Jan. 3rd, 2023
Dear Biogeosciences Editor and Reviewers,

We appreciate your review and comments on "Exploring the impacts of unprecedented climate extremes on forest ecosystems: hypotheses to guide modeling and experimental studies". Your time spent on this peer-review process is appreciated. Below is a point-by-point response to the reviews, and a description of how the manuscript has been revised accordingly.

Reviewer 3 agreed with the authors in the last revision, that since we do not intend this paper to be a classic model experiment, then "it is not necessary to do more simulation experiments and model validation since the simulations are just for illustrating the model behavior". However, reviewer 3 would like to see more of a review of "of VDMs processes and possible model development strategies, beyond the two models that are used to do simulation case studies."

We, the authors, agree with this comment that it is useful to include descriptions of model processes as represented in other VDMs (and some LSMs for comparison), and include recommendations for improvements, even though this will increase the length of the manuscript. Examples of the updated text describing additional VDMs are below.
However, we would like to be clear that the intention of this manuscript is not to be a classic review-**only** paper, and thus not structured as a typical review paper. We apologize if this was misleading in the previous author responses.
We are aiming for it to be a **perspectives paper, and a guidebook paper** for helping to guide the need for future experiments and/or monitoring data. Thus, we are "using a handful of novel model results to guide that discussion". The title of the paper is ….”hypotheses to guide modeling and experimental studies", not a "review of modeling and experimental studies".
We would like to clarify that the original "research" aspects of this study were the new UCE model results, and specifically the integrated C-loss with sensitivity to different climate change treatments which has not previously been done with these models, and is a knowledge gap that was filled by this study.

In the revised manuscript we have included descriptions of additional VDMs, to help compare against the two main VDMs used here (ED2 and LPJ-GUESS) to evaluate carbon loss from UCEs. These models are listed below in the new table that was added to the supplemental materials.

Table S1. Terrestrial model full name, select characteristics, and associated references for the models listed throughout the manuscript.

Model	Full Name	Type & Canopy	Dynamic Vegetation?	Plant Hydraulics?	References
CABLE	Community Atmosphere-Biosphere-Land Exchange	Big leaf; Single layer	No	No	Wang et al., (2011);

CABLE-POP	Community Atmosphere-Biosphere-Land Exchange - Population Orders Physiology	Cohort; Single layer	No	No	Haverd et al., (2018)
CLM5	Community Land Model v5	Big leaf; Single layer	No	Yes	Lawrence et al., (2019)
ED2-hydro	Ecosystem Demography v.2 - Hydro	Cohort; Multi-layer	Yes	Yes	Xu et al., (2016); Xu et al., (2021)
FATES	Functionally Assembled Terrestrial Ecosystem Simulator	Cohort; Multi-layer	Yes	No	Fisher et al., (2015)
FATES-HYDRO	Functionally Assembled Terrestrial Ecosystem Simulator - Hydro	Cohort; Multi-layer	Yes	Yes	Fang et al., (2022)
JSBACH4.0	JSBACH v4 DGVM	Patch-tiling; Single layer	No	No	Nabel et al., (2020)
JULES	Joint UK Land Environment Simulator	Big leaf; Single layer	No	Yes	Eller et al., (2020)
LM3-PPA	Land Model v3 – Perfect Plasticity Approximation	Cohort; Multi-layer	Yes	No	Weng et al., (2015)
LPJ-GUESS	Lund-Potsdam-Jena General Ecosystem Simulator	Cohort; Multi-layer	Yes	No	Smith et al., (2001); Smith et al., (2014)
Noah-MP-PHS	Noah-Multiparameterization - Plant Hydraulics Scheme	Big leaf; Single layer	No	Yes	Li et al., (2021)
ORCHIDEE	ORganizing Carbon and Hydrology in Dynamic EcosystEms	Big leaf; Single layer	Yes	No	Krinner et al., (2005); Druel et al., (2019)
SEIB-DGVM	Spatially Explicit Individual-Based Dynamic Global Vegetation Model	Individual; Multi-layer	Yes	No	Sato et al., (2007)

TFSv.1-Hydro	Trait Forest Simulator v1 - Hyrdo	Individual; Multi-layer	No	Yes	Christoffersen et al., 2016

To make the paper more in-line as a perspectives paper, we will remove some instances that resemble a classical modeling experiment/comparison paper. For example, we removed the site description of the two sites from Section 2 of the manuscript to the Supplemental Material. However, comments from reviewer #1 was concerned about the lack of model validation compared to site level observations. Therefore, we kept the text in the manuscript on basic model validation to still address review #1 comments.

