Review for Hydrology and Earth System Sciences

Title: Assessing glacier melt contribution to river runoff at Universidad glacier, central Andes of Chile

Authors: Bravo, Loriaux, Rivera, Brock

PAPER SUMMARY AND RECOMMENDATION

Bravo et al. estimate the runoff contribution of Universidad Glacier (~34°, central Chile) to the upper Tinguiririca River catchment (outlet at 560 m asl) during the austral summer 2009-10. The authors use a set of meteorological, glaciological and hydrological measurements to run a point-scale energy balance model and to calibrate a degree-hour model, which is later used to calculate melt over the entire glacier extent. The authors find that glacier melt rates are extremely high (>10 m w.e.) at the glacier terminus and that the runoff contribution of the glacier represents a 10-13% of the summer runoff of the upper Tinguiririca River catchment. This contribution reaches almost 20% during late summer (March) with daily peaks of 34%. They also conclude that a temperature-index model provides good estimations due to the availability of on-glacier data, the large observed melt rates and the use of diurnally varying lapse rates.

The topic addressed by this study is appropriate for the scope of HESS. Despite the key hydrological contribution of Andean glaciers to the semiarid catchments of central Chile and Argentina, on-glacier meteorological and hydrological data are still rare and few studies have explicitly simulated melt and runoff from glaciers in this region.

The authors have properly answered to the comments of the reviewers regarding the methodology, which is now very clearly presented. Figures and Tables are of good quality. I do not think that much more work is needed to correct or produce new results. However, I think that the Discussion and Conclusions sections need to be substantially improved. These sections present arguments that are not clearly justified (please see major comments) and there are still many necessary corrections of style and grammar (see technical corrections) before the article is acceptable for publication.

MAJOR COMMENTS

1. Conclusions

Some conclusions are confusing and not all of them are properly supported by the obtained results. The authors might consider restructuring the conclusions based on to the proposed objectives. I copy here the conclusions:

a. "Good agreement was found between melt estimated from degree-hour and energy balance models, and ablation stake and sonic ranger records at the lower weather station site in the ablation zone, supporting the application of a simple temperature-index method of calculating total glacier melt at this location. The degree-hour model was distributed at the glacier wide scale accounting for hourly variations in the local temperature lapse rate, which tended to be shallower during the daytime, when most melt occurs."

This conclusion is very confusing, as it mixes results ("Good agreement was found…") and methods ("The degree-hour model was distributed…"). In my opinion, the most relevant conclusion in this paragraph is that a degree-hour model provides a good simulation of surface lowering at the glacier tongue. This is probably because surface temperature is constantly close to 0°C and negative latent heat fluxes are negligible.

b. "The ablation regime is dominated by incoming shortwave radiation, with highest melt rates occurring during December to February, and is also characterized by high air temperature which is almost continuously positive on the lower ablation zone between November and March. These climatic conditions result in very high melt totals, which exceed 10 m w. e. melt on the lower tongue and are thus greater than melt values reported for other glaciers in central Chile. This is attributed to the relative insignificance of sublimation to total ablation, and the high insolation due to low cloud cover and latitudinal location, combined with predominantly positive air temperature. Melt totals were much lower in the accumulation area due to lower temperatures and persistent snow cover above about ~3800 m."

As incoming longwave radiation was not measured, I'm not sure if the authors can state that incoming shortwave controls the ablation regime. Or what do they mean exactly? That melt correlates to shortwave radiation or that incoming shortwave is the main energy input? Please be more explicit. In fact, at the end of January, incoming shortwave clearly decreases, but the energy available for melt keeps constant (or even increases) (Figure 7). Furthermore, if the regime is dominated by shortwave radiation a good explanation must be provided for the successfully use of a temperature-index model. Would an enhanced-temperature index model (that includes shortwave radiation) improve simulations?

The comparison with other glaciers does not support the hypothesis that melt rates on Universidad Glacier are larger than those on other glaciers of the central region. Only one glacier in the central region is used for comparison (Juncal Norte Glacier), but the simulated period was different (I think that Pellicciotti et al. 2014 used data described in Ragettli and Pellicciotti 2012: only the period December 2008 to February 2009). Furthermore, only one season at each glacier is not enough to provide a meaningful comparison. The hypothesis of large melt rates at Universidad Glacier is interesting, but should be better justified. If this is the case, is Universidad Glacier retreating faster than other glaciers? Has this been observed? Is there any other evidence that supports this hypothesis? Surface sublimation on Juncal Norte is also negligible on the glacier tongue (Pellicciotti et al. 2008).

