Review of "Hydrological response of Andean catchments to recent glacier mass loss" by Caro et al.

Dear reviewer, we appreciate your valuable comments.

In this document, we present our replies (in purple) together with the changes we made to answer your comments. For each of your comments (in *Italics-black*), the text corrected for the 1st round of review is written in red color, whereas our proposed changes to your comments for this second round of revisions are in blue.

Referee #1

This study investigates the changes in glacier mass, area, and runoff for different glaciated catchments in the Southern Andes from 2000-2019. The study uses the Open Global Glacier Model, calibrated with geodetic mass balance data from 2000-2019, and forced by a bias corrected climate dataset. The focus of the study is on all land-terminating glaciers (i.e., lake and marine-terminating glaciers are excluded) and specific attention is given to how the changes in climate over 2000-2009 vs. 2010-2019 affect the glacier runoff across the different catchments, which notably span different climatologies. The main conclusions are that most glaciers are losing mass leading to increases in runoff in the Tropical Andes and Dry Andes. Furthermore, results are consistent with previous studies and the glacier contribution to runoff is highest for some catchments in the summer and others in the transition season prior to summer.

This is the second time I'm reviewing this article and I'm pleased to say the manuscript is greatly improved! Excellent job. The methods are now incredibly detailed and thus easy to understand what was done and what the advances are. Specifically, the major advance/novelty is the use of a bias-corrected climate dataset and the in-situ glaciological observations. Hence, even though the study primarily confirms existing knowledge (although they do not some key differences and do a nice job framing results with respect to previous studies in the discussion), it is a valuable contribution to the literature.

My comments are primarily related to improving readability as several areas were a bit unclear; however, rephrasing these or being more explicit will resolve these issues easily. Similarly, several areas felt quite repetitive, so sentences/sections could be removed, which would also reduce the length of now a fairly long study. I thus would suggest accepting subject to minor revisions. General and specific comments are described below.

General Comments

Abstract is very detailed. Suggest shortening and highlighting only the key research findings.

We edited the abstract. It was shortened from 472 words to 314 words

Text corrected for the 1st round of review:

"Abstract.

The impacts of the accelerated glacier retreat in recent decades on glacier runoff changes are still unknown in most Andean catchments, increasing uncertainties in estimating water availability. This particularly affects the Outer Tropics and Dry Andes, heavily impacted by prolonged droughts. Current global estimates overlook climatic and morphometric disparities among Andean glaciers, which significantly influence simulation parameters. Meanwhile, local studies have used different approaches to estimate glacier runoff (sum of the melting snow/ice and rainfall on the glacier) in a few catchments. Improving the accuracy in 21st century glacier runoff projections hinges on our ability to calibrate and validate the models on the basis of corrected historical climate inputs and calibrated parameters across diverse glaciological zones. Here, we simulate glacier evolution and related glacier runoff changes between 2000 and 2019 in 786 Andean catchments from Colombia to Tierra del Fuego (11,282 km2 of glacierized area, 11°N-55°S) using the Open Global Glacier Model (OGGM). We also emphasize on climate correction, parameters calibration, and results evaluation within the workflow simulation. Our homogeneous methodological framework across the Andes considers the diverse glaciological zones in the Andes. The atmospheric variables from the TerraClimate product were corrected using in situ measurements, underlining the use of local temperature lapse rates. Meanwhile, the glacier mass balance and volume were calibrated glacier-by-glacier. Furthermore, procedures by glaciological zones allow us to correct mean temperature bias up to 2.1°C and increase the amount of monthly precipitation. The related calibrated parameters, such as melt factor (for mass balance) and Glen A (for ice thickness), show strong alignment with cold/warm and dry/wet environmental conditions. The simulation results were evaluated with in situ data in three documented catchments (glacierized surface area > 8%) and on monitored glaciers. Our results at the Andes scale show that the glacier volume and surface area were reduced by 8.3% and 2.2%, respectively, between the periods 2000-2009 and 2010-2019. The glacier loss during these periods is associated with a decrease in precipitation (9%) and an increase in temperature (0.4 ± 0.1°C). Comparing these two periods, glacier and climate variations have led to a 12% increase in mean annual glacier melt (86.5 m3/s) and a decrease in mean annual rainfall on glaciers of -2% (-7.6 m3/s) across the Andes, both variables compose the glacier runoff. The results at the catchment scale indicate glacier runoff contribution in agreement with

