

Interactive comment on “Glacier changes on Sierra Velluda massif, Chile (37° S): mountain glaciers of an intensively-used mid-latitude landscape” by A. Fernández et al.

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Authors' response to Anonymous Referee #1 on “Glacier changes on Sierra Velluda massif, Chile (37°S): mountain glaciers of an intensively-used mid-latitude landscape” by A. Fernández et al.

General comments

We will include a new figure 1 in which the glacier analyzed can be clearly seen as their present state, and will include data from the relevant glacier inventory (Rivera, 1989). (See specific comments)

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We agree with the referee in terms of the sections' length versus their relative importance in the scope of the manuscript. However, we consider that the methodological aspects must be attached to the present document, since they point out to relevant limitations of the data and procedures used. For the potential reader, that information can provide useful tools to analyze and criticize the paper's scope and limitations. Therefore, we propose to shorten the main paper and move some aspects of the Satellite Imagery and DEM validation to a supplementary information file.

We rechecked the discussions and conclusions section. The English will be improved and speculative sentences will be deleted. (See specific comments)

Comments to questions from the manuscript evaluation criteria proposed by The Cryosphere

3. Are substantial conclusions reached? Yes, but at present the discussion could be improved significantly.

Authors' comment: We will improve the English and will delete speculative sentences.

4. Are the scientific methods and assumptions valid and clearly outlined? Yes, but too much attention has been paid to the finest details which makes the methodology section too long.

Authors' comment: We propose to move as much as 4 pages to a supplementary information file.

5. Are the results sufficient to support the interpretations and conclusions? To some extent yes, but the authors go too far in my opinion linking the observed glacier changes with climate changes, ENSO-PDO, the behavior of other glaciers in Chile, and proxy climate evidence from the region.

Authors' comment: See specific comments.

7. Do the authors give proper credit to related work and clearly indicate their own

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new/original contribution? Yes and no. Important previous glacier inventories in the area should have a more prominent place within the manuscript.

Authors' comment: We will include more data from Rivera's (1989) inventory in a new figure 1.

8. Does the title clearly reflect the contents of the paper? Not really. The title does not indicate the time frame under investigation (last decades? Last millennium? The Holocene?) and introduce the land use changes in this region which are only marginally relevant for the purposes of this study.

Authors' comment: We propose a new title: "Glacier changes on Sierra Velluda massif, Chile (37°S), from 1828 to 2007: integration of Historical records, GIS and Remote Sensing techniques".

9. Does the abstract provide a concise and complete summary? In my opinion should be improved substantially.

Authors' comment: We will improve the abstract in terms of the referee's observations.

10. Is the overall presentation well structured and clear? See general comments above. I believe the paper should be significantly shorter and focus specifically on the analysis of glacier changes at Sierra Velluda, leaving the methodological discussion for an accompanying study perhaps.

Authors' comment: See comments above and below.

11. Is the language fluent and precise? In some section. The Discussion and Conclusions section should be improved significantly.

Authors' comment: The English will be improved.

Specific comments Page Line Comment

NOTE: To locate the page number used by the referee in the current discussion paper,

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the reader must add 1.

685 1-5 It is my understanding that central Chile is known as a “hot spot” not because the reasons proposed by the authors but because of its very rich and greatly endangered biodiversity (a very high number of endemic species under great stress from human activities). Please check and clarify if necessary. In addition, I think that putting the retreat of glaciers and their impact on this regions water resources as the introductory sentence of the paper is a bit misleading. I am not saying here that glaciers in the area are not important as water resources, but regionally their impact seems to be quite small compared to rainfall and snow. Mean monthly streamflow data for the Bio-Bio river at Rucalhue (data available at <http://www.dga.cl/productosyservicios/informacionhidrologica/>), indicate this river is a major river in terms of monthly and annual discharges and can reach (on average!) up to 700 m³/second during peak discharges in June and July. The March 2011 report shows that the river has, on average, a bimodal hydrograph with a peak in mid winter (Jun-Jul) and a second peak in spring (Oct-Nov). Thus to me it is highly unlikely that the small glaciers at SV (ca. 25 km² in area) and the other relatively small glaciated areas within the basin contribute significantly to the runoff of the Bio-Bio river, which is clearly fed mostly by rainfall in winter and by snowmelt at the beginning of the warm season.

