Biogeosciences Discuss.,
https://doi.org/10.5194/bg-2020-409-AC2, 2021

Biogeosciences
Discussions
Open Access

Interactive comment on "Quantifying the Importance of Antecedent Fuel-Related Vegetation Properties for Burnt Area using Random Forests" *by* Alexander Kuhn-Régnier et al.

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Received and published: 8 April 2021

Dear Meg Krawchuk,

Thank you for your positive and constructive review, which we feel will greatly improve the paper. Below we have outlined the changes we will make to address the points raised.

Referee comments are cited in *italics* and author's responses in normal font. Responses are separated by horizontal lines.

The manuscript "Quantifying the importance of antecedent fuel-related vegetation properties for burnt area using random forests" quantifies biophysical drivers of burned area across the globe with a particular focus on understanding how characterization of fuel build-up (and likely curing of fine fuels) in the months leading up to fire contribute to prediction in variability of area burned. The study is important and timely in that it aims to improve models of fire activity at a global scale, relevant to global fire-vegetation-climate system. The results of the study improve our knowledge of fire-fuel-climate relationships and the geography of them. In general, this is a robust study that appears to focus mostly on the novelty of the modelling aspects rather than novelty in what is learned ecologically. Along the lines of the latter, ecological learning and context, I feel the authors could improve the introduction and discussion substantially for the modeller and non-modeller audience by delving in more depth to the wide range of existing fire studies that have asked this same question about antecedent conditions and fire activity, and placed the work and findings within that context.

Also, many of the figure captions are very hard to digest. Please consider providing the take home message to the reader to help them work through the often dense load of abbreviations and description. In other words, hold the reader by the hand. E.g., for most readers, Figure 6 caption is close to cryptic?

In the updated manuscript, previous studies investigating antecedent conditions will be mentioned more in the introduction and discussion (see further responses below).

Regarding figure captions, additional information has been added in order to point out the most significant features more clearly. Furthermore, the introduction of ALE plots has been modified to remove the discrepancy between e.g. "1D" and "first-order" ALE plots, which are both referring to the same thing, thereby introducing the differences between first- and second-order plots in the Methods section. For example, we have updated the caption for Fig. 6 (in the manuscript): "Second-order ALE plot showing the

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combined zeroth order (mean), first order, and second order modelled effects of FAPAR and FAPAR 1M on BA from the 15VEG_FAPAR model, taking into account all other variables. Grey boxes indicate missing data. See Fig. S7 for the sample count matrix which demonstrates the correlation between the variables and thus shows that samples are unlikely to fall into the top-left or bottom-right bins. Evenly spaced quantiles are used in the construction and labelling of the plots. It can be seen that the combined effect of FAPAR and FAPAR 1M on BA is positive if FAPAR is low while FAPAR 1M is high."

Line comments:

Title. I wonder if a title that describes the key findings might be more interesting than the current, methods-related title?

The title has been changed to "The Importance of Antecedent Vegetation and Drought Conditions as Global Drivers of Burnt Area" to reflect the key findings more closely.

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l. 21. The sentence on human impacts seems out of place with flow of ideas.

This sentence was originally included to highlight the multiplicity of factors involved in controlling wildfires. This paragraph has been rewritten to further pronounce the climatic and ecological factors that are the dominant topics of our discussion, while mentioning these differential human impacts below.

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l. 27. This jump between fire events and fire regimes would benefit from more detail. Perhaps avoid the fire regime terminology here, and focus on events only?

In this instance, we will replace “fire regimes” → "fire activity" to avoid confusion. The following sentence refers to a decrease in global mean burnt area and therefore should clarify that we are interested in large-scale patterns.

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l.29. not clear what is meant here by climate becoming increasingly important. It is important. Do you mean more-so that climate change will increase fire activity/severity?

Considering the relative importance of several wildfire drivers (e.g. climate, vegetation structure, or ignitions), we meant to indicate that the relative importance of climatic influence on wildfires is predicted to increase in certain regions. We have now removed this sentence to increase the clarity of the introduction and focus more on wildfires drivers and their interactions.

