We would like to thank Edward Bair for his efforts to read our manuscript and provide constructive feedback that will undoubtedly improve this paper. We have reviewed the feedback carefully and offer our responses below.

Our comments are listed in red text and are numbered 1-16.

ATES Paper Peer Review – Edward Bair – 06 July 2024

The Avalanche Terrain Exposure Scale (ATES) v2 is an update to a 20-year-old system introduced in Canada as a risk management tool for backcountry travel. This new version of ATES offers improvements that combine developments over the past two decades into a single model.

After reading the manuscript along with the original ATES model article (Statham et al., 2006) and subsequent developments (e.g., Campbell and Gould, 2013), I've gained an appreciation for the deep refinement of ATES. However, I'm unclear about why, with version 2.1, there is a need for a peer-reviewed publication, when there was not for the original ATES nor its interim conference papers. Likewise, I have concerns about the re-use of previously published material. As outlined in the review criteria, publication in NHESS requires new work that is scientifically significant, like the original ATES. ATES v2.0 has some new features, but appears as an incremental improvements on two decades of work. A figure or table summarizing the evolution of ATES since its inception would be helpful. The requirement for a substantial new advance is why there are often not peer-reviewed manuscripts for new versions of a model. There are examples (e.g., Sturm et al., 1995; Sturm and Liston, 2021; Dozier, 2022; Dozier et al., 1981), but the authors must convince the reviewers that the changes are substantial enough to change the understanding of the topic. Conversely, given that the previous ATES work has been published mostly in conference proceedings, there are issues with preservation. For example, the "permalinks" for ISSW Proceedings are not an authoritative archival method, whereas the Digital Object Identifier that is produced for this discussion article is. The authors should consider stating their motivation for a peer-reviewed article directly in the manuscript.

1. The reviewer is correct that ATES v1/04 and the ATES Zoning Model have both been published in ISSW conference proceedings in 2006 and 2013 respectively. As described in this manuscript, the ATES system has been widely adopted over the past 20 years (e.g.: Canada, United States, New Zealand, Norway, Sweden, Switzerland, Austria). Thus, a significant gap now exists in the literature when a risk management system that has been so widely adopted, has no peer-reviewed article as its baseline reference. Our objective is to fill this gap by publishing a modern, peer-reviewed baseline reference for ATES which corresponds with our revision to ATES v.2.

We are aligned with the objectives of this NHESS Special Issue, as our goal is to expand on our ATES v.2 ISSW paper (Statham and Campbell, 2023). By design, this means republishing and expanding on material that is in the ISSW conference proceedings. We quote from the NHESS website *"We invite all ISSW presenters interested in a peer-reviewed scientific publication to* *submit manuscripts that explain their research in more detail than in the conference proceedings. To be considered, these papers need to be scientifically more rigorous, which means that they contain expanded technical information, additional details on methods, and a more complete description of results and conclusions."*

ATES v.2 is a significant update to the model. It merges the previous two ATES models (Statham et al., 2006; Campbell and Gould, 2013) into a single ATES v.2, resolving conflicts that existed between them. It presents two important new terrain classification levels (Class 0 and 4), it introduces ATES for waterfall ice climbing (Table 2) which is new, and it removes the glaciation criteria, which was a defect in the original model.

The manuscript itself provides new, detailed explanations on each of the eight Technical Model (Table 3) criteria and defines commonly used terminology (Table 4, slope angle terminology) and field-based assessment techniques (Table 7, avalanche frequency) and introduces them into the literature. This will provide a baseline for future reference and developments. Figures 1, 2, 3, 4, 5, 6, 7, 8 and 10 are all original, previously unpublished figures.

Section 5, Application of ATES is all new information that has been expanded from Statham and Campbell (2023). None of the previously published conference papers (2006, 2013) contain any description of how to apply the ATES method. This manuscript introduces ATES feature types (Table 10) and gives graphic examples of mapping methods (Figure 10).

We submit that Figures 9, 11 and 12 are used (with permission) from other publications, but because this article will serve a baseline reference for the ATES method, we would be remiss not to describe important developments by other authors that are available today (Figure 9, colour choice and Figures 11 and 12, AutoATES).

