

Reviewer 2

General comments:

1) The manuscript is well written and presents a sound classification schema of glaciers based on their sensitivity to environmental change. The methodology has solid support in the literature, and the consideration of this new classification is likely to be a valuable contribution to the management of glaciers, especially concerning their hydrological services.

2) The work is presented as a contribution towards the development of GPL, particularly as a solution to inadequate definitions in the Chilean GPL projects. In that sense, there is no clear articulation between the proposed classification and the GPLs. Both Chilean and Argentinean GPLs avoid conflict and ambiguities by protecting all glaciers equally, regardless of their type, size, location or debris cover. In that context, it is hard to understand how this classification schema can help the design of a law proposal of consensus and without the "legal issues" mentioned for the Argentinean GPL. If the authors propose a type-dependent level of protection (as stated in lines 224-225, 261), that should be clearly stated and followed with well-elaborated reasoning to support that proposal. Arguably, a type-dependent level of protection will only complicate things, especially given that the classification is sometimes ambiguous (lines 115-116) and changes with time (lines 159-164). In some sections, it even seems that the authors suggest a case-by-case assignation of the level of protection (lines 274-278). Much emphasis was put on the usefulness of the proposed classification for glacier management. However, the Argentinean GPL and Chilean GPL proposals aim to protect glaciers, not to manage them. If the authors are mainly suggesting a type-dependent monitoring program or the addition of this classification to national inventory fields (as stated in line 271), this should be clearly stated from the start. In such a case, they should also include a more detailed explanation of how this classification will help water resources management and a throughout motivation of the methodology. For example, why a classification is better than a "sensitivity index" or case-by-case modelling.

RESPONSE: We have modified the first paragraph in the introduction to highlight the usefulness of the classification scheme proposed with respect to legislation in general, including the GPL. We have also added a few sentences to the discussion starting on line 257 to highlight how incorporating the classification scheme in combination with water-scarcity could improve the GPL by making it possible to match the level of protection to the water resource need resulting in protection that would be region-specific, meet the needs of society without over- or under-protecting, and could evolve through time as the climate and water availability changes. We agree that introducing the proposed classification would likely complicate the proposed GPL and make it more difficult to pass this law. However, the currently proposed GPL is limited in its ability to effectively protect glaciers as a single classification for all glaciers makes it rigid in both space and time. We have also added a couple sentences to the first paragraph of the introduction to highlight the usefulness of the proposed classification for glacier management (EIA).

We are proposing a type-dependant level of protection. We have added a paragraph to the discussion starting on line 260 that addresses the level of protection. We think that the specific

decisions with regards to the level of protection for each region and assigned to each glacier category proposed are public policy decisions that require balancing many factors such as water resources and the economy and are beyond the capacity of authors of this paper to decide. However, we do provide some general recommendations.

In the discussion we have added a sentence to suggest that the classification scheme be added to the national inventory by glaciology professionals who created the national inventories (DGA in Chile, IANIGLA in Argentina). We have added information to the paragraph starting on line 227 of the discussion on the limitations of case-by-case modelling (lots of in situ data required) and advantages of applying the classification scheme (can be completed efficiently with data already available).

3) Following the facts detailed in lines 31-32, it seems inaccurate to refer to glaciers/landforms as sensitive/insensitive. The differences seem to be related only to the timescales of their response to environmental changes. Maybe fast/slow response might be better terminology.

RESPONSE: We agree that in the submitted version of the paper the differences are related only to timescales in their response to environmental changes. Our initial idea was a broader scope that also includes factors such as sensitivity to light-absorbing aerosols (e.g. black carbon). We have incorporated some text on black carbon into the manuscript introduction, section 3 and the discussion so that this is clear. Given that we have clarified the scope of “environmental changes” we have continued to use the terms “sensitive/insulated”.

4) The main proxy to assess glacier change is mass balance, which depends on accumulation and ablation. However, this works seems to focus entirely on the ablation part of the equation.

In avalanche-fed glaciers, which is often the case for categories 2 or 3 (semi-sensitive and insulated), there could be a high climatic sensitivity associated with the snow accumulation on surrounding slopes that are not even part of the glacier. While such glaciers would "melt away slowly" due to their debris cover, their mass gain mechanism might have a very high sensitivity to environmental changes. In these cases, their water storage capability at inter-annual timescales would also have a high sensitivity to environmental change.

