

Interactive comment on “Amazon forest structure generates diurnal and seasonal variability in light utilization” by D. C. Morton et al.

Anonymous Referee #1

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Review, ‘Amazon forest structure generates diurnal and seasonal variability in light utilization’, by Morton et al. (2015)

General comments

This paper reports seasonal and diurnal patterns of light utilization in Amazonian forest, which are independent of total absorption of PAR, and which would expect to significantly affect vegetation productivity. The study is significant in explaining seasonal variability in particular, inclusion of realistic structure from new airborne lidar measurements, and highlights the need to consider light use efficiency and canopy structure in modelling productivity.

The results predict a strong seasonal cycle independent of leaf area changes, and

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gives a quantitative estimate of $\sim 2\text{--}3\%$ annual variation due to interception by non-photosynthetic elements, and $\sim 7\text{--}10\%$ due to light saturation. In dry season we may expect higher light levels due to decreased cloudiness, but the effect of aerosols and sun angle also is modelled. While the results are based on model predictions alone, the magnitude agrees broadly with previous estimates combining model and flux tower estimates for Amazonia (Alton et al 2007a). Much previous work has been carried out on understanding and modelling light saturation effects, but many questions remain especially in modelling complex canopies under highly variable light conditions (see review, e.g. by Kanniah et al 2012). This study is novel in considering 3D structure in detail by including state-of-the-art lidar measurements, detailed modelling of interception by non photosynthetic elements and the focus on explaining seasonal variability of photosynthesis in tropical forests.

The main caveats are reliance on model output alone and interpretation of magnitude of results. DART is a very good model which has been widely used and tested, but inclusion of leaf-level light use efficiency is new to this model, and some approximations are made which are likely to give a reduced sensitivity to light saturation and the impact of diffuse light. In addition, leaf-level light response may be expected to show acclimation to light levels both seasonally and with canopy position (Kitajima et al 1997; Valladares et al. 1997). Neglecting this by contrast is likely to give greater sensitivity to saturation/diffuse light impacts. However no current models can claim to include all effects satisfactorily. The final question raised (including by the title) is how much of the seasonal effect should we attribute to three-dimensional structure, and how closely should this be modelled? We would expect to see some impact of light saturation at high light levels in a one-dimensional model also (e.g. Mercado et al. 2009). Running DART with uniformly distributed foliage could establish the impact of 3D structure.

In summary, this is an important study giving the first estimate of the role of structure and light saturation in seasonal variation of Amazonian photosynthesis, and should be published after revision to address the specific points below.

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Specific comments

1. Model structure and instantiation (i) The model is set up using high density lidar point data, with careful processing to create uniform spatial sampling density, and the appearance of the scene shown in Figure 1 is realistic. However the paper would benefit from a clearer explanation of exactly how the canopy structure was set up for the DART model. (Also, presumably the cell represented in figure 1 is repeated in simulation rather than running as an isolated cell, but this should be stated).

(ii) "leaf area . . . was allocated to 1 m³ voxels based on the distribution of multistop lidar returns" How was this done? In particular how was point density scaled to vertical profile of leaf area density, which should account for interception increases with canopy distance. Probably the results are not too sensitive to the process used here, but it would be good to clarify.

(iii) How are branches represented/inserted in relation to the measured leaf area density? This is important as the results of the study depend in part on what fraction of direct light is intercepted by leaf vs non-leaf plant elements. Sun angle changes are expected due to lower sun angles being increasingly intercepted by vertical trunk/branch structures, but this is not typically modelled, so this is an interesting part of the simulation.

(iv) If voxels are at 1 m³ resolution, how are finer structures than this represented? This includes both branches and leaves, and casting of shadows by elements within the voxel.

2. Modelling of interception and light use efficiency.

(i) "Estimates of IAPAR for each 1 m³ voxel were post-processed to account for light saturation effects based on a photosynthetic light response curve from leaf-level measurements of tropical forest trees"

This seems one of the most major approximations used here, and it would be good to

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comment or quantify the impact. In particular light saturation is estimated based on a model of leaf-level PAR (Kitajima et al 1997), but applied using an absorption level averaged over all leaves within 1 m². This is likely to work well if light is diffuse (overcast conditions or deep in canopy), but misses the dispersion of leaf intercepted PAR in full sunlight, where some leaves will experience high light conditions (~2000 $\mu\text{mol}/\text{m}^2/\text{s}$) while others much less due to both shadowing by leaves and orientation away from the direct beam. The approximation will likely underestimate the expected impact of diffuse vs direct light, as locally light is already effectively modeled as perfectly diffuse at the leaf level. The authors should clarify the approximations used and likely impact on results.

(ii) A further approximation is the assumption of the same leaf photosynthetic rate model for all positions in the canopy. In reality there is adaptation of leaves to higher/lower mean light conditions, both spatially and seasonally (Kitajima et al 1997; Valladares et al. 1997), which acts to reduce the variation of canopy level photosynthesis with light levels, making total canopy response more linear to light. While correct values may be difficult to obtain, and are typically sub-optimal in natural vegetation, ignoring variability may change the light utilization calculation by 10-15% (Haxeltine and Prentice 1996, Alton et al., 2007b). A full modelling study of these effects is beyond the scope of the paper, and would be a good topic for future research, but the authors should state clearly the approximations used and their likely impact on results in presenting conclusions.

(iii) Figure 3: The meaning of the numbers could be more clear: 'Leaf absorbed PAR' here refers to per m² of ground surface, compared with the same name in Figure 2 uses same terminology to refer to absorption per m² of leaf area averaged over 1 m³ volume. The maximum intercepted PAR is shown to peak at ~1300 $\mu\text{mol}/\text{m}^2/\text{s}$. This seems rather low, with direct sunlight values potentially in excess of 2300 $\mu\text{mol}/\text{m}^2/\text{s}$. Is the data used time averaged?

(iv) Section 3, line 24 "including the fraction of leaves experiencing light-saturated con-

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ditions” – please clarify the definition of ‘light-saturated’ used here. Is it the case that all leaves within 1m³ voxel are either light saturated or not?

3. Conclusions/interpretation of results

The conclusions are well drawn, and should be clarified to include the caveats noted in the methods discussed above ((2(i) & 2(ii)). A further point made which would benefit from greater quantification is the extent to which seasonal and diurnal variation is influenced by 3D structure (as opposed to light levels/diffuse fraction which have been previously modelled with 1D canopy models). In particular:

(i) how sensitive are the results to the particular canopy structure (e.g. does it matter if leaf area is allocated differently, or voxel size changes)?

(ii) How important is 3D structure to the results? This could be discussed more critically, or ideally tested by reallocating LAI to a homogenous distribution (ie each cell contains same leaf area density), for same total scene LAI. For example we would expect to see increased total IPAR, since clumping is reduced, and impact also on canopy BRDF, but of interest here is impact on canopy light use efficiency and its seasonal pattern – how important is inclusion of 3D structure to model this?

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