This review is conducted as a joint effort within the EGU peer review mentoring program under the mentorship of the TC editor Hanna Lee. The review provided below is a collective summary from myself as well as the trainees of the program.

This study describes FreeThawXice1D, a one-dimensional permafrost heat-transfer model designed to simulate excess ice melting and subsequent ground subsidence over centuries to millennia while conserving energy and remaining numerically stable with large time steps. The authors focus specifically on improving spin-up to achieve thermal equilibrium, adaptive mesh refinement, flexible boundary condition that approximates snow and surface heat exchange without full energy-balance forcing by setting up idealized test cases. The study is primarily a numerical methods and model-capability demonstration rather than representing real-world permafrost thaw processes, highlighting how accurate spin-up and dynamic regridding are crucial for representing deep ice-rich permafrost thaw.

The manuscript presents an innovative and technically strong open-source release 1-D permafrost model (FreeThawXice1D) with energy conservation, adaptive meshing, and efficient spin-up. While the manuscript focuses on technical details of the numerical methods, it fails to clearly describe the novelty of this study and the scientific purpose of the model development. At this time, the manuscript reads more like a technical description of a model and not a scientific paper enough to attract broader audience interested in permafrost processes and modeling. A stronger contextualization of the main purpose, validation or comparison, better figures and structure, and an explicit limitations section is warranted to guide users on when the model is (and isn't) applicable.

Below are some of the main concerns that need to be addressed.

The spin-up case is highly idealized using one type of soil and large amounts of excess ice. It is not clear how realistic this case set up is. To demonstrate and increase generality, the authors should conduct at least one or two contrasting soil setups, e.g.

- coarse sand/gravel with low heat capacity and low excess ice
- peat or organic-rich soil with high heat capacity and high unfrozen water content
- a moderate ice-content silt (30–50 %)
- comparison of existing data or literature may also be necessary to demonstrate whether the model results are reasonable or not
- sensitivity test

This could be small additional runs enough to show that the model is robust beyond one synthetic silt column with large amounts of excess ice.

Apart from not representing various realistic cases of soil columns, the model has several limitations. It is difficult to understand what the application of this model could

be as the study does not show climatic responses of permafrost. In addition, hydrological process representation is missing in this 1D model, thus it is unclear what the fate of water after excess ice melting will affect additional heat balance change associated with excess ice melting, which could be a large energy transfer mechanisms in permafrost soils. This may be beyond the scope of this study; however, such large limitations are largely ignored in the discussion section. The authors claim 'FreeThawXice1D is a practical tool and stepping stone in further research.' But I struggle to understand the practicality of this model that the future users outside of this model developer group can use this model for. I suggest including model limitations and future work paragraph in discussion section. Also, the authors can provide some examples of how this model can be used either in introduction or discussion section.

The current version of the manuscript is quite figure heavy and the figures are not necessarily very clear in their purpose, therefore, they appear quite redundant. Additionally, the figures are not very aesthetically presented (e.g. captions don't fully explain what's shown, missing or inconsistent panel labels, confusing units (mm vs m), and hard-to-read colors). In my opinion, the main paper could cut down the number of figures from 14 to 7-8 with concise composite figures with clear purpose. For instance, figures 7 & 8 may be merged, figures 10 & 11 could be combined as split panels in one figure, and figures 12 & 13 can be more simplified and be more explicit. I suggest the authors to thoroughly check the captions and legends during the revision and increase reader friendliness of the figures.

Below are line by line comments.

Line 50: While it is acknowledged that existing models have limitations, a more detailed exploration of these shortcomings is crucial for underscoring the relevance of this study. Merely stating that limitations exist does not adequately convey the need for developing a new model. Please provide a better contextual background on what is specifically lacking in the existing models and why the new model developed is needed.

Line59: Can you be more specific about in what context this is more desirable?

Line64: It is mentioned in the introduction that the work builds on previous work by Tubini et al. 2021, but there is no mention of that it is an extension of the FreeThaw1D model until line 370. Only then it is suggested that the model already existed, and only new features were added. It is unclear in the introduction of the six aspects are mentioned are new specifically to this model, were already part of the previous model. To enhance clarity, it is recommended that the introduction be revised to explicitly state that this work is an extension of the FreeThaw1D model, rather than a wholly novel development; with clear descriptions of which aspects already existed and what is the novelty in this specific model. This could be further expanded within the methodology where currently the full model is described as new / implementing other methods for

the different aspects. At this time, the purpose of the model development or extension is not clear. Please describe the general model framework and the purposes of this model use.

Section 2.5 Excess ice: It appears that excess ice only melts in this model as well. So why simulating thousands of years is important and necessary when it will only melt?

Section 2.7 Regridding: I am very confused why regridding is necessary in a 1D model. Could you elaborate?

Section 3.1: It is very difficult to understand what experiments have been conducted for what purpose. Is it simply to compare the regridding effects? If so, regridding effects on what aspects of the model representing permafrost thaw processes? Please add more description to help the readers.

Line298: How likely is this scenario? Can you reference a dataset or a study showing how plausible this scenario is?