RESPONSE: It is true that debris-covered glaciers that are avalanche-fed are sensitive to changes in precipitation (Burger et al., 2019). However, we expect that an avalanche-fed semi-sensitive glacier would still be less sensitive to climate than a sensitive glacier. Ayala et al. (2016) found this to be the case for Pirámide glacier in the semiarid Andes. This mainly avalanche-fed debris-covered glacier was considerably less sensitive to changes in climate than the other two nearby debris-free glaciers studied. Our aim is to incorporate factors that will help distinguish between the categories, rather than factors that result in variable sensitivity within a category, so we have decided not to include the sensitivity associated with avalanches when initially defining the categories with optical imagery. In the discussion we do suggest that the initial classification could be refined using various approaches including physically-oriented numerical mass balance modelling within which the impact of avalanche input could be incorporated.

5) The use of the term "landform" makes the manuscript very confusing. While it can refer to anything (a glacier, a ridge, a mountain), it is often used to refer to a glacier, where the direct use of the term "glacier" would make the text much clearer. In some cases, for the same glacier the text says that it is a landform composed of multiple glacier types, and that it is a glacier composed of multiple landform types (line 118: "Where a landform is made up of multiple glacier types (Fig. 1a [Tapado Glacier])", lines 125-126 "Tapado Glacier [Fig. 1a] is made up of the three distinct landform types..."). Other sections use the concept of "glacier morphology" (line 161). More consistent use of the terminology is necessary: "Glacier" and "surface-type" could be better concepts to use (instead of randomly interchange either of those by "landform").

RESPONSE: We agree and have changed all instances of "landform" to "glacier."

6) In the context of GPL and glacier inventories. It seems that the authors propose the use of their methodology nationwide or throughout the Andes. However, the examples presented in figures and Table 1 are biased to the semi-arid Andes; the same is true regarding the accuracy check proposed in line 234. All examples are within four degrees of latitude. It must be clear what is the geographical area for which this methodology has been designed. If the application area is the whole of the Andes, the authors should address the different challenges posed by tropical and Patagonian glaciers.

RESPONSE: We have added a paragraph to the introduction starting on line 49 to explain why we chose to focus on the semiarid Andes (this area is particularly relevant for water resource evaluation) and clarified that the semiarid Andes scheme provided is meant to serve as an example upon which classification schemes for other regions could be based. We have also added a paragraph to the introduction discussing the large variation in climate, topography, and glacier characteristics that exists from north to south in the Andes and recognize that the dividing line (debris thickness threshold between categories) will vary from north to south. We have added a new paragraph starting on line 243 that details how the dividing line might vary from north to south and why with an emphasis on the difference between the semiarid Andes and Patagonia.

Specific comments (numbers refer to manuscript version 2) :

7: In the context of this paragraph and in particular the GPLs, "landform types" have a very different and more specific meaning than used in the rest of the text, as the most controversial definitions that have hindered consensus of the Chilean GPL are the definitions of Glacier, Periglacial, and permafrost. However, "landform types" in the manuscript refers interchangeably to glaciers or parts of a glacier with a distinct surface type (based on debris cover). This difference gives the impression to the reader that this work offers a direct solution to the definitions controversy that, has been in part, the cause of the lack of consensus, which is wrong.

RESPONSE: We agree that the classification scheme proposed does not directly resolve the definitions controversy that has hindered the consensus of the Chilean GPL. We have modified the introduction to present the usefulness of the classification scheme in a broader context to help effectively protect, manage, and monitor glacier water resources by differentiating between glacier types.

21-22: Given that the authors seem to be opening the discussion over the idea of not protecting all glaciers equally but depending on their hydrological behaviour. It seems very important to elaborate on what legal issues have hindered the application of the Argentinean GPL, or at least give a reference for that affirmation.

RESPONSE: We have broadened the scope of the introduction to present the usefulness of the classification scheme for legislation and the EIA. Given the reduced focus on GPL we do not think it is necessary to elaborate on the legal issues that have hindered the application of the Argentinian GPL.

23-24: This requires further elaboration. It is unclear how distinguishing between glacier types can reduce the legal ambiguity. In general, one would think that the current approach of Chilean and Argentinean GPLs (protecting all glaciers regardless of type) is less ambiguous than differential protection based on a glacier classification schema.

