Response to comments on “Global mapping of lake-terminating glaciers” (essd-2025-315)

Reviewer 3

This study presents a global inventory of lake-terminating glaciers based on the RGI 7.0 glacier inventory and published datasets of glacial lakes. The key approach involves determining the relationship between glaciers and glacial lakes (direct contact or not) in different cases, considering the ambiguity in the published datasets, which map glaciers/lakes based on images with varying time stamps that may differ by several years or over a decade. The authors adopted a manual interpretation strategy, with clear guidance on different categories of glacier-lake relationships, each implying a different level of confidence on the impact of lake water on glacier dynamics. The manuscript is well-written and logically clear, except for a few instances of inappropriate naming (e.g., lake-level) and ambiguous implementation of different classifications. I believe that this dataset with consistent quality control benefits future investigation and modelling of glacier dynamics (velocity changes, mass balance) in response to climate warming.

Thank you for the in-depth review, we respond to all concerns with the proposed changes individually below. Please note that following suggested changes from other reviewers, some of the basic terminology and ordering of ‘categories’ (previously ‘levels’) have now changed.

Major comments

My main concern lies in the ambiguous definition of lake-terminating glaciers and how the current classification represents in the temporal span. If the lake-terminating glaciers refer to glacier terminuses that are in direct contact with glacial lake water, then the manual inspection is to rule out glaciers with supraglacial lakes and glacial lakes surrounding glaciers in the lateral zones. However, Figure 2d (lake-level 2) appears to include glaciers that are not directly in contact with the glacier terminus. It seems that lake-level 3 are not regarded as lake-terminating glaciers in the results and analysis (Line 135-137). In addition, it is also interesting to see how the data products of this study differ from a simple classification method, e.g., flagging lake-terminating glaciers by simply overlapping the buffering of glacier outlines with lake outlines. Such a comparison can help understand how the expert inspections implemented in this study improve the classifications.

The concerns regarding the introduction of some sort of ambiguity is understandable and we agree that allowing ‘expert judgement’ to make the call introduces some grey zone where definitions are not as clear cut as they would be in an automated approach. To be clear, the automated approach was originally favoured, but evaluating the available data (lake inventories, consistency across regions) as well as the difficulty in making automated judgements (What to do about a lake that is visibly in contact with ice but with an outline that does not intersect with the glacier outline, both of which in turn are at times not precise? When is a lake at the terminus and when is it just located along the glacier margin?) led us to converge on the more manual approach. To underline the difficulty, we show below a comparison between the approach taken in the study, vs a much more traceable automated approach, namely identifying all glaciers from the RGI as lake-terminating that intersect with a lake from three global inventories (Shugar et al. 2020; Zhang et al. 2024; Song et al. 2025, Table 1, Figure 1, Figure 2). The results highlight a number of issues:

a) As we show in the manuscript, the differences in lake number and area between the global inventories is large (Table 1, Figure 2), begging the question, which one to rely on as adequate.
b) In many regions the numbers of lake-terminating glaciers identified by the automated approach comes closer to the numbers we find in our study, when we move from a very crude ‘intersect glacier with all lakes’ approach to the more refined ‘within buffer around terminus and 100 m away from glacier outline’ approach, but this is not always the case and it rarely brings the number to a match (Table 1, Figure 2 and 3).
c) The simple intersection between lake and glacier does provide numbers of in similar orders of magnitude in some regions but not others (Figure 3, Table 1) but can not tell us whether the lake is at the terminus.
d) While applying a buffer is easily done, adding 100 m around glacier termini increases the number of glaciers intersecting with lakes considerably in most regions (Table 1) but there is no way of telling whether 100 m is adequate at a global scale. We can show that when the buffer is increased, we find a much larger agreement rate (Figure 1), but also false positives increase rapidly (Figure 4), which then puts us back in the situation of having to evaluate manually.
e) The difference between automatically and manually flagged glaciers is always large, and not consistent. While we do not want to argue that the lake inventories are inadequate - indeed we use them as an aid - the large differences across all regions (mapped by different contributors) suggests that an automated approach alone does not adequately address the issue.
f) The approaches also disagree on many glaciers, with many automated lake termini not being recognized as such by our approach and vice versa (see Table 1) for certain regions, while in others it could work, but the issue of false positives remains.
g) The automated approach would not allow us to differentiate between different categories as we are able to do with an expert informed approach.