We agree with the reviewer that the "permalinks" for ISSW Proceedings are not an authoritative archival method, whereas the Digital Object Identifier that is produced for this discussion article is. Our objective is to correct this gap for the ATES system and create a more robust reference.

The article contains reprinted material, sometimes verbatim. As cited, Tables 4-6 are from Campbell and Gould (2013) and Figure 12 appears verbatim in Sykes et al. (2024, Figure 10) as well as in parts of Toft et al. (2024, Figure 4). In fact, most of the figures and tables (Figure 9, Figure 11, Table 8, Table 10, Table 11) are from previous publications. At the least, these reproductions beg the question: what's new here?

2. Table 4 links commonly used slope angle terminology with slope angle values and is not from Campbell and Gould (2013). The use of slope angle terminology such as "low angle" (Table 4) is ubiquitous across the avalanche forecasting and backcountry travel sector. ATES v.2 defines the meaning of this language by linking the terminology with slope angle values.

Tables 5 and 6 are adapted from Campbell and Gould (2013) and form an essential baseline for ATES mapping parameters, they cannot be left out. Table 5 was previously published as a footnote, and Table 6 has been adapted to include Class 4 terrain.

Figure 12 is verbatim from Sykes et al. (2024) but note that Statham is a co-author on this publication and both Statham and Campbell undertook the validation study that this paper (and Figure 12) describes. There have been three ATES publications through NHESS in 2024: Sykes et al. (2024), Toft et al. (2024) and this manuscript. While we have tried to eliminate overlap, some overlap is inevitable and necessary to holistically describe the work that has been done.

Figure 9 is used with permission and illustrates a unique colour choice and mapping approach done in Austria. Colour choice for ATES remains an area for future research, and this figure is a good example that was published in the ISSW 2023 proceedings. We will improve the captioning on this figure to explain the need for future research into ATES colours.

Figure 11 has not been previously published. This is an image of new autoATES mapping done by Alberta Parks and is on their website. This is the first public online publication of an AutoATES map in Canada and is published on the Alberta Parks website.

Table 8 is taken directly from CAA (2016) and is the baseline reference for avalanche size in Canada. This table has been unchanged for decades and is an essential reference point when describing avalanche magnitude.

Table 10 is all new and has only been published in Statham and Campbell (2023), which is the ISSW paper that this manuscript is expanding on for the special edition.

Table 11 is previously published in Statham et al., 2018 where it was developed for application to avalanche hazard assessments. The same scale breakdown has direct application to terrain assessments and thus the table is republished here as part of the Application section, which is new information.

Given that ATES is likely to be applied to remote areas, the AutoATES v2 open-source code is a significant new contribution. It is discussed in Section 5.2.1 and should have been included in a "Code availability" section (https://www.natural-hazards-and-earth-system-sciences.net/submission.html#manuscriptcomposition). Yet there is already a publication for AutoATES v2.0 (Toft et al., 2024). Thus, this section too contains previously published information.

3. We agree that the AutoATES v.2 open-source code is a significant new contribution, and we will improve our manuscript to a better direct the reader to the "code availability" found in Toft et al. (2024). However, our manuscript is not about AutoATES, although it is referenced, thus we have not developed any code to make available.

Not present, although maybe present in previous ATES literature which could have been cited, is a discussion of the limitations of the static hazard model. If there is no snow, there is no snow avalanche hazard, regardless of terrain. Given that the majority of backcountry use (i.e., hiking) comes in the summertime, that is a significant limitation. Further, as someone who has spent considerable effort mapping snow from satellites, I find the omission of the changing snowcover to be a major model shortcoming. A static map is certainly easier to produce, but the authors could at least discuss how a dynamically modeled or remotely-sensed snowcover could be incorporated into the ATES model.

4. We agree that this manuscript should improve its description of static versus dynamic hazard models. We will expand on this following Line 29 where the concept of the static model is introduced, and we will describe two key references regarding static and dynamic hazard maps (Harvey et al., 2018, Schmudlach and Köhler, 2016).