RESPONSE: Defining the different glacier types included in the GPL would clarify which glacier types are in fact protected. For example, it is currently not clear if rock glaciers are protected or not. Some rock glaciers (primarily active rock glaciers) are included in the national inventory so one could assume that these are protected, but this is not explicitly indicated in the law. Assuming rock glaciers are included, a practical definition of rock glaciers should be included in the GPL to clarify which landforms are considered rock glaciers (e.g. only active rock glaciers or also inactive ones?). The definition provided in this paper for insulated landforms could be used for this purpose.

39: The switch between the "glacier" terminology and the use of "landform" should be explained here. Otherwise, simply keep using "glacier."

RESPONSE: We agree and have changed all instances of "landform" to "glacier."

77-80: It seems against the objectives of this work to base the threshold of debris thickness on a single glacier. Arguably, debris type can have a significant influence, as well as the partitioning of the different melt processes affecting a glacier. In areas where sublimation is the primary melt process, a thin layer of debris might be enough to reduce melting significantly. In other cases, such as the temperate glaciers of New Zealand and Patagonia, a large amount of the melting is due to rain, and perhaps a much thicker debris cover is required to reduce melt rates. Pirámide glacier might be representative only of glaciers where shortwave radiation is the dominant melting process.

RESPONSE: We agree and have therefore included an additional paragraph in the discussion to address how the threshold of debris thickness might change with latitude (starts on line 243).

121-123: Again, it seems against the objectives of this work to include ambiguous criteria like this (what is "very minor"?).

RESPONSE: We agree and have specified what we mean by "very minor" (< ~20% of the surface area).

Figure 2: Please include coordinates or some ID (either in the figure or caption) for all unnamed glaciers (b-f). Alternatively, add to the caption a reference to the additional information available in Table 1.

RESPONSE: The coordinates for all unnamed glaciers (b-f) are included in Table 1.

144-149: It is confusing to use the term "landform" when you mean "glacier". Unless the authors want to refer to different sections of a glacier but with different surface types, however, if that is the case, it does not make sense to say that the insulated part of Tapado Glacier is insensitive to environmental change while its accumulation area is a sensitive "landform".

RESPONSE: We agree and have changed all instances of "landform" to "glacier."

159: "It is likely" seems a euphemism for something that unquestionably will happen.

RESPONSE: We have deleted this sentence.

Table 1: What is the point of comparing this article classification with DGA/IANIGLA classification? Each of these is classifying completely different attributes of the glacier: Glacier sensitivity to environmental change in this article, glacier shape/main characterizing feature for DGA, and glacier debris cover for IANIGLA.

RESPONSE: A major motivation for including these classifications is precisely to show that the classification schemes are different between the two countries and that the scheme used by the DGA is not very helpful for evaluating water resources. We elaborate on these classifications and their usefulness for evaluating water resources in section 4.

214: Which are the distinct hydrological roles? The authors only point to differences in the timescales and the degree to which these glacier types play a role as water reservoirs.

RESPONSE: We have explicitly defined the hydrological role in the first paragraph of the introduction.

"Here we define hydrological role as including contributions to the catchment as well as the impact on storage and drainage of water. For example, glaciers that are more sensitive to changes in climate (e.g. debris-free glaciers) provide a relatively large annual contribution to streamflow now, while rock glaciers are less sensitive and provide a longer-term reservoir (Jones et al., 2018), in some cases even acting as perched aquifers (De Pasquale et al., submitted)."

While strictly speaking if the hydrological role is defined as a particular function within an ecosystem, differences in timescales of water contribution (short-term versus long-term) represent the same hydrological role. However, we would like to continue to use the term "hydrological role" since this term has been used to describe differences in timescales in previously published papers on the subject of rock glaciers and water resources (e.g. Jones et al. 2018; De Pasquale et al., submitted; Schaffer et al., 2019). If the reviewer feels strongly about not using this term please suggest an alternate term. We would be open to using it.

227-229: While that might be more objective, it seems a nightmare from a legal point of view. One can picture a development project affecting a sensitive glacier because a logistic regression happens to assign it to the wrong category.

RESPONSE: We agree and have removed the suggestion to use logistical regression. Instead, we have proposed other quantitative methods that are more appropriate.

256-257: As for line 214, it seems that "role" is not the best word to distinguish between the hydrological effects of different types of glaciers.

RESPONSE: We have explained why we use the term "hydrological role" in the response to the comment on line 214.

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