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RC2: The manuscript entitled "The significant role of snow in shaping alpine treeline responses in modelled boreal forests” aims to investigate the effect of snow on the treeline shift. However, in my opinion, reading the article looks like this is not the main focus of the manuscript. The structure of the article is center on the sensitivity analysis of the forest dynamic model LAVESI. In the methodology section is reported the description of a new way to incorporate the effect of the snow cover in the LAVESI model, but the results section is just partially focused on the outcomes of this process. Some issues in the incorporation of this process are detected and reported in the specific comments below. Moreover, the study areas are not adequately described and neither pictures or orthophoto are reported. For me it is complicate to understand the real characteristics of the three investigated sites.

AC: Thank you for your insightful feedback and constructive critique during the first review of our preprint. Your comments provide important guidance for improving our manuscript. We will carefully consider all referees' suggestions to enhance the clarity and quality of our study, ensuring it aligns with the high standards of Biogeosciences.

RC2: The approach adopted in this manuscript is the progressive variation of the model inputs and so it is basically a sensitivity analysis of the LAVESI model.

AC: We did not conduct a progressive variation of the model inputs but, as correctly noted, performed a sensitivity analysis. In the context of pattern-oriented modeling, this is a standard approach in ecological individual-based modeling (see Grimm & Railsback, 2005, Individual-based Modeling and Ecology, Princeton University Press; Grimm et al., 2005, Science, 310: 987-991).

RC2: Furthermore, there is no comparison between the model outputs and the actual forest characteristics making impossible to evaluate the reliability of the model outcomes and consequently the future scenarios.

AC: In pattern-oriented modeling, a simple model is iteratively refined to more accurately reproduce observed patterns. As part of the validation process, model outputs are compared with actual forest characteristics. While we have fitted the treelines, this was not done in a spatially explicit manner. The original LAVESI model (Kruse et al., 2016) has been systematically extended to incorporate dispersal processes influenced by wind speed and direction (LAVESI-WIND 1.0; Kruse et al., 2018), landscape topography and additional boreal forest species (LAVESI-CryoGrid v1.0; Kruse et al., 2022), and forest fire dynamics (LAVESI-FIRE; Glückler et al., 2024). Both the pattern-oriented modeling approach and the sensitivity analysis have been consistently applied across these studies.

RC2: The manuscript need to be deeply restructured and also the methodological approach deeply revised. In my opinion the final suggestion for the manuscript is a rejection encouraging the authors to work on it for a resubmission.

AC: As also pointed out in Referee Comment 1, we will revise and clarify the description while maintaining the methodology, as it aligns with established ecological modeling standards.

RC2: Below I report the specific comments.

Introduction: the section is too long and I suggest the authors to reduce it of about 50 lines. Moreover a general comment to this section is to restructure the description of the drivers and factors influencing the treeline shift. As it is, in my opinion it results a little bit complete to follow.

AC: We will shorten the introduction while preserving all essential content. Currently, the influencing factors are categorized into abiotic climatic factors, species-dependent factors, abiotic non-climatic factors, and other biotic factors. We will further emphasize this classification and illustrate it with a graphical overview.

RC2: Line 187: for run, the authors intended years? So, the model time resolution is equal to 1 year if I understood correctly. Please specify it.

AC: The model description outlines that within one simulation step, which is one year, the relevant processes are incorporated consecutively as submodules (see lines 175-176). We will reiterate this in line 187 for clarity.

RC2: Section 2.1: how do the species-specific parameters included in the model were derived? Please refer also to the species you are going to simulate reported in table 1.

AC: We will compile a complete table of species traits and model variable values in LAVESI and include it in the manuscript appendix. We will provide a clearer explanation of the site-specific results by directly linking environmental factors and species traits to site-specific variability, thereby enhancing the understanding of the observed differences across sites.

RC2: Line 194: How does the tree mortality rate is included in the model? Please specify what tree and environmental related parameters where used to model this process.