We will also use the Introduction to better describe the avalanche risk framework that ATES fits within (Statham, 2008; Statham et al., 2018), which will include descriptions of the dynamic nature of avalanche hazard and its interaction with exposure and vulnerability to create risk. Reviewer #3 has suggested this, and we believe we can address this reviewer's concerns here too.

Static terrain maps are a foundation of dynamic hazard maps; an underlying DEM or even ATES map is necessary to combine with a dynamically modelled or remotely sensed snowpack to develop dynamic avalanche hazard maps. The whole point of ATES is to provide a static terrain exposure model with ordinal categories that can be easily interpreted for public recreation and workplace avalanche safety (Tables 1 and 2). ATES can integrate with dynamic avalanche hazard/danger models to give a kind of risk rating to assist with basic decision making. The Avaluator (Haegeli et al., 2006) was the first decision framework to integrate the changing snowcover with ATES ratings (rather than simply slope angle).

Schmudlach and Köhler (2016) integrated Swiss avalanche bulletins with static terrain maps to create dynamic avalanche hazard maps on their popular website https://www.skitourenguru.ch, first for Switzerland and now including most of central Europe. The Swiss terrain hazard maps developed by Harvey et al., (2018) are another example of static terrain maps that provides crucial input to dynamic avalanche hazard models.

We agree with the reviewer that dynamic avalanche hazard maps are important, and likely the future as snowpack models continue to develop, but they are based upon using static terrain data, and that is the role of ATES.

In short, I commend the authors efforts with ATES v2, however this manuscript requires considerable revision to justify how it is a new contribution. Currently, it appears to be a summary of previously published work rather than an original research article. I'm stopping short of rejecting the manuscript and suggesting it be resubmitted as a review article, but the authors should consider that route.

NB 6/5/24

Minor:

Abstract

What's new here? Consider adding l 530-536 and maybe l 37 – 40 to the Abstract

5. We will consider adding this to the abstract.

Introduction: Element-at-risk sounds like agency jargon. Define.

6. "Element-at-risk" is not agency jargon, but a term defined in Jamieson (2018) and widely used in natural hazards risk assessment (e.g.: Papathoma-Köhle et al., 2007; Sterlacchini et al., 2014). Assets-at-risk is a synonym. We will modify Line 21 to read "…where the elements-at-risk such as skiers, climbers, snowmobilers or workers and exposed to avalanche hazard, but mobile and free to travel unrestricted through the landscape".

2 Background

I'm still unclear why impact-based hazard mapping can't be used for backcountry recreation. Impact-based models can generate runouts without historical observations. Perhaps it's because impact-based models rely on low probability events, i.e., 10-300 year return periods?

7. We will change our explanation of this in the Background section, as the RAAMS model has been used in Switzerland to develop the Swiss terrain hazard maps (Harvey et al., 2018). Based on this, clearly an impact-based method <u>can</u> and has been used for backcountry recreation. But most of the time, impact-based methods are impractical for operations looking to incorporate ATES ratings. In lieu of running RAAMS on a landscape scale, which most operations cannot do, exposure-based methods are easier to implement and take advantage of localized terrain exposure knowledge.

L 71 Correct ATES Zoning model to ATES Zoning Model

8. Yes we will correct.

Section 3.1 This class 0 issue highlights the shortcomings of a model that doesn't use current conditions. No snow means no avalanche hazard, regardless of terrain. This limitation should be discussed.

9. Agreed, no snow means no avalanche hazard regardless of terrain. This same issue exists for dry snow climates, where there is often little or no snow but still an occasional snowpack and steep mountains (i.e.: leeward side of mountain ranges). To handle this, ATES relies strongly on the assessment of avalanche frequency (Section 4.2.5, Table 7).

Here are two examples:

1. A dry area that never receives a snowpack will have an avalanche frequency of *Never*, which defaults the ATES rating to Class 0. Compare this to a large, flat area with a deep snowpack climate where there is an avalanche frequency of *Never*, it will also be Class 0. Both of these locations will never see snow avalanches, thus they are Class 0.

