limited' sites (a) and 'light-limited' sites (b). Sites with $\Delta\mathrm{EVI}_{wet-dry}$ between the two thresholds had a mixed influence of the two climate variables and were qualified as 'mixed'. The names of the classes represent the main climate limitations deduced from the climate control on canopy photosynthetic capacity observed in our results. The y-axis represents the R^2 values of the linear models normalized EVI as a function of normalized precipitation (a) and as a function of maximal temperature (b), respectively for the sample with $\Delta\mathrm{EVI}_{wet-dry}$ above the threshold (a) and below the threshold (b). Optimal threshold of $\Delta\mathrm{EVI}_{wet-dry}$ for climate variable influence on normalized EVI was defined by a break in the decrease of R^2 values, which is represented by red dashed lines.

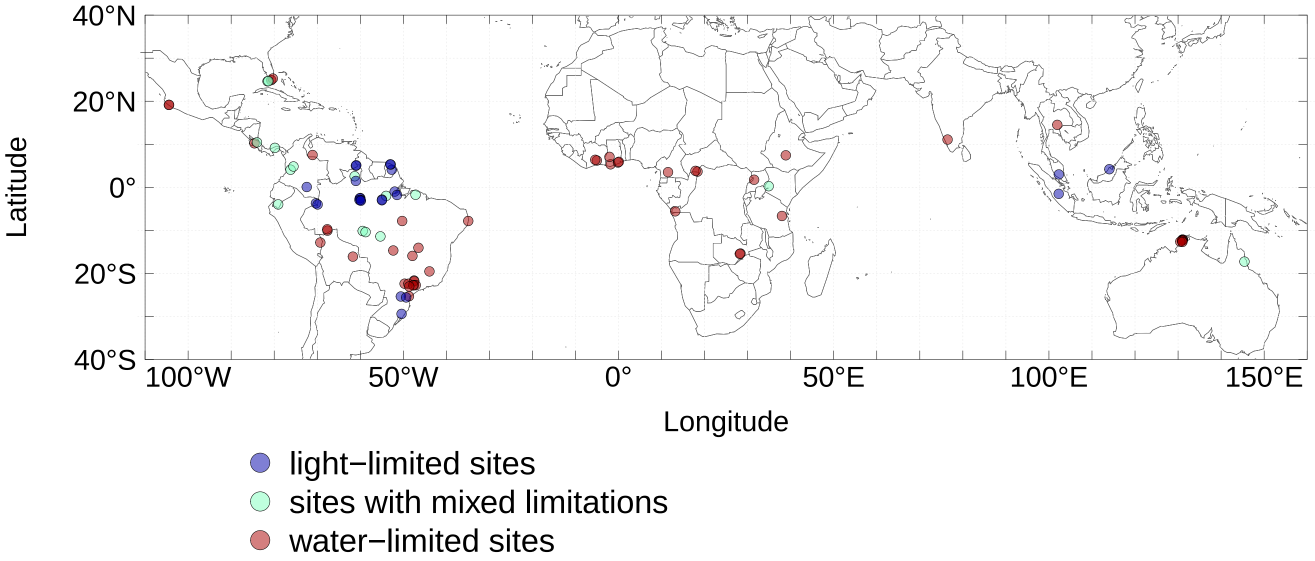

Figure 7. Locations and climate limitations of the 89 experimental sites. water-limited sites ($\Delta EVI_{wet-dry} > 0.0378$), sites with mixed limitations ($\Delta EVI_{wet-dry}$ [-0.0014;0.0378]) and light-limited sites ($\Delta EVI_{wet-dry} < -0.0014$), (Fig. 6 for the definition of the thresholds).

