Thank you to reviewer #1 for your very helpful review. The suggestion to further consider the uncertainty associated with our field data led to additional analysis that strengthens our original point, and we have outlined the additional work and changes made in this response. Reviewer comments are in italics, responses are in blue. Line numbers are from the original manuscript.

General comments:

Bias in MODIS VCF is a known issue. The study by Adzhar et al. adds new interpretation to the issue by comparing the latest version (Collection 6) of the satellite-based dataset with field data collected at ecological sites (24 forest and 24 savanna sites). The authors developed a simulation technique to address the scale discrepancy between the 100m x 100m sites and the 250m x 250m MODIS pixels, and extrapolated the derived relationship across the tropics. The study went on and analyzed the bias patterns of MODIS VCF per land-cover class using the MODIS land cover product. A major finding of the study is that MODIS VCF underestimates tree cover in tropical savannas and woody savannas, which has important implications for carbon cycle and forest restoration potentials. The paper is well written and easy to follow.

Specific comments:

Multiple definitions of "tree cover" exist in the literature. The manuscript provides a clear definition of Canopy Area Index (CAI, the fraction of ground covered by tree crowns). A primary semantic difference between CAI, and percent tree cover of MODIS VCF (the portion of skylight orthogonal to the surface that is intercepted by trees), is whether within-crown gaps are taken into account (CAI) or not (VCF). Within-crown gaps can be non-linear and species specific. For example, a recent analysis by Tang et al. (2019) shows that within-crown gap in a 30m pixel increases as tree cover increases and reaches a maximum of ~10% for conifer trees. The current study addressed the definitional discrepancy by dividing MODIS VCF by 0.8 based on Hansen et al. (2002). A discussion on the uncertainties associated with applying this uniform relationship will benefit the manuscript. Better yet, quantitatively analyze the uncertainty with the collected in situ data, if possible.

The within-canopy gap fraction correction factor (CGF) can vary with vegetation type (Lloyd et al., 2008; 0.34-0.60) and change with crown cover (Tang et al., 2019: 0.96 - 0.7).

To test how sensitive the results are to our assumption of a constant CGF value, we incorporated a cover (C) dependent CGF term into equation (1). We define CGF as:

CGF(C) = k C1- where 0 and 0 <k 1 (r1)

CGF is a constant value of k when = 1. Therefore, the 0.8 from Hansen et al. (2002) uses k = 0.8 and rou = 1. When <1 increases CGF at smaller covers.

Applying variable CGF to VCF in equation 1:

logit(VCF/k) = C0 + log(C1/(1-C2) (r2)

When we apply the constant CGF of 0.8 in the m/s, we do so before the clumping conversion of VCF to trobit size grid. To make our results comparable, we normalised VCF using the 0.8 value before analysis.

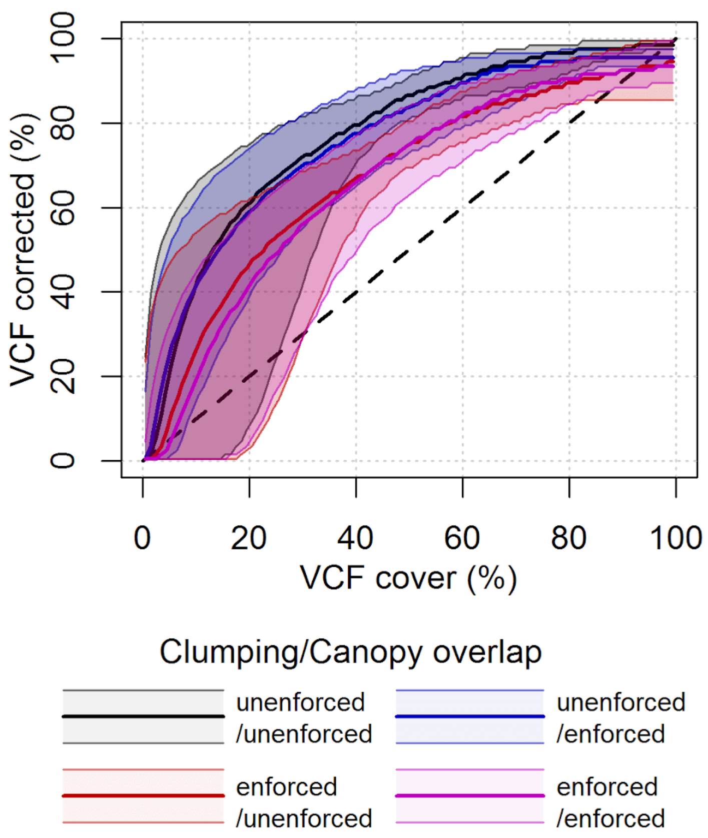

Figure r1. The correction curves as per Fig. A5 using equation r2 in place of equation 1.