As we note in the manuscript, we do not want to suggest that the expert judgement based approach is perfect, but we argue that with the current datasets and methods available, it seems prudent to provide a baseline dataset based on this expert judgement. Future improvements in data analysis, may further move the classification towards a more reproducible automated method.

We now suggest to include a more detailed argument for this decision in the Methods section, and provide a number of figures that outline the potential alternative approach with global and regional inventories as an Appendix.

Table 1: Number of glaciers identified as lake-terminating by the approach followed in this study (*This study*, including all categories 2 and 3), an automated approach intersecting the inventory by Shugar et al. (2020) (time period 2000 +4 therein) with all glaciers in the RGI7 (*Shugar2020*), an approach where we place a buffer of 100 m around the glacier before intersecting (*Shugar2020**), and a version where we only do this within a radius of 1 km around the terminus position, according to RGI7 (Shugar2020**). This last column corresponds to the approach taken for the following figures, where then different buffer sizes

are tested. In brackets are true positives in comparison to the approach taken in this study. The same data are shown in comparison to the data from Zhang et al. (2024) and Song et al. (2025). Note that the datasets of Shugar2020 and Song2025 have no data in regions 7 and 19.

RGI Region	*This study*	*Shugar 2020*	Shugar 2020*	Shugar 2020**	Zhang 2024	Zhang 2024*	Zhang 2024**	Song2025	Song2025*	Song2025**
1	187	209 (82)	193 (95)	180 (89)	332 (55)	387 (64)	362 (52)	935 (176)	998 (175)	985 (175)
2	352	127 (67)	233 (104)	232 (104)	408 (105)	742 (149)	733 (148)	1060 (307)	1381 (334)	1361 (332)
3	184	138 (26)	26 (17)	23 (14)	634 (136)	242 (92)	221 (85)	324 (79)	114 (45)	106 (42)
4	184	346 (100)	342 (95)	323 (92)	424 (88)	539 (111)	498 (102)	1120 (167)	1201 (150)	1147 (144)
5	294	376 (111)	414 (115)	400 (112)	913 (169)	886 (174)	824 (159)	936 (184)	945 (180)	894 (173)
6	14	23 (8)	13 (7)	10 (6)	25 (10)	17 (11)	17 (11)	90 (14)	58 (14)	57 (14)
7	60	0	0	0	75 (18)	47 (18)	44 (17)	0	0	0
8	227	131 (57)	208 (73)	204 (72)	98 (72)	201 (111)	197 (110)	395 (190)	492 (199)	481 (198)
9	32	132 (20)	90 (21)	83 (21)	100 (12)	56 (19)	44 (14)	115 (23)	63 (25)	59 (25)
10	69	25 (9)	31 (10)	31 (10)	62 (21)	121 (41)	121 (41)	232 (53)	295 (59)	294 (59)
11	66	8 (5)	13 (7)	13 (7)	7 (4)	21 (9)	21 (9)	87 (42)	113 (48)	112 (47)
12	11	5 (2)	5 (3)	5 (3)	2 (1)	13 (4)	13 (4)	60 (9)	74 (10)	74 (10)
13	715	194 (108)	256 (143)	255 (143)	307 (135)	856 (338)	851 (335)	1575 (433)	2092 (529)	2079 (527)
14	337	52 (33)	76 (62)	76 (62)	159 (69)	382 (193)	376 (193)	574 (230)	767 (283)	763 (283)
15	420	180 (140)	299 (191)	296 (191)	219 (112)	555 (252)	546 (251)	788 (294)	1068 (360)	1048 (358)

16	72	43 (24)	57 (28)	55 (28)	29 (13)	95 (28)	94 (28)	237 (54)	302 (64)	297 (64)
17	575	143 (105)	212 (135)	209 (132)	433 (196)	780 (280)	770 (273)	884 (402)	1272 (450)	1261 (447)
18	15	13 (9)	15 (9)	15 (9)	7 (3)	10 (5)	9 (4)	360 (13)	48 (12)	48 (12)
19	22	0	0	0	26	30 (15)	28 (13)	0	0	0

