Response to Referee 1

AUTHOR
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General Comments

Comment 1.1

> This article comprehensively addresses the modelling challenges of predicting peat depth from terrain variables. It takes high resolution terrain variables (derived from LiDAR) and low resolution (comparatively) airborne radiometric data across two individual peat landscapes in Norway and used Random Forest machine learning algorithm to train combinations of these variables to a multitude of peat depth probes and GPR peat depth measurements taken in order to establish the predict power of such variables for peat depth mapping.

Comment 1.2

> Overall, I found the article to be generally well written, with a very comprehensive and detailed description of modelling mechanism, error derivation, and feature choice. It is a very long article, going into great detail in several areas, and below I suggest at least one section/topic that could be removed entirely to reduce length and increase overall readability. I suggest the authors review all sections for conciseness and reduce the article length where possible. The level of detail may mean a reader less familiar with machine learning modelling may find the article hard to follow. While I do find the article to be within the scope of SOIL, I would be concerned that it focuses heavily on the modelling methodology.

Thank you for your positive comments on the article and for your suggestions to improve its readability. We have taken your advice to review the article for conciseness and have made several changes to reduce its length, while retaining the key details of the modelling methodology. In particular, we have removed the section on peatland extent mapping, which was not central to the main focus of the study, and we have shortened some of the other sections as well. We have moved some of the more detailed descriptions of the methodology to the appendix, to make the main text more accessible and focused.

Comment 1.3

> Additionally, there were several areas where the language used was quite casual for a scientific article. Several are highlighted under minor considerations below.

Thank you for this advice and the specific examples you provided. We have gone through the manuscript and revised the language to make it more formal and scientific, while aiming to retain clarity and accessibility.

Comment 1.4

> Finally, the main concern noted is the imbalance between the consideration given to radiometric data compared to terrain variables. Considering the title is stating terrain being “better” than radiometrics, and given the emerging understanding of the use of radiometric data in peat land mapping, there is are some fundamental errors in the methods presented, which may be biasing the conclusion alluded to in the title.

Thank you for raising this concern. We address the specific comments on this theme below, and believe that our responses show why we disagree that there are fundamental errors in the methods. For the same reasons outlined below, we do not think that the conclusion the title alludes to is biased.

Specific Comments

Comment 1.5

> The first concern in the comparison of radiometric data to lidar terrain variables is related to the choice of radiometric variables. The authors opt to use potassium, uranium and thorium ground concentration units alongside the Total Count data from the full energy spectrum. These ground concentration measurements are derived from counts per second measurements on the airplane which are calibrated, usually using pads of known concentrations at a calibration facility. Therefore, concentration of any radioelement is a measurement of the concentration of that element in the top ~ 60 cm – 1 m of the soil. However, peat soils are different. Being organic, they don’t contain the typical geological material that make up soils. Therefore, they act as an attenuative environment to gamma rays. As the potential source of gamma rays in peat areas is blocked and attenuated by the peats, the concentration calibration is no longer physically valid. While these concentration data are indeed provided by the contractors of such surveys, it is now recognized that the counts per second measurement is a more appropriate unit when considering attenuation of gamma rays in peat soils (O’Leary et al, 2022, 2024). In particular considering depth, the deeper the peat, the greater the attenuation of gamma rays. Similarly, the wetter the peat the greater the attenuation of gamma rays. The use of concentration data is not valid for a study in predicting peat depth. I recommend either the authors convert these concentrations to counts per second, or remove all but the Total Count data from their analysis and consider take the next concern into account.

Thank you to the referee for pointing out this concern and providing a thorough explanation of their reasoning. We appreciate the references, which we have consulted.

After careful consideration, we disagree that the radiometrics variables we used are not valid for predicting peat depth. In particular, we assert that converting the concentrations we use to counts per second – as the referee suggests – would produce identical results. That is because the method we use to predict peat depth (Random Forest) is insensitive to any monotonic transformation of the predictors, like the scalar conversion between concentration and counts per second (see Table 10.1 on p.351 in Hastie, Tibshirani, and Friedman 2009). The Random Forest algorithm is based on decision trees, which partition the predictor space into regions based on the values of the predictors. As a result, any monotonic transformation of the predictors will not change the partitioning of the

As a result, any monotonic transformation of the predictors will not change the partitioning of the predictor space, and therefore will not change the predictions made by the model (see Fig. 9.2 on p.306 and Algorithm 15.1 on p.588 in Hastie, Tibshirani, and Friedman 2009). Appendix B3 in Baranwal et al. (2013) and Appendix A2 in Ofstad (2015) confirm that the concentration values we use in our models are simply the counts per second multiplied by a constant conversion factor.

