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Interactive comment on "Modelling the Ruin of Forests under Climate Hazards" *by* Pascal Yiou and Nicolas Viovy

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Anonymous Review #1 We thank the reviewer for the constructive remarks that will help clarify the manuscript.

1. The authors adapt the 'ruin' theory of finance to that of forest growth. Using the base of the Cramer-Lundberg ruin model they develop a simple model to estimate tree survival/growth based on exposure to heatwaves/droughts. The work is interesting and novel but I struggled a bit with understanding what it is gaining over more conventional approaches to estimate ecosystem sensitivity to climate. I have three main issues with the paper. First, what is the true benefit of adopting this approach over, for e.g. a process-based model or one based on a simple statistical approach? This wasn't

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effectively conveyed in the paper. While the approach is obviously novel, it is needed to show that this is more than novelty for novelty's sake.

The introduction will be rewritten. Our approach is a rather "simple statistical model", which explicitly focuses on the death of trees, and that is meant to explore the whole probability distributions of risks. The ruin model comes with the important concept of ensemble simulations to estimate probability distributions. Process based models yield computing limitations that hinder estimates of probability distributions. So, our proof of concept essentially paves the way for more extensive simulations with more sophisticated/realistic models.

2. Second, there is little attempt to evaluate if the model's outputs are reasonable. I think some attempt to evaluate the results will be helpful. There was a small amount (e.g. L 180) but given the quantified thresholds and different behaviour between growth strategies, I think more could be done.

Indeed, and this is acknowledged in the paper. Our argument is that if a complete mechanistic model can be simplified (e.g. through scaling analyses), our model presents the essential ingredients that it should contain. This will be clarified in the revised manuscript, especially in the discussion section. In addition, we will redo simulations with parameters that can be explicitly constrained by observations.

3. Lastly, what exactly the model was predicting wasn't clear. At various points it was death of trees (presumably, L 52) or perhaps growth (L 181). They are, of course,linked but they are not the same thing. This conceptual muddiness makes for chal-lenging reading.

As explained above, the objective of the model is to predict for which condition (both climate extreme events and the way vegetation deals with its capacity to manage such events) a whole forest will die by losing its capacity to grow. It is necessary for that to take into account for forest growth but this is not the final objective. This point will be clarified in the manuscript.

4. Lastly I would strongly suggest a toy problem to show how this model works on a known system. This comment is not clear to us: the model *is* a simplified model. Its toy version (i.e. without interannual memory) is the Cramer-Lundberg model, which is extensively described in the statistics literature.

Since I think this paper is publishable, I suggest major revisions but it does need a large overhaul prior to that.

Specific comments:

6. Line 21 - What body of literature in the last few years? There is only one ref and it is from 2005.

This point was overstated. We will tone down or remove the paragraph on collapsology, which might be far fetched, and which does not appear in the discussion.

7. L31 - I think 'ruin' needs to be properly defined. It is not a typical term in the papers of ESD and I am not yet sure at this point in the paper how I should interpret it.

The connection with ruin theory will be clarified in a more pedestrian way.

8. L42 - Is this meant to imply that xylem embolism only kills branches and can't kill entire trees?

No: xylem embolism can indeed kill the whole tree. But it can also only kill some parts of the tree which jeopardize its ability to growth during the following years. This will be corrected in the manuscript.

9. L45 - But trees typically carry far more carb reserves than needed to refoliate manytimes over, commonly dying with large reserves still intact. Also it is not clear whether carbon starvation is the leading cause of death in many cases (e.g. Rosas et al. 2013,Piper 2011, Rowland et al. 2015),

The reviewer is perfectly right: Trees in general die without a full depletion of carbohydrate reserves. However, a lot of studies, including those cited in the paper showed

that when trees die (not directly related to an extreme event as embolism) they are largely depleted in NSC compared to living ones. In particular as NSC are not only used for developing leaves but also for a lot of defending processes. So there is a level of NSC under which trees cannot survive to any supplementary stress. So in our representation a 0 value of R doesn't mean no NSC but a value under which the probability of tree die becomes very important. Likewise it is true that carbon starvation is one of the causes for tree death but not the main one: xylem embolism for instance is also an important cause. Partial embolism is also a factor that can alleviate the capability of trees to grow after extreme events. This is the reason why we mention the text embolism, and not only of carbon starvation. What is called "reserve" in the model should then be viewed not only as carbohydrate reserves but more generally "what can impact the growth of trees". We thank the reviewer for this comment, as this was confusing in the text. This will be better explained in the manuscript.

