# Reviewer 2

We thank the reviewer for their careful reading of the manuscript and their detailed feedback on the input data, methodological transparency, and presentation. Their comments highlight the need to explain the spatial representativeness and ages of the pollen records more explicitly, clarify how differences in spatial and temporal resolution are handled, and make the methodological descriptions easier to follow.
We will expand these explanations, provide site-specific source area information and available sample ages in an appendix, and deepen the discussion of temporal mismatch, source area uncertainty, and environmental controls not captured by the current predictors. Several concerns can already be clarified from the existing implementation: the pipeline uses the individual source area radii published with the LegacyVegetation dataset, and land cover fractions are calculated using pixel areas, thereby accounting for their variation with latitude. Furthermore, our comparison of the CCI maps between 1992 and 2022 shows that only 2.93% of land pixels changed their mapped land cover class during this period. This suggests that the choice of reference year affects a relatively small proportion of the study area, although it does not resolve the broader temporal mismatch between pollen samples, climatic variables, and satellite observations.
We do believe that the technical detail is necessary for a manuscript introducing a novel method, but will supplement it with more accessible explanations, introduce terminology and acronyms as they appear, check the definitions of equation symbols, and enlarge and separate the maps. We will also refine the introduction and discussion to emphasise the methodological contribution and its limitations more clearly. While we maintain that this contribution is appropriate for *Climate of the Past*, we recognise the need to distinguish the pipeline's value as a proof of concept from the reliability of individual reconstructed patterns. Below, we address the reviewer's concerns individually and describe the planned revisions.

This manuscript describes a new methodology to create spatially continuous land cover maps based on pollen spectra recovered from sediments. The method has three main parts: 1) creating a statistical relationship between modern pollen spectra and contemporary satellite remote sensing-based land cover maps, 2) using this statistical model with a fossil spectrum and raster fields of bioclimatic variables to create an estimate of land cover in the "source area" of the paleoecological archive, and 3) using another statistical model based on machine learning to both interpolate and extrapolate reconstructed land cover from a source area to create a spatially continuous land cover reconstruction over a defined spatial domain.

This study represents a novel and ambitious attempt to address a longstanding goal of the palaeoecological community, that is to create continuous reconstructions of land cover based on paleoecological records. While the authors succeed, admirably noting a range of caveats in their discussion, the presentation of the method and results of this study are so flawed it is impossible to have any confidence in the final result.

Because the reconstruction results are presented only superficially – only five time slice maps are included in the manuscript and the time series reconstruction does not include dynamic ice

or sea level extent – this paper would probably be better suited for a journal more focused on geoscientific modeling methods as opposed to *Climate of the Past*.

For these reasons, I cannot recommend this manuscript for further consideration for publication.

## General Response:

We thank the reviewer for their input and valuable feedback in their general response. We will address each of the mentioned points separately.
While the methods section may be written densely, we do believe this level of detail to be necessary to describe the novel methods, which are the focus of this manuscript. We will incorporate additional explanations to make the text easier to follow and increase understanding for readers with a limited background in statistics, mathematics or machine learning.
In the same vain, we would like to make clear that the manuscript's focus is not the resulting dataset but rather the methodological pipeline as a proof of concept for downscaling rough resolution paleo vegetation information. We will refine the manuscript's introduction as well as discussion to shift the focus more on the method's novelty and inherent uncertainties and drawbacks. This would need to be addressed in further methodological developments, before a "carefree" use of the dataset would be possible.
Lastly, since simulations and model-based interpretation as well as proxy development are listed in the journal's aim and scope, we do believe the manuscript to be a good fit for Climate of the Past. In addition, manuscripts that focus on outlining new methods are regularly being published in Climate of the Past. We list a couple of examples below:

- Eichenseer, Kilian, und Lewis A. Jones. „Bayesian Multi-Proxy Reconstruction of Early Eocene Latitudinal Temperature Gradients". Climate of the Past 20, Nr. 2 (2024): 349–62. https://doi.org/10.5194/cp-20-349-2024.
- Schätz, Franck, und Rüdiger Glaser. „From Manual Classification to Transformer-Based Language Models: Assessing the Quality and Consistency of Historical Convective Event Records". Climate of the Past 22, Nr. 10 (2026): 1833–61. https://doi.org/10.5194/cp-22-1833-2026.
- Fénisse, Gabriel, Manuel Chevalier, Odile Peyron, David Vincent Bekaert, und Pierre-Henri Blard. „Advancing Last Glacial Maximum Paleoclimate Reconstructions in Europe Using Pollen Data: A Multi-Method (Mega)Biomization Approach". Climate of the Past 22, Nr. 8 (2026): 1507–36. https://doi.org/10.5194/cp-22-1507-2026.