previous studies in the Maipo catchment (34°S, Chile). However, we suggest that the largest glacier runoff contribution in the La Paz catchment (16°S, Bolivia) is found during the transition season. Additionally, we calculated for the first time the glacier runoff contribution in the Baker catchment (47°S, Chile). In summary, our calibrated and validated modeling approach, organized by glaciological zones and based on our local understanding, utilizing the same methodological approach, stands as a crucial requirement for simulating future glacier runoff in the Andes."

Edited text:

"Abstract.

The impacts of the accelerated glacier retreat in recent decades on glacier runoff changes are still unknown in most Andean catchments, increasing uncertainties in estimating water availability. This particularly affects the Outer Tropics and Dry Andes, heavily impacted by prolonged droughts. Current global estimates overlook climatic and morphometric disparities among Andean glaciers, which significantly influence model parameters. Meanwhile, local studies have used different approaches to estimate glacier runoff in a few catchments. Improving 21st-century glacier runoff projections relies on calibrating and validating models using corrected historical climate inputs and calibrated parameters across diverse glaciological zones. Here, we simulate glacier evolution and related runoff changes between the periods 2000-2009 and 2010-2019 across 786 Andean catchments (11,282 km^2 of glacierized area, 11°N-55°S) using the Open Global Glacier Model (OGGM). TerraClimate atmospheric variables were corrected using in situ data, getting a mean temperature bias by up to 2.1°C and enhanced monthly precipitation. Glacier mass balance and volume were calibrated, where melt factor and Glen A parameter exhibited significant alignment with varying environmental conditions. Simulation outcomes were validated against in situ data in three documented catchments (with a glacierized area > 8%) and monitored glaciers. Our results at the Andes scale reveal an average reduction of 8.3% in glacier volume and a decrease of 2.2% in surface area between the periods 2000-2009 and 2010-2019. Comparing these two periods, glacier and climate variations have led to a 12% increase in mean annual glacier melt (86.5 m^3/s) and a decrease in rainfall on glaciers of -2% (-7.6 m^3/s) across the Andes, both variables compose the glacier runoff. We confirmed the utility of our corrected regional simulations of glacier runoff contribution at the catchment scale, where our estimations align with previous studies (e.g., Maipo 34°S, Chile), provide new insights on the seasonal glaciers' largest contribution (e.g., La Paz 16°S, Bolivia) and new estimates of glacier runoff contribution (e.g., Baker 47°S, Chile)."

Methods are now very detailed. Thanks for this.

Section 4.3 states there is a similar regional pattern; however, this is largely due to overparameterization issues with the model and the assumption of having different temperatures of melt onset for the different regions (L263-264). The authors should mention this *overparameterization issue and avoid overinterpreting their "regional patterns". That said, this is well discussed in Section 4.4. I would recommend removing Section 4.3.*

We agree, we removed Section 4.3

Specific Comments

L23 – "emphasize on" consider new word choice.

We removed L23

Text corrected for the 1st round of review:

"We also emphasize on climate correction, parameters calibration, and results evaluation within the workflow simulation."

L24 – repetitive of L20.

Reply: We deleted L24

Text corrected for the 1st round of review:

"Our homogeneous methodological framework across the Andes considers the diverse glaciological zones in the Andes."

L25-27 – likely too detailed for abstract, which is already quite long.

Text corrected for the 1st round of review:

"The atmospheric variables from the TerraClimate product were corrected using in situ measurements, underlining the use of local temperature lapse rates. Meanwhile, the glacier mass balance and volume were calibrated glacier-by-glacier. Furthermore, procedures by glaciological zones allow us to correct mean temperature bias up to 2.1°C and increase the amount of monthly precipitation."