AC: The fundamental methodology for determining seed and tree mortality was originally developed by Kruse et al. (2016) and has been updated since. We will provide a clear explanation of how the tree mortality rate was calculated, detailing the environmental parameters that influence this process and the mechanisms behind their effects.

RC2: Line 221: the threshold of 5°C for distinguish between rainfall and snowfall needs to be accurately motivate. The value of 5 sounds quite high in my opinion. How do you motivate it? Temperature daily fluctuation in case of precipitation is really low so I would expect that a mean daily temperature slightly less than 5°C will lead to rainfall precipitation. This is a crucial point, and it needs to be clarify and accurately motivated since it can majorly affect the simulation results.

AC: Our approach is based on the empirical function from Sato et al. (2007), which in turn refers to the precipitation partitioning approach from Ichii et al. (2003). Ichii et al. (2003) used a gradual transition, where snowfall accounts for 50% of total precipitation at 2°C. In our model development, we initially incorporated this approach but subsequently adjusted the threshold as part of a model tuning process. Specifically, we compared simulated and observed snow accumulation patterns and iteratively refined the temperature threshold to improve model accuracy. However, we acknowledge that this value may vary depending on regional climate conditions, and we will clarify this tuning process more explicitly in the revised manuscript.

RC2: Line 245-250: about avalanche induced mortality, the authors never mentioned the role of the slope as predisposing factor for snow avalanche release. It is generally defined that a slope between 27° and 55° is the range where avalanches can occur.

AC: We implemented snow movements downslope in extreme years which happen with a chance increasingly when exceeding the 99.9th percentile of snow height in the full climate forcing series. This movement is simply implemented as downslope independent from the slope angle. Further, in this simplification we named this process avalanche. In the snow module description, we then described the process and stated that mortality is added where a modelled avalanche impacts the leading edge of tree stands, with its destructive force diminishing downslope due to protecting tree growth (see lines 250-251). We will provide a more detailed explanation that snow accumulation and snow movement were modeled for each grid cell, considering the slope direction.

RC2: Section 2.3: For me this section results slightly complicate to follow because it is a pure description of the model and the relative processes. I would encourage the authors to use formulas and/or diagrams or flowcharts in order to have also a clear view of the developed model.

AC: We will include additional formulas where needed and in-text formulas are not sufficient. We will create a flowchart to clarify the interrelated processes. Additionally, a graphical overview of all influencing factors will be provided to facilitate a better understanding of the overall framework.

RC2: Table 1: are the locations reported in a local or a geographic coordinate system? It looks to me east north but the xmin etc. is confusing me.

AC: We will update the names to 'Longitude' and 'Latitude' for clarity.

RC2: I would suggest to add also the total area modelled for each study site.

AC: We will also specify the total simulation area for each study site at this point.

RC2: A small map would be beneficial to clearly identify the location of the investigated sites.

AC: As requested, we will include a map to visually illustrate the locations of the study sites.

RC2: Lines 304-308: Why do the authors compute the sensitivity analysis of the parameters of the model? For me it is unclear the motivation of this operation.

AC: As previously mentioned, this approach is a standard method in ecological modeling (Grimm & Railsback, 2005; Grimm et al., 2005). The methods section further explains that the sensitivity analysis is conducted to evaluate and compare the influence of various factors on the migration rate of the alpine treeline and to identify key drivers and assess how variations in these factors influence treeline dynamics (see lines 299-300).

RC2: Section 5: for really understand the morphology of the sites and the condition it would be beneficial to add an image with the orthophoto of the investigated areas with contour lines or something similar.

AC: Satellite images of the study sites are already included in the preprint. However, we have noticed that Figures A1 and B1 mistakenly display the same image, which we will correct. We initially decided against including these images in the main section to avoid excessive length but are happy to move them if desired. Additionally, we can provide photos and full panorama images of the field plots online.

RC2: Section 5: It would be of great value if the authors can compare the actual condition of the study site with the results of the spin up simulation. In this way it is possible to assess the reliability of the model and therefore the validity of the future scenarios.