To try to avoid confusion on this point, we have added a short explanation in the Methods section that the distinction between counts per second and concentration is not relevant for our analysis and it does not affect the predictive power of the radiometric variables in our models.

Comment 1.6

> There is an additional argument missing from within the authors discussion, namely the fact that we never know the initial source strength, or counts, of the gamma rays for a given footprint. The measurement at the airplane is an attenuated version of this initial source. This attenuation is controlled by the attenuation coefficient for a given element and depth, soil moisture, bulk density and porosity (Beamish 2013) of the peat soils. From a purely physics/ modelling point of view, this makes the prediction of peat depth an underdetermined problem. Even if the soil moisture, bulk density and porosity was known absolutely, the initial source is never known and so any number of peat depths may result in any given gamma count at the airplane. Additionally, this modelling exercise cannot be performed on Total Count data as this is summed from the entire measurement energy spectrum, which contains multiple element specific attenuation coefficient, meaning the Total Count data is only ever indicative of attenuation variability across a site, with no ability to model anything quantitative. This puts Radiometrics in a natural disadvantage for a quantitative prediction of peat depth. Given the title of this article, I find that the discussion around the radiometrics lacked sufficient detail to make a fair comparison, which naturally results in such a bias towards terrain variables in such a modelling context. This is therefore not a result per say, but more a perfectly expected outcome. For this concern, I suggest a more comprehensive discussion around the physical limitations of radiometrics in the prediction of peat depth.

Again, we thank the referee for a clear and comprehensive explanation of their concern.

We agree that the physical modelling of peat depth from radiometric data is an underdetermined problem, for the reasons that the referee states. However, our prediction of peat depth is not based on a physical model, but rather on a statistical model that learns the relationship between the predictors (radiometric and terrain variables) and the response variable (peat depth) from the data. A mechanistic relationship – in this case the physical attenuation of radiation through peat – is what leads us to expect a statistical relationship in the first place, but the model is otherwise agnostic to the nature and origin of that statistical relationship. That is also why we are able to treat Total Count data the same as the other radiometric variables, even though it can only indicate attenuation variability. Indeed, it is exactly attenuation variability across a site that we expect to be useful for predicting peat depth, and our methods allow the model to decide which of the radiometric variables are most useful and the functional form of the statistical relationship.

It is important to note here that the radiometric and terrain predictors are on equal footing – it is the strength of their statistical relationship with peat depth (including non-linear relationships and interactions with other predictors) that is compared in our analyses and title. Moreover, we assert that there is a clearer mechanistic explanation for a relationship between radiometric variables and peat depth than there is for terrain variables and peat depth. The referee outlines this physical basis for the radiometrics, whereas for terrain variables potential mechanisms are more tenuous, or at least less consistent. For example, terrain slope in peatlands may reflect the topography that underlies the peat layer (e.g. in blanket bogs) or the position along the microtope (e.g. the rand in raised bogs) – neither of which is necessarily strongly related to the thickness of the peat layer. The fact that radiometric measurements integrate across some part of the soil profile is a reason to expect, *a priori*, that these variables might predict peat depth better than measurements that technically only reflect the land surface, like LiDAR and the terrain models derived from it (see for example section 7.2 in Minasny et al. 2019; Reinhardt and Herrmann 2019; Beamish and White 2024). We do not think it is correct, therefore, to conclude that there was a bias towards terrain variables in our analysis, or that the results are a perfectly expected outcome.

The referee's comment does expand the list of possible explanations for the poor performance of radiometric variables in our models, and we have added to our discussion based on the comment, as suggested.

Comment 1.7

> The main focus of this article is on the prediction of peat depth. However, the authors include several sections of the possibility of peatland extent mapping. This is not mentioned at all in the abstract, or the introduction in great detail. As this article is already quite long and complex, I suggest the removal of any sections and text related to mapping peat land extent as it is not the focus of the article and only acts to add unnecessary complexity to an already very technical methodology. The authors even mention in Line 535 that their aim was not to map extent. I suggest the removal of all reference to peatland extent prediction and instead focus on the prediction of peat depth. A much shorter reference to the importance of peatland extent knowledge could perhaps be mentioned in the conclusions, but a full analysis and discussion (section 4.1.4) is not appropriate in this article.