10. L50 - There needs to be a clear definition of 'ruin'. The farther I read the more convinced I am that this terminology needs to be more clearly set.

Thanks for the comment, as indeed the concept applied to forest needs to be clarified. Ruin in the context of the paper means that a forest stand cannot survive or, in other words the majority of trees are dying. This concept of ruin can be applied to a forest in general but also to a given tree species, which means in this case that this species will disappear from the forest but that a forest with other more tolerant species can still exist. The definition will be clarified in the revised manuscript

11. L52 - What is meant by 'disappearance of trees'? There death and total respiration?

Thanks for the comment. The term was not clear: this just means tree death. It will be corrected

12. L55 - what does 'average capital' mean here?

It means "average reserve". This will be added.

13. L59 - how is hazard defined in the context of this paper? It is a term that has many interpretations.

“Hazard” means: a potential source of harm (see e.g. https://en.wikipedia.org/wiki/Hazard). Our modelling exercise illustrates the three terms of that definition (potential, source, and harm). This will be clarified in the text.

14. L65 - Please spend some time making this more intelligible to readers from the natural sciences. Pretty much nobody who reads ESD will come from a financial background so it is worth the word count to better expand on the terminology. E.g.’balance between competing companies’ - what companies? ’the capital vanishes’ - whose?

OK. This will be clarified (see point L79 below).

15. Eqn 1 - shouldn’t pt have the t subscripted?

No: it is p \times t. A fixed premium rate p is collected each year t. Of course, p could also depend on t (which is what we do in Eq. (6)). We will add a $\cdot$ between p and t in Eq. (1) to clarify this.

16. L71 - I suggest dropping the ’horizon’ terminology. This might be a carry-over fromthe insurance models but this is not a common way to talk about this in ecosystemmodelling. The summary for policymakers of the IPCC AR5 (1st chapter; https://www.ipcc.ch/srocc/chapter/summary-for-policymakers/) states:

“C.1.1 The temporal scales of climate change impacts in ocean and cryosphere and their societal consequences operate on time horizons which are longer than those of governance arrangements (e.g., planning cycles, public and corporate decision making cycles, and financial instruments).”

We use “horizon” with the same meaning of the IPCC AR5. Therefore, we think that it is appropriate to use “horizon” when speaking of a time bound in an ESD paper. We will make this clear in the manuscript, so that the readers who are not familiar with IPCC language do not think that it is insurance jargon, which we do not speak.

17. L79 - other insurance companies bidding for the same clients to sell insurance to?- Small point, consider the tenses used. There are several instances of future tense that don't make sense. They make the reader wonder if this is going to appear in some future paper or ?

We meant to say that, as insurance companies compete with each other to get clients (i.e., you or us), they have to find a balance between a high premium rate (to ensure an income for them) and attracting clients from other companies (i.e. being somewhat cheaper). The necessity for this economic balance gives an upper bound for the premium rate. In other words, having a very high premium rate might not solve the problem of ruin for insurance companies, because they would lose all their clients to less greedy companies. This basic concept of capitalist economy will be clarified in the text, although it is marginally important for the paper. The future tenses will be checked.

18. L102 - does this mean you don't let them allocate resources to their stems? So they can't grow?

No: obviously it means allocation to all the organs of the plants, so we will correct this.

19. L 104 - Fix the cite Handeregg.

OK. Sorry for the typo.