The large scale patterns of our VCF correction curve when variable CGF is applied (Fig. r1), remain unchanged compared to when the CGF was a constant value (Fig. A4 in the manuscript). VCF mainly underestimates cover regardless of clumping or overlap except for low and high covers where VCF may overestimate tree cover. The transition between under and overestimating does take more extreme values, and this test suggests that assuming constant CGF provides a conservative estimate for the overall correction required for VCF. Therefore, incorporating varying CGF does not alter our main conclusion that VCF significantly underestimates tree cover in savanna-like systems. Also, Lloyd et al. (2008) found no universal relationship between CGF-crown cover and Tang et al. (2019) was conducted in a conifer-dominated landscape. We therefore stick with constant CGF when extrapolating VCF mismatch across the tropics in the main m/s as this map is only meant to indicate likely regions where VCF may require more detailed study, and now include a description of CGF as a potential cause of uncertainty in the discussion:

"...different in-situ measurement techniques tend to measure different types of tree cover (e.g. Fiala et al., 2006; Korhonen et al., 2006; Rautiainen et al., 2005) and each will require a conversion to enable direct comparison with MODIS VCF. In our case, to account for gaps between tree crowns, we applied the 0.8 'gap correction factor' to the CAI. However, on a plot by plot basis the GCF and resulting tree cover could vary widely (Lloyd et al., 2008). With further in-situ data that describes tropical vegetation type-specific GCF variation, we may be able to incorporate site-specific GCFs into our analysis."

The manuscript can also benefit by adding a clear description of how Canopy Area Index (CAI) is measured or calculated. The reference of Torello-Raventos et al. (2013) is provided, *but the details are not sufficient for understanding how CAI is derived and what's the uncertainties associated with CAI at the site level, especially for those who are not familiar with this paper. From Torello-Raventos et al. (2013), it appears that CAI was not directly measured at sites, but was calculated using allometric equations. Then, what is the uncertainty level associated with CAI estimations at the 100 m x 100 m sites, attributable to the allometric equations or the reference data underlying the allometric equations? Site-level uncertainty could be associated with specific direct measurement techniques. Moreover, tree cover definitions and measurement techniques could be connected, as hemispherical photography, terrestrial laser scanner, airborne waveform and discrete-return lidar all tend to measure different types of tree cover (e.g. Fiala et al. 2006, Korhonen et al. 2006, Rautiainen et al. 2005, Tang et al. 2019).*

<u>CAI:</u> We have included and updated text, further explaining how CAI was derived:

CAI is defined as the sum of the projected areas of individual tree canopies divided by the ground area. In the TROBIT project, plot-CAI was derived as follows (Torello-Raventos et al.,2013; Veenendal et al., 2015): Individual tree projected crown area was determined using the average of crown radii measured along the four cardinal points (i.e. from the centre of the stem to the distance furthest from the stem). The plot-wide CAI value is made up of the sum of the upper-stratum, mid-stratum, and subordinate-stratum crown areas. Membership to a stratum is determined by the tree's dbh (upper-stratum: dbh > 10 cm, mid-stratum: 2.5 cm < dbh < 10 cm, and subordinate-stratum: dbh < 2.5 cm, height > 1.5 m). About 50 trees per stratum per plot were measured to derive plot-specific allometric relations between stem diameter and crown area (supplement B of Torello Raventos et al. (2013)). These were then applied to the whole plot to establish plot-level CAI.

<u>Site level uncertainty:</u> Our Bayesian optimization approach accounts for potential errors in TROBIT cover, which includes those caused by allometric construction of CAI, provided errors are unbiased and roughly consistent across sites (Gelman et al., 2013; Kelley et al. 2021). Systematic errors may affect our results, though our correction curves remain robust even if systematic errors in canopy areas were an order of magnitude larger than the range of errors reported in Supplementary Information B of Torello-Raventos et al. (2013) (Fig. r2).