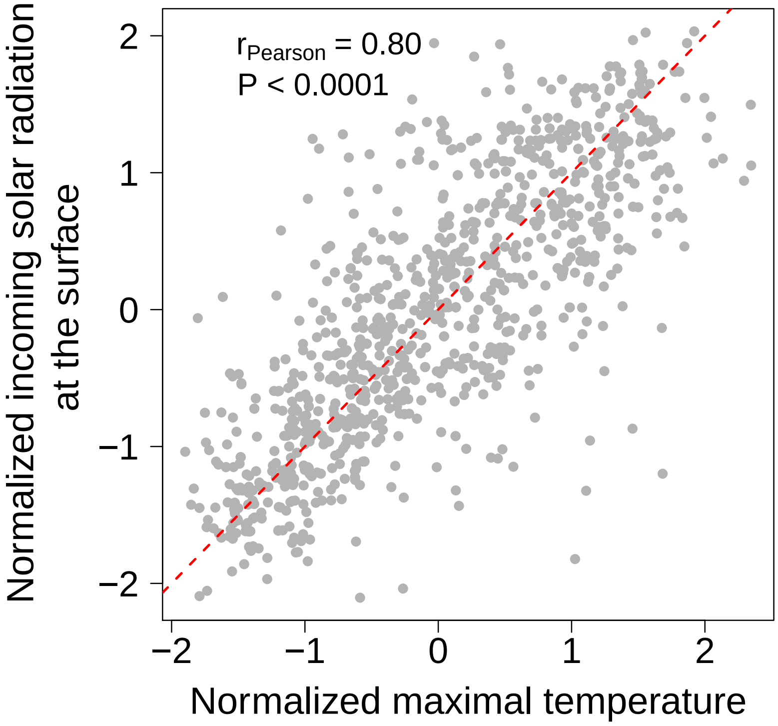

Figure 8. Association between normalized maximal temperature from Climate Research Unit and normalized incoming solar radiation at the surface from CERES. Monthly incoming solar radiation at the surface (incident shortwave radiation) refers to radiant energy with wavelengths in the visible, near-ultraviolet, and near-infrared spectra and is produced using MODIS data and geostationary satellite cloud properties (Kato et al., 2011). The red dashed line is the identity line $y = x$.^{FW}~~Light as an indirect index of solar radiation on the forest floor in light-limited sites. Solar radiation at the top of the atmosphere is not different in dry and wet seasons for these sites, whereas maximal temperature appears to be a good index of the solar insolation at the surface as it integrates both solar radiation and solar interception due to cloud cover. Dry season is defined as months with precipitation < 100 mm.~~