20. L108 - does the p0 change spatially?

Here we considered the model on a given point, and in the simplified application presented in the paper we assume a constant NPP, but obviously if this model is applied regionally p0 can change spatially (as well as the others model parameters).

21. How is it determined?

p0 is heuristically chosen so that Rmax is reached in 20 years when no hazard occurs. This choice is debatable and could be constrained by tree species. Following

the two reviewers' remarks we will revise the different parameters (including p0) to be defined from literature and then better represent real cases. This will be clarified in the manuscript.

22. Does B have an upper limit? Assumedly it is constrained such that p(t) >= 0 as I am not sure what a negative p would mean since the loss is supposed to come from the S term.

Indeed: if trees do not shrink (negative p), an upper bound for B would be $p_0/E(S)$, where $E(S)$ is the mathematical expectation of S.

23. L118 - is there any ref you can use for proof of this here?

This is a classical result in statistics: the probability distribution of the number of times that a time series exceeds a high threshold converges to a Poisson distribution. This will be clarified in the text, with a reference to classical but pedestrian textbooks (e.g. Coles, S. An introduction to statistical modeling of extreme values. Springer series in statistics. London, New York: Springer, 2001.), and references in the atmospheric science literature (e.g. Smith, R. L., and T. S. Shively. Point process approach to modeling trends in tropospheric ozone based on exceedances of a high threshold. Atmospheric Environment 29(1995): 3489 99.)

24. L155 - Can it be expanded upon how to estimate these parameters from observations? It is one thing to suggest the possibility but I think it is more helpful to try and relate these parameters to something more grounded.

Our sentence is indeed vague. A_h and B relate how climate hazards impact the growth of trees. As a first approximation, they could be obtained from a correlation between the climate conditions during identified droughts (e.g. 1976, 2003, 2018, 2019) and tree growth parameters (e.g. tree ring width/density, NPP), which are determined in situ of from satellite observations (NPP). We believe that obtaining such a correlation/regression is a whole methodological paper in itself. This important point will be

discussed in the revised manuscript.

25. Section 2.2 - this whole section is a bit abstract. It would be beneficial to have included a toy example. Even a simple financial one where we could see how these equations play out. I would like to see that included especially with a figure. I think that would benefit the paper and help the reader wrap their head around these concepts. After all,this is the first paper to intro the concept in the eco modelling lit.

26. Section 2.3 (sample trajectories) just does that by illustrating what trajectories look like.

27. L156 - So what units would all of these have? I am unsure what an Rmax means,100%? If %, then of what?

A percentage could be more meaningful, although this would not change the gist of the paper (see point below). This will be changed in the revised manuscript.

28. L 164 - 'reserve units' - this seems like we should be able to use real units here.

Rmax represents the upper limit of tree "reserves" as tree do not tend to accumulate reserves indefinitely. If a sufficient level is reached plant will allocate its remaining assimilate to growth of different organs. Concerning the units, if we considered that R represents stricto sensu carbohydrate reserve we should indeed use gC.m2 for instance. However as discussed previously and noticed by the reviewer, considering only carbohydrate reserve as driver of tree growth and tree die is too restrictive as others processes as xylem embolism should also be considered. So in such a theoretical model, "reserve" should be considered as all "that allow trees to initiate growth on next year" and then cannot be associated to a specific unit and then 100 is an arbitrary unit scaled with the others parameters of the model and calibrated to give reasonable results compared to observations.

29. L 161 - is this missing an "and" so would be 'and one of the trajectories with a ruin'?

OK. An “and” will be added.

30. Fig 1 a,b - please make it so that it is possible to get some info from this figure. Have multiple y-axis (sep plots) as right now it is not useful. Also I don’t really understand how this works. Since it is 5-median-95 then I understand why the median is above the 5 and 95. But this looks like the actual 95 quantile realization was chosen (rather than the representative behaviour). Why not choose the mean and then give us the average behaviours? Right now it just looks like so much noise. As far as I can tell this figure is trying to make an important point that the model can capture differences due to aniso/iso strategies, so I think it is worth the effort to make it more convincing.

