Reply to comments of Miriam Coenders-Gerrits

We thank Miriam Coenders-Gerrits for her comments; they were very helpful to improve our manuscript. Our responses to the comments are provided in bold (below each comment).

General comments

The paper by Zimmermann et al is a very interesting paper. It encompasses a statistical analysis to determine those forest indicators that can be used to estimate throughfall (and interception) during secondary forest succession. The authors compare throughfall data from the developing ASP-sites with the mature BCI-forests. They assume that the interception values of the BCI-forests can be used as a benchmark to determine whether the interception rates at the ASP-sites are 'stabilized' to the value of a mature forest. This is a valid assumption as long as the BCI and ASP have (or will have in time) a similar vegetation type. The paper does not discuss whether this is a valid assumption or not.

The plots on BCI serve as a reference because the vegetation on the island represents the natural vegetation of the central Panama Canal Watershed (Foster and Brokaw, 1996). BCI is at close distance from ASP with the same climate and soils. Therefore, forests in the ASP area can be expected to develop towards the same (mature) forest type as on BCI.

Furthermore, the title refers to rainfall interception, while throughout the entire paper throughfall is analysed. Although interception and throughfall are directly correlated (ic = 1-tr), it might be good to either change the title to 'throughfall', or show interception results.

We modeled throughfall because this was the variable which we measured in the field. The title, however, should attract the interest of a wide community of researchers and decision makers. That's why we prefer to use interception instead of throughfall in the title.

The paper is well written and well structured. Only the section where the Bayesian Model Averaging is explained should be clarified in such way that it is better understandable for non-Bayesian experts. Hence it is recommended to explain the jargon and restructure this section. This also holds for description of the BMA-results.

We tried to simplify the section on Bayesian Model Averaging. However, we consider that some basic knowledge of Bayesian statistics will always remain essential to understand the details.

The statistical analysis is innovative and helps to unravel the dominant forest descriptors to estimate interception. However, the authors could elaborate on the limitations of their study. For example, what is the effect of only looking at linear relations between throughfall and the forest descriptors? The study is based on a two-month measuring period in the rainy season, how does this relation hold in the dry season?

We agree that it is important to indicate limitations of a study approach. In our manuscript we have indeed addressed several of such limitations. For instance, we mention the relatively large error of mean throughfall estimates (Sect. 3.1), we outline the problem of multicollinearity (Sect. 3.4), we point to the problem of detecting the interception signal of young forests (Sect. 4.1), and we discuss how to improve models that apply forest structure parameters for predicting canopy interception (Sect. 4.3).

We did test if other types of relationships, such as quadratic ones, could help to improve our models but except for openness (see our reply to your comment on the transformation of openness, Page 8024) this was not the case.

Although we never intended to extrapolate our findings to a whole year, the distribution of rainfall between dry and wet season suggests that our findings are representative in terms of the overall water balance (see also our extensive replies to comments of reviewer #2 and #3 on this issue).

Specific comments

Page 8003

L14: Fig1a => 1b.

We refer to Fig. 1a because this part of the figure allows locating Barro Colorado Island in the central Panama Canal Watershed.

L25-26: For clarity add that the 95 forest inventory plots are called 'prediction sites' and the 20 plots 'throughfall plots' (see Fig 1d-f).

Thank you for this observation, it indeed helps the clarity of the manuscript to make such a clear distinction. We chose to use the term "SFD plots" when we refer to all plots from the secondary forest dynamics study, which were used in this study, while the term 'throughfall plots' is now reserved for the plots of the throughfall monitoring campaigns (i.e. 16 of the SFD plots plus the four mature forest plots on BCI). This new nomenclature is described in section 2.2.1 of the revised manuscript.

Page 8005

L4: How can you make 5x5m quadrants (i.e. 4 parts) when the plots have a size of 20x5m or 30x60m?

You are right. We replaced the word "quadrant" with "subplot".

L18: You took the average rainfall for the five collectors? Please clarify.

We clarified the description of our rainfall estimates and wrote " … At each rainfall site, we placed five to ten collectors to obtain an estimate of mean rainfall … ".

Page 8006

L20-21: Does 'long-term' refer to the two months measuring period?