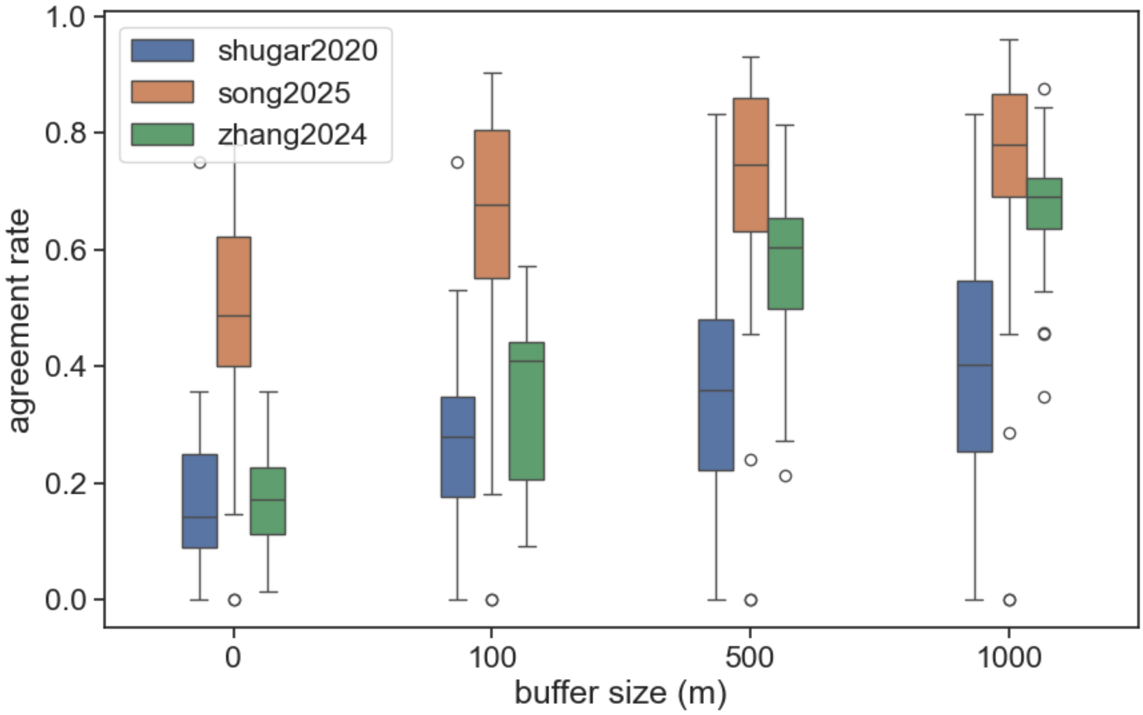

Figure 1: Agreement rate between the manual mapping done in this study, against an automated approach using three different global lake inventories. For each RGI glacier, we intersected a buffer of 0, 100, 500, and 1000 m around the terminus coordinates with the lake inventories. The agreement rate is the number of glaciers where both the automated approach and the manual approach agreed, divided by the number of lake-terminating glaciers mapped manually. However this also leads to more false positives (See Figure 3).

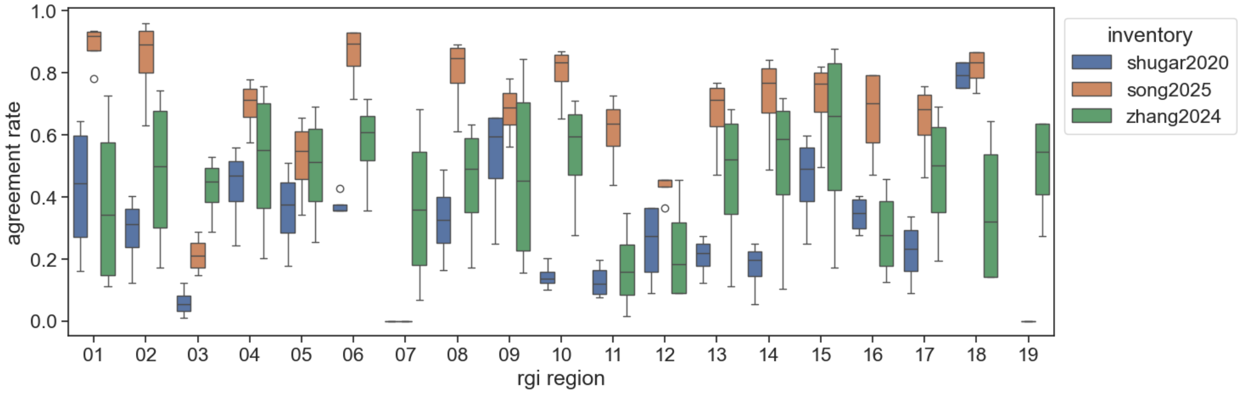

Figure 2: Agreement rate between the manual mapping done in this study, against an automated approach using three different global lake inventories. For each RGI glacier, only for the 0 km buffer. The agreement rate is the number of glaciers where both the automated approach and the manual approach agreed, divided by the number of lake-terminating glaciers mapped manually. However this also leads to more false positives (See Figure 3).