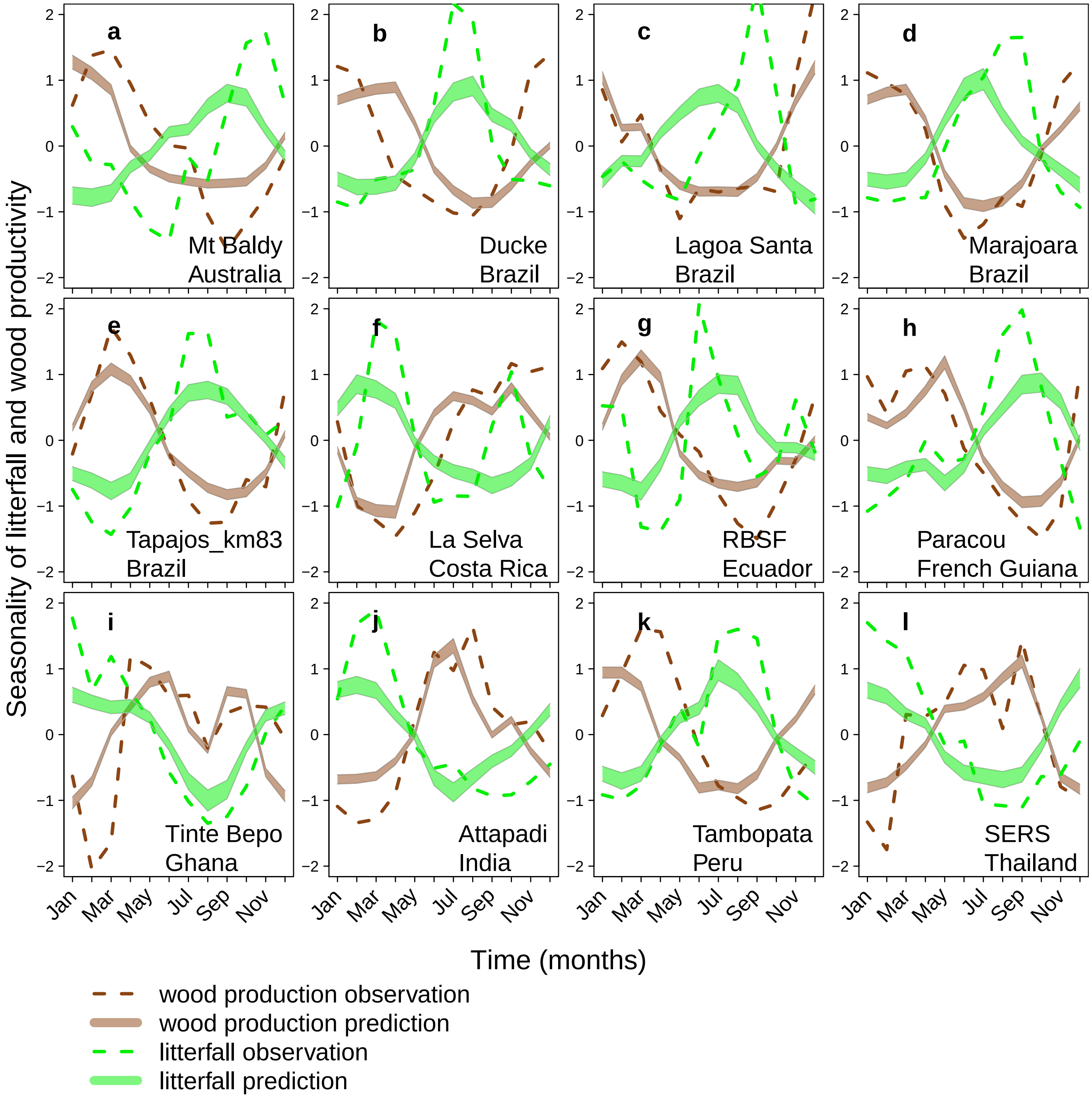

Figure 9. Observations and predictions of wood productivity and litterfall seasonality in sites where both measurements were available. The outliers in our analysis, Lambir and Caracarai, are not represented. Y-axis have no units as the variables were normalized.