This paper was intended to describe current model mechanisms that could affect pre-drought resistance and post-drought recovery and suggest critical areas further research (see Table 1 and Table 3), including many processes such as hydrodynamics, mortality, allocation, community assemble, phenology, carbon storage, etc. Each of these mechanisms could be their own separate review paper, therefore we only included summaries and critical highlights of each.
In the updated manuscript, we refer the readers to "existing review papers of different VDM development, processes, and uncertainties can be found here: Fisher et al., (2018); Bonan (2019); Trugman et al., (2019); Hanbury-Brown et al. (2022); Bugmann and Seidl (2022); and specifically related to plant hydraulics see: Mencuccini et al., (2019); Anderegg and Venturas (2020)."

Additional responses to specific reviewer comments:

Key:
Gray text: comment from reviewers
Black text: response from the authors
Red text: edits or new text added to the manuscript

Reviewer 3 expressed concerns about:

1. **R3: "**Generally, I agree with the authors' argument that, as a review paper, it is not necessary to do more simulation experiments and model validation since the simulations are just for illustrating the model behavior. However, if it is a review paper, I think, it is necessary to include more detailed analysis of VDMs processes and possible model development strategies, beyond the two models that are used to do simulation case studies."

Answer: We agree with this comment that it would be useful to have more background of VDM processes and different model development strategies (beyond the two models used in the paper). To address this comment, we made substantial changes to Section 2 of the paper, which is now called: "Vegetation Demography Model (VDM) Strategies". We will start this section by talking more generally about the use and strategies of VDM application in investigating unknown future climate extremes, and as one update, provide more specific examples of which models use mechanistic hydrodynamics or

not. Since ED2 and LPJ-GUESS are the only models used to showcase the integrated carbon loss results, we retained a more detailed description of the capabilities of these two models (Section 2.1).
We also changed the naming of section 2.2 from “Modeling protocol” to “Modeling guide” to convey more of a potential guidebook option for future research.

In the Discussion section of the new manuscript, we will also provide examples from other VDMs. R3 suggested specific examples related to canopy dynamics, mortality, allocation, and community assemblage in their “specific comments” section, and we will update the text accordingly. Please see below for the new Discussion text that is included in the manuscript.

The beginning of Section 2 text has been updated to include the following:

“We argue that VDMs are well suited to address climate change impacts due to the inclusion of detailed process representation of dynamic plant growth, recruitment, and mortality, resulting in changes in abundance of different PFTs, as well as vertically stratified tree size- and age-class structured ecosystem demography. Community dynamics and age-/size-structure are emergent properties from competition for light, space, water, and nutrients, which dynamically and explicitly scale up from the tree, to stand, to ecosystem level. Within this characterization, VDMs also differ between each other and are set up in different configuration, allowing for various testing capabilities. For full names of each model listed below and references, see Table S1. For example, VDMs can aggregate and track the community level disturbance into either patch-tiling sampling (e.g., ED2, FATES, LM3-PPA, ORCHIDEE, JSBACH4.0) or statistical approximations (e.g., LPJ-GUESS, SEIB-DGVM, and CABLE-POP). VDMs could also vary in representing light competition within either multiple canopy layers (e.g., ED2, FATES, LM3-PPA, LPJ-GUESS, SEIB-DGVM) or in a single canopy (e.g., JSBACH4.0, ORCHIDEE, CABLE-POP).

Powell et al. (2013) compared multiple VDMs and LSMs to interpret ecosystem responses to long-term droughts in the Amazon and are informative when conducting model-data comparisons, but studies of the cascade of ecosystem responses and mortality to UCEs are lacking. In a cutting-edge area of development, new mechanistic implementation of plant competition for water and plant hydraulics in VDMs (i.e., hydrodynamics) are improving our understanding of plant-water relations and stresses within plants, such as with TFSv.1-Hydro (Christoffersen et al., 2016), ED2-hydro (Xu et al., 2016), and FATES-HYDRO (Ma et al., 2021; Fang et al., 2022). Compared to more simplistic representation of plant acquiring soil moisture not connected to plant physiology (e.g., LPJ-GUESS, LM3-PPA, CABLE-POP, SEIB-DGVM). For hydrodynamic representations in ‘big-leaf’ LSMs such as CLM5, JULES, and Noah-MP-PHS see Kennedy et al., (2019), Eller et al., (2020), and Li et al., (2021) respectively.

