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The Cryosphere Discussions

Interactive comment on "Glacier changes in the Pascua-Lama region, Chilean Andes (29° S): recent mass-balance and 50-year surface-area variations" *by* A. Rabatel et al.

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Anonymous referee #1 comment:

1.- Lack of sufficiently long time-series to compare to the PDO. The authors establish a statistically significant link between measured precipitation and mass balance. The PDO link could be tested if statistics were given for the relationship between PDO and measured precipitation. Please do not restrict the analysis to a linear trend, which is the most used statistics in this paper. If it is an oscillation, a sinusoidal function might be a better fit.

Authors reply:

The disussion about the link between glacier changes over the last fifty years and the PDO has been completly modified, according to comments made by both referees and by Mauri Pelto.

Anonymous referee #1 comment:

2.- Mixing of metrics. While mass balance can be a direct reaction to climate forcing, surface area change would need to be converted into volume (and therefore mass) if a stronger case is to be made. The authors indicate that there is a large variation in ice depth between glaciers and glacierets, therefore a same surface area variation reflects a very different mass change in every case. The same climate forcing may induce very different area changes depending on ice thickness, and therefore they are not directly comparable. Relative surface area is strongly dependent on the initial area and very biased toward small glacierets. For example, a hundred percent surface area loss in a 0.1 squared units glacieret is only a 10% loss for a glacier of 1 squared unit, averaging both, as it is done in the paper, would give a 55% surface area loss which is meaningless.

Authors reply:

This has been changed, in the abstract as well as in the text. As encouraged by the referee we now mention the total area loss with respect to the total initial area: "which shows that the total glaciated surface area reduced by about 29% between 1955 and 2007."

Anonymous referee #1 comment:

3.- Poor description of the methodology to deal with a complicated surface such as snow penitents. A map or sketch of ablation stakes distribution would help. Pelto (2000) has shown that sampling density may affect glacier mass balance determination. It would be interesting for the reader to get an idea of how the glaciers were sampled.

Authors reply:

A new figure has been added (Figure 3 A and B), showing the ablation stakes distribution on Guanaco Glacier and Esperanza, Toro 1 and Toro 2 glacierets. "Figure 3: A) Guanaco Glacier with the location of the ablation stakes, the AWS and a qualitative delineation of area with/without penitents and area with a thicker snowpack. B) Same for Esperanza, Toro 1 and 2 glacierets. Note that most of Toro 1 and 2 lower parts are debris-covered."

Anonymous referee #1 comment:

Long ago LaChapelle (1959) indicated potential errors derived from ablation stakes. On these glaciers the surface is covered by penitents, which are caused by differential ablation, therefore a small displacement of the ablation stakes may render very different results. Ablation has a minimum on the penitent's peaks and a maximum on the troughs. How was this measured?

Authors reply:

In the third section "Method and Data", a sentence has been added to describe the measurements made on the penitents and the stakes located in a penitent field: "For the areas where penitents can be found, several morphological parameters of the penitents are measured, such as: the size of the blade (length and width), the distance between two blades and the distance between the hollow and the foot of the stake (Figure 4)." A scheme was also added (Figure 4 in the new version). "Figure 4: Simplified scheme showing the measuremets realised on the penitents themselves and the ablation stakes located in an area with penitents."

Anonymous referee #1 comment:

At what point was the stake considered to be representative of average ablation? How the actual ice volume loss was calculated? How many measurements of penitents' height and separation were made? What is the likely resulting error in the estimation? This does not seem to be a trivial problem, yet there is no information on how it was

tackled. Any solution to these measurements problems would be highly appreciated by other workers in the region and will be a welcome contribution to future campaigns

Authors reply:

As mentioned in the text (section 4.1.5): "Comparison of measured summer ablation and penitent height at 28 ablation stakes on the six ice bodies showed a significant correlation (r^2 = 0.64, p<0.01) between these variables." So the stake measurements are considered to be representative of ablation in the penitents field. However, such a type of measurements on penitents are only realized since 2006-2007. They were initiated by CEAZA. For the mass balance calculation, as specified in the "Method and Data" section: "The ice body surface area was subdivided manually to allocate each stake a portion of glacier surface for which it was deemed representative. This surface area division was carried out primarily on the basis of elevation, with additional consideration of where transient snow cover, penitents or debris cover were persistent surface features." The resulting errors is hard to quantify, because the shape/size of the penitents, their density/distribution vary strongly from one place to another at the glacier surface.