Sorry: there is typo. The 95th quantile should be in blue and the median in black. The caption will be corrected. The upper panels are indeed hard to read. Another representation that synthesizes the statistical features of the identified trajectories will be proposed.

31. L177 - The model used here doesn’t equate any reserves to stem (line 102). Is there any paper to point to that has directly linked the two? Does the Cailleret paper then do that? As written that isn’t clear.

In the text we mention only allocation to roots and leaves because these are the organs that play a direct role in growing. But obviously it does mean that reserves are not allocated to other parts of the plant as stems and trunk. But to avoid confusion will we correct this in the text.

32. L181 - But aren’t the simulations showing the decrease in reserves and not growth?If you are equating the reserves to growth, what does it mean when they trend to 0? No growth for a tree doesn’t necessarily mean death but earlier that seems to be what is suggested (line 52). This whole paragraph is playing it very loose with terminology and relating poorly defined components of the ruin model with different real world observations. This needs to be tightened up considerably to be made consistent.

Thanks for the comment. Actually, a living tree cannot have null growth anyway. However, Indeed growth is obviously different from reserves. In particular with the same level of NSC the tree ring growth will depend on the climate condition of the year. But considering the relative difference between tree ring growth of healthy trees and dying trees is used as a proxy of NSC in papers like Caillerets et al. since it allows to disentangle the effect of climate and then it is well correlated to NSC status (as it is not possible to directly measure NSC of trees already dead). In the model, we also consider a relative change in reserve status (as mentioned before Rmax is fixed to an arbitrary value of 100), the comparison between the change in R and the relative change in tree ring growth make qualitatively sense. This will be detailed in the text.

33. Fig 2 could be made into a table and my suggested toy example be added as a figure.Fig 2 has little interesting information that a table couldn't show. OK. This figure was meant to reassure statisticians, but Table 1 summarizes the same information.

34. Table 1 - HW = heatwave?

Yes. This will be clarified in the revised manuscript.

35. L239 - These numbers make me think you should then be able to go into the literature to find out how reasonable these are. Are there any reports that would substantiate what your model has found?

This type of estimate is coherent with other studies (e.g. Parey et al. Validation of a stochastic temperature generator focusing on extremes, and an example of use for climate change. Climate Research 59, no 1 (2014): 61 75; Kharin et al. Changes in temperature and precipitation extremes in the CMIP5 ensemble. Climatic change 119, no 2 (2013): 345 57).

36. L241 - repeated text that makes it confusing.

This will be corrected to avoid confusion.

37. Fig 4 - how is the avg reserve before ruin >0 when ruin was defined as R(t) = 0

(lines70, 101)? How much before ruin is used in the calculation? I think this needs a time period defined and specified. Is 4e meant to have ruin year for the y axis label?General - I would suggest that instead of 'cash' and 'credit' the terms be more ecologi-cal like 'aniso' and 'iso', it would help the reader place into context.

We show the average of reserve conditional to time before ruin. So, if $\tilde\tau$ is the min between the ruin time and 100 years, we show the distribution (along all samples) of $1/{\tilde\tau} \sum_{t=1}^{t=\tilde\tau} R(t)$. This will be clarified in the text. We will rephrase the terminology to a more ecological context.

38. L 244 - Since the stat significance is mentioned here. Would it make sense to indicate in the figure which differences were significant?

This will be emphasized in the revised manuscript.

39. L248 - I would not use 'globally' but rather something like 'On the whole'. Globally can be read as in, well, globally.

OK.

40. L256 - It does provide an estimate for sure, but I see little attempt here to evaluate the estimates. Can more effort be putting into evaluating the differences between the two strategies and whether any observations support the model results?

OK. We will provide examples of simulations with values that are constrained by the literature (e.g., He W, et al., Patterns in nonstructural carbohydrate contents at the tree organ level in response to drought duration. Glob Chang Biol. 2020 Jun;26(6):3627-3638. doi: 10.1111/gcb.15078).

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