

## **Author's response to Anonymous Referee #2**

We would like to thank anonymous Referee #2 for his/her constructive and useful comments that have significantly improved the manuscript. We agree that discussion and conclusion needed to be improved (as Referee#1 also suggests), so have changed the text accordingly. Here, we provide a brief point by point response to the general comments (enumerated) of the Referee #2:

- 1) Specify if the glacier contribution to runoff is coming from the snow or the bare ice.**

### **Author's response**

This is a good suggestion. As the referee indicates we can separate between melt from snow over the glacier and bare ice. We added this information in the manuscript.

- 2) Validation of the degree-hour method in Figure 6**

### **Author's response**

We have extended the comparison between EB and temperature-index model until the end of January 2010 improving the validation of the degree-hour method. After that date, and as the referee noted in the minor comments for Fig.7, the radiation (shortwave and net) was reduced sharply. So we did not use data of February and March.

- 3) Comparison to other studies (section 4.3)**

### **Author's response**

We added the data that the referee suggested.

- 4) DHF for snow**

### **Author's response**

We used all time steps (24 h \* 52 d) to estimate the DHF for snow, since the hours with negative temperatures were set to 0°C to calculate the mean temperature. With this procedure we obtained a DHF of 0.1188 mm we h<sup>-1</sup> °C<sup>-1</sup>. However, the percentage of hours with negative temperatures during the period were close to 25%. Using only the positive time steps, the mean temperature was 4.6°C which gives a DHF for snow of 0.1192 mm we h<sup>-1</sup> °C<sup>-1</sup>. The impact of these changes on the DHF value is therefore negligible. Anyway, we changed the explanation of this procedure in the text.

## **Response to minor comments**

In general we agree with all suggested text corrections and minor comments. Here, we respond directly to every minor comment:

**Please correct systematically throughout the paper the use of capital letters for glaciers and rivers. Universidad glacier -> Universidad Glacier, Tinguiririca river -> Tinguiririca River.**

Done

**Check the use of present and past tenses. You frequently change from one tense to another, especially in the methods section.**

Checked

**1/11: “during late summer and autumn”**

Changed

**1/12: “To address these shortcomings”, why in plural? You only describe the fact that few studies are available.**

We changed to singular

**1/15: “to compare”**

Changed

**1/28: “water is a crucial resource”**

Changed

**1/28-29: Could you add more references apart from Masiokas et al. 2006 to sustain this sentence? The study of Masiokas et al. 2006 is about snowpack variations and not water uses.**

We discussed and added more references regarding water uses (e.g. Meza et al., 2013).

**1/30-31: Please reword: “In this region, winter precipitation is driven by the interactions...., and summer runoff (or summer water supply) by the storage and release from glaciers and the seasonal snow cover”.**

Done

**1/32: Maybe replace “water supply” by “runoff generation”.**

Done

**1/35: I think you need to replace “altitude” by “elevation” if you refer to terrain. How do you calculate the 4000 m asl? Is it the average of the peaks? Do you have a reference?**

We replaced “altitude” by “elevation” and added a reference indicating the mean altitude of the Andes in the region.

**2/2: “warm temperatures”**

**Consider to change “trigger” by “produce” or “cause”**

Done, we changed “trigger” by “cause”

**2/3: “rivers in the Andean basins of central Chile are mainly driven by the melting of the seasonal snowpack.”**

**Please specify that you refer to the highest river sections. The annual regime is driven by winter precipitation in the lower sections.**

We explained “high” was related to Central Chile Andes basins

**2/3-4: The expression “is related to the existence” sounds awkward.**

We changed by “is related to the presence”

**2/6-7: “For example, Peña and Nazarala (1987) estimated that the contribution of glacier melt to the Maipo River basin in summer 1981/82 was maximum in February and represented 34% of total discharge”.**

**Please provide the elevation of the outlet and the percentage of the glacierized area of the catchment analyzed by Peña and Nazarala (1987). Also if by “glacier melt” they include the seasonal snow over the glacier.**

We provided the information of the outlet. On the other side it is not clear in the work of Peña and Nazarala (1987) if glacier melt include snow over the glacier. However the 34% contribution corresponds to February of a dry year. The same authors indicate that “snow remaining at the end of a dry year is negligible”. This makes suppose that the indicated percentage is referred only to ice.