Edited text:

"TerraClimate atmospheric variables were corrected using in situ data, getting a mean temperature bias by up to 2.1°C and enhanced monthly precipitation."

L32-33 – unclear what these values refer to as there are two variables and two periods, so would expect 4 numbers. Please clarify.

Text corrected for the 1st round of review:

"Our results at the Andes scale show that the glacier volume and surface area were reduced by 8.3% and 2.2%, respectively, between the periods 2000-2009 and 2010-2019"

Edited text:

"Our results at the Andes scale reveal an average reduction of 8.3% in glacier volume and a decrease of 2.2% in surface area between the periods 2000-2009 and 2010-2019."

L53-57 – need to provide context of the time period these results are being discussed in. I assume it's end of century.

Text corrected for the 1st round of review:

"They defined glacier runoff as all the melt water and rainfall coming from the initially glacierized area as given by the Randolph Glacier Inventory version 4.0. and found an increase in glacier runoff in the Tropical and Dry Andes during the recent decades, but a more contrasted signal in the Wet Andes: no glacier runoff change was observed in some catchments, whereas others showed a reduction or an increase."

Edited text:

"They defined glacier runoff as all the melt water and rainfall coming from the initially glacierized area as given by the Randolph Glacier Inventory version 4.0. and found an increase in glacier runoff in the Tropical and Dry Andes until 2020, but a more contrasted signal in the Wet Andes: no glacier runoff change was observed in some catchments, whereas others showed a reduction or an increase."

L57-58 – "… overlook the diverse climates and morphologies of Andean glaciers" is very vague. Climate data was used, which should account for some diversity of climate. Unclear if morphologies is referring to glacier types (e.g., land-terminating, marine-terminating) or something different. Please be specific to help with readability.

Text corrected for the 1st round of review:

"However, their estimations overlook the diverse climates and morphologies of Andean glaciers (Caro et al., 2021)."

Edited text:

"However, their estimations overlook the diversity in climate conditions and glacier morpho-topography across the Andes and inside large catchments (Caro et al., 2021): such as, latitudinal and/or longitudinal climate variations and glacier characteristics (glacier size, slope and aspect)"

L84 – suggest removing the word "precisely" as this is a bit misleading for global modeled products. The sentence appears to be describing that the model can be applied at the glacier scale as opposed to how accurate it can predict changes.

Text corrected for the 1st round of review:

"Therefore, OGGM and the glaciological global dataset, in combination with in situ meteorological and glaciological measurements, considering the differences of Andean glaciological zones, can be used to precisely quantify the glacier retreat and the related hydrological responses at the catchment scale across the Andes"

Edited text:

"Therefore, OGGM and the glaciological global dataset, in combination with in situ meteorological and glaciological measurements, considering the differences of Andean glaciological zones, can be used to quantify the glacier retreat and the related hydrological responses at the catchment scale across the Andes"

L96-97 – "Whereas…" is not a complete sentence.

Text corrected for the 1st round of review:

"The model was run with monthly air temperature and precipitation data from the TerraClimate dataset (Abatzoglou et al., 2018) that were corrected using in situ data. Whereas the simulation procedure considered the glacier mass balance and volume calibration."

Edited text:

"Considering the significant hydro-glaciological variations in neighboring catchments and the potential biases within climatic datasets, the air temperature and precipitation data from the TerraClimate dataset (Abatzoglou et al., 2018) were corrected using in situ data across the Andes. On the other hand, the simulation procedure considered the calibration of glacier surface mass balance and glacier volume."

L107 – suggest just referencing Figure 1 in parentheses after the previous sentence and deleting this sentence.

Text corrected for the 1st round of review:

"This section comprises the processed data used as input and during the modeling framework. This framework is described in Figure 1."

Edited text:

“This section comprises the processed data used as input and during the modeling framework (Figure 1).”

L145 – suggest removing results from the methods section.

Text corrected for the 1st round of review:

“These results are available in Table S2 and Figure S2.”