**General comments**

We added our responses below each of the reviewer's points.

A critical flaw in this study is the lack of information about the modern pollen data used to establish the central relationship between land cover and pollen spectra. It is possible that the authors did a thorough job of considering the time of collection and pollen source area, but this is impossible to tell from reading the current manuscript. The phrase “source area” is used at least 28 times in the manuscript, but nowhere is it described how this was determined. As far as I could tell, information on basin type and size, and therefore pollen source area, come from the LegacyVegetation dataset (Schild et al., 2025). It is not possible from reading the paper describing that dataset to immediately see the definitions of the pollen source area for every site; nevertheless, this key information should be included in the current manuscript for every site that was used in the reconstruction.

> We thank the reviewer for pointing out that the definition of the pollen source areas needs to be made more explicit in the current manuscript. We use the site-specific source area radii provided with the LegacyVegetation dataset. We will describe how these source areas were determined and how they are used in the methodological pipeline. In addition, we will provide a table in the appendix listing the sites used in the reconstruction, their respective source area radii, and the available information on basin type and size. This will make the relevant information accessible without requiring readers to consult the underlying dataset.

In any case, I am highly skeptical that the pollen “footprints” shown e.g., in figure 3 can extend to what appears to be >100km from individual pollen archives. This is reinforced by a look at Figure 6 in Schild et al. (2025), which shows that several sites in Alaska and northwest Canada in the LegacyVegetation dataset are not represented by “at least one large lake (≥ 50 ha) or several smaller basins” and therefore must represent the broad scale vegetation patterns more than 100km from the site. In fact, for peatlands and small lakes, the pollen spectrum might be representative of a very small area indeed, perhaps dominated by the vegetation in an area only a few 10s of meters from the archive and therefore could only be represented by a single pixel in the satellite land cover map.

> We agree that the spatial representativeness of pollen records needs to be considered carefully, particularly for peatlands and small lakes where local vegetation can contribute strongly to the pollen spectrum. The reconstruction uses the source area radius assigned to each individual record in the LegacyVegetation dataset, rather than a uniform radius across all sites. We will show which sites contributed to the reconstruction and provide their respective basin sizes and assigned source area radii.
>
> We will also clarify the distinction between basin size, the assigned pollen source area, and the spatial footprints shown in the figures. In particular, we will discuss the uncertainty associated with large source area estimates and how this may affect the interpretation of the reconstructed land cover. Using the published radii does not remove this uncertainty, and we agree that this limitation should be stated more clearly.

Digging deeper into the raw LegacyVegetation dataset, which I should not have needed to do, I see that the "pollen source radius" for sites in the North America sub-dataset range from 262m to more than 500km. At a bare minimum, the manuscript needs to go into much more detail about the spatial representativeness of every site used in the model calibration, use a different source area for every site based on the characteristics of the archive, and all of this metadata needs to be included as part of the manuscript.

We would like to clarify that the pipeline already uses the individual source area radii published with the LegacyVegetation dataset for each record. We therefore do account for differences in the assigned spatial representativeness of the input records. However, we agree that the current manuscript does not explain this sufficiently.

Since the manuscript focuses on presenting the methodological pipeline, we believe that reproducing the full description of the input dataset in the main text would introduce considerable redundancy. We will instead expand the description of how the site-specific radii are used and provide the relevant metadata for all included records in an appendix, while retaining the reference to Schild et al. (2025) for the underlying dataset and its development.