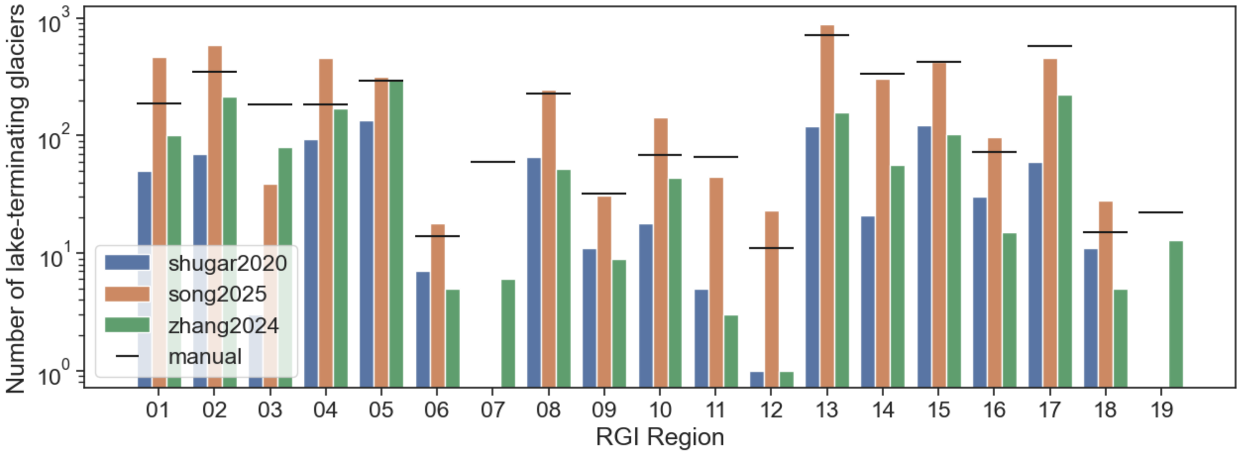

Figure 3: Number of lake-terminating glaciers identified using a buffer of 0 km (i.e., lakes intersect terminus). Black lines show what was manually identified in each region.