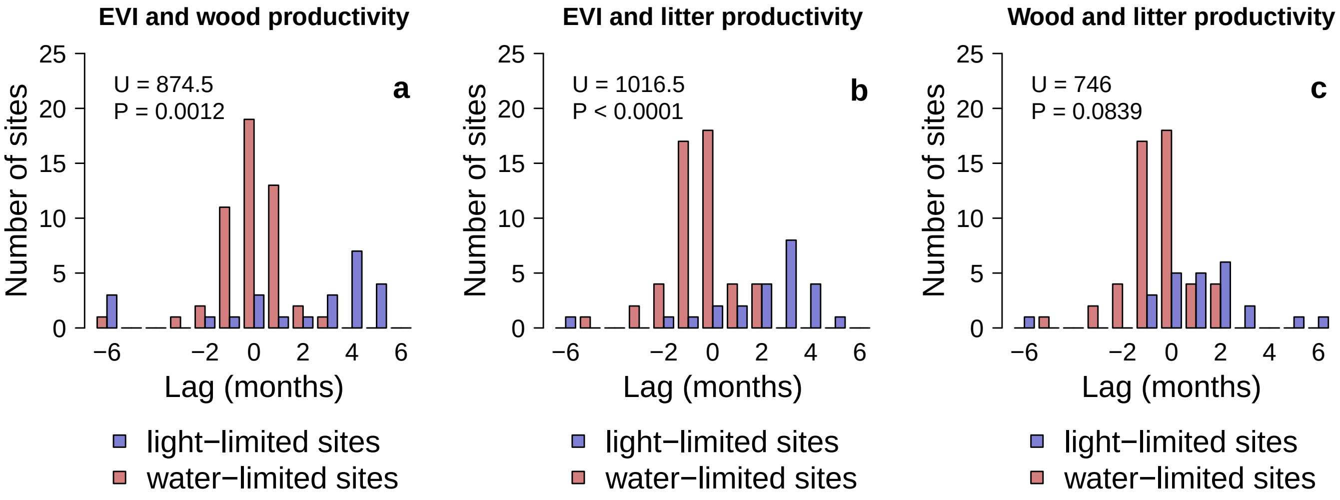

Figure 10. Cross-correlation between monthly EVI and wood productivity (a), EVI and litter productivity (b) and wood and litter productivity (c) for water- and light-limited sites. The x-axis indicates the time-lag to get the maximum correlation between the variables. When no observations were available for wood and litter productivity, predictions from the climatic model were used (Table 4). To facilitate graphical representation, cross-correlation (a) is positive, (b) and (c) are negative. A positive cross-correlation at lag one month indicates a similar seasonal pattern in the time series with a time lag of one month, while a negative cross-correlation at lag one month indicates an opposite seasonal pattern with a time lag of one month. All the water-limited and light-limited sites were represented (respectively 50 and 24 sites) as only 4 water-limited sites in (a) and 3 in (b), and only 2 light-limited sites in (c) have no statistically significant cross-correlation.[FW] ~~Cross-correlation between monthly EVI and wood productivity (a), EVI and litter productivity (b) and wood and litter productivity (c) for water- and light-limited sites. When no observations were available for wood and litter productivity, predictions from the climatic model were used (Table 4). To facilitate graphical representation of cross-correlation (a) is positive, (b) and (c) are negative.~~

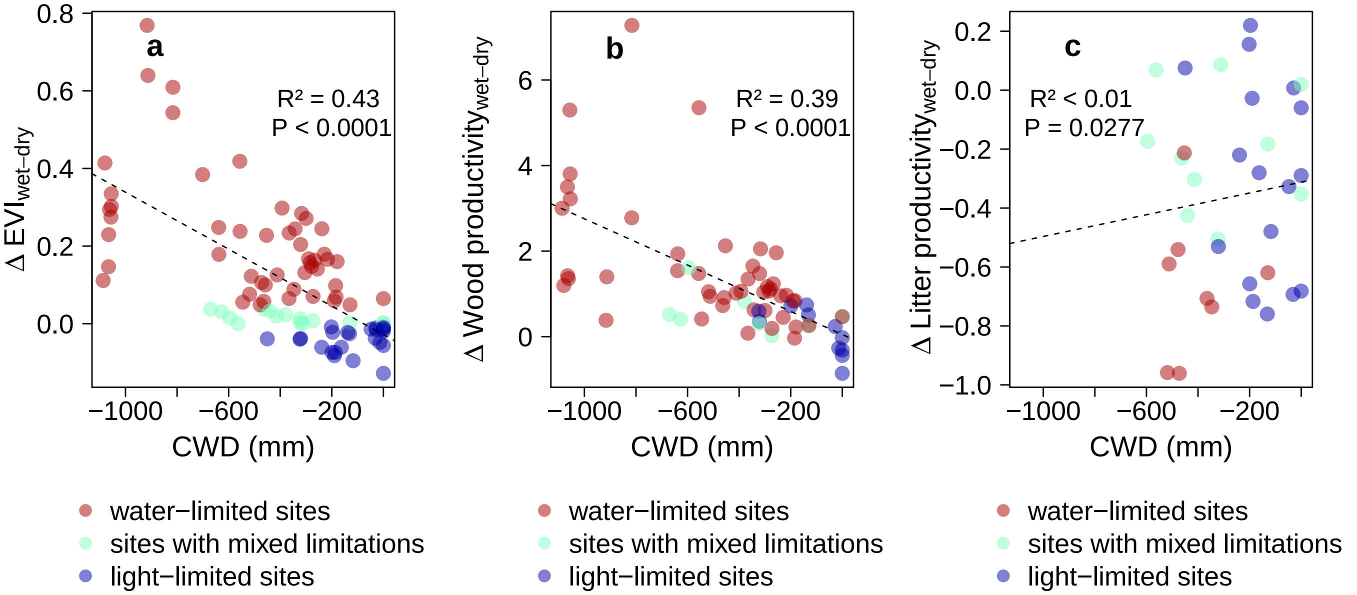

Figure 11. Associations between site's ΔEVI$_{wet-dry}$ (a), ΔWood productivity$_{wet-dry}$ (b) and ΔLitter productivity$_{wet-dry}$ (c) with the environmental variable maximum climatological water deficit (CWD). Dashed lines are the regression lines. ΔEVI$_{wet-dry}$, ΔWood productivity$_{wet-dry}$ and ΔLitter productivity$_{wet-dry}$ indices are the differences of mean of the wet- and dry-season of the variable normalized by the annual mean, where dry season is defined as months with potential evapotranspiration above precipitation (Guan et al., 2015). For the sites where evapotranspiration is never above precipitation, dry season is defined as months with normalized potential evapotranspiration above normalized precipitation.