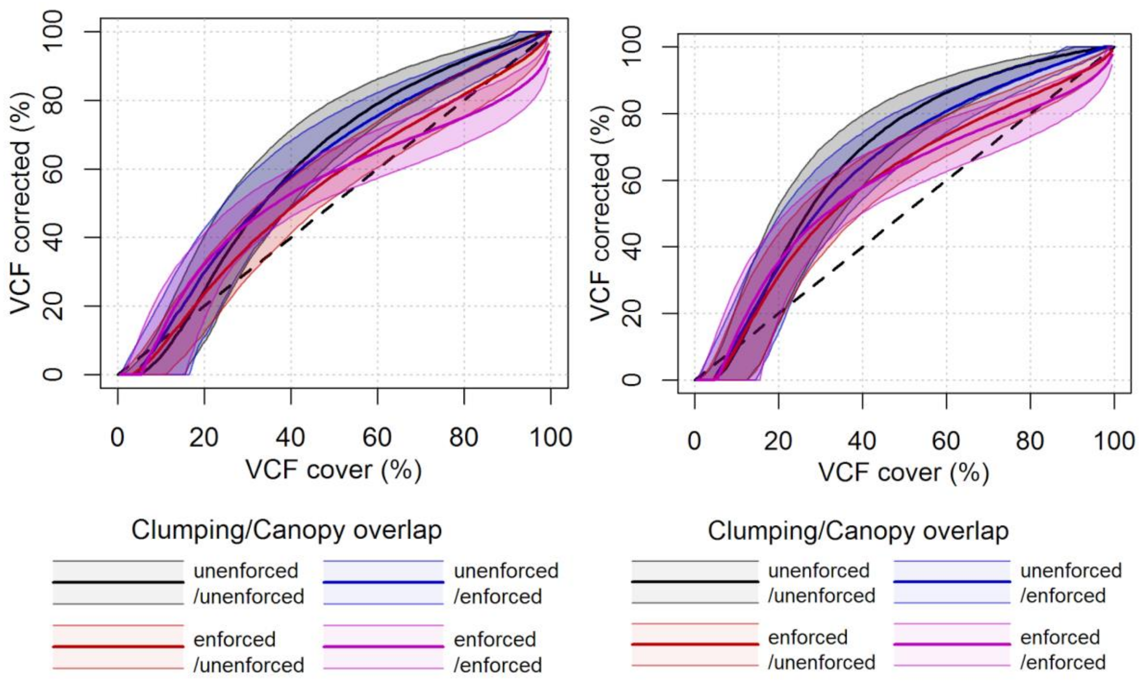

Fig r2. Correction curves as per Fig. A4, but with systematic (left) underestimation and (right) overestimations of 10% in the canopy area index across all TROBIT sites.

Also, text has been added in the discussions to highlight the site-level tree cover uncertainty associated with measurement techniques.

The inherent scale discrepancy between 100 m x 100m sites and 250m x 250m pixels is nicely addressed by simulations. Comparison results between the four types of simulations are also interesting. The authors could consider including the Landsat VCF data (Sexton et al. 2013) in the analysis, which is a satellite-based product most close to MODIS VCF. With a 30m x 30m spatial resolution, Landsat VCF can be averaged to close to the site scale, and a circa-2005 Landsat VCF product is available. This might generate additional insights, and might help resolve the difference with Brandt et al. 2020 in the Sahel region.

We chose to use the MODIS VCF product specifically because it's one of the most widely used products in climatic and vegetation modelling, and has been for many years (see examples of studies in the introduction). While the 30 m GLCF product introduced by Sexton et al., 2013 is on a scale much more easily comparable to our field data, there are only 2 maps available (for 2000 and 2005), neither of which covers the field campaign period for the TROBIT project. In ecosystems as dynamic as tropical savannas, addressing the temporal mismatch would be very challenging.

In addition, performing the analysis we carried out in this paper on the GLCF product would take approximately 70 times longer than it did for MODIS VCF, rendering this correction technique computationally unfeasible for use on this much smaller scale.