**2/10-12: Please provide one or two sentences with the main conclusions of Pellicciotti et al. (2008). Otherwise this reference is not very meaningful.**

We added “...zone, showing that the ablation process is dominated by incoming shortwave radiation.”

**2/12-14: Please provide the elevation of the outlet and the percentage of the glacierized area of the catchment analyzed by Ragetti and Pellicciotti (2012). Also if by “glacier melt” they include the seasonal snow over the glacier.**

We added this information

**2/14-16: Please check this sentence. “Results are available only for one basin” sounds strange.**

We changed to “Despite these advances, results are limited to one basin and cannot necessarily be extrapolated”

**2/17: “or on the impact of...”**

Done

**2/18-19: can you be more specific? What do you mean by “melt patterns”? Temporal, spatial?**

Both, we explained this in the text

**2/20: deficiencies -> knowledge gaps, issues**

Done

**2/33: the words “which convergent” are not clear.**

Re-written; “which converge at an altitude of ~2900 m asl”

**From where did you obtained the ELA? References?**

We re-estimated the ELA. See below Minor comment 8/3-6

**2/33-34: Below this ->Below this elevation, below the ELA**

Changed: “below this elevation”

**3/10: “After the analysis of energy fluxes at the location of the lower AWS, a temperature-index model was calibrated and applied at the glacier scale. Resulting melt amounts were used to estimate total glacier discharge, which is compared with downstream discharge records.”**

Changed as suggested

**3/21: Please choose another title. Snow density is not an ablation measurement.**

Re-written: “Ablation measurements: stakes and sonic ranger”

**3/22: re-measured -> read**

Changed

**3/26: melt -> of surface ablation. The ablation stake also includes sublimation.**

Changed

**3/27: “(Table 1). The sensor recorded surface ...”.**

Changed

**3/31-32; Please provide more details about the regression between Modis and Landsat products. At least the basic principles.**

We added more literature

**3/35: elevational distribution of snow cover -> snow line**

Changed

**4/1: What is the acquisition date of the DEM? Is it similar to that of the study period?**

Unfortunately ASTER GDEM did not give time acquisition. We added this point as one uncertainty in the melt estimation.

**4/3: “Images were used...” ,Modis images?**

We changed by “MODIS product were used...”

**4/3-4: Remove “For modelling purposes”.**

Removed

**4/8: remove the second “applied”.**

Removed

**4/10-11: “, which we refer to as the degree-day factor, ...”.**

Changed

**4/11-12: stake 1 melt measurements -> stake 1 ablation measurements.**

Changed

**4/11-13: This sentence is not clear. Please reword, perhaps you should split it in two.**

Re-written; “We use stake 1 ablation measurements (Table 2) and the mean positive air temperature (3.5 °C) at the AWS1 to estimate a DHF for snow. Dividing the ablation value by the mean of positive air temperature (Braithwaite et al.,1998), we obtained a DHF for snow of 0.12 mm w.e. h<sup>-1</sup> °C<sup>-1</sup>.”

**4/12: “negative temperatures are set to 0°C” This sounds very strange. Say instead that you set to zero all melt occurring at time steps when the air temperature is below the temperature threshold.**

Deleted

**4/13: Please place the value 3.5°C in another part of the sentence.**

Done

**4/13 “With these values” What values?**

Changed

**4/13: “Following the procedure of Braithwaite et al. (1998)” What procedure? Please briefly explain it. Do you divide the total ablation by the total number of hours or only by those with positive air temperatures?**

For the total number. We have clarified this point. See general comment 4).

**4/14: Why would you multiply by 24? I would think that melt only occurs during daytime (maybe 14 or 16 hours per day).**

See general comment 4).

**4/16: Please add at the beginning of the sentence a short explanation of why you cannot use the same procedure as for snow: “As we do not have ablation stake measurements in the period when the ice surface is exposed, we use a range of published....”.**

Added

**4/21: Can you use only one symbol? Either Df or DHF.**

We prefer to keep both symbols. The first one is the mathematical symbol for the equation as the editor suggests. If we use DHF in the equation, this means that D times H times F (which is not correct). For the text we preferred to maintain DHF to reduce the extension of the text.