Specific points

Anonymous referee #1 comment:

2308.11: Abstract. "bodies have lost 44 $\pm$ 21% of their 1955 surface area" This is the arithmetic mean of individual area losses. This is biased toward small glaciers, where a small absolute change results in a very large relative change. As indicate above, please attempt a volume calculation, or at least give the total area loss with respect to the total initial area, not the average of individual ice bodies. The actual figure is closer to 21%.

Authors reply:

This has been changed, in the abstract as well as in the text. As encouraged by

the referee we now mention the total area loss with respect to the total initial area. The volume lost calculation would be possible using photogrammetry, but unfortunatly, flight parameters and cameras calibration are unknown for the older aerial photographs (1955-56 and 1978). Computing the volume from an area/volume relationship would not bring a good estimation of these ice bodies volume. Nicholson et al. (2009) have shown in Figure 2 that Marangunic relationship linking surface and thickness (1979) is not relevant for the cornice glacier type of the Pascua-Lama region.

Anonymous referee #1 comment:

2308.22: What is the "Arid diagonal"?

Authors reply:

This expression define one of the Earth's driest region. It is commonly used in papers dealing with glaciology, hydrology and climatology in this region. However, the wording has been changed to be more explicit and a reference was added: "the so-called "South America Arid Diagonal" (23-28°S, Schwerdtfeger, 1970)."

Anonymous referee #1 comment:

2308.22: What is an "'apparent' limit of glaciation"

Authors reply:

The sentence: "and coincides with an apparent northerly limit of glaciation in Chile" has been removed since its meaning appears difficult to understand.

Anonymous referee #1 comment:

2308.23: "almost absent". Masiokas and others (2008) indicate the existence of glaciers in the Copiapo River basin (28°S) and further north.

Authors reply:

You are right, it is true that few ice bodies can be found north from our study area.

Consequently "almost absent" has been replaced by "scarce".

Anonymous referee #1 comment: 2308.25: The nearest study site is probably Cerro Tapado, which is not mentioned at this point, and where mass balance have been derived from ice cores (Ginot et al 2006), as indicated later in 2309.16

Authors reply:

We are talking about glacier mass balance measurements. There was no direct mass balance monitoring on Glacier Tapado before CEAZA develop an ablation stakes network there in 2008. That's why the ice core made on the Cerro Tapado is not mentioned at this point of the Introduction.

Anonymous referee #1 comment:

2309.25: Please specify "ice flow" also in 2310.10

Authors reply:

It has been done.

Anonymous referee #1 comment:

2311.14: Escobar and Aceituno (1998) report a link between precipitation and ENSO, and more specifically El Niño 3. Yet the text seems to be using ENSO and PDO indistinctly.

Authors reply:

The PDO has been removed from this sentence.

Anonymous referee #1 comment:

2311.15 "Automatic weather stations (AWS) operated within the Pascua-Lama mine site show that temperature seasonality is linked to the annual cycle of solar radiation intensity" This seems to me a very convoluted way of saying that it is warmer in summer. Please improve readability.

Authors reply:

This sentence has been reformulted as follow: “Automatic weather stations (AWS) operated within the Pascua-Lama mine site show the seasonality of temperature with warmer temperature during summer, i.e. Dec.-Jan.”

Anonymous referee #1 comment:

2312.19 This is addressed in the main points, but please explain which criteria was used to select the area, and give a map or scheme of the stakes distribution.