The striking difference between open shrub and savannas (Figure 3) is puzzling, even with the discussion provided. Much like fractional land cover (e.g. MODIS VCF), the accuracy of discrete land cover classification such as the MODIS IGBP land cover product is also generally lower over open canopy ecosystems, and misclassifications often occur among *those classes. Could the in situ data provide some estimates on the accuracy of MODIS land cover product as an additional analysis? In addition, if open shrubland and grassland do have higher accuracy, for completeness, this might be better pointed out in the abstract.*

The reviewer is correct to highlight classification accuracy as a possible explanation for the observed difference between open shrub and savannas in Figure 3. The MODIS IGBP confusion matrix (Table S6 in Sulla-Menashe et al., 2019) shows that the majority of the 'open shrubland' class' commission error is with the 'grassland' class. MODIS VCF tree cover in areas classified as 'open shrublands' is therefore likely to be lower than expected from the IGBP definition. The matrix also shows a high commission error (> 0.7) for 'savannas' involving all IGBP classes considered in our study and very high commission and omission errors (> 0.9) for 'closed shrublands'. We have rewritten relevant parts of our discussion section to focus on accuracy:

"...we found discrepancies between the tree cover ranges in the IGBP class definitions and the class specific ranges estimated through MODIS VCF (Fig. A5), which suggests that the 5 m height threshold may not always apply in MODIS VCF. There is also no clear relationship between TROBITs upper stratum canopy height and the difference in TROBIT and VCF covers (Fig. A6). In this case, the inclusion of trees below this 5 m height in the TROBIT inventory would not fully explain this underestimation. For example, MODIS VCF recorded tree cover in the 'open shrublands' and 'closed shrublands' classes of the MCD12Q1 product (Fig. A5), even though the height range for these classes is 1 - 2 m. For the IGBP 'savannas' class, MODIS VCF yields a percent tree cover range that matches closely with the 'savannas' class definition (between 10 % and 30 %), despite the differing tree thresholds for MODIS VCF and IGBP (5 m minimum for MODIS VCF, and 2 m minimum for IGBP) are different. These discrepancies suggest one of the following three things: 'open/closed shrublands' and 'savannas' contain trees taller than 5 m; MODIS VCF is distinguishing trees below the 5 m threshold; or, some combination of both.

The accuracy of the MCD12Q1 product is also class dependent (Fig. 4). The accuracy for 'closed shrublands' is particularly low. It is mainly confused with open shrublands, woody savannas and savannas. There is also confusion to a lesser extent between open shrubland, woody savannas, savannas, and grasslands. These between class omission and commission errors could be another explanation for the discrepancy between the IGBP class tree cover ranges and those estimated through MODIS VCF.

More work needs to be done to evaluate how effective both MODIS VCF and MCD12Q1 are at implementing the height thresholds in their respective 'tree' definitions, as this may have implications when MODIS VCF and MCD12Q1 (and their tree definitions) are used for global model calibration or validation."

We mainly used the IGBP product to get a general sense of how MODIS VCF behaves across different cover types, and the product is reliable enough for this purpose. How well the IGBP product classifies land cover matching its class definitions is certainly something that requires further examination, and using in-situ data (such as our TROBIT dataset) as a reference to assess it would be something to consider for further study. However, this would require a different statistical approach to the one developed here.

Technical corrections:

Figure 1. Quite a few savanna sites have TROBIT tree cover > 60%, which falls in the definition of forest in the text (lines 22-23). Are those sites better considered as savanna or treated as forest sites?

Owing to the enormous structural variation that can be found in savannas, we use 'mean tree height' as a major distinguishing factor over tree cover to delineate forest from savanna. As per Veenendaal et al. (2015) and Torello-Raventos et al. (2013), a stand needs to have both tree cover exceeding 60 % and a mean tree height of or exceeding 6 m to qualify as a forest, as per lines 120 -125. Many modelling studies also delineate forest and savanna by height (e.g. Prentice et al., 2011; Sato et al., 2021; Martin Calvo, 2015; Kelley et al. 2013). The plots classified as 'savanna' as per the TROBIT project can therefore have a tree cover > 60 % and still not count as 'forest'.

Line 313, change "classed" to "classified"

We have changed line 313 in the revised manuscript.

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