The discussion section provides a deeper investigation of model response to UCEs related to droughts. An exhaustive review of all VDMs, and all plant processes is too large to be done here. Existing review papers of different VDM development, processes, and uncertainties can be found here: Fisher et al., (2018); Bonan (2019); Trugman et al., (2019); Hanbury-Brown et al. (2022); Bugmann and Seidl 2022; and specifically related to plant hydraulics see: Mencuccini et al., (2019); Anderegg and Venturas (2020). We use LPJ-GUESS and ED2 as example VDMs in an initial guide framework to explore hypotheses around vegetation mortality and integrated carbon loss from UCEs and climate change impacts, and highlight limiting model processes. Since field data needed to evaluate UCE responses are, by definition, unavailable, we do not perform model-data comparisons. Rather, we use the model results and conceptual framework as a road map to explore our hypotheses and illustrate their implications for ecosystem responses under UCEs, not historical drought events."

To account for the added text of describing additional VDMs, and to remove instances that resembled a more classic modeling experiment study. For example, we moved the description of the two sites from section 2.2 to the Supplemental Material.

2. **R3:** "There are many processes…related to the responses to the "unprecedented climate extremes (UCEs)". These processes, for example, may include physiological processes (photosynthesis, respiration, plant hydraulics, allocation, etc.), demographic processes (regeneration and mortality), community processes (e.g., competition and community compositional shifts), and soil organic matter decomposition and biogeochemical cycles. If the authors claim this is a review paper, it should be more comprehensive and insightful in discussing these processes than current version.
Answer: We agree that many plant processes are sensitivity to, and influence the response to UCEs. Thus, we have Table 3 that describes a summary of driving mechanisms (e.g., ecosystem or plant processes and state variables) that could be used to guide future research in manipulation experiments, data collection, and model development and testing, as related to furthering our understanding of UCE resistance and recovery. A critical look at these processes (such as phenology, plant hydraulics, carbon storage, allocation, soil water availability, functional diversity, etc.) emerged from the hypothetical drought simulations used in this study. We now see that our first paper submission did a poor job at highlighting Table 3 and Table 1, which described many of the ecological processes and mechanisms, and we have improved the manuscript by highlighting these evaluations.
We apologize if our previous author responses were misleading, because we did mean to claim or intend that this manuscript is a review-only paper. We are aiming for it to be a perspectives paper, and a guidebook paper for helping to guide the need for future modeling experiments and/or monitoring data.

At the beginning of the Discussion section, after this sentence "These nonlinearities may arise from multiple mechanisms that we begin to investigate here, including shifts in plant hydraulics or other functional traits, C allocation, phenology, and stand demography, all which vary among ecosystem types." We include this new sentence to make it clear to the reader that we provide suggestions for model mechanisms to further explore at line 559: "A critical look of driving model mechanisms, which emerged from the hypothetical drought simulations used here, are summarized in Table 3."

We also include this new sentence in the Introduction:

"Table 1 describes a summary of model mechanisms that affect pre-drought resistance and post-drought recovery and we suggest are critical areas further research."

Specifically related to leaf turnover and mortality, we also include this new text starting at line 582:

"Leaf loss is one component of total carbon turnover flux equations in terrestrial models, in addition to woody loss, fine-roots, and reproductive tissues. Having a better understanding of when extreme levels of phenological turnover contribute to stand-level mortality could be improved. Among other turnover hypothesis explored, Pugh et al. (2020) found that phenological turnover fluxes where just as important as mortality fluxes in driving forest turnover time in the VDMs: LPJ-GUESS, CABLE-POP, ORCHIDEE, but not the LSM JULES."

Specifically related to carbon allocation strategies, we also include this new text starting at line 671:

"Further eco-evolutionarily-based approaches such as optimal response or game-theoretic optimization, as well as entropy-based approaches are useful when wanting to simulate higher levels of complexity (reviewed in Franklin et al. 2012). With more frequent UCEs and if plants need to reduce water consumption, the optimal strategy of allocation between leaves and fine roots should change, therefore the goal functions (e.g., fitness proxy) in optimal response modeling can account for costs and benefits of allocation shifts between all organs (Franklin et al. 2009, 2012)."