**5/3: Since these are negative values, maybe write “with a minima in magnitude”.**

Changed

**5/6: It should be “entrainment of warm air from the upper atmospheric layers”. Please see the articles from van den Broeke (1997a, 1997b) in Pasterze Glacier for a more theoretical perspective. Insolated bare rock surfaces can also locally increase near-surface air temperature, but I don’t think that “entrainment” is the right term.**

We changed by “advected”

**5/6-7: Could you please check if wind directions reveal up-winds from the proglacial valley? Petersen and Pellicciotti (2012) observed this feature in Juncal Norte Glacier.**

We check this. During the afternoon, data from AWS1 show up-winds. However katabatic winds still are the prevalent during all day. We showed this in a new Fig. 4

**5/12: “was determined following Oerlemens (2010)”. Remove also the parenthesis.**

Changed

**5/17: Why do you need the reference of Oerlemans and Klok to neglect the heat from the rain? Or is the reference wrongly placed?**

We used this reference as an example, since they neglected heat from rain in their calculations. We added e.g. in the reference to clarify.

**5/19: “The sensible heat fluxes were calculated...”**

Changed

**5/22-23: Do you assume the same value of  $z_0$  for snow and ice?**

No. We assumed to be 0.001 m for melting snow and 0.01 m for ice on mid latitude glaciers (Brock et al., 2006). We added in the manuscript.

**6/3-5: I guess this is ok, but you are assuming the surface temperature as 0°C for the sensible heat fluxes, so, to be consistent, everything should be evaporation.**

That’s right we clarified this point in the manuscript

**6/13: You missed the evaporation rate.**

Added.

**6/26: Do not mention what you did not do, delete “There were no direct measurements...”**

Changed

**6/28: Add a space before “Water level...”**

Added

**7/30: replace “almost always” and “more frequently” by a percentage of time.**

Replaced

**8/3-6: Can you say something about the ELA with this procedure? If we use the elevation of the snowline at the end of the ablation season as an indicator of the ELA that year, we would get a number much higher than the value of 2900 m asl (mentioned in line 2/33).**

Effectively the ELA was wrong (too low). We changed the value at 2/33 and explained the estimation procedure. Also we discussed the value obtained from the ASTER image (Fig1) and the values obtained using MOD10A1

**8/14: Please use the same number of significant digits for the DHFs (in lines 4/18 you use only two).**

Ok, we used two all along the text.

**8/18-19: Please see main comment number 2.**

ok

**8/32-33: Move to methods.**

Done

**9/3: October -> November**

Changed

**9/15: “purposes”.**

Done

**9/19-20: Do you have data before November 24? Why don't you start the comparison on October 1?**

Yes we have AWS data before this date, however the pressure sensor only have data from this date and on



**9/23: “...contributions from glaciers...”**

Changed

**9/23: Please mention these lakes in the catchment description.**

Added

**9/29-31: Please explain this sentence better:**

**“At the beginning of the common period”: What period do you mean exactly?**

We added the explanation about the period. **“in the basin”: what basin? The largest one?**

We referred to the entire high Tinguiririca basin (added)

**Why is the high daily variability associated with the control of air temperature over snowmelt?**

The interdaily variability of the air temperature is similar to the interdaily variability of the runoff in the DGA station. We added air temperature as reference in Fig. 13.

**10/3: “is suitable”**

Changed

**10/4: “high melt regime” is not a very precise term. Do you mean something like “large retreat during last years”? Please precise.**

We deleted “high melt regime” to avoid confusion

**10/5: Please see main comment 2.**

Ok

**10/8: “locally-calibrated”, “on-glacier”**

Changed

**10/9-12: Please connect this sentence better with the rest of the discussion. Why are you discussing off-glacier temperature data here?**

**10/13: in converting -> to convert**

Changed

**10/23-24: This sentence is a bit obvious. A temperature-index model is always very sensitive to air temperature variations. Please remove or explain better this idea.**

Removed

**10/25-27: Check the grammar of this sentence. It is very difficult to read.**

Changed

**10/29-30: I am not sure if you are expressing your results correctly. Please be more precise. Based on Table 4, I would say that the average contribution is between 10% and 13% over the entire period. Individual daily values range between 3 and 34%.**

Yes, we changed 10% by 3%

**10/36: high levels -> high-elevation sites**

Changed

**10/37: Remove “which generate more water per surface unit than the non-glaciated area”.**

Removed

**11/1-6: This is not really a discussion of your results.**

We used Carrasco et al. (2005) and LeQuesne et al. (2009) as general precedent relating frontal retreat and temperature trends in the glacier. We agree that it is not directly a discussion of our results, instead is a discussion of the implications of the context of glacier retreat and future melt.

