

Response to Referee #1

1. General comments

The authors attempt to build causal links between plant traits, climate and ecosystem functions by constructing a Bayesian Network (BN), where links between traits and functions are based on expert knowledge, while the climatic variables are informed by the model. The authors then reevaluate the relative importance of plant traits and climate in determining ecosystem functions through a sensitivity analysis based mainly on FLUXNET data. Building on this they argue that climate indirectly affects ecosystem functions via its control on plant traits. We agree that, from an ecological perspective and considering the increasing availability of data, exploring different methods to analyze the interactions climate-vegetation involved in the ecosystem functions is a relevant and meaningful research topic. However, the paper is missing an appropriate model validation (making it difficult to evaluate the robustness of the results) and suffers from reproducibility issues as some important methodological points and choices require clarification or additional information. We start by providing some major concerns followed by minor comments in order of appearance.

Response: Thank you for your insightful comments, which have been very helpful in improving the manuscript. This manuscript will be revised in accordance with your comments. In terms of model validation, we will try to use k-fold cross-validation to measure the performance of the model in prediction. In terms of reproducibility, we will list the references supporting the links in BN and clarify the node discretization schemes to make the methodology section more detailed and transparent.

2. Specific comments

- The data used in this study relies on a database collected by Magliavacca et al. (2021). In the cited paper, there are three complementary variables to quantify water use efficiency (G1, WUEt and uWUE); Rb was calculated in terms of both mean and max (95th percentile) values; and aCUE data is also available. The authors do not specify the criteria they followed when choosing which variables to include in the BN among the available variables in Magliavacca et al. (2021). Why was uWUE used and not the other water use efficiency metrics? How sensitive are the results to this choice? Why was the calculation of Rb unique in using the mean – compared to the other ecosystem function variables? If the network was based on expert knowledge, why to exclude aCUE which is explicitly included in the expert framework (Fig 1)? What would be the effect of adding CUE as an extra constrain? How sensitive is the network to its inclusion?

Response: Thank you for your insightful comments. Since the scale of this BN network is relatively coarse, it is difficult to include various variables that represent similar meanings together. wUEt and uWUE are similar, although not identical, thus we have chosen only one of them. Similarly, using the 95th percentile of Rb rather than the mean of Rb may represent a different issue and meaning. However, given that this study is primarily a discussion of methodology, we have chosen only one of these similar variables. In the modified version, CUE

could be considered for inclusion in the BN, and CUE, as the terminal variable, should not have much impact on the sensitivity of the other variables.

- In the BN (Figure 1), the causal relationships plant traits – ecosystem functions were assigned based on expert knowledge (Reichstein et al, 2014). Then, the climatic variables and the respective causal relationships were added: how were the links climate-plant traits and climate-ecosystem functions determined? Considering that BN based on expert knowledge rely heavily on the prior understanding of the processes, the approach used to assign these links should be clearly stated in the methods.

Response: Thank you for your insightful comments. We have realised that the description of this section is not detailed. Therefore, in the revised version, we will list the literature supporting the possible impacts of climate variables and describe in more detail the possible impacts of climate variables.

- Each plant-trait and ecosystem-function variable used in this study has a clear equivalent in the expert knowledge frame (upper panel in Figure 1) (Reichstein et al., 2014), except for AGB – which is unique in the authors model. Please provide more information about the assignment of links to this variable. How did you link G_{max} with AGB? Why not to link LAI_{max} to AGB? AGB is confounded with wood density, height and other size metrics as plant diameter. Which variable on Reichstein's frame is being represented with AGB? How was the confounding controlled for? Can the authors ensure no circularity was added to the framework? This is because AGB from Globbiomass is inferred from models and algorithms that use as input remote indicator variables that are correlated with many of the other variables in the authors network. Finally, AGB from Globbiomass is subject to large error – how was this error controlled for?

Response: In the Globbiomass dataset (Santoro et al., 2018), the growing stock volume (GSV) estimates were obtained from spaceborne SAR (ALOS PALSAR, Envisat ASAR), optical (Landsat-7), LiDAR (ICESAT) and auxiliary datasets with multiple estimation procedures. AGB was obtained from GSV with a set of Biomass Expansion and Conversion Factors (BCEF) following approaches to extend on ground estimates of wood density and stem-to-total biomass expansion factors to obtain a global raster dataset. Therefore AGB can include more relevant information about Wood density etc. than LAI_{max}. We will explain in more detail in the text the reasons for using AGB here to avoid confusion as you have suggested. Considering that the AGB does not only affect the LAI_{max} through H_c, a link between the AGB and the LAI could be added as you have pointed out. In addition, the AGB data may indeed be subject to large errors and correlate with other variables in BN in this paper. We will add in the discussion section that there are possible implications of uncertainty in the data for nodes such as AGB.

Reference

Santoro, M., Cartus, O., Mermoz, S., Bouvet, A., Le Toan, T., Carvalhais, N., Rozendaal, D., Herold, M., Avitabile, V., Quegan, S., Carreiras, J., Rauste, Y., Balzer, H., Schmullius, C., and Seifert, F. M.: *A detailed portrait of the forest aboveground biomass pool for the year 2010 obtained from multiple remote sensing observations*, 18932, 2018.

- More information is required regarding the specific criteria taken into account when defining the discretization thresholds. It is mentioned in the text (Lines 113-114) that the “meanings of the thresholds” were considered, but it is not completely clear how the thresholds were chosen nor what their meanings are. Ideally, BN models developed using different discretization methods should be considered and compared. If the results of such models are different, the choice of one method over the other should be justifiable (see e.g. Nojavan et al., 2017 - Comparative analysis of discretization methods in Bayesian networks).