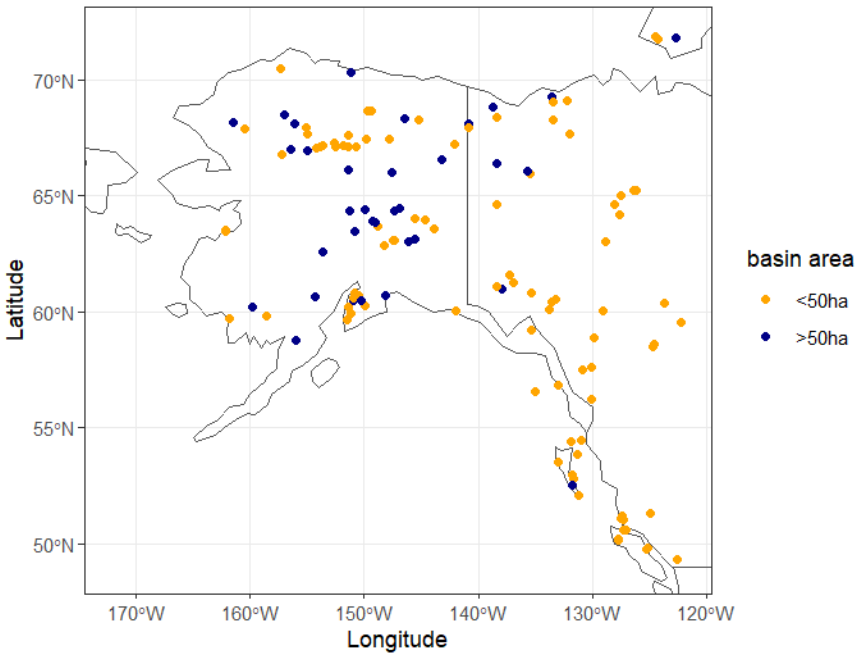



Fig. 1: Location and basin size in respect to 50ha of the records included in the method demonstration.

Furthermore, the period of collection of the "modern" pollen sample must be clarified. It is noted in the discussion of Schild et al. (2025) that "…pollen-based estimates are derived from records that span a much longer timescale than the modern forest cover data available, even though modern time slices are used for validation." This key information also needs to be included in the

current manuscript. In fact, it is highly likely that nearly all the pollen data used in the model calibration represents deposition that occurred decades to centuries (even a millennium) before the year 2020 CCI land cover map used in this study. Since the CCI-C3S land cover maps cover the period 1992-2022, it begs the question why the authors didn't at least take a temporal average of land cover over the available period instead of a single timeslice. Or multiple calibration models against every individual year of CCI land cover maps.

We thank the reviewer for suggesting that the full temporal coverage of the CCI land cover product should be considered. To assess the sensitivity of our choice of a single land cover timeslice, we compared the available CCI maps between 1992 and 2022. Within the study area, 2.93% of land pixels were assigned more than one land cover class during this period (Fig. 2). Among these pixels, the vast majority had only two distinct classes, while only a small proportion had more than two (Fig. 3).

These results indicate that the mapped land cover classes remained largely stable over the available period and suggest that the choice of a single year affects a relatively small proportion of the study area. However, this comparison does not resolve the potential mismatch between older pollen samples and the satellite observations. We will therefore provide the available age information for the pollen samples used in calibration and expand the discussion of how their temporal representativeness and age uncertainty may affect the pipeline.