**11/2: What is the elevational retreat of Universidad Glacier?**

Elevation retreat is close to 70 m between 1955 and 2007 (LeQuesne et al., 2009).

**11/3-6: The idea of “peak water” is interesting. Other authors have suggested that this peak will not happen in the Andes or it already happened (Ragettli *et al.*, 2016). If you keep this paragraph, consider to extend this discussion adding more literature: (Rubio-Álvarez and McPhee, 2010) and (Cortés *et al.*, 2011) also examined streamflow trends of Chilean rivers.**

We added the suggested references to the discussion.

**11/14-15: This is not clear: “is located at a particular climatic zone which maximizes summer melting” What does it mean “to maximize summer melting”?**

**11/16: Check the grammar.**

Ok

**11/23: “estimated”**

Changed

**11/24: “debris-free” and “debris-covered”**

Changed

**11/25 “snow rich years, such as 2013-2014”.**

Changed

**11/28: “In this study, we have investigated”**

Changed

**11/29: “using a distributed degree-hour melt model”**

Changed

**11/34: “. The ablation...”**

Changed

**12/7: “MacDonell et al.”**

Changed

**12/8-9: “off-glacier air temperature measurements to the glacier boundary-layers”**  
**This sentence is not clear and you did not analyze the regional scale. For a comparison to a regional scale maybe you can use results from (Mernildet *al.*, 2015, 2016).**

We clarified and addressed this point.

**12/15: I am not sure if the groundwater flow is depleted in summer.**

As referee 1 suggested we introduced changes in this topic, adding more literature discussion.

**12/18: What is your source for those numbers?**

We added a reference for SST

**12/20: “Carrasco, 2005”**

Changed

**12/23: “In the long term”**

Changed

**12/17-23: These are not conclusions from your study. They sound more like a discussion. Please move or restructure.**

Moved to discussion

**12/29: “thank”.**

Changed

**12/35: add volume and page numbers**

Added

## **TABLES**

**Table 4: Are those max and min values daily values?**

Yes. We added this in the explanation

## **FIGURES**

**Figure 1: Please move A to the left and refer to the letters (A, B and C) in the caption (instead of upper left, etc).**

Changed

**Figure 2: Add letters to the panels and refer to wind speed and relative humidity in the caption.**

Added

**Figure 4: Can you split this plot in several hours? similar to figure 7 in (Petersen and Pellicciotti, 2011). It would be interesting to observe the diurnal cycle of wind directions and when is the katabatic flow disrupted.**

Changed

**Figure 5: Can you add other reference elevations? For example, the ELA or the altitude of the AWS2.**

Added

**Figure 6: Why do you cut this plot in December? Please see main comment 2.**

We changed the extension. See General comment 2).

**Figure 7: “latent and sensible heat fluxes”.**

Changed

**Is there a reason why the incoming shortwave radiation changes so sharply around January 23?**

There is not a clear reason so we preferred discarding this data. See General comment 2).

**Figure 8: Another panel showing the differences between these two panels would be very informative.**

We added a new panel with these differences. We also indicated how much corresponded to ice melt and how much corresponded to snow melt on the glacier.

**How do you calculate ablation for October and November 2009 if you do not have the air temperature lapse rates for that month?**

We assumed the same lapse rate observed in the common period. We clarified this in the manuscript.

**Figure 9: Why don’t you show results for S1?**

Result from S1 are showed in Fig. 6

**Why don’t you show results with an uncertainty range as in Figure 6?**

We only plotted results from one DHF (0.38 mm w.e. h<sup>-1</sup> °C<sup>-1</sup>). However we added both result to show the uncertainty range.

**Figure 10: If you discarded it, don’t show the HydroChile data after the earthquake.**

Done

**Add the correlation coefficient you calculated in lines 9/11.**

Added

**Figure 12: “and the HydroChile station”**

Changed