Reply:

This line will be moved to the results in line 309.

L240 – “In a second time,” I assume this refers to post-processing? Perhaps “After simulations were completed, …” or this could be deleted.

Text corrected for the 1st round of review:

“The spatio-temporal configuration of the model used in this study is at the glacier scale and at the monthly time step. In a second time, results were analyzed by glacierized catchment, glaciological zone and region.”

Edited text:

“The spatio-temporal configuration of the model used in this study is at the glacier scale and at the monthly time step. The simulation results were analyzed at different spatial scales: by glacierized catchment, glaciological zone, and regionally.”

L277-282 – this feels very repetitive of earlier in the methods. Given the length of the methods now, I would recommend deleting this.

Text corrected for the 1st round of review:

“Simulated processes such as the surface mass balance and glacier volume were calibrated (Table 1 and Figure 2). The simulated glacier volume was calibrated using Farinotti et al. (2019) product at a glaciological zone scale to fit the Glen A parameter. In addition, it was assumed that the glacier outlines of all glaciers were made for the year 2000. For instance, in the case of glaciers for which the outline was delimited based on data acquired before or after 2000, this area was considered for the simulations starting in 2000.”

Reply:

We edited this paragraph and moved some lines to line 275.

Edited text:

“The simulated glacier volume was calibrated using Farinotti et al. (2019) product at a glaciological zone scale to fit the Glen A parameter (Table 1 and Figure 2).”

To liine 275:

Text corrected for the 1st round of review:

"glacier outlines were obtained from RGI v6.0 (RGI Consortium, 2017)".

"glacier outlines were obtained from RGI v6.0 (RGI Consortium, 2017), assuming the glacier outlines of all glaciers were made for the year 2000."

Table2 and throughout, I highly encourage zones to just be listed as "Dry Andes 1", "Dry Andes 2", etc. to improve readability. When reading comparisons of DA1 and WA2 (e.g., L297) it becomes very hard to follow.

We agree. We edited the new version with your suggestions.

L323-331 – The first sentence is incredibly hard to follow. Please rephrase. I think what is being stated is simply that only 36% of the total glacierized area of the Andes was simulated. This whole paragraph could likely be one sentence and likely belongs in the methods.

Text corrected for the 1st round of review:

"The annual mass balance and glacier dynamics per glacier are simulated by considering 36% of the total glacierized surface area across the Andes (11°N-55°S) to obtain the glacier area and glacier volume at an annual time scale, as well as the glacier runoff (glacier melting and rainfall on glaciers) at a monthly time scale. In more details, over 85% of the glacierized surface area in the Dry Andes (18°S-37°S) and 79% in the Tropical Andes (11°N-18°S) is considered, which corresponds to 11% (3,377 km^2, in 321 catchments) of the total glacierized area of the Andes. For the Wet Andes (37°S-55°S), 29% of the glacierized surface area in the region is considered, which corresponds to 26% (7,905 km^2, in 465 catchments) of the total area in the Andes (see the distribution of the catchments in Figure 2a). The simulated lower glacierized surface area in the Wet Andes results from the filtering out of the numerous calving glaciers found there."

Edited text:

"The 36% of the total glacierized surface area across the Andes (11°N-55°S) are simulated to obtain annual glacier area and glacier volume, as well as the monthly glacier runoff (glacier melting and rainfall on glaciers)."

We moved the other lines to Section 2.1.3 Glacier data in Glacier inventory.

"Overall, 36% of the total glacierized surface area across the Andes is considered. Over 85% of the glacierized surface area in the Dry Andes (18°S-37°S) and 79% in the Tropical Andes (11°N-18°S) are considered, which corresponds to 11% (3,377 km^2, in 321 catchments) of the total glacierized area of the Andes. For the Wet Andes (37°S-55°S), 29% of the glacierized surface area in the region is considered, which corresponds to 26% (7,905 km^2, in 465 catchments) of the total glacierized area in the Andes (see the distribution of the catchments in Figure 2a). The simulated glacierized surface area is lower in the Wet Andes due to the filtering out of the numerous calving glaciers found there."