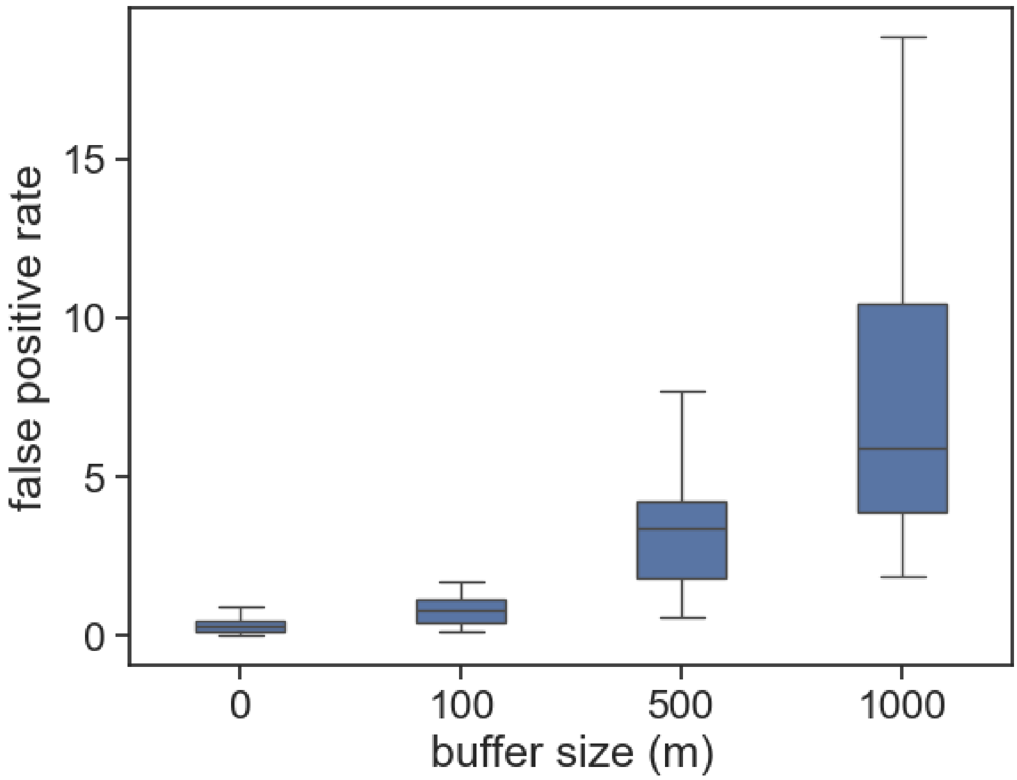

Figure 4: False positive rate for regional inventories, grouped by buffer size in meters. False positive rate is defined as the number of glaciers that were flagged as lake-terminating by the automated approach that were not flagged by the manual approach, divided by the number of glaciers flagged by the manual approach.

A second concern is about the stability of the current classification of lake-terminating glaciers, given the dynamics of glaciers and glacial lakes, particularly in certain regions such as High Mountain Asia, which show high increases in the number and area of glacial lakes in recent decades (Shugar et al., 2020; Zhang et al., 2024). I understand the alignment of the reference year 2000 for consistency; however, the 'imperfect' nature of current glacier and lake mapping, e.g., time consistency and resolution, may imply that such a classification needs to be representative over a time span, e.g., 1999-2005. This is also necessary for future studies to examine the different behaviors of lake-terminating glaciers over a relatively long time span (otherwise, we would need to determine the glacier type case by case, e.g., when the glacier becomes connected with lake water and when it detaches from lakes). From this perspective, I support the inclusion of some cases (e.g., Figure 3a) as lake-terminating glaciers, or by referencing lake outlines/images from nearby years. At least, the authors need to discuss the potential applications and the cautions need to be paid with the current classifications.

We agree that the dataset needs to be used with care, and the link to the time period around 2000 is important. We have discussed this with the analysis around Figure 8. We now additionally emphasize this in the second to last paragraph of the Conclusions as well.

Specific comments

I have very few additional specific comments, as the manuscript is well-written, and some details have been pointed out in other comments.

Title: A title such as "A global inventory of lake-terminating glaciers" may be more appropriate as the work is essentially a classification of glacier types based on existing mapping results.

We would prefer to stick to the current title as 'a global inventory of [...] glaciers' would suggest we are providing a new inventory here, while we are actually working with an existing one (RGI7).

Line 132-133：marine-terminating glaciers are given a term_type value of 1 or 3? It is mentioned that they are assigned as type 0 in Lines 106-107.

The attribute **term_type** is from RGI7 and pertains to the type of terminus (not the specific category of lake termini). Glaciers that end in the ocean are assigned the category of 0 if they do not also end in a lake.

Line 262-264: This implies that we could rely on the current classifications for assessing the long-term glacier mass balance of lake-terminating glaciers and others. However, the direct contact of glacial lake water with the glacier terminus can change rapidly, given the strong glacier terminus retreat and expansion of glacial lakes, which have been widely reported in the mountainous glacierized regions in the past decades. A single reference year (e.g., 2000) of the classification does not seem to be sufficient.

In a potential modelling study the inventory should of course not be used as a static fact, but could be used as an initial known state. We have now clarified this with the addition of ‘as an initial state’.

References:

Shugar, D. H., Burr, A., Haritashya, U. K., Kargel, J. S., Watson, C. S., Kennedy, M. C., Bevington, A. R., Betts, R. A., Harrison, S., & Strattman, K. (2020). Rapid worldwide growth of glacial lakes since 1990. *Nature Climate Change*, *10*(10), 939–945. https://doi.org/10.1038/s41558-020-0855-4

Song, C., Fan, C., Ma, J. *et al.* A spatially constrained remote sensing-based inventory of glacial lakes worldwide. *Sci Data* **12**, 464 (2025). https://doi.org/10.1038/s41597-025-04809-z

Zhang, T., Wang, W. & An, B. Heterogeneous changes in global glacial lakes under coupled climate warming and glacier thinning. *Commun Earth Environ* **5**, 374 (2024). https://doi.org/10.1038/s43247-024-01544-y