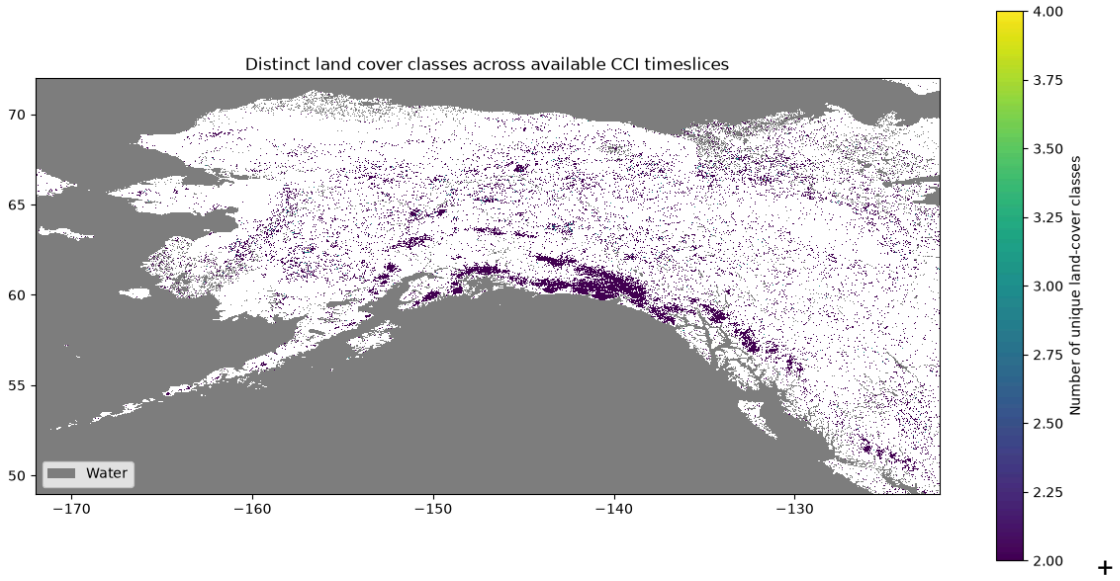



Fig. 2: Map of CCI landcover pixels with changes during between 1992 and 2022.

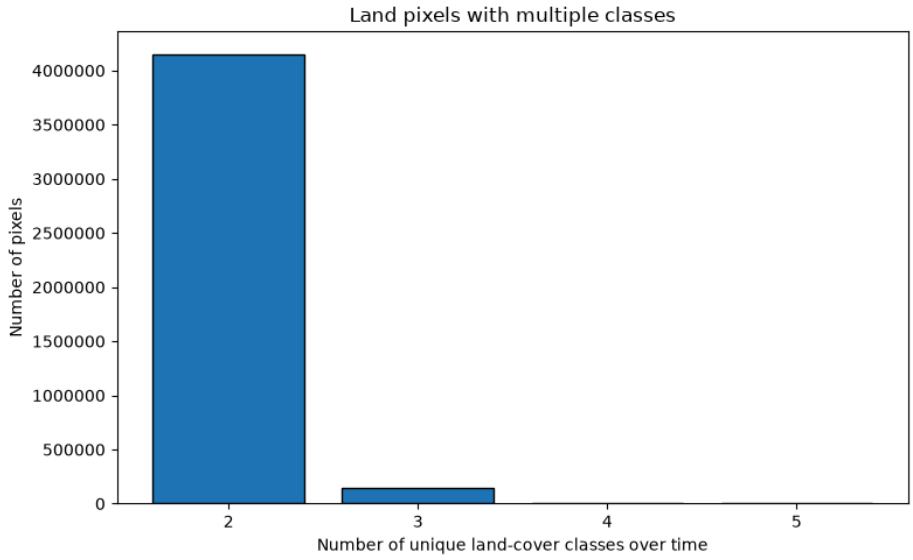



Fig. 3: Distribution of the number of distinct land cover classes between 1992 and 2022 for those pixels which experienced changes at all.

While large-scale potential natural vegetation in much of the study area may have been relatively stable over the last century, disturbance, including widespread wildfires, nearly certainly changed land cover at the 300m pixel resolution used in the study. Again, at a bare minimum the manuscript must provide transparent, detailed information about the age of each modern pollen spectrum used in the model calibration step and some discussion and analysis of how the temporal mismatch between land cover map and pollen age may have affected the model outcome.

> We agree that stability in broad vegetation patterns does not exclude changes at the scale of individual land cover pixels. Disturbances such as wildfires may affect the vegetation represented by a pollen sample and the satellite land cover map differently. In addition, changes in vegetation may occur without a corresponding change in the mapped land cover class.
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> We will include the available ages of the pollen samples used in model calibration and deepen the discussion of the temporal mismatch between these samples and the land cover observations. This will address both uncertainty in the sample ages and differences in the periods represented by the two data sources, as well as their potential implications for the calibration and resulting reconstructions.

Likewise, the CHELSA bioclimatic variables represent a climatological mean over 1981-2010 (Table 1) and so are mismatched in time with the 2020 CCI land cover map.