"Melt totals were much lower in the accumulation area…" This is obvious. Please delete or explain further.

c. "During the late ablation season, in February and March 15 2010, when other runoff sources such as snowmelt become depleted, the daily contribution of Universidad glacier to total runoff in the Tinguiririca reached as high as 34%."

As the authors state that there is a 1 or 2 days of lag between the simulated runoff from Universidad Glacier and streamflow measured at the DGA station (lines 10/15), daily values should not be used to estimate the percentage of glacier contribution. Calculations should be made only at the monthly scale, i.e. the 3rd and 4th column of Table 3 should be deleted.

2. Discussion

a. "Forcing temperature-index models with off-glacier data is problematic due to the depression of near-surface air temperature within the glacier boundary layer (Shea and Moore, 2010) under positive ambient temperature conditions"

Actually, many researchers argue that on-glacier data is affected by the glacier surface temperature and that temperature-index models should be forced only with off-glacier temperature data, because it is a better indicator of ambient conditions. As the authors did not evaluate the degree-hour model using off-glacier data, they cannot state that on-glacier data works better than off-glacier on this glacier.

b. Others comments

The discussion of the uncertainties misses the uncertainty in degree-day factors, which is actually very large. Figure 12 shows that the uncertainty in cumulative runoff at the end of the season is about 7±1 m^3 x 10^7, i.e. about 15%. As the streamflow at the DGA station is very large, this uncertainty is translated as a small percentage of total streamflow (10-13%). Hock (2003) provides a table with a large range of values, how did the authors choose the range between 7 and 9 mm d-1? Did they do some previous tests or used another reference? Another important missing source of uncertainty is the calculation of the snow line from MODIS.

The authors should add a discussion about the shortcomings of using a temperature-index model in relation to a more physically-based model. This is one of the aims proposed by the authors (number 2) Do you think that the degree-hour model could be missing something important? Maybe shading effects? Radiation fluxes? Is the model appropriate to simulate long-term mass balance or should only be used to simulate ablation at the glacier tongue?

Please include in the discussion the influence of debris-covered areas on the glacier tongue. Are the large observed melt rates substantially reduced by the thermal insulation of debris? Maybe those values above 11 m are not realistic?

MINOR COMMENTS

The Introduction could benefit from a better structure in which climate, hydrology and economic characteristics are separately described.

Please check the use of terms "runoff" and "streamflow". I think that they are not the same: Runoff is the portion of precipitation or melt that does not infiltrate or evaporate. Streamflow is the runoff of surface water through a channel.

2/22: Why is 40°S important?

2/27: "To address some of these issues", which ones? Please be more specific or delete.

2/29: what do you mean by "surface controls"?

2/35: Section 1.1? This section numbering is odd. I wouldn't use 1.1 if there is not a 1.2.

3/10: Did you observe penitentes on the glacier? These could be an indication of non-negligible sublimation.

5/24-25: This should be included in the discussion. Maybe total ablation values larger than 11 m w.e. are not realistic.

7/26: Please add the value that you calculated for the slope from Aster.

8/6-8: Please explain better the procedure to calculate k. What value do you obtain? Do you use the water level sensor to calibrate it?

8/13-17: What did you find at AWS2? Is this station more influenced by free atmospheric flow? Is there a predominant wind direction?

8/24: This section should be moved to 3.3, i.e. after presenting results from the EBM.

9/6: "Incoming shortwave radiation …" but you did not measure the incoming longwave radiation.

12/7: Please be consistent in these comparisons. You are not comparing melt rates (which should be given in units of time), but total melt amounts. However, these total melt amounts are not really comparable because they were calculated for different time periods (Juncal Norte Glacier: December-February, Phichillancahue Glacier: January-March, Universidad Glacier: October to March). Is melt at Universidad Glacier really larger than at the other glaciers of the region? Please see main comment 1b.

13/29-30: “The potential for hydropower…” This sounds like a study site description.

13/31: “More studies…” What type of studies? or do you mean more long-term stations?

Figure 8: The description/discussion of this figure is very short.

Figure 11: Consider deleting this figure or extending its description/discussion. The authors state that it shows an efficiently channelized drainage system, but it is not clear from the figure. Maybe you can add a comparison of calibrated k values with those from other glaciers?

TECHNICAL CORRECTIONS

Please correct systematically throughout the paper the use of capital letters for glaciers and rivers. Universidad glacier -> Universidad Glacier, Tinguiririca river -> Tinguiririca River. In the revision statement, the authors state that they have done that, but they did not (e.g. in the title).