SUPPLEMENTARY TABLES

Table S1. Number of sites with significant negative (neg), significant positive (pos) or non-significant relationship (no) between the seasonality of wood productivity and each of the climate variables (varclim). Signs $+$ and $-$ indicate the mean sign of the climate variable relationship with the seasonality of wood productivity at lag -1, 0 and +1 month.

sign (lag -1, 0, +1 month)	varclim	neg	no	pos
$+++$	pre	3	6	59
$+++$	cld	2	8	58
$---$	dtr	4	9	55
$+++$	swc	8	9	51
$+++$	rad	2	21	45
$+++$	vap	3	21	44
$+++$	tmn	4	21	43
$+++$	tmp	17	15	36
$---$	pet	13	20	35
$--+$	tmx	20	26	22

Table S2. McNemar test of proportion p-values for each of the climate variables used to predict wood productivity. p-value < 0.05 indicates that a different proportion between the two climate variables cannot be rejected.

	pre	cld	dtr	vap	tmn	swc	rad	pet	tmp	tmx
pre	1.00	0.39	0.52	0.01	0.00	0.13	0.02	0.00	0.00	0.00
cld	0.39	1.00	0.54	0.02	0.01	0.20	0.02	0.00	0.00	0.00
dtr	0.52	0.54	1.00	0.01	0.00	0.53	0.02	0.00	0.00	0.00
vap	0.01	0.02	0.01	1.00	0.96	0.00	0.80	0.02	0.01	0.00
tmn	0.00	0.01	0.00	0.96	1.00	0.04	0.55	0.06	0.00	0.00
swc	0.13	0.20	0.53	0.00	0.04	1.00	0.03	0.01	0.04	0.00
rad	0.02	0.02	0.02	0.80	0.55	0.03	1.00	0.04	0.00	0.00
pet	0.00	0.00	0.00	0.02	0.06	0.01	0.04	1.00	0.48	0.00
tmp	0.00	0.00	0.00	0.01	0.00	0.04	0.00	0.48	1.00	0.05
tmx	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	1.00

Table S3. McNemar test of proportion p-values for each of the climate variables used to predict wood productivity for the cluster where vap has a positive effect. p-value < 0.05 indicates that a different proportion between the two climate variables cannot be rejected. For this subset, vap and pre are highly correlated ($\rho_{Pearson}$ = 0.849, p-value < 0.001).

	pre	vap	tmn	rad
pre	1.00	0.80	0.80	0.80
vap	0.80	1.00	0.92	0.99
tmn	0.80	0.92	1.00	0.99
rad	0.80	0.99	0.99	1.00

Table S4. McNemar test of proportion p-values for each of the climate variables used to predict wood productivity for the cluster where tmp has a positive effect. p-value < 0.05 indicates that a different proportion between the two climate variables cannot be rejected. For this subset, tmp and pre are correlated ($\rho_{Pearson}$ = 0.659, p-value < 0.001).

	pre	tmp	tmx	pet
pre	1.00	0.80	0.02	0.00
tmp	0.80	1.00	0.39	0.00
tmx	0.02	0.39	1.00	0.06
pet	0.00	0.00	0.06	1.00

Table S5. Number of sites with significant negative (neg), significant positive (pos) or non-significant relationship (no) between the seasonality of litter productivity and each of the climate variables (varclim). Signs $+$ and $-$ indicate the mean sign of the climate variable relationship with the seasonality of litter productivity at lag -1, 0 and +1 month.

sign (lag -1, 0, +1 month)	varclim	neg	no	pos
$- - -$	cld	0	8	27
$+ + +$	dtr	1	8	26
$- - -$	pre	1	12	22
$+ + +$	pet	1	14	20
$+ - -$	rad	4	12	19
$+ + +$	tmx	3	13	19
$- - -$	vap	3	15	17
$- - -$	tmn	5	13	17
$- - +$	swc	5	15	15
$+ + -$	tmp	8	15	12

Table S6. McNemar test of proportion p-values for each of the climate variables used to predict litter productivity. p-value < 0.05 indicates that a different proportion between the two climate variables cannot be rejected.