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ll.19-32. This paragraph has a lot of material packed in that would benefit from clearer organization and focus.

This paragraph has been reorganised. The sentence about human impacts on line 21 has been moved to a new paragraph, which discusses the impact of climate change on fire. Thus, the biophysical drivers of fire (and their coupling) are discussed separately.

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ll. 53-62. Seems like connecting the ideas to the global work on a similar topic e.g., by Krawchuk and Moritz (2011) https://doi.org/10.1890/09-1843.1, and references therein, would be helpful and warranted. I know this might seem self-centred, but it’s actually pointedly relevant.

We have added this paragraph about previous studies to the introduction:

“A number of regional and global studies have indicated the importance of antecedent fuel build-up for BA. For example, links between fire activity and antecedent productivity have been found in South Africa (Van Wilgen et al., 2000), central Australia (Griffin et al., 1983), grass and shrublands in the western US (Littell et al., 2009; Westerling et al., 2003; Swetnam and Betancourt, 1998), NSW Australia (for bushfire fuel) (Jenkins et al., 2020), and southern Africa (Archibald et al., 2009). Global studies have identified similar relationships (a positive relationship between pre-season productivity and fire activity in the following dry season) in some dry areas. By studying the correlation between growing period (i.e. antecedent) soil moisture and fire activity, Krawchuk and Moritz (2011) found fire activity in dry regions to be related to antecedent productivity. Similarly, van der Werf et al. (2008) found a similar relationship for arid ecosystem (e.g. N. AUS), where antecedent wet conditions coupled with instantaneous drying were important. Other global studies have identified northern Australia as obeying this relationship too (Randerson et al., 2005; Spessa et al., 2005). In a more recent global analysis, O et al. (2020) found that for arid regions, wet anomalies (soil moisture) lead to increased fire later in the year by increasing fuel loads and biomass. Thus, it is clear that a better understanding of the timescales of fuel accumulation, the interaction between biophysical drivers and fuel build-up, and the effects of antecedent weather conditions on both fuel loads and fuel drying is needed in order to improve predictions of BA."

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l. 105. Why would you fill those data gaps with the minimum value? I don't easily follow the rationale. If less than 50% data, should these not be excluded from the dataset, or at least a median or mean be used?

The algorithm used to discern the location of 'permanent' as opposed to 'transient' gaps utilises the amount of missing information for a specific month at each location. For example, if a certain grid cell was missing data for more than 50% of all Decembers in the record, these gaps in December would be treated as a permanent gap and therefore subject to filling by minimum values. Remaining gaps are treated as transient and therefore filled using the regression model outlined in the text.

Unfortunately, simple exclusion of the times lacking data is not possible for our analysis because we rely on antecedent samples throughout. Thus, data gaps (which predominantly affect extreme latitudes in winter due to snow cover, but also occur due to cloud cover or limitations of passive satellite sensors in winter at extreme latitudes) have to be filled in order to allow analysis of summer months at those locations.

The algorithm we use to fill data gaps for the SWI, FAPAR, LAI, SIF, and VOD datasets is based on an algorithm proposed by Forkel et al. (2017). If 50% or more of the observations at a given location and month are missing, we assume that this indicates missing data during the winter, since other causes for data gaps (e.g. cloud cover) are assumed to be predominantly transient. Note also that locations with very little data (regardless of whether such data gaps always occur in the same month, as above, or at any point throughout the year) are discarded if no observations are available for more than 52 months out of the total 88 months investigated.

The winter data gaps identified above are then filled using the minimum value observed at that location because of the seasonality of the filled variables. For example, FAPAR would be expected to be at its minimum during the winter. Consequently, we use the minimum observed value to indicate a low FAPAR value during this time.

As can be seen in Fig. 1, virtually no samples are being filled with the minimum value outside of winter, as we assume above.