Specifically related to community composition, we also include this new text starting at line 812:

"Due to VDMs being able to exhibit dynamic biogeography they are more useful at predicting shifts in community composition beyond LSMs capabilities. Further areas of advancement (described in Franklin et al. (2020)) is including models of natural selection, self-organization, and entropy maximization which can substantially improve community dynamic responses in varying environments such as UCEs. Eco-evolutionary optimality (EEO) theory can also help improve functional trait representation in global process-based models (reviewed in Harrison et al., 2021), through hypotheses in plant trait trade-offs and mechanistic links between processes such as resource demand, acquisition, and plant's competitiveness and survival; traits associated with high degrees of sensitivity in models. The power of prognostic VDMs to predict shifts in demography and community migration with climate change is large, but rarely is being constrained with plant-level EEO theory, and thus will likely need to use stand level competition and coexistence principles of how plants self-organize (Franklin et al. 2020)."

3. **R3:** "Many review comments (especially the Specific comments) are dismissed by simply arguing "this is a review paper" or never mentioned. I think a point-by-point response is still necessary."
   Answer: We apologize if we missed some specific comments from previous reviewers and did not address their points adequately. Under the Interactive Discussion we

noticed that some comments were missing from the last review period, and we have added new author replies under the “reply to RC”. We hope we have addressed any outstanding comments.

4. **R3**: “The authors should update accordingly by including the discussions of the key processes and generalize model development perspectives in the VDMs beyond these two models. I didn’t see this kind of revisions in the revised manuscript”
   Answer: Similar to comment #1 above, we have updated the manuscript to include descriptions of other VDMs beyond the two models used here. We have also included more discussion of general VDM processes and model development that could be prioritized for understanding ecosystem response to UCEs.
   See comment #6 below for updates to leaf loss and mortality.
   See comment #7 below for updates to the role of plant hydraulics in other VDMs.

   Specifically related to carbon allocation strategies, we also include this new text starting at line 658:
   “Global scale terrestrial models are beginning to include optimal dynamic C allocation schemes, over fixed ratios, that account for concurrent environmental constraints on plants, such as water, and adjust allocation based on resource availability such as in LM3-PPA (Weng et al., 2015),”

   We would like to emphasize the integrated-c-loss and integrated-c-change due to climate change as a new methodology to explore in all VDMs, not just a one-time application used here. Therefore, we have introduced this approach earlier in the abstract.
   “As a result of nonlinear ecosystem responses to UCEs, that are qualitatively different from responses to milder extremes, we consider both biomass loss and recovery rates over time, by reporting a time-integrated carbon loss as a result of UCE, relative to the absence of drought.”

5. **R3:** Concerns with linear vs. non-linear ecosystem response.
   Answer: We agree that complex biological life systems are not linear. The previous text (i.e., mentions of linear vs. nonlinear response) was not an appropriate description of what we were trying to convey, and has been corrected in our revised manuscript. The correct hypotheses that we were trying to test was comparing different degrees, or amplitudes, of nonlinearities, with carbon loss becoming more strongly nonlinear with increasing UCEs. Therefore, we removed text that described the null hypothesis as a linear relationship between carbon stock and drought, and instead are describing the null hypothesis and near-linear, and alternative hypothesis as different degrees of non-linearities.

In section 1.1 we updated the following text:

“Change in vegetation C stock is related to drought intensity and/or drought duration in a near-linear relationship (Fig. 1a, H0, null hypothesis), which has some observational support from annual and perennial grassland ecosystems, shrublands and savannas across the globe (Bai et al., 2008; Muldavin et al., 2008; Ruppert et al., 2015). We recognize that most ecological systems are nonlinear, thus alternatives to the null hypothesis are that biomass loss increases non-linearly with increased drought intensity”

6. **R3:** “LAI and its profile (Section 4.1.1 The role of phenology and phenological strategies prior to UCEs)”. Lines 485~487: “ED2 predicted a very weak biomass loss at the time of UCEs (Fig. 2a), suggesting large-scale leaf loss is not a direct mechanism of plant mortality in ED2.” This is a good place to explain the mechanisms of leaf loss, plant growth, and mortality in VDMs and weakness of current VDMs, by using ED2 as a case.

   Answer: In an effort to make this more of a “perspectives” paper we took the reviewers advice and used ED2 as a case to explain the mechanisms of leaf loss and growth/mortality in VDMs.