	pre	cld	dtr	vap	tmn	swc	rad	pet	tmp	tmx
pre	1.00	0.11	0.57	0.23	0.25	0.07	0.39	0.53	0.03	0.55
cld	0.11	1.00	0.26	0.00	0.05	0.02	0.05	0.11	0.02	0.11
dtr	0.57	0.26	1.00	0.06	0.06	0.01	0.23	0.13	0.00	0.07
vap	0.23	0.00	0.06	1.00	0.88	0.70	0.28	0.42	0.10	0.23
tmn	0.25	0.05	0.06	0.88	1.00	0.78	0.88	0.43	0.76	0.92
swc	0.07	0.02	0.01	0.70	0.78	1.00	0.69	0.26	0.39	0.51
rad	0.39	0.05	0.23	0.28	0.88	0.69	1.00	0.54	0.43	0.94
pet	0.53	0.11	0.13	0.42	0.43	0.26	0.54	1.00	0.01	0.53
tmp	0.03	0.02	0.00	0.10	0.76	0.39	0.43	0.01	1.00	0.03
tmx	0.55	0.11	0.07	0.23	0.92	0.51	0.94	0.53	0.03	1.00

Table S7. McNemar test of proportion p-values for each of the climate variables used to predict wood productivity for the cluster where tmp has a positive effect. p-value < 0.05 indicates that a different proportion between the two climate variables cannot be rejected. For this subset, cld and tmn are correlated ($\rho_{Pearson}$ = 65.0, p-value < 0.001).

	cld	tmn	vap	swc
cld	1.00	0.39	0.26	0.17
tmn	0.39	1.00	0.80	0.57
vap	0.26	0.80	1.00	0.30
swc	0.17	0.57	0.30	1.00

Table S8. Intercepts and slopes of the fitted linear models to explain seasonal EVI of Fig. 5 (b) and (c) with the seasonal climate variables precipitation (pre) and maximal temperature (tmx) according to the climate limitation class.

model response	site limitation	parameters	Estimate	std. error	t value	p-value	R^2
EVI	water	(Intercept)	0.0000	0.0231	0.0000	1.0000	0.6518
		Precipitation	0.8073	0.0241	33.4551	< 0.001	
EVI	mixed	(Intercept)	0.0000	0.0684	0.0000	1.0000	0.0921
		Precipitation	0.3035	0.0714	4.2503	< 0.001	
EVI	light	(Intercept)	-0.0000	0.0510	-0.0000	1.0000	0.1882
		Precipitation	-0.4338	0.0533	-8.1418	< 0.001	
EVI	water	(Intercept)	0.0000	0.0391	0.0000	1.0000	0.0029
		Maximal temperature	-0.0535	0.0408	-1.3112	0.1903	
EVI	mixed	(Intercept)	0.0000	0.0717	0.0000	1.0000	0.0005
		Maximal temperature	0.0230	0.0749	0.3063	0.7597	
EVI	light	(Intercept)	-0.0000	0.0365	-0.0000	1.0000	0.5841
		Maximal temperature	0.7643	0.0381	20.0410	< 0.001	