Authors' response: From the referee's comment, we recognize that the use of the general term “water resources” should be changed for a more explicit “Hydropower generation”. Magrin et al (2007, pag. 606) actually show Central Chile hydropower generation affected by glacier retreat, in conjunction with biodiversity, and land degradation issues. In this sense, the importance of glaciers is crucial. Also, the referee mentions streamflow data to cast a doubt the importance of these glaciers (and in general all glaciers in the region) in runoff. As mentioned, we will specify “Hydropower generation” but actually the data used in the comment does not correspond to the Laja Lake watershed. That station is located in another sub-watershed of the Bio Bio basin,

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actually located to the south of the study area (and outside the study area). Also, the referee should be aware that most of the stations in the upper Bio Bio basin are controlled for their use in agricultural and hydropower generation (CADE-IDEPE, 2004), so some of them might not be representative of the study area, although in the Laja River pluvial influences are minimal (see the same reference). In this sense, the Laja lake level change can be more representative because the hydropower generation uses the natural discharge from this lake (which is fed by many of the Sierra Velluda's glaciers) and there is not other use above the lake basin. In the same document used by the referee can be clearly seen that the lake level has its maximum in April and November. So, pluvial influences are minimal. We want to highlight that the paper almost always mentions The Upper Bio Bio basin and more explicitly the Laja lake.

References CADE-IDEPE, 2004. Cuenca del Rio Bio Bio. Dirección General de Aguas. Magrin, G., C. Gay García, D. Cruz Choque, J.C. Giménez, A.R. Moreno, G.J. Nagy, C. Nobre and A. Villamizar, 2007: Latin America. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 581-615.

685 6-8 In one sentence it says the focus are volumetric changes and in the following sentence it says frontal, areal and volumetric changes. Please rephrase as the 2nd sentence is more accurate.

Authors' response: We will change the sentence for "this paper analyzes bibliographic sources, satellite images and DEMs to estimate frontal, areal, and volumetric changes in the Sierra Velluda, located in the upper Rio Bio Bio basin (37.5°S and 71.4°W)"

685 6 Please provide geographic coordinates for the study area. It would be important to mention somewhere in the abstract the total area covered by glaciers in the SV massif at the beginning and/or at the end of the period under investigation.

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Authors' response: The areas will be mentioned and the location was actually included in the former answer.

685 9 This sentence in the abstract is not clear, please rephrase. To me it is not clear the need to perform an analysis of significance in relation to the measures of accuracy of glacier changes. If I understood correctly from the text (page 690, lines 15-21; page 702, lines 13-19), the authors assess only those frontal and areal changes that are significantly different over a certain period of time. If that is correct, I don't understand why changes that are NOT statistically significantly different in two different dates should be discarded, as they are also providing important information, i.e. They indicate that glaciers have not changed much in size during the period under study (they have remained of approximately the same size), and that in itself is an important finding!

Authors' response: The use of this method is because it is important to not consider changes that can be biased due to the resolution of the data. If we use a change which is inferior to the uncertainties of the data used, we can give a false idea (or measure) of actual change or stability. We do not claim that the glaciers have not changed in those periods; we claim that with the data available it is impossible to ensure that changes have occurred or have not occurred. Therefore, although we cannot reject the null hypothesis for each "less than 1" period, to include that data in the overall assessment will introduce an additional unnecessary uncertainty which would accumulate progressively. In Geographic terms, those margins cannot be located accurately. Therefore, we will not include the data which showed a signal to ratio less than 1.

685 12-14 I think the discussion of the 1828 "maximum" position of the glacier front is somewhat confusing. The evidence available is not related to a glacier advance or to the maximum position reached by the glacier during the Little Ice Age, for example, and therefore it is quite complicated to try and relate this data point with the evidence provided by other proxies. The information is just an indication that in the past (1828) the glacier was more extensive than at present, but there is no way to find out (or at

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least it was not clear to me from the text) if the glacier was advancing, retreating or stationary at that time. Therefore I think it is too complex extrapolate this single date to what other climate proxies might be telling from this region.