Following a suggestion of reviewer #2 we changed this sentence. In the revised version the ambiguous term “long-term data” is not used anymore.

Eq 1: I would recommend changing this equation into

$$i_c = 100 - t_r = \frac{\hat{\bar{T}}(\mathbf{x}_i)}{\hat{\bar{R}}(\mathbf{x}_1)} \cdot 100$$

We would prefer to stick to the original version:

$$t_r(\mathbf{x}_i) = \frac{\hat{\bar{T}}(\mathbf{x}_i)}{\hat{\bar{R}}(\mathbf{x}_i)} * 100$$

The reason is that we consider the suggested equation to be too complicated because it includes two steps: calculating relative throughfall (first step) and calculating interception (second step). Please note that the suggested equations should read

$$i_c(\mathbf{x}_i) = 100 - t_r(\mathbf{x}_i) = 100 - \left(\frac{\hat{\bar{T}}(\mathbf{x}_i)}{\hat{\bar{R}}(\mathbf{x}_i)} * 100 \right).$$

Page 8007

L11: Please explain the Shannon diversity index.

We added an explanation in the revised manuscript.

L16: Anticipated => hypothesized.

We deleted the sentence because it seemed to be redundant.

Page 8008

L8: Did the authors also look at e.g., the Nash-Suttclife and/or log(Nash-Suttclife) performance? These two error measures are especially sensitive for the high and low values, respectively.

We used the Root Mean Square Error (RMSE) to validate our predictions because this measure is simple, easy to interpret, and provides information on model performance in <u>absolute terms</u>. The Nash–Sutcliffe efficiency measure (Nash and Sutcliffe, 1970), in contrast, provides a normalized measure (-inf to 1) by comparing the performance of a particular model against the simplest model (one that uses a constant mean value for predictions). Because <u>Nash values heavily depend on the system under study</u> (e.g. Schaefli and Gupta, 2007) their use (and the use of the reference model) should be considered with care. In our case, we would use the mean relative throughfall from all sites as a reference model. Nash values based on this reference model, however, would be of little value because of the comparatively poor performance of the reference model

(i.e. the mean relative throughfall of all plots could not capture the large variation of relative throughfall among our plots).

L10-12: Explain what is the calibration and the validation period. Also explain the leave-one-out cross validation method.

We are not sure about what the reviewer means with calibration and validation "period". Briefly, leave-one-out cross validation works as follows: 1) observation x_1 is left out of the data, 2) the model is calibrated on the remaining observations, 3) the difference between prediction for x_1 and observation x_1 is noted. The next iterations of the cross-validation repeat this procedure for x_2 … x_n.

Sect2.3.4: I don't understand this. Please explain in a different way. What is meant by 'model', 'completely flat prior' (P8009 L6), 'hyper-g-prior' (P8009 L11). Why do you have two models (an explanatory variable is included in the model or not, i.e. two possibilities?)? What are the explanatory variables? You seem to use 8 explanatory variables? Are these the ten listed in Table 2 minus BA1, BA5? Please, explain and restructure this section.

We tried to give some more explanations and listed the explanatory variables used in this section (this list was formerly included in the results section). We also corrected the number of possible models, which was incorrect in the submitted manuscript. We hope this helps a bit. A discussion on g priors seems to us to be beyond the scope of this manuscript. Readers might not be familiar with Bayesian statistics, but in order to maintain the paper focused on rainfall interception and keep the (already long) method section within limits, we hope that the provided references will help the readers that are interested in the details.

Page 8009

L27: Which forest inventory data is used? All ten as shown in Table 2? Please explain.

We completely re-wrote this section. In the revised version we clearly state that we only used BA_{ratio} data for predictions.

Page 8010

L6-10: I don't understand what we can learn/benefit from this analysis. Please clarify.

In section 3.5 and 4.1 we outlined what we can learn from this analysis. In section 3.5 we wrote: " … The predicted values still differ from throughfall of mature forest on Barro Colorado Island (BCI), though more than half of the SFD plots already show relative throughfall values which are within the credible interval limits of relative throughfall at the mature forest sites (Fig. 4b). … ". This finding is the basis for the following argument provided in section 4.1: " … we expect that the influence of forest succession on interception at landscape scales is detectable only if secondary forests < 10 years are abundant because only early successional stages show canopy interception values that are consistently lower than those of mature forests (cf. Fig. 4). …".