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ll. 122-125. I can see what you're trying to do with these simplifying equations, but they still need further explanation to help the reader understand the process.

We have added the sentence "For example, the 12-month antecedent X 12M was transformed by subtracting the instantaneous (month 0) value of X, thereby yielding the anomaly in X, X Δ12M, that may be easier to interpret." Additionally, we have adjusted the notation to make the distinction between the instantaneous variable (X

0M) and the variable, X, itself clearer.

Section 2.4 There are portions of this section that I don't understand. This is not your fault, it's just a bit over my head. But wanted to mention that I'll just need to trust the authors that the calculations are appropriate and correct.

We have rephrased parts of this section to convey the calculations more clearly.

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ll. 209/210. Interesting that the model can't capture the zeroes. I suspect this is largely based on uncertainty with the ignition-related variables?

One of the reasons the model may struggle to predict the exact value of '0' may be because the model (random forest) consists of many smaller models (decision trees), where the final model prediction is computed as the mean of the individual predictions of the smaller models. Thus, all 500 individual models would have to predict '0' to yield this value overall, which does not appear to occur in our model, given the stochastic nature of the training process.

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l. 234. Interesting that there isn't a pattern.

We agree that this figure is not very easy to interpret, but what it is showing is that where there are improvements, the improvements are relatively large. But there is no coherent spatial patterning in it. Nor do we necessarily expect to see a spatial patterning in the improvement, because we anticipate antecedent conditions to be relevant in most areas.

We find that over half the grid cells improve (56%, as stated in the manuscript), and where there are improvements, these tend to be larger than the instances of worsening performance. This can more clearly be seen in Fig. 2, where the error comparison is visualised as a histogram, with the error multiplied by –1 (i.e. <|Err(ALL)| - |Err(CURR)|>) being shown in orange to more clearly visualise the skewness of the distribution. The skewed distribution of the errors clearly demonstrates that improvements are larger, thereby leading to the overall global improvement of R2 score.

Ll 252/253. This is very neat. And the geography is interpretable. Excellent.

We have added some additional links between these results and the SHAP value maps (Fig. 7 in the manuscript) to clarify the link to the geography.

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ll. 299/300. Could you please make it clearer what the new learning is that we gained from this analysis. There is quite abundant literature on antecedent climate/vegetation effects on fire. You do have a novel contribution, but please highlight what it is.

We have rewritten this to highlight the novel contributions more clearly:Âă

"We have shown that antecedent vegetation conditions that influence fuel build-up and antecedent conditions that influence fuel drying strongly influence BA in a given month. Many previous studies have shown that current climate and vegetation properties are important overall determinants of BA (e.g. Aldersley et al., 2011; Bistinas et al., 2014; Forkel et al., 2017, 2019a; Joshi and Sukumar, 2021). The influence of antecedent climate conditions on fuel buildup and on fuel drying has also been identified as crucial in many regions (e.g. Van Wilgen et al., 2000; Griffin et al., 1983; Westerling et al., 2003; Swetnam and Betancourt, 1998; Jenkins et al., 2020; Archibald et al., 2009; Krawchuk and Moritz, 2011; van der Werf et al., 2008; Randerson et al., 2005; Spessa et al., 2005). Indeed, spatial variability in fuel loads and fuel moisture are important determinants of the geographical patterning of BA (Archibald et al., 2009; Boer et al., 2021). Our model-based analyses allow us to distinguish between the immediate and antecedent impacts of fuel loads and fuel dryness on BA, while also allowing their relative contributions to be determined. We have further shown that current and antecedent conditions can influence BA in opposite but intuitively understandable ways: wet conditions in antecedent months, for example, lead to more fuel buildup in fuel limited regions and promote increased BA whereas wet conditions during any given month reduce fuel dryness and thus limit BA. Furthermore, we have demonstrated that antecedent conditions >1 year are not important on a global scale. A similar conclusion was reached by Forkel et al. (2017). Furthermore, the critical timescale for fuel build-up varies with vegetation type, with longer timescales being more important in temperate regions and recent conditions being more important in the tropics. The effect of vegetation variables is also biome-dependent because of differing climatic constraints. The length of the dry-day period in the current month has the largest impact on BA but antecedent DD can also be important, particularly in temperate regions. FAPAR was shown to be the most significant vegetation variable, and only a single vegetation variable is required for accurate BA prediction if antecedent conditions are included. There are also significant, mostly intuitive, interactions between variables. For example, antecedent productivity (FAPAR) coupled with instantaneous drying (Dry Days) was determined to be important, in accordance with previous studies (e.g. van der Werf et al., 2008)."