1/11: melt -> glacier ablation (you also analyze surface sublimation)

1/12: Here and throughout the article: Universidad glacier -> Universidad Glacier

1/12: Here and throughout the article: Tinguiririca river -> Tinguiririca River

1/14: ->distributed temperature-index and runoff routing model (delete melt)

1/14: Please check the grammar of this long sentence or split it in two. “meteorological measurements” are not used to “compare total model modelled glacier melt to river flow measurements”. “meteorological measurements” are only used to drive the melt models.

1/18: delete “a contribution”

1/19: total runoff -> streamflow at the outlet of Tinguiririca River Basin

2/2: Please check with the native English speakers (I’m not) in the author’s list the use of “which”. I think that it is not used correctly in this sentence.

2/13: Same as in 2/2.

2/13: on -> for the

2/13: “current future”?

2/17: “in the glacier ablation zone” -> “on …”

2/30: across -> during?

2/34: Tinguiririca

2/38: November to January -> November and January

3/2: Consider to remove “lower”, or is there an “upper tongue”?

3/18-19: Consider to remove the sentence in the parenthesis.

3/26: -> “on the ablation zone”

3/27: -> “on the accumulation zone”

3/34: -> “on the ablation zone”

4/8: “We used the…” for what? Check the grammar.

4/9: using “a regression”?

4/12: What is the resolution of Aster GDEM?

4/14: altitude -> elevation

4/16: We have used -> We used. Please be consistent with the verb tense.

4/31: “calculated ice melt”

4/34: Consider to replace “a” by “M”.

5/14: Fig 2 -> Fig 3?

5/15: over an average day -> on an average day?

5/18: Please consider the use of this wording: “While the LR minima are likely to be related to …., the afternoon maxima are potentially caused by the erosion …”.

5/22: “we distribute air temperature”

5/28: “Check grammar: “We restrict use of data only up until this date”.

5/29: occurs -> occurred.

5/34: “and, as summer precipitation amounts are small, ”

6: If I checked correctly, terms P and e_sat were not explained.

6/7: Is k the same as k_0?

6/9: Where -> where

6/9: “Finally,”

6/11: Delete the “,”.

6/14: add “where”

6/24: The reference to Hock (2005) is not necessary for that equation.

6/25: Mention that only positive Ψ values are used for that equation.

6/29: Add “where”.

7/9: You already described z.

8/2: Consider: “At each grid cell and time step, glacier melt obtained with the ….”.

8/10: Consider to reduce the section title. “Meteorological and snow conditions” should be enough.

8/11: Please consider something like: “During the period December-March, air temperature is almost constantly above 0°C at AWS1, but it shows more frequent negative nocturnal values at AWS2.”

8/13: “variability, but hourly values”.

8/22: Please check the term “high cloud cover”, it might be misunderstood as high in elevation.

8/25: “compared to melt”

8/31: Delete: ”between 0.29…”.

8/35: “in the range of the values estimated by…”

9/19: -> “similar to those at the end of October”.

9/25-26: “At the hourly scale, water discharge estimated…”

9/26: Consider: “the values derived from the water pressure sensor”.

9/35-36: “between 50% and 66%” (delete “the”).

10/3: Delete “Mean total”.

10/10: “After the peak in runoff” (delete “the”).

10/19: “from glaciers in the central region of Chile”.

11/11: “becomes depleted” -> “depletes”.

11/14: missing space after Tinguiririca.

11/18: Is this information relevant if the trend was not significant?

11/18-22: Check grammar or split.

11/24: “wheter” -> “whether”. Furthermore, if you use “whether”, then you need to provide two

alternatives.

11/29: “for e.g.”?

11/35-36: Move this to the Introduction or to the Study area.

12/23: estimate -> estimated.

12/34-36: Please split this sentence. It is too long and difficult to follow.

12/34: You didn’t really investigate the “climatic conditions”. This would require a long time series.

13/7: “greater than melt values reported for other glaciers in central Chile”.

13/13: “will be” -> “should be”?

Figure 1:

19/2“Location of Universidad Glacier” (delete “the”).

19/2: delete “entire”.

19/4: “indicates the locations of stream gauge”?

Figure 2:

“Hourly time series of observed meteorological variables”.

Figure 3:

“of hourly lapse rates”.

“upper and lower box limits”

Figure 5:

Indicate the date of the ASTER image also in the caption

Figure 8:

c) difference of panels a and b.

Figure 10:

“and the HydroChile…”

Figure 11:

“estimated from the pressure sensor”.

Figure 13:

Delete “for reference”.