AC: ***The treeline was adjusted to match the current observed position through a fitting process, which, although conducted, has not yet been explained in detail within the manuscript. We will address this more thoroughly in the revised version. However, it is important to note that achieving an exact match in a stochastic model is inherently challenging. The model generates mean positions based on multiple runs, with some simulations advancing further while others lag behind. This variability is a result of the stochastic nature of the model, and it allows us to explore the associated uncertainties. For further clarification, please refer to the section on stochasticity in Grimm & Railsback (2005).***

RC2: Line 330: What is the definition of treeline? It is necessary to define how the authors have identified it. Is it based on a certain density of trees or something similar?

AC: The definition of the treeline in this study is described in lines 328-329: Treelines were determined using threshold-based criteria of one hundred trees per hectare.

RC2: General comment for the methodology section: Authors investigated which factors are the most important/influent for the migration rate. I would say that the common approach for simulating future scenarios is to have a solid and reliable model either tested with field data or from literature in similar conditions. Consequently, models are used to predict future change by just modifying the environmental variables or the initial conditions, obtaining in this case the probable shift of the treeline. In this manuscript the procedure is not classical, and the authors look like they want to investigate which variable of the model can affect the treeline shift and how. To me this approach is more similar to a simple exercise respect to really understand the possible dynamic of the treeline shift for the three study sites. This feeling is corroborated by the absence of comparison between the current condition of the forests and simulation spin up for the three study areas. In other word the factors influencing the tree line shift are the environmental one and not the parameters of the model.

AC: The aim of our study and sensitivity analysis was to evaluate and compare the influence of various factors on the migration rate of the alpine treeline, identify key drivers, and assess how variations in these factors influence treeline dynamics. As outlined by Grimm & Railsback (2005) and Grimm et al. (2005), this approach is a standard method for determining the influence of input factors on model output. This methodology has also been applied in several other LAVESI studies, such as Kruse et al. (2016, 2018, 2022) and Glückler et al. (2024). Similar approaches have been used in other studies, including Zurell et al. (2011), who linked species distribution models with an individual-based model to assess climate-induced

range shifts in black grouse, and [Malchow et al. (2024)](), who used a spatially explicit individual-based model to analyze red kite population dynamics. Additionally, [Zurell et al. (2018)]() applied species distribution models to evaluate the risks faced by migratory birds due to climate and land cover changes. These studies demonstrate that integrating process-based models with sensitivity analyses is a widely used method for understanding ecological dynamics under environmental change.

RC2: Line 359: please add a couple of sentences to introduce the results instead of directly showing Table 3.

AC: In accordance with the suggestion, we will add an introductory sentence at this point.

RC2: Table 5: The table should be moved to the results section.

AC: As suggested, we will move Table 5 to the results section.

RC2: Lines 458-462: I would say this is a quite obvious result. The study areas are different, and I would expect exactly this result.

AC: We will provide a more detailed explanation of the site-specific differences in the sensitivity analysis results, thereby clarifying or reassessing the significance of this section.

RC2: General comment to the results and discussion section: The authors report the outcomes of the modelled scenarios discussing and comparing the relative results, but the real problem is that a reliable scenario has not been identified. In the manuscript there is no identification of a modelled scenario that can be representative of current/actual forest conditions and of the future one. Without this definition is not possible to quantify the alpine treeline shift.

AC: We appreciate the reviewer's concern regarding the identification of a representative scenario for current and future forest conditions. However, our study is not designed to provide deterministic predictions of future treeline positions. Instead, it is a sensitivity study aimed at understanding the relative influence of different factors on treeline migration dynamics. Our model was tuned to represent observed patterns, but the primary objective is to assess the key drivers and interactions shaping treeline shifts rather than to predict an exact future distribution. By systematically varying input factors, we can identify the processes most relevant for treeline migration, which can help refine future projections and improve ecological understanding rather than provide a single "correct" scenario. We will clarify this point more explicitly in the manuscript.