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Climate of the Past Discussions

Interactive comment on "Glacier equilibrium line altitude variations during the "Little Ice Age" in the Mediterranean Andes (30°–37° S)" *by* Álvaro González-Reyes et al.

Anonymous Referee #1

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General comments (overall quality)

This manuscript is an innovative research on the ELA evolution in the Mediterranean Andes (MA) during the 1500-1850 period. Past ELA modelling, including Little Ice Age (LIA) readvances, are scarce in the MA so this could be a significant contribution. The ELA reconstruction is based on state of the art, enhanced-temperature index model, adjusted with available ELA data and run with the input of three GCM. The model setup and data input are adequately described.

Nevertheless, I think the climate-ELA relationship for this region is excessively simplified. The ELA is a glaciological parameter, not a climatological one. Although it can,

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and has been approximated with climatic analysis, it should always relate to glaciological observations (i.e.: glaciological mass balance, end-of–summer snowline, geomorphological evidence...). Accumulation and ablation are driven by climate but also strongly controlled by a large set of factors (glacier size, shape, dynamics, geomorphometry, climatic regime). In particular, I consider that the modelling exercise of this manuscript is loosely adjusted to four ELA observations in the largest and thus non-representative glacier of the MA for calibration, and to one for validation. If this point is not addressed I do not see how the conclusions can be generalized to a vast geographic domain encompassing thousands of very different ice masses.

More generally, the ELA should be considered with some caution in this region where, since the pioneer studies, it was acknowledged that some of these glaciers act as reservoir glaciers so the ELA can be, depending on the years, entirely over or under the existing glaciers (Lliboutry, 1965). This large variability, mostly attributed to precipitation (Rabatel and others, 2011; Masiokas and others, 2016; Farías-Barahona and others, 2019) might explain why some of the longest glaciological mass balance series do not provide information of a key glaciological variable such as ELA (Escobar and others, 1995; Leiva and others, 2007).

Therefore, I consider this manuscript should undergo major revisions prior to publication. For this I propose two alternatives. Either a larger set of calibration and validation data is produced/compiled, which is more according to the vast geographic domain proposed by the authors, but it might be out of the scope of this research piece. Or the modelling effort and its conclusions should be narrowed to an area or a set of glaciers where an acceptable calibration/validation data set exists.

Specific comments

Regarding calibration, only four ELA observations are provided for one glacier (Universidad) and they do not seem to fit the modelled data very convincingly (Fig A1), with 3 out 4 observations falling outside of the modelled error bars and errors being not systematic. These differences range from almost nothing to hundreds of meters, which is even more disturbing, considering that Universidad is the largest glacier in the region and the several thousand other glaciers have a much lesser size and elevation range (Barcaza and others, 2017; Zalazar and others, 2017). There are some additional glaciological mass balance observations series in the MA (i.e: WGMS, 2017) and, although little ELA information is provided, more could be done to use available data. For instance, the longstanding Echaurren Norte data could be used to verify if modeled ELA follows measured mass balance since 1978. Additionally, end of summer snowline elevation for some glaciers could be used to validate modelled ELA of the past decades. This would provide a more robust estimation of the ability of the model to capture the current ELA behaviour over the entire target region (MA). Only once this is first step is achieved, is it worthy to try and reconstruct former regional ELA.

Also, while enhanced temperature-index might be suitable for large temperate glaciers in the Central Andes (31-35°S), where sublimation accounts only for 1-6 % of ablation (Pellicciotti and others, 2008; Kinnard and others, 2018), it does not appear suitable for the smaller cold glaciers both in the Central and Desert Andes (19-31°S) where sublimation can account for 80 % of ablation so energy balance approach should be used instead (Pellicciotti and others, 2008; MacDonell and others, 2013; Kinnard and others, 2018). Further, mass balance observations in the Desert Andes show little dependency of ablation and accumulation to elevation (Rabatel and others, 2011 in particular fig 6) so the use of vertical gradients to account for this processes is a major simplification which could lead to important uncertainties, especially in smaller glaciers. It also raises questions as to how to estimate ELA when it is not directly observed on glaciers.

Regarding the validation, one possible approach could be to compare past modelled ELA with geomorphologically-derived ELA in some sites. Medium altitude of present glacier (Leonard and Fountain, 2003) and highest elevation of lateral moraines of past glaciers could also be used as climatic ELA proxy for LIA glacier extent. Dated moraines were used to constrain climate modelling for the LGM (Zech and others, 2011). Of course the main limitation, as mentioned by the authors, is the lack of late neoglacial chronologies in the region (i.e. dated moraines) for the 1500-1850 period. But, without them, it is hard to assess the performance of the ELA reconstruction and thus the validity of the ELA behavior analysis during the LIA.

Technical corrections

Line 475. Include the chapter tittle in the Kinnard et al 2018 reference. This is a key reference and only the book tittle is given.

Figure 2. Please indicate what the boxes, dashed lines and circles indicate (percentile confidence intervals?). Include this information in the other box plots of the manuscript (Figs A1 and A2).

Figure 3. According to recent inventories, modern medium elevation (climatic ELA proxy) for all debris free ice masses of MA is close to 4300 m asl, ranging from over 2400 to over 6500 m asl. This figure does not accurately represent the present value or the large variability of probable modern ELA.

Figure A1. This is important calibration data and should be moved to main section.

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