   We include the following new text starting at line 582: “Leaf loss is one component of total carbon turnover flux equations in terrestrial models, in addition to woody loss, fine-roots, and reproductive tissues. Having a better understanding of when extreme levels of phenological turnover contribute to stand-level mortality could be improved. Among other turnover hypothesis explored, Pugh et al. (2020) found that phenological turnover fluxes where just as important as mortality fluxes in driving forest turnover time in the VDMs: LPJ-GUESS, CABLE-POP, ORCHIDEE, but not the LSM JULES.”

   We did some word-smithing to the final sentence in section 4.1.1 to improve our point of highlighting areas for improvement in VDMs. We also added the final sentence about examples used in other VDMs (e.g., FATES model). It now reads:

   “VDMs could be improved by better capturing different plant phenological responses to UCEs by better representing a range of leaf-level morphological and physiological characteristics relevant to plant-water relations such as leaf age, retention of young leaves even during extreme droughts, (Borchert et al., (2002)), and variation in hydraulic traits as a function of leaf habit (Vargas et al., (2021)) (Table 3). Two such examples are seen in the FATES model where the possibility for “trimming” the lowest leaf layer can occur when leaves are in negative carbon balance due to light limitation thus optimizing maintenance costs and carbon gain, as well as leaf age classifications providing variations in leaf productivity and turnover.”

   In section 4.1.1 we provide an example from another VDM (CABLE), stating that when “evaluating the simulated response to CO_2 fertilization, LAI was the largest source of variability in CABLE (Li et al., 2018).”

7. **R3:** Mortality (mentioned in 4.1.2 The role of plant hydraulics prior to UCEs).
   In section "4.1.2 The role of plant hydraulics prior to UCEs", the authors mentioned different mortality settings in the two case models, but no details and no mentions of other models.
   Answer: We agree that this section would be a good place to describe connections between mortality and role of plant hydraulics in other VDMs (other than ED2 and LPJ-GUESS). However, other reviewers have pointed out that our manuscript is already very long and an exhaustive review of plant hydraulics in more models would greatly increase the length of this paper. We would like to find a good balance, and briefly explain other models, but also point the readers to model evaluation manuscripts where they can find more information.

   We include the following new text starting at line 618:
   "Of the VDMs that are beginning to incorporate a continuum of hydrodynamics (e.g., ED2 (described in Methods 2.1 section) and FATES-HYDRO (Fang et al., 2022 based on Christoffersen et al., 2016), they are able to solve for transient water from soils to roots, through the plant and connect with transpiration demands. Therefore instead of the plant water stress function being based on soil water potentials, it is replaced with more realistic connections with leaf water potentials. Mortality is then caused by hydraulic failure via embolism controlled by the critical water potential (P_{50}) that leads to 50% loss of hydraulic conductivity. For advancements in tree level hydrodynamic modeling see the FETCH3 model (Silva et al., 2022), for justification for plant hydrodynamics in conjunction with multi-layer vertical canopy profiles see Bonan et al., (2021)."

   In Section 2 of the updated manuscript, we also include the following text on plant hydraulics in other models:
   "In a cutting-edge area of development, new mechanistic implementation of plant competition for water and plant hydraulics in VDMs (i.e., hydrodynamics) are improving our understanding of plant-water relations and stresses within plants, such as with TFSv.1-Hydro (Christoffersen et al., 2016), ED2-hydro (Xu et al., 2016), FATES-HYDRO (Ma et al., 2021; Fang et al., 2022). Compared to more simplistic representation of plant acquiring soil moisture not connected to plant physiology (e.g., LPJ-GUESS, LM3-PPA, CABLE-POP, SEIB-DGVM). For hydrodynamic representations in 'big-leaf' LSMs such as CLM5, JULES, and Noah-MP-PHS see Kennedy et al., (2019), Eller et al., (2020), and Li et al., (2021) respectively."

8. **R3:** Allocation (4.1.3. The role of carbon allocation prior to UCEs)
   The authors attributed shedding leaves as a strategy of allocation. I think it more close to a strategy of reducing water consumption. With more frequent UCEs, the optimal strategy of allocation between leaves and fine roots should change. How it will shift is an interesting topic that may need to discuss in this section. See a review paper: (Franklin et al., 2012)
   Answer: We thank the reviewer for this point, and providing the Franklin paper on 'Modeling Carbon Allocation'. We have updated the text to point out the strategy of changing allocation between leaves and fine root under water stress, and the need to reduce water consumption. We also included the Franklin et al., 2012 reference in Table 1.