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l.307/308. These temporal scales of fuel build up are on the order of 50-100 years, so not really a relevant comparison to your 1-2 years timescales, is it?

We have made the impact of limiting our antecedent variables to at most 2 years clearer in the text, since this does of course prevent us from accounting for long-term fuel build-up as would be relevant for these biomes:

"The failure to detect an influence of longer-term fuel build-up on BA probably reflects the short time interval (1–2 yrs) considered for antecedent fuel build-up, far shorter than the timescales of coarse fuel build-up in these ecosystems. The seasonal differences captured by our analyses may be unimportant in regions where long fire return times (or fire suppression) allow fuel build-up over longer periods."

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l. 346. I don't follow this statement "Moisture-limited regions were more strongly affected by suppression of fire at instantaneous timescales". From what evidence is this statement based, how does this fit into your analyses and interpretation? What does it mean? Might be because this is a confusing use of the term "suppression".

We have rewritten this part to avoid using "suppression" in favour of "limitation", which more accurately describes our intent; instantaneous conditions reduce fuel available to burn due to moisture. In these regions, antecedent conditions are also expected to be less important due to lack of seasonal fuel build-up patterns. This statement is based on Fig. 7a in the manuscript, where it can be seen that in moisture-limited regions, the instantaneous timescales (drying in and up to the current month) are most important for enabling fire.

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Interactive comment on Biogeosciences Discuss., https://doi.org/10.5194/bg-2020-409, 2020.