2. An area of steep, complicated mountain terrain that is dry all summer may not have any summer avalanche hazard, but due to its snow climate may still have an avalanche frequency of 1:1 (events:years) because of the winter season, which will default the ATES rating to Class 3.

Class 0 is not a limitation; Class 0 is a feature of the ATES method and establishing it within ATES v.2 and in this manuscript is crucial. This factor was the primary motivation for updating the ATES system. It is fundamentally important (and difficult) to be able show where avalanches do not occur, and the fact that ATES v.1/04 did not have Class 0 was a significant limitation.

We see several areas where we can improve our manuscript to better explain this.

- We will modify the Background section to explain the limitation of not having Class 0 terrain in the original ATES, and the resulting conflict with ATES Zoning Model with does use Class 0.
- We will improve our description of avalanche frequency (Section 4.2.5) to ensure the interaction between snowpack and terrain are captured within ATES.
- We will improve our description on Line 160-161 of the ATES defaults around avalanche frequency to better show how much weight this carries.

Table 3 : 1:1 years? Please provide units. 10:1

10. Yes we will add units back in (we had them previously).

Section 4

The inputs to these tables are likely not available in many parts of the world, e.g., route options seems to require pre-mapped routes or trails. This could use some further explanation.

11. We will expand on Section 5.2 - Assessment methods (lines 427-453) to include a better explanation of how to these input tables can be assessed based upon data availability.

The inputs to these tables can be collected using various methods, both qualitative and quantitative. Certainly, some of the quantitative inputs (i.e.: DEM, forest cover) may not be available in many parts of the world and will require a generalized assessment, resulting in larger scale ratings. Other inputs (i.e.: frequency/magnitude) will mostly be subjective as avalanche frequency based on historical records or impact-based hazard mapping is not yet available on a landscape scale. Route Options and Exposure both require a location on the ground in order to assess, and this requires pre-mapped, or previously travelled routes or trails. Local knowledge of trails, backcountry routes or climbs is an essential input in lieu of pre-mapped routes. The system is intended to be used by field practitioners as well as desktop GIS specialists, ideally a team of both.

So, while all of these inputs would benefit from data that may not be available, the ATES system is designed to be subjective and allow field practitioners to undertake assessments based on their observations and experience in the terrain, in lieu of hard data. Subjectivity is addressed on Lines 26 and 160, but we will improve this explanation in Section 5.2.

Table 4-6 are reprints of Campbell and Gould (2013). What's new here?

12. Addressed earlier in response #2.

214 –Unsupported slope needs clarification? With respect to what axis? Even a serac is supported in the slope normal direction.

13. The term "unsupported slope" is widely used by field practitioners to describe a slope on the vertical axis that rolls over suddenly and steeply at the top and offers minimal toe support at the base of the slope (i.e.: convex shape). In the mechanized ski industry, helicopter ski runs that are the least frequently open for skiing (i.e.: most hazardous) are characterized as having more unavoidable unsupported terrain shapes (Sterchi and Haegeli, 2019). Unsupported slopes are well described in Landrø et al., (2020). This contrasts with "supported slopes" that have a concave shape in the vertical axis, resulting a gradual transition to lower angle terrain and the perception of more toe support.

214 – "possible source". It's not a possible source. It is a source of tensile stress.

14. Agreed, we will change this.

Table 10 – representing an area with a point is an oxymoron

15. Representing an area on a map using a point is necessary at larger scales. Google Maps is the most obvious example of this, where areas, features, locations, etc. are displayed using a pin (point) on the map. As the map scale become smaller and more detailed, often these points will expand to show more detail. But at the larger scales, a point on the map is how you show an area.

5.1 Spatial scale

General comment, not the authors fault. The ISSW proceedings are not resolving on my browser without manually typing in. These proceedings need DOIs, not "persistent links" which don't resolve well and do not have changeable underlying links. What happens when we are no longer using PHP, or arc.lib.montana.edu is no longer the base URL? Retrievability, especially for older works, is a major problem with grey lit citations. See my comments on preservation.

16. Agreed. This is one of the reasons we want to publish this manuscript and create a more robust, modern reference with a DOI for the ATES system.

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