We include the following new text starting at line 671:

"Further eco-evolutionarily-based approaches such as optimal response or game-theoretic optimization, as well as entropy-based approaches are useful when wanting to simulate higher levels of complexity (reviewed in Franklin et al. 2012). With more frequent UCEs and the need for plants to reduce water consumption, a shift in the optimal strategy of allocation between leaves and fine roots should change. The goal functions (e.g., fitness proxy) used in optimal response modeling can account for these shifts in costs and benefits of allocation between all organs (Franklin et al. 2009, 2012)."

Text that was related to "shedding leaves" (as pointed out by the reviewer) was located in the plant carbon storage section 4.1.4 (storage of non-structural carbohydrates (NSCs)) where we describe one way for maintenance of NSCs is that trees can resorb a fraction of leaf C during leaf shedding in ED2. We also mentioned that interactions with rising atmospheric CO_2, NSCs, and leaf shedding "needs to be further explored".

9. **R3:** In line 464~466 "shifts in plant hydraulics or other functional traits, C allocation, phenology, and stand demography": The processes mentioned in this sentence are for one PFT. However, for VDMs, the shifts also include structural and compositional changes.
   Answer: We thank the reviewer for pointing out that VDMs also include processes like structural and compositional changes across varying community assemblages (i.e., not just one PFT), and this sentence has been updated accordingly.

   We include the following new text starting at line 556:
   "…including shifts in plant hydraulics or other functional traits, C allocation, phenology, stand size-structure and/or age demography, and compositional changes, all which vary among ecosystem types. A critical look of driving model mechanisms, which emerged from the hypothetical drought simulations used here, are summarized in Table 3."

10. **R3:** I suggest adding a section discussing about the community level reorganization due to UCEs or re-organize the section "4.2.3 The role of stand demography post-UCEs" for this. Please refer to the papers (Mencuccini et al., 2019; Franklin et al., 2020; Harrison et al., 2021).
    Answer: To address this comment we have added text to include the optimality approaches described in Franklin et al., 2020, Harrison et al., 2021. (A note that the Mencuccini et al. 2019 was a review of water fluxes in plants and was included in the plant hydraulics section).
    The research area of optimality approaches in modeling (i.e., eco-evolutionary optimality (EEO), evolutionarily stable strategy (ESS), entropy-based approaches, self-organization) is *very large*, and could be its own separate paper(s). We have tried to

highlight how optimality hypotheses can be used to describe community level compositional changes due to UCEs, but we cannot go into full description of each of these concepts here.
We have re-organized the section “4.2.3 The role of stand demography post-UCEs” to include these new topics. We also included the Franklin et al., 2020 reference in Table 1 and Table 3.

We include the following new text starting at line 812:
“Due to VDMs being able to exhibit dynamic biogeography they are more useful at predicting shifts in community composition beyond LSMs capabilities. Further areas of advancement (described in Franklin et al. (2020)) is including models of natural selection, self-organization, and entropy maximization which can substantially improve community dynamic responses in varying environments such as UCEs. Eco-evolutionary optimality (EEO) theory can also help improve functional trait representation in global process-based models (reviewed in Harrison et al., 2021), through hypotheses in plant trait trade-offs and mechanistic links between processes such as resource demand, acquisition, and plant’s competitiveness and survival; traits associated with high degrees of sensitivity in models. The power of prognostic VDMs to predict shifts in demography and community migration with climate change is large, but rarely is being constrained with plant-level EEO theory, and thus will likely need to use stand level competition and coexistence principles of how plants self-organize (Franklin et al. 2020).”

11. **R3:** Successional patterns (4.2.4 The role of functional trait diversity & plant hydraulics post-UCEs): Lines 680~681: “disturbance, competition will likely shift the plant community towards one that is composed of opportunistic, fast-growing pioneer tree species”. I think this is an issue of recovery trajectory. If the climate conditions are the same and the PFTs are available, the vegetation should recover to its pre-UCE states, depending on model setting.
Answer: We thank the review for pointing this out. The references associated with this sentence are from field experiments, not model results. We have updated the text to say “Higher” disturbances rates (implying repeated, more extreme disturbances) will likely shift the recovery trajectory of the plant community.