SUPPLEMENTARY FIGURES

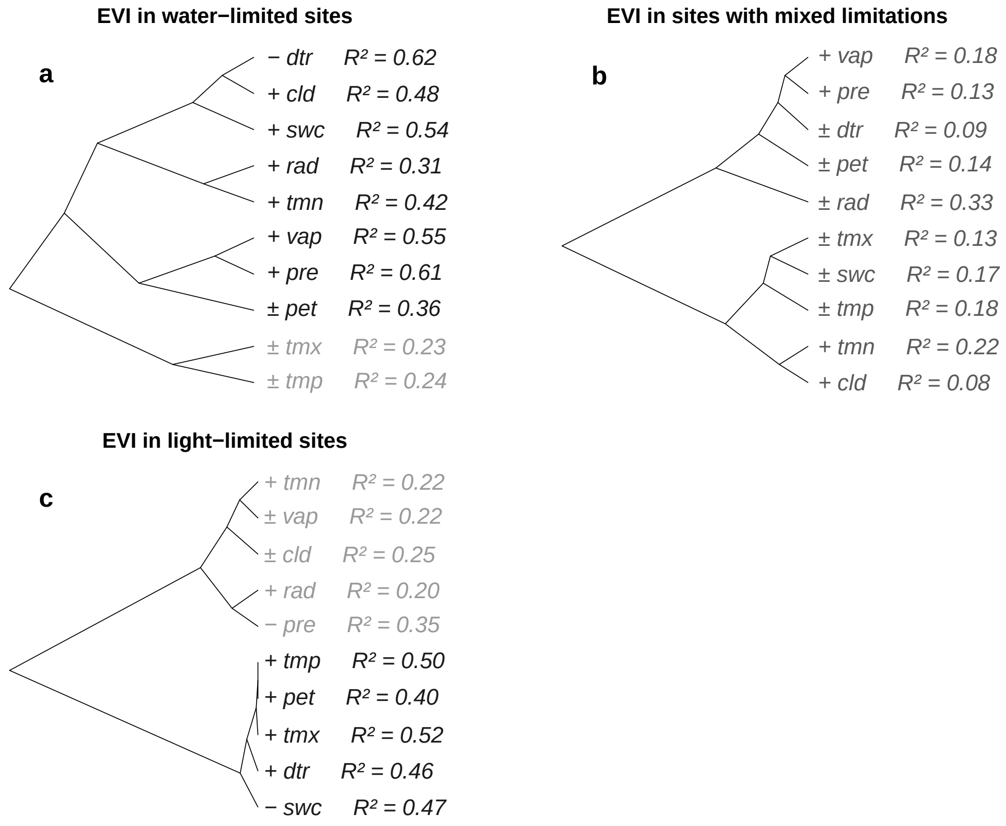

Figure S1. Dendrogram of monthly associations of climate variables and EVI for water-limited, mixed and light-limited sites. $+$ indicates a positive correlation between the climate variable and EVI in all the sites of the group (groups: water-limited, mixed or light-limited), $-$ indicates a negative correlation in all the sites of the group, while $\pm$ indicates a positive correlation for a part of the sites of the group while a negative for the other. Climate variables in the same cluster indicates that they are highly correlated, that is, they produce the same prediction in terms of values but also predict the same effect for the same sites. Different shades of grey indicate the relative strength of associations for each cluster with the seasonality of EVI; black indicates the strongest association. cld: cloud cover; pre: precipitation; rad: solar radiation at the top of the atmosphere; tmp, tmn and tmx are respectively the daily mean, minimal and maximal temperatures; dtr: temperature amplitude; vap: vapour pressure; pet: potential evapotranspiration; and swc: relative soil water content.

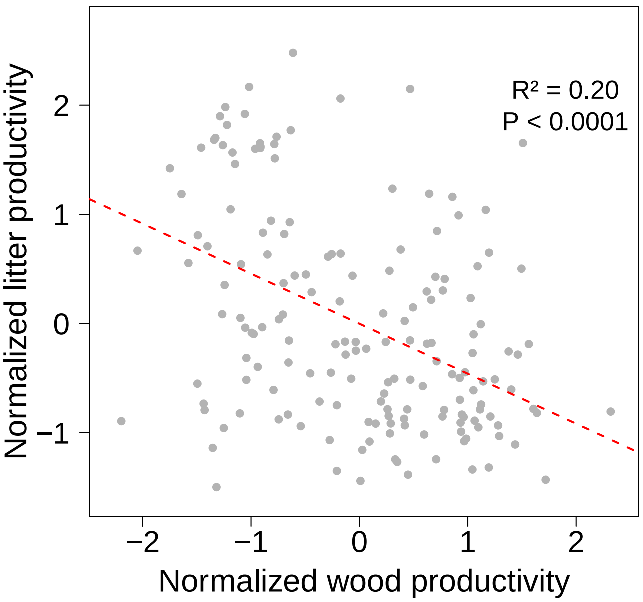

Figure S2. Wood productivity versus litter productivity observations. The red dashed line is the linear model between both variables.