Thank you for this helpful suggestion. We initially thought it would be worth including the analysis on extent mapping – especially since our occurrence data at Skrimfjella is a good test set – but based on the comments of both referees, we recognize that it distracts too much from the main focus. We have removed all sections related to mapping peatland extent (including section 4.1.4), to shorten the manuscript and improve its readability. We still discuss briefly the importance of coupling peat depth and extent mapping, since we consider this a research need directly related to the present study, but we have shortened this section as well.

Technical Corrections

> Line 58- 59. There is no need to include this sentence with an example here, as the next paragraph goes into the necessary detail on Slope. This is an example of how the authors might reduce the overall size of the article.

Thank you. We have removed this sentence and looked to remove similar cases.

> Section 2.2 I would suggest moving this opening paragraph to the end of this section as it acts more to sum up how the authors are using the various predictors. It mentions several of the predictors directly, but the are not described until later sections (for example 2.2.1). This would increase the readability of this section.

Thank you for this suggestion. This opening paragraph is intended to give a brief overview of the full suite of predictors before going into a complete description of how each predictor was derived. We think therefore that it is best placed at the start of the section, but we have tried to improve its readability within the structure (including the mentions of specific predictors).

> Line 179: Remove “also using White Box” as this is obvious.

Thank you.

> Line 258: The authors mention density; however, they do not expand on this. Was this measured in the field, or an operator’s observation and subjective interpretation of density?

Thank you. We have clarified that this was the operator’s observation and subjective interpretation.

> 371: What is the relevance of the Persons correlation coefficient of 0.7. Was this tested at all? Readers may not be familiar with this so it should be explained a bit more.

Thank you. We have added some more context to explain the 0.7-cutoff.

> Table 2: I recommend putting a vertical line between the results for both sites so as to easier distinguish between them.

Thank you. We have reexamined the formatting of the table.

> Heading Section 4.1.1 – “but not useless!” is very casual language to be using in a scientific article. This is just one example of this casual language. I suggest the authors review the article for this throughout.

Thank you for this example. We have gone through the manuscript and revised the language to make it more formal and scientific, while aiming to retain clarity and accessibility. We have removed this phrase and similar casual language throughout the manuscript.

> Line 464: “low hanging fruit” is also casual and colloquial and may not be understood by all cultures.

Thank you. Removed.

> Line 515: “large stocks really are large” – very vague and non-scientific comment. What is large?

Thank you. Clarified.

Thank you. Clarified.

> Line 530: remove the question at the start of this section.

Thank you. Removed.

> Line 549: This section is the first mention of the radiometric survey parameters. I would recommend moving some of this section to the Methods and Material section as it is useful descriptors of how the data came to be.

Thank you. We have added a very brief summary of the radiometric surveys to the *Materials and methods* section, while retaining the reference to an appendix for the full details.

> Line 564: Typically, airborne radiometric surveys have strict conditions that they must fly under. One is related to rainfall occurrence and airborne surveys should not happen directly after rainfall. The authors statement with regards to air moisture should be clarified as otherwise the contractor may have been at fault by provide incorrect data, which would have implications for the usage of radiometric data in this area in this study.

Thank you. We have clarified our statement based on the information in the report by the Geological Survey of Norway.

> Line 628 – 629: remove the sentence starting "The rest of this section...." As it is unnecessary.

Thank you. Removed.

> Line 634: "luxury" is again a very casual phrasing within a scientific article.

Revised.

> Line 664: "tricky" – casual

Revised.

> Finally, there is no definite conclusion to this article, nor a heading stating same. I suggest the authors either add a section at the end and move some text here to highlight the main conclusions as currently the "discussion" section is quite large and probably not appropriate to act as a combined discussion and conclusion section.

Thank you for this helpful recommendation. We have added a *Conclusions* section to summarize the key findings of the study. This summary highlights the main results and their implications, which we hope will help readers more easily see how the study addresses its research aims of quantifying predictive accuracy and identifying key predictors.

We have also used this addition to reduce the length of the *Discussion* section, by reserving some of the more general discussion points for the *Conclusions*.

References

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