Response: Thank you for your insightful comments. We will specify the basis for the discretization of each node (considering the distribution of values or the specific meaning of the thresholds). In addition, the use of different discretization schemes does have implications for causality and sensitivity analysis, which we will explain in more detail in the Discussion section.

- Not all FLUXNET stations used in Magliavacca et al. (2021) have data available for all the variables. Only 94 out of 203 sites have data regarding vegetation structure, N%, LAI_{max}, H_c and AGB. This means that there is a substantial amount of missing data in the model. Please report the missing fractions in the manuscript, or another indicator of the amount of missing data treated with the Expectation-Maximization method that is mentioned in the text (Line 131). Also, how robust are the results to the imputation methods used? It is critical to show that the results are not dependent on data imputation when a large amount of data is missing.

Response: Thank you for your insightful comments. We will explain this issue in more detail in the text. The use of Expectation-maximization has the potential to introduce uncertainty and bias the relationship between other nodes and plant trait nodes in favour of the 94 sites with available plant trait data. The possible effects of this data incompleteness and the resulting uncertainty will be described in more detail in the Discussion section.

- One core question arising from this study is: how to show that the artificial-rules-based model can reveal the real rules compared with a data-driven model? It is, therefore, necessary to show validation results in the paper. What validation methods did the authors use? how does this validation result compare to typical standard seen in similar studies? If a validation (i.e. k-fold), and robustness checks are done and reported, then the model results can be interpreted with more certainty. However, with the available data in the current version of the manuscript, the model performance cannot be assessed. We believe, that even though the BN was calculated for categorical data instead of continuous data, there is always a need to show that the model predicted well through model validation techniques. Validation results are also important for comparison/verification with future ecological-knowledge-based models.

Response: Thank you for your insightful comments. Despite the limited amount of data, we will consider doing a k-fold cross-validation. The level of the highest

probability of a node predicted by BN can be compared and validated against the actual values (e.g. reporting error matrix).

- Finally, to prevent confusion and over interpretation of the result, the authors should acknowledge that BN are not necessarily causal networks, they are essentially a set of conditional (in)dependencies that factorize the joint probability distribution of all the variables. Causal deductions hence may not be made (Ramazi et al., 2020 - Exploiting the full potential of Bayesian networks in predictive ecology).

Response: Thank you for your insightful comments. BN relies to some extent on the links between nodes set by the modeller. We will mention this limitation of BN in the discussion section.

3. Technical corrections

3.1. Introduction

- Since the main focus of this study are ecosystem functions, a clear and concise definition of this term is needed in the Introduction section. Also, it would be useful adding some supporting references regarding the theory linking the functional traits included in the paper and Reichstein et al.'s frame.

Response: Thank you for your insightful comments. We will add more relevant texts and references in Introduction section.

- There are some terms used along the paper referring to climate variables, vegetation structure variables, or ecosystem functions. These terms change along the manuscript. Try to use a consistent terminology. Examples of these terms are:

Line 27: “complex ecosystems”, “environmental systems”.

Line 37: “environmental conditions”

Line 60: “environments”

Line 158: “ecosystem service functions”

Line 271: “ecosystem systems”

Response: Thank you for your insightful comments. These will be revised and unified.

- Lines 66-67: The paper by Gregorutti et al. (2017) is used to support the statement that IMP-based attribution can be unreliable when the aim is explaining systematic causality. The cited paper does not discuss systematic causality. Please support this idea with appropriate references.

Response: Thank you for your insightful comments. IMP-based attribution has difficulty in dealing with mutual non-independence in predictors. For example, if both NDVI and EVI are used in model A and only NDVI is used in model B, then the IMP of NDVI in model A will be lower than that in model B. We will use a more appropriate literature or modify the description here.

3.2. Methodology

- Line 95: “Climatic variables:...”

Response: It will be added.

- Table 1: Though the detailed methods for the ecosystem functions’ calculation is in Magliavacca et al. (2021), provide a complete summary for each variable in the column “Approach”. E.g. if the percentile used in the calculations will be reported, report it for all the variables consistently (GSmax – 90th percentile). The use of medians instead of means for some of the variables may also be important information.

Response: Thank you for your suggestion, we will add this column.

- Line 119: Figure 1 is presented as a column with three panels. It is not clear what the author refers to when pointing to the lower left panel.

Response: The figure caption will be corrected.

- Lines 142-147: This sentence is quite long. Try to split it or make it shorter.

Response: It will be revised.

3.3. Results

- Line 154: Incomplete sentence at the end of this line: “... SWin, VPD, and showed...”

Response: It will be revised.

- Figure 3: In the text, some information is extracted from this figure regarding the correlations climate vs. ecosystem functions and ecosystem functions vs. ecosystem functions. More information can be extracted from this figure regarding the correlations ecosystem function vs. plat traits and plat traits vs. climate.

Response: We will add some description text with this information.

- Figure 4: Can the display of this figure be improved? E.g. locating the tables in a more equidistant layout.

Response: It will be improved.

- Lines 195-196: When looking at Figure 1, it is not clear what the author is referring to with the loop of Tair controlling LAI_{max}. What variables are included in this loop? This word should be used with caution since it could be taken as equivalent to a feedback.

Response: We will check and update the structure of BN and re-analyse the relevant results.

3.4. Discussion

- The interactions among plant traits, climate and ecosystem function variables may be complex when high-order effects are considered. Does the author think these effects play an important role when trying to explain the causal links to ecosystem functions? If these effects are not considered in this study, this limitation should be stated in the Discussion section.

Response: Thank you for your insightful comments. Our BN does not take into account the higher order effects of each node. This is of interest, but may have higher requirements for expert knowledge. It may be useful to combine this with the relevant literature that studied the impacts of higher order effects. In the discussion section we refer to the potential of using BNs to analyse the effects between such inclusion of higher order effects.