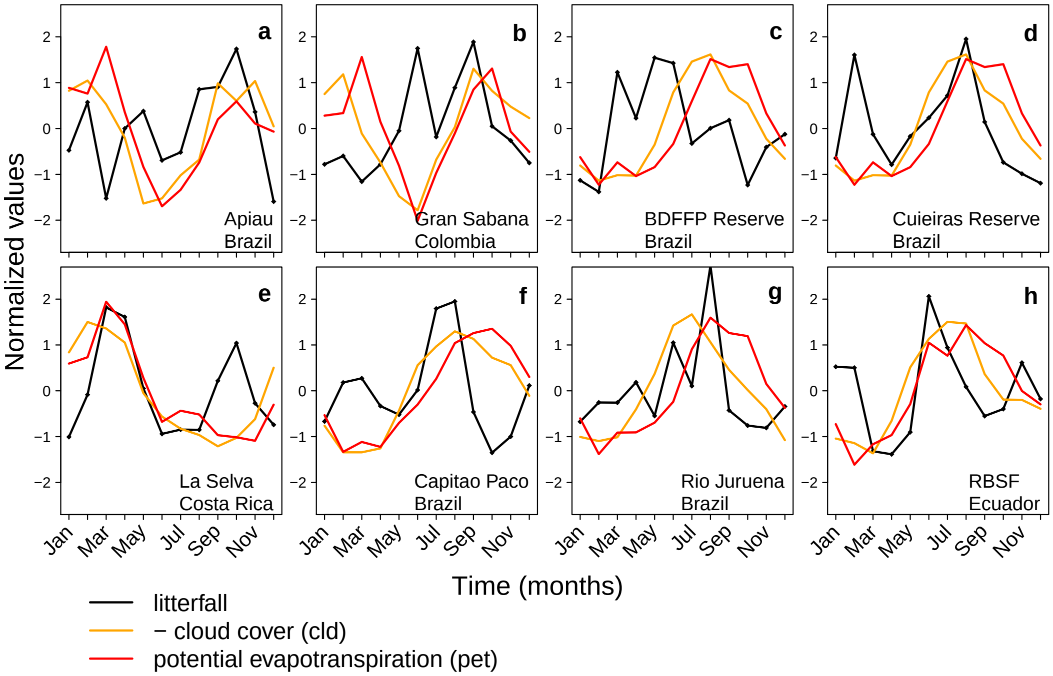

Figure S3. Normalized litter productivity, potential evapotranspiration (pet) and cloud cover (cld) for the sites with no relationship to cloud cover in linear analysis. Cloud cover is multiplied by -1 to facilitate the representation.

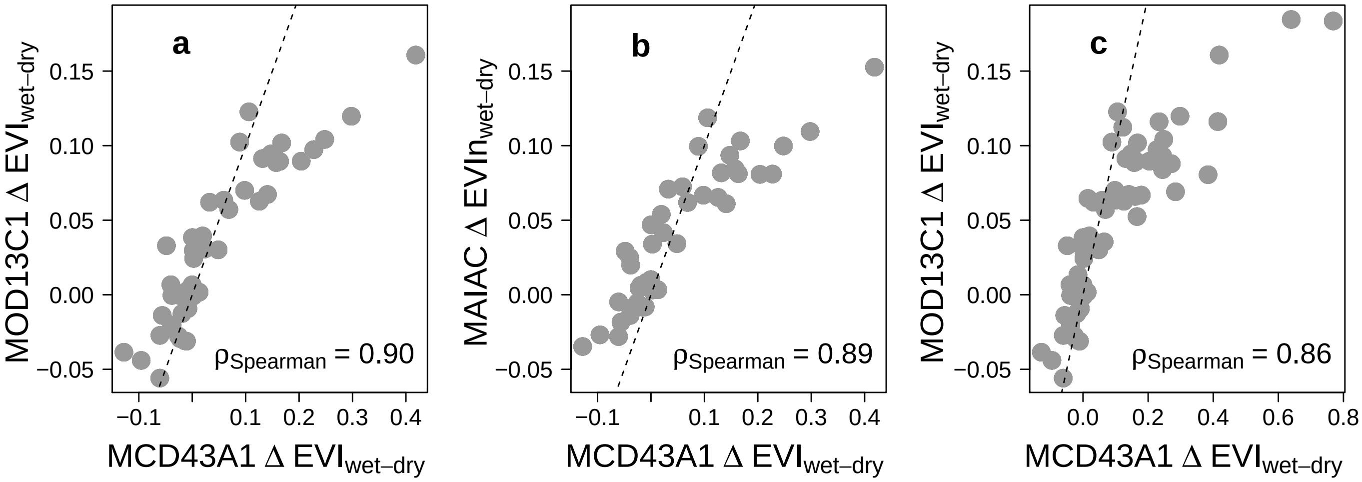

Figure S4. Relationships between $\Delta EVI_{wet-dry}$ from MODIS MCD43A1 (this article) and MOD13C1 and MAIAC products for the South American sites (a) and (b), and for all the sites (c) Guan et al. (2015). The climate data used for the computation of $\Delta EVI_{wet-dry}$ from MODIS MCD43A1 (this article) and MOD13C1 and MAIAC products Guan et al. (2015) are independent. The black dashed line is the identity line y = x.