L23-25: What is the sense of the skewness? Please clarify.

The skewness gives an idea about the shape of a distribution, and large values (skewness > 1) are often caused by outlying values, as is the case in this study. We mention the skewness because it adds to the uncertainty in our mean throughfall estimates.

Explain how SE ($\sigma / \sqrt{n}$?) and CV (σ / μ) are calculated. Then CV is dimensionless.

We follow standard practice in which CV is expressed in in percent (CV, % = standard deviation / mean * 100).

Page 8011

L16-22: For clearness, add that this analysis has been done on the 20 (or 16 plots).

We hope that the revised section on site selection (section 2.2.1) clarifies this issue.

Page 8012

Table 4 and Figure 3 have very much overlap. Maybe combine the two.

This is correct. We deleted Table 4.

Page 8013

L3-7: As mentioned before: I don't understand what we learn from this analysis. Please clarify.

Please see our reply to your earlier comment on the same issue.

Page 8014

L1-15: I think it is also important to mention the effect of transpiration on stand age. As correctly mentioned interception is lower at young stand compared to mature stands, however transpiration shows an inverse pattern (see e.g, Kuczera, 1987; Shiklomanov et al, 1988): young stands have high transpiration rates compared to mature stands. Please elaborate on this.

Data on transpiration seem to be ambiguous, as data from Puerto Rico, for instance, suggest that transpiration plus soil evaporation can be quite similar for pastures and mature forests (cf. Sect. 6.4 in Beck et al., 2013).

In the original manuscript we briefly outlined the role of transpiration (Sects. 1 and 4.1). Since we lack knowledge about transpiration rates in our study forests and because the role of transpiration is not the focus of our manuscript, we prefer not to speculate about the changes in transpiration during secondary forest succession.

Page 8016

L5-6: This cannot be concluded from this study. Please remove.

Following suggestions of reviewer #3, we provided additional data (new Fig. 5) which indeed allow us to conclude that the "fast change in canopy interception during forest succession clearly predates the recovery of soil permeability".

Page 8023

I am a bit surprised by some of the results. I would expect that openness, BA_1, BA_5, SD_1, SD_5, and BA_{ratio} would be positively correlated to tr, but BA_5, SD_5 are negatively correlated. How is this possible? Please, elaborate. Same holds for the correlation between openness and SD_1 and SD_5. I would expect them to be positively correlated.

During forest succession, the basal area of stems > 5 cm dbh (BA_5) and the stem density of stems > 5 cm dbh (SD_5) increases while relative throughfall decreases. Therefore, we detected negative relationships between throughfall and BA_5 and SD_5, respectively. The stem density of stems < 5 cm dbh (SD_1), however, decreases because trees grow (they enter the size class > 5 cm dbh), stems die (thinning), and (in addition) fewer saplings grow in older forests because it is too dark at the forest floor (as openness decreases). Therefore, SD_1 and openness are positively correlated (i.e. both parameters decrease during forest succession) and SD_5 and openness are negatively correlated (i.e. openness decreases and SD_5 increases during forest succession).

Page 8024

Why is the openness log-transformed? In the text this is not mentioned.

We $\log_{10}$-transformed openness to linearize the relationship between relative throughfall and openness. We noted the transformation as a footnote in Table 3 to ensure reproducibility of our results.

Page 8026

I would also plot forest age vs tr for the 20 plots.

We prefer to present the values of throughfall and forest age in a table (Table 1) as it provides the same information but also can be used in future research by other scientists.

Page 8028

How should I interpret this figure? What is the meaning of the 'sign' (also in Table 4). Please clarify.

We changed the description of the figure into: " … Cumulative posterior model probabilities resulting from the BMA approach. The colours denote the sign of a coefficient's expected value: blue refers to a positive sign (<u>indicating a positive relationship with relative throughfall</u>), red to a negative sign (<u>indicating a negative relationship with relative throughfall</u>). Note: the model with BA_{ratio} as the only predictor clearly has the largest weight.

References

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