Authors reply:

The criteria are mentioned in the text: “This surface area division was carried out primarily on the basis of elevation, with additional consideration of where transient snow cover, penitents or debris cover were persistent surface features.” As mentioned before, a map presenting the ablation stakes distribution was added (Figure 3 A and B, see a previous answer).

Anonymous referee #1 comment:

Is there runoff from these glaciers? If so, is there an estimation of how much water is lost? What percentage of melting refreezes and what exits the system. The portion that refreezes does not alter the mass balance, and for all the ice bodies to be cold ice the amount of refreezing should be limited.

Authors reply:

Yes, as mentioned at the end of the Introduction: “The contribution of glacier ablation to the hydrological regime of the watershed is examined by Gascoin et al. (this issue).” As a consequence, we ask the reader to refer to this companion paper. Furthermore, the discussion about sublimation/melting and comparison with runoff measurements is the main topic of the forthcoming paper dealing with surface energy balance measurements.

Anonymous referee #1 comment:

2318.2: “They also suggest that high intensity of radiation for near-infrared and infrared wave-lengths are crucial at the start of penitent growth;” Bergeron and others (2006) made a slightly different statement: “Filtering the light or creating wind eliminates penitente formation in our experiments. The absorption of light by snow is much higher for near-infrared and infrared wavelengths than for other spectral regions[13]; therefore, the intensity of these wavelengths controls the ablation rate. Selectively filtering out infrared wavelengths inhibits penitente formation in our setup. Similarly, using a fan to provide a steady breeze of 2.5 m s-1 over the snow surface eliminates penitente production.” Please be more accurate with quotations. Did you also observed that a steady breeze of 2.5 m/s eliminates penitent production?

Authors reply:

Our quotation of Bergeron et al. 2006 has been revised according to your remark. Yes we observed that no penitent is formed at the level of the AWS on Guanaco Glacier were the average annual wind speed is about 6 m s-1. The following sentence as been added: “It is particularly the case at the level of the AWS; where high wind (anual average of 6.4 m s-1 for Guanaco Glacier) prevents penitents production; in agreement with results obtained by Bergeron et al. (2006).”

Anonymous referee #1 comment:

2318.3: “these wavelengths are likely to be higher at the boder of the ice-bodies due to a larger emission from heated surrounding rocks (e.g. Francou et al., 2003).” The contribution of the surrounding rocks to the thermal infrared is likely, the contribution to the near-infrared is unlikely if we are to believe Planks Law at the temperatures registered in this site.

Authors reply:

You are right, this sentence has been reformulated: “They also suggest that high in-

tensity of radiation at thermal infrared wavelengths is crucial at the start of penitent growth; irradiance at these wavelengths is likely to be greater at the borders of the ice bodies due to a larger emission from surrounding rocks".

Anonymous referee #1 comment:

2318.9: "by creating and maintaining conditions more favourable to melting, the presence of penitents could partly explain the more negative summer mass-balance on the glacierets." Which fraction of that melting refreezes?

Authors reply:

It is very hard to quantify at the glacier scale. It depends if the water is trapped between the penitent blades or if it can runoff. If the water is trapped, the whole amount can refreeze (except the portion that evaporated).

Anonymous referee #1 comment:

2319.3: "Glacierets consistently experienced a greater percentage surface-area loss over all the periods than glaciers." This might be simply a consequence of their initial smaller surface area.

Authors reply:

As mentioned in the text, it should also be a consequence of larger ablation, as shown by field measurements.

Anonymous referee #1 comment: 2320: The whole PDO discussion would benefit from an statistical analysis of measured precipitation near Pascua Lama. The time series of Guanaco is far too short, and although it supports the correlation with Echaurren is not conclusive. 2321.3: "Since precipitation is driven by the PDO" This is a rather bold statement. Is it really driven by, or simply correlated?

Authors reply:

All the