Authors' response: We will delete the word "maximum" from the paper. We will improve the abstract by using this sentence: "which compare relatively well with maximum frontal positions identified in other glaciers in Central Chile and Argentina".

685 17 It is not clear here if the general shrinkage is related to ENSO or the PDO? Please be specific as these are quite different ocean-atmospheric features acting on different time scales (inter-annual vs. multi-decadal) along the Pacific basin.

Authors' response: We will reformulate this sentence by changing some aspects of the discussion section (see below).

685 23-25 I understand this is a highly altered region in south-central Chile but in order to support this claim I think it is necessary to show (at least as approximate figures) what is the actual contribution of glaciers to the surface runoff of the Bio Bio basin. As I said earlier I am not convinced that glacier melt is nearly as important hydrologically as snowmelt or winter rainfall in this region, and therefore the claim that this region is of concern due to the impact of glacier retreat on water resources is difficult to support with the streamflow data available.

Authors' response: We will use "Hydropower generation" instead of "water resources". See response to comment 685 1-5.

686 1-3 It is not clear here why is it more important to develop studies of climate change where climate has a transitional character than in other regions of the planet (where climate is better defined maybe?)? Please explain better.

Authors' response: The focus of this sentence is to show that this zone is a good example of mid-latitude systems. We will highlight the importance of this zone in terms of population and natural resources for the country instead of a "climate change ex-

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ample”. Thus, the sentence will be “Additionally, despite the transitional character of the climate (Devynck, 1970), the high population’s density (INE, 2002), and the importance of agriculture (54% of the country’s total) and forestry (58% of the country’s total) activities, this zone has not been sufficiently studied yet”.

686 8 replace “extant” by existing? Authors’ response: It will be replaced.

686 7 I think it is absolutely necessary to discuss in much more detail the work by Valdivia (1984) and Rivera (1989) in this area. Are the glaciers in these earlier studies the same glaciers discussed in this paper? If they have already developed glacier inventories for this region, please provide total areas, location and other relevant details from these studies. Is there a way to incorporate this previous information that would allow a visual comparison of glacier sizes that could be shown in addition to the figures provided here?

Authors’ response: We will include a detailed map of the Sierra Velluda (in figure 1) and more information from the Rivera’s inventory there. Valdivia’s inventory is used as a reference to show how old the data are, but it does not have data from Sierra Velluda, actually.

686 12 In the abstract (line 8) you say “frontal, areal and volumetric changes”. Please be specific.

Authors’ response: It will be written as in the abstract (already changed).

686 to 695 All these pages have in my opinion too much detail and could be trimmed quite substantially. I would strongly suggest focusing only on the main points necessary to understand the methodology and the key aspects of your analyses without getting into much detail on less relevant aspects of the study (e.g. instead of describing the websites where the images were obtained, I would just mention which images and dates were used; instead of discussing the many options of band ratios available for identifying glacier ice in the literature, just focus on the band ratio that worked best for

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your area). Please also indicate which threshold you selected for the band ratio you applied for mapping your glaciers (currently not mentioned in the text). Please also see my comment above regarding the scope of the paper. I would suggest removing most of the methodological discussion on the uncertainty calculations and DEM comparisons and leaving only what is absolutely necessary to understand the main results presented here. Although these tests appear to be an interesting set of analyses for this area, I think that, as presented, the detailed description in these 10 pages does not help the manuscript as it makes it too long and arid before the reader gets to the main point which is the discussion of glacier changes in the SV.

Authors' response: We will create a supplementary information file to post in conjunction to the main paper. We will write the threshold in the text (2). Approximately 4 pages will be removed from the main text and relocate in a supplementary information file. Please see general comment's response for more details.

696 4 Please indicate which year you are talking about here.

Authors' response: Will be indicated (1828).