The sentence has been updated to: “In field experiments, higher disturbance rates have shifted the recovery trajectory and competition of the plant community towards one that is composed of opportunistic, fast-growing pioneer tree species, grasses”

12. **R3:** Lines 685~691: For the issue “ED2 exhibited a strong recovery in the evergreen PFT as well (over two other deciduous PFT types), inconsistent with the above literature”, the authors assumed the reason is in the response to drought (i.e., plant hydraulics issue). It could be the nitrogen issue, related to the feedback between leaf traits (LMA) and litter decomposition. Please see (Aerts, 1995, 1999)
Answer: We agree that nitrogen cycling feedbacks between leaf traits and litter decomposition could be an explanation for the evergreen recovery. However,

biogeochemical cycling was not investigated in this study, as we tried to focus more on hydraulic traits and processes. Regardless, we would like to point out to the reader that differences in nitrogen demands, etc. should be considered.

We include the following new text starting at line 839:

"Nitrogen cycling feedbacks were not investigated here, but could also be an explanation for a strong evergreen PFT recovery."

Reviewer 4 expressed concerns about:

1. **R4:** A component of the inter-modeling comparison.

R4: I am hard to understand what is happening in the models when I see the simulation results in Figure 3. I expect higher environmental CO2 (eCO2) to deliver higher tolerance to drought for plants. Therefore, higher eCO2 would deliver higher carbon storage in vegetation under drought conditions. But, runs with only-increased-eCO2 frequently result in lower vegetation carbon than runs with warming-plus-increased-eCO2 (Fig. 3 a,e,f,g,h,i). In lines 412-413, the authors also mentioned that "losses are exacerbated when accompanied with warming and even with eCO2, with 800 ppm having a more detrimental impact than 600 ppm (Fig. 3a-c)."

The authors already notice this problem because they state, "The VDM simulations suggest that the combination of elevated warming and eCO2 will exacerbate consequences of UCEs by reductions in both C stocks and post-drought biomass recovery speeds" (Lines 715-716). Although, I do not want to encourage authors to increase the length of the discussion, as it is already too long. But, the authors should state the possible reason(s) for this mismatch.

Answer: We appreciate the reviewer highlighting this point about elevated CO_2 climate change results.
The reviewer points out that the 'only CO_2 fertilization' treatment should give higher carbon storage, and higher biomass. But, in 5 of the 12 results in Figure 3 (Fig. 3 a,e,f,g,h,i) the only-increased-eCO_2 results in lower vegetation carbon, or a more negative integrated C change (blue lines), compared to runs with warming-plus-increased-eCO2 (red lines).

We believe a main explanation for this is related to the structural overshoot response with CO_2 fertilization that we describe in our conceptual Figure 1. There is an amplification of vegetation biomass due to eCO2, and either favorable historical conditions, or recovery from smaller disturbances (or both). Our argument is that when there is are **extreme droughts (or mortality events)** the loses are compounded since there is previously more biomass stock in the system, and there ends up being a negative C change from baseline, or the mortality overshoot. This theory is also confirmed when we see that the highest eCO2 (800ppm, purple lines) results in the lowest carbon change, when combined with the highest drought intensities (Fig. 3g,h,i,j).
We will make this clear in the revised manuscript.

In Section 4.1.3 “The role of carbon allocation prior to UCEs” we discuss this connection between the structural overshoot with eCO_2 and then the mortality overshoot with UCEs. “Mortality overshoot, as a result of structural overshoot, could be an explanation for the negative integrated-C-change (i.e., C loss) in the majority of eCO_2-only simulations (18 out of 24 scenarios; Table 2).”

We have updated the line in the summary to include the explanation of structural overshoot with eCO_2 and increased competition for resources at line 870: “The VDM simulations suggest that the combination of elevated warming and potential structural overshoot from eCO_2 (or inaccurate representation in NSCs allocation/usage priority) will exacerbate consequences of UCEs by reductions in both C stocks and post-drought biomass recovery speeds (Fig. 3).”

We have also updated the sentence at line 500 to only include Fig. 3b-c, not Fig. 3a-c. And we incorrectly listed the CO_2 ppm. It should read the other way around that the lower 600 ppm led to a more detrimental impact in carbon loss (in ED2) compared to the higher 800 ppm CO_2. This better matches the reviewers’ comments that higher eCO_2 should deliver more carbon to the vegetation. “losses are exacerbated when accompanied with warming, even with eCO_2, with 600 ppm having a more detrimental impact than the more elevated 800 ppm (Fig. 3b-c).”