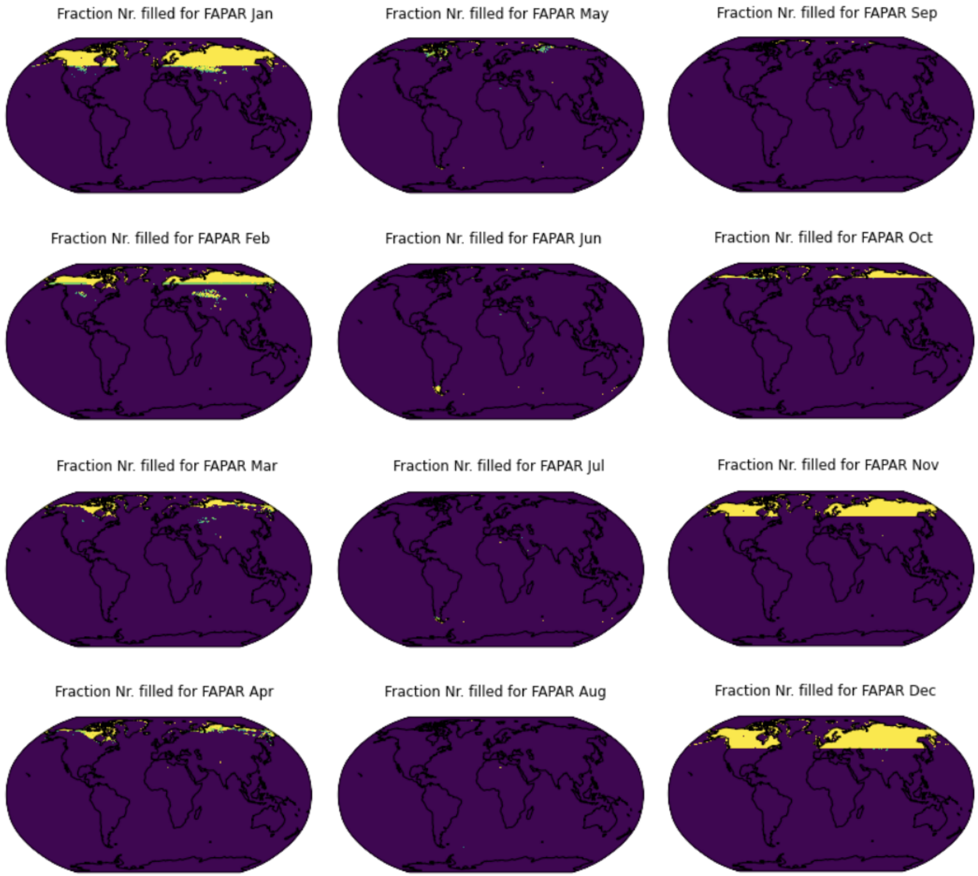

Fig. 1. The proportion of filled samples for FAPAR, with yellow indicating that all occurrences of a given month at a given location were filled and purple indicating no filling was done.

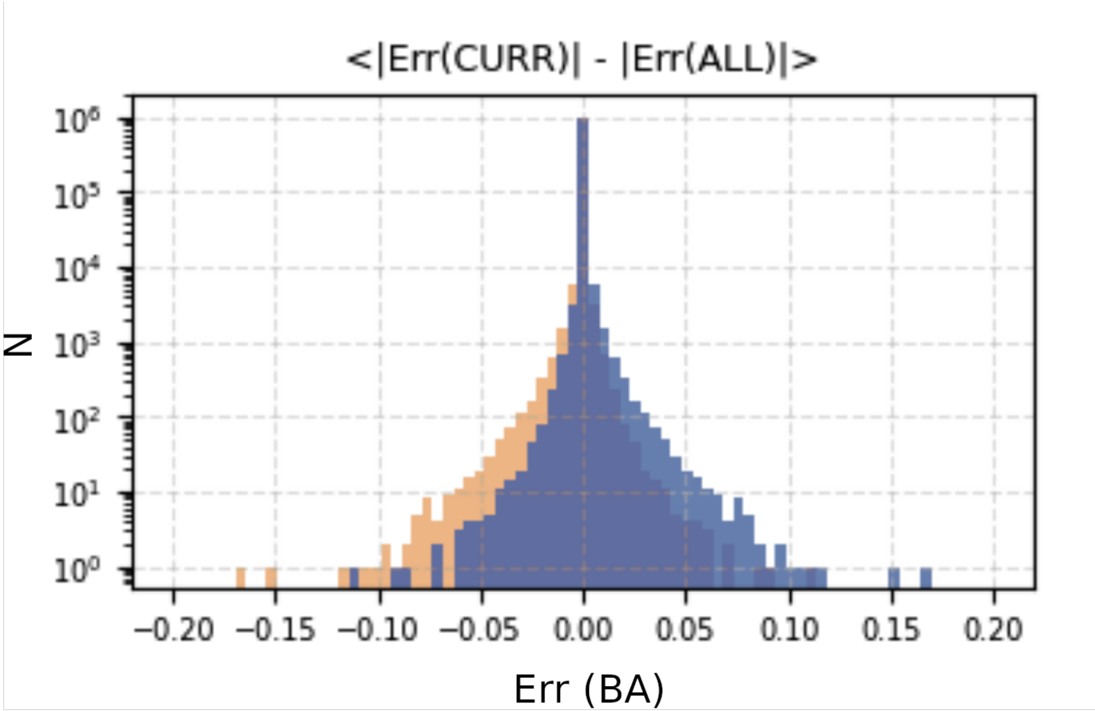

Fig. 2. The change in burnt area (BA) prediction error magnitude between the ALL and CURR models. The change multiplied by -1 is shown in orange to more clearly visualise the skewness of the distribution.