> We acknowledge that the CHELSA climatological mean for 1981–2010 and the CCI land cover map for 2020 represent different periods. The CHELSA variables were

> included to describe the climatic conditions associated with land cover, using a climatological mean rather than the conditions of an individual year.
>
> Our comparison of the CCI maps between 1992 and 2022 shows relatively little change in the mapped land cover classes across the study area. This suggests that the choice of the CCI reference year may have a limited influence on the calibration, although it does not establish that the temporal mismatch with CHELSA has no effect. We will make this distinction clearer and discuss the mismatch as an additional source of uncertainty.

The Copernicus CCI land cover maps are provided on an unprojected lon-lat grid of 10 arc-seconds. This means that the pixel size changes with latitude and the pixels are not equal-area; how was this handled in the model calibration step? Was a circular area interest defined? This is how it appears on the maps, although the given the size of the spatial footprint, the land cover pixel count would be different with latitude and so a circular search area of fixed radius would be inappropriate. It needs to be clarified how the CCI land cover fractions were adjusted to account for varying pixel area.

> We thank the reviewer for highlighting the need to clarify this step. During calibration, the contribution of the selected CCI pixels is determined from their area rather than their number. The variation in pixel area with latitude is therefore accounted for when calculating land cover fractions within the source areas. A given number of pixels is not assumed to represent the same land area throughout the study region. We will expand the methods section to explain this calculation more explicitly.

In the discussion section, no mention of edaphic controls on land cover is made. Soil type, bare bedrock, permafrost, and other landscape features have an important control on the biogeography of the study area. Why were variables including soil texture, slope, or landscape age not included among the environmental variables used to inform the regression and interpolation analyses?

> We agree that soil properties, permafrost, exposed bedrock, and topography can exert important controls on land cover in the study region. The environmental variables included in the present implementation do not capture all of these influences. Since the manuscript presents the methodological pipeline as a proof of concept, we see the inclusion of additional environmental predictors as a useful direction for further development.
>
> We will discuss this limitation more explicitly and identify soil texture, slope, permafrost conditions, and landscape age as potential additional predictors. Their inclusion could help account for land cover differences that are not adequately explained by the current set of environmental variables.

**Some notes on presentation**

- The manuscript is so full of jargon and technical language that the reader might be persuaded to skip the methods section, accept the authors' approach at face value, and concentrate on the results. This is wrong for any manuscript that introduces a novel method. While one might accept the study's results, as a novel methodology the approach taken here needs to be described in a much more pedantic way. Many interested readers of *Climate of the Past* and ultimately data users will not be experts in geostatistics and machine learning and so it is important for the credibility of the authors to be more transparent and clear about what they did and how they did it. For example, technical terms such as "centered log ratio transformation", "RDA", "PCA", "Hellinger distance", "network simplex algorithm", "softmax weighting", "Aitchison distance", etc. could be placed in a table similar to Table 1 with a name, symbol or acronym, and units if applicable, etc.
- For every equation in the manuscript, all symbols need to be described, with units included as appropriate.
- The maps shown in Figure 3 are far too small to interpret. If space in the journal is an issue, a link to full-resolution maps must be provided. I recommend splitting this large figure into several components and reproducing all maps with much higher resolution.

We thank the reviewer for these suggestions. While we agree that the methods section should be accessible to readers with different disciplinary backgrounds, we do believe that the level of technical detail is necessary to describe the novel methodological pipeline precisely and allow readers to assess and reproduce the individual steps. The terminology used refers to specific mathematical and statistical procedures, for which less technical wording alone would not provide an equally precise description. However, we recognise that these procedures and their role in the pipeline could be explained more clearly.

We will therefore supplement the technical descriptions with more accessible explanations of what each major step does, why it is included, and how it relates to the overall approach. We will also ensure that technical terms are explained and acronyms are introduced when they first appear. This should help readers follow the methodology while retaining the detail needed to evaluate it.

We will check all equations to ensure that every symbol is defined and that units are provided where applicable. For dimensionless quantities, we will make this explicit where relevant.

Lastly, we agree that the maps in Figure 3 would benefit from a larger presentation. We will split the figure into separate components and increase the size and resolution of the maps so that their spatial detail can be interpreted more easily.