L32-333 – same issue as with abstract. Two time periods and two variables are being reported, yet only two values are shared. Please clarify.

Text corrected for the 1st round of review:

"Between the periods 2000-2009 and 2010-2019, the glacier volume and area in the Andean catchments decreases by -8.3% (-59.1 km^3) and -2.2% (-245 km^2), respectively, associated with a mean annual mass balance of -0.5 ± 0.3 m w.e. yr^{-1} (Figure 2d)."

Edited text:

"Considering mean values for the periods 2000-2009 and 2010-2019, the glacier volume and surface area in the Andean catchments show a decrease by -8.3% (-59.1 km^3) and -2.2% (-245 km^2), respectively. This corresponds to a mean annual mass balance difference between the two periods of -0.5 ± 0.3 m w.e. yr^{-1} (Figure 2d)."

Figure 2 – "SMB" is currently being used for "simulated mass balance". It is clear that this is a modeled product, so including "simulated" is unnecessary. I recommend removing this S. This also will avoid confusion with the common acronym SMB for surface mass balance. I'll note that this also is inconsistent with Figure 5 which uses SMB for "specific" mass balance.

We agree with your comment. We will change "SMB" by "MB" in the figures and along the text.

Text corrected for the 1st round of review:

"The (d) annual simulated mass balances are presented in each glaciological zone"

Edited text:

"The (d) annual specific mass balances are presented in each glaciological zone"

L369 – be explicit what the model limitations are. Is sublimation, which is described as a limitation for the Dry Andes, also a problem for the Tropical Andes?

Text corrected for the 1st round of review:

"Model limitations are observed in the Zongo glacier (r = 0.3 and bias = -224 mm w.e. yr^{-1}) in the Tropical Andes. In the Dry Andes, no correlation is observed in the three monitored glaciers

(Guanaco, Amarillo and Ortigas 1); this is mainly because sublimation, an ablation process that is not represented in the model, is dominant for these glaciers."

We edited these lines and also we incorporated new references.

Edited text:

"Model limitations are observed on the Zongo glacier (r = 0.3 and bias = -224 mm w.e. yr^{-1}) in the Tropical Andes. In the Dry Andes 1, no correlation is observed in the three monitored glaciers (Guanaco, Amarillo and Ortigas 1); this is mainly because sublimation is very high on these glaciers, reaching 81% of the annual ablation (MacDonell et al., 2013). On the other hand, sublimation is lower southward in the Dry Andes 2 with 7% of the annual ablation (Ayala et al., 2017). For the tropical zone, sublimation is close to 13% in Outer Tropics (Sicart et al., 2005) and 5% in Inner Tropics (Favier et al., 2004)."

Ayala, Á., Pellicciotti, F., MacDonell, S., McPhee, J., Burlando, P. Patterns of glacier ablation across North-Central Chile: Identifying the limits of empirical melt models under sublimation-favorable conditions. Water Resources Research, 53(7), 5601– 5625. https://doi.org/10.1002/2016WR020126, 2017.

MacDonell, S., Kinnard, C., Mölg, T., Nicholson, L., Abermann, J. Meteorological drivers of ablation processes on a cold glacier in the semi-arid Andes of Chile. Cryosphere 7:1513–1526. https://doi.org/10.5194/tc-7-1513-2013, 2013.

Favier, V., Wagnon, P., Chazarin, J.-P., Maisincho, L., and Coudrain, A. One-year measurements of surface heat budget on the ablation zone of Antizana glacier 15, Ecuadorian Andes, J. Geophys. Res., 109, D18105, https://doi.org/10.1029/2003JD004359, 2004.

Sicart, J. E., Wagnon, P., and Ribstein, P. Atmospheric controls of heat balance of Zongo Glacier (16°S. Bolivia). J. Geophys. Res. 110:D12106. https://doi.org/10.1029/2004JD005732, 2005.