696-697 I think it is important to indicate here some basic but crucial facts such as how many glaciers are considered, their total area, range of sizes, altitudinal range, etc. Given the coding adopted to identify SV glaciers, I think it is also very important to also provide a well labelled, clear and good size figure indicating where the glaciers are located, their relative position within the SV, etc. This is not easy to discern in the figures provided with the manuscript.

Authors' response: See response 686 7

696 9 Please indicate which glaciers you are referring to here.

Authors' response: We will change the sentence by using this "In that table, note that the analysis of glaciers RC108376/1 and RC108376/2 begins in 1977 and 1975, respectively, because. . ."

697 15-17 The reasoning followed in the sentence about the dynamics of the glaciers /7 and /8 is confusing. Please explain better.

Authors' response: We will change that sentence for the following: "Also in 2006, the glaciers RC108376/1 and RC108370/8 did not exist or were smaller than the threshold used in this work. This indicates that these ice bodies were glacierets."

698 9 Replace "glaciered" by glaciated?

Authors' response: It will be replaced.

699 11 From Fig. 5 it is not apparent that a "significant reduction" has taken place in the SV. The figure shows some retreating fronts but also several advances and by looking at the figure it is hard to assess which is the net result of these changes. Maybe a better way of portraying these changes would be to present cumulative changes over time? That would probably show the end result in more clearly.

Authors' response: The figure is actually a cumulative. We can split the figure in two (areal and frontal changes) and plot the linear trend to show the overall change in each glacier. Also, we will improve the caption to make explicit that the graphs show cumulative changes.

Also, we will change the first part of that section using the following sentence before "changes": "In terms of the statistical significance measure used in this study, the majority of Sierra Velluda's glaciers have shown important reductions in the studied period (Tables 4, 5 and 6). These general changes. . .".

699 18 Please see comment above regarding the 1828 position of the glacier. The evidence presented here points to a more extended frontal position of the glacier in the past but cannot be related specifically to a glacier advance (as seems to be implied here in the comparison with the Cipreses glacier). This data just indicates a point in time of the glacier front which was ca. 676 m more extensive than today, but I think it is risky to refer it to a "maximum" position as we have no clues if this was in fact a

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maximum position during a certain period of time or not.

Authors' response: We will delete the word "maximum" (see response 685 12-14)

699 25 What evidence???

Authors' response: We will eliminate that sentence (from "The evidence" to "(Veit, 1996)").

700 2-5 It is quite hard to follow this reasoning. Please explain better.

Authors' response: This sentence will be replaced by the following: "A larger glacier in that time corresponds well with other records in central-southern Chile."

701 8 ENSO or PDO? Which one are you referring to here? See above, ENSO and PDO are not the same thing, please be specific.

Authors' response: The sentence will be changed for the following "On the other hand, the consequent reduction of glaciers from the 1970s to the 2000s agrees with some changes detected in temperature and precipitation trends".

700-703 Most of the information provided in these final pages is quite interesting but in many cases it is difficult to follow the reasoning used to relate this complementary information with the changes observed on SV glaciers. I find there is too much information and that it is used to make highly speculative inferences that are very difficult to support without proper testing or additional data. In particular, I find the discussion about the relationship between SV glaciers and climate changes not very strong, and would suggest not extending the conclusions beyond what can be demonstrated empirically by the results of this study.

Authors' response: We will eliminate speculative sentences: 701 (15-18; 20-21), 702 (5 -12). Also, we will modify some sentences (see comments above).

Finally, I would also suggest revision of the English language used in the text (especially in these last pages with the discussion of results and the assessment of additional

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evidence from the region).

Authors' response: It will be improved.

Tables 4-6 In order to save space, maybe these three tables could be merged together and the results for frontal, areal, and volume changes presented in just one table?

Authors' response: We will try to merge the three tables in one.

Figure 5 Maybe presenting the cumulative changes over time would show a clearer picture and support better the claim for a significant reduction of glacier area in this region.

Authors' response: See response 699 11

Interactive comment on The Cryosphere Discuss., 5, 685, 2011.

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