Figure 5 – specify if the mass balance is cumulative or not. It appears that it is cumulative.

Text corrected for the 1st round of review:

"Recent specific mass balance"

In Figure 5, MB is not cumulative.

Edited text:

"Recent annual specific mass balance"

L666 – the conclusion mentions the "accuracy" that has been improved, but it's unclear what this "enhanced accuracy" is being compared to. Later in this bullet it mentions compared to global values, but I did not see any estimates of what the error was for global models; hence, *how can one state that these are more accurate when it's unknown how accurate the other models are?*

We appreciate this comment. You are right, so we edited these lines as follows.

Text corrected for the 1st round of review:

"The correction of temperature and precipitation data, coupled with parameter calibration conducted at the glaciological zone scale, notably enhanced the accuracy of mass balance simulations and glacier runoff estimations."

Edited text:

"The correction of temperature and precipitation data, coupled with parameter calibration conducted at the glaciological zone scale, enabled obtaining annual estimates of glacier mass balance and runoff closer to what has been measured in glaciers and some Andean catchments."

References – check that all studies included in the text are included in the references. Rounce et al. (2020) is cited but not in the references.

We checked the references and included the one by Rounce et al. (2020).

Referee #2

I thank the authors for the revisions they made. While the Introduction section is substantially reworked, it is still bit difficult to understand what actual goal and expected utilization of results - considering existing knowledge about Andean glaciers - are. Instead, the authors describe what they did (second to last paragraph of Intro), but fail to buid the story explaining and justifying why. I appreciate the amount of the work done but I ask the authors to kindly invest additional time to frame, justify and put into context their study appropriately. I recommend minor revisions.

We appreciate your comments. We edited the Introduction section on the basis of the last comments of Referee 1. Additionally, we edited the Introduction to better articulate our research goals and highlight the potential future applications of our results.

Text corrected for the 1st round of review in red and edited text in blue

The largest glacierized area in the southern hemisphere outside the Antarctic ice sheet is found in the Andes (RGI Consortium, 2017; Masiokas et al., 2020). Andean glaciers supply water for roughly 45% of the population in the Andean countries (Devenish and Gianella, 2012) and for ecosystems (Zimmer et al., 2018; Cauvy-Fraunié and Dangles, 2019). Continuous glacier shrinkage has been detected since the late 1970s, with intensification observed over the past two decades (Rabatel et al., 2013; Dussaillant et al., 2019; Masiokas et al., 2020). Glacier volume loss has helped modulate river discharges, mainly in dry seasons (*e.g.*, Baraer et al., 2012; Soruco et al., 2015; Guido et al., 2016; Ayala et al., 2020).

Few studies have estimated glacier changes and their effects on hydrology using observation or modeling focused on specific Andean catchments. For instance, the global-scale study by Huss and Hock (2018) comprised 12 Andean catchments (1980-2100). They defined glacier runoff as all the melt water and rainfall coming from the initially glacierized area as given by the Randolph Glacier Inventory version 4.0. and found an increase in glacier runoff in the Tropical and Dry Andes until 2020, but a more contrasted signal in the Wet Andes: no glacier runoff change was observed in some catchments, whereas others showed a reduction or an increase. However, their estimations overlook the diversity in climate conditions and glacier morpho-topography across the Andes and inside large catchments (Caro et al., 2021): such as, latitudinal and/or longitudinal climate variations and glacier characteristics (glacier size, slope and aspect). This affects the simulation results, as they heavily rely on climate inputs and calibrated parameters. For instance, varying temperature lapse rates could result in significant disparities in glacier melt and the determination of solid/liquid precipitation on glaciers (Schuster et al., 2023). Furthermore, the selection of precipitation factor values is also crucial. Based on local studies, the glacier runoff contribution (glacier runoff relative to the total catchment runoff) in the Tropical Andes was estimated to be around 12% and 15% in the Río Santa (9°S) and La Paz (16°S) catchments, respectively (Mark and Seltzer, 2003; Soruco et al., 2015). For the La Paz catchment, Soruco et al. (2015) found no change in the glacier runoff contribution for the period 1997-2006 compared with the longer 1963-2006 period. This was attributed to the fact that the glacier surface reduction over the time-period was compensated by their increasingly negative mass balance. In the Dry Andes, the Huasco (29°S), Aconcagua (33°S) and Maipo (34°S) catchments showed a glacier runoff contribution comprised between 3 and 23% for different catchment sizes between 241 and 4843 km^2 (Gascoin et al., 2011; Ragettli and Pellicciotti, 2012; Ayala et al., 2020). These catchments had mainly negative glacier mass balances which were slightly interrupted during El Niño episodes (2000-2008 period), thereby reducing glacier runoff. In the Wet Andes, Dussaillant et al. (2012) estimated that some catchments in the Northern Patagonian Icefield are strongly conditioned by glacier melting. In addition, Hock and Huss (2018) did not identify changes in the glacier runoff of the Baker catchment since 1980-2000. However, these studies focused on a restricted number of catchments, employing diverse input data and methodologies over different periods. As such, these local estimations may not be indicative of the broader trends across the entire Andean region. Notably, even neighboring glacierized catchments can exhibit substantial variations in climatic and topographic characteristics (Caro et al., 2021).

Nowadays, the availability of global glaciological products such as glacier surface elevation differences and glacier volume estimation (Farinotti et al., 2019; Hugonnet et al., 2021; Millan et al., 2022) allows for large-scale glacio-hydrological simulations with the possibility to accurately calibrate and validate numerical models at the glacier scale. In addition, modeling frameworks such as the Open Global Glacier Model (OGGM, Maussion et al., 2019) have been implemented to simulate the glacier mass balance and glacier dynamics at a global scale. Therefore, OGGM and the glaciological global dataset, in combination with *in situ* meteorological and glaciological measurements, considering the differences of Andean glaciological zones, can be used to quantify the glacier retreat and the related hydrological responses at the catchment scale across the Andes, while taking the related uncertainties into account. Currently, reconstructions of glacier surface mass balance across the Andes (9-52°S) rely on a temperature-index model. Notably, higher mean melt factor values are identified in the Tropical Andes (0.3-0.5 mm h^{-1} $°C^{-1}$), compared to the Dry Andes (0.3-0.4 mm h^{-1} $°C^{-1}$) and Wet Andes (0.1-0.5 mm h^{-1} $°C^{-1}$) (*e.g.*, Fukami & Naruse, 1987; Koisumi and Naruse,1992; Stuefer et al., 1999, 2007; Takeuchi et al., 1995; Rivera, 2004; Sicart et al., 2008; Condom et al., 2011; Caro, 2014; Huss and Hock, 2015; Bravo et al., 2017).

Here, using OGGM, we estimate the glacier changes (area and volume) and the consecutive hydrological responses called glacier runoff (which is composed of glacier melt [ice melt and snow melt] and rainfall on glaciers) for 786 catchments across the Andes (11°N-55°S) with a glacierized surface of at least 0.01% for the period 2000-2019. This approach allows us to study the behavior of glaciers across the entire Andes and within specific catchments (for instance those previously studied). Considering the significant hydro-glaciological variations in neighboring catchments and the potential biases within climatic datasets, the air temperature and precipitation data from the TerraClimate dataset (Abatzoglou et al., 2018) were corrected using *in situ* data across the Andes. On the other hand, the simulation procedure considered the calibration of glacier surface mass balance and glacier volume. Both, corrections of climate as well as calibrations (at the glacier scale) were performed considering the climatic and morphometric differences in the Andes, represented through the glaciological zones (Caro et al., 2021). Given that the most important uncertainties in simulating future glacier evolution come, among other factors, from the implementation of the models during the historical period, we validate our simulation and calibration outcomes against observed data from glaciers and catchments.

Section 2 presents the data and methods. In Section 3, we describe the glacier changes and hydrological responses at the glaciological zone and catchment scales across the Andes. In Section 4, we discuss our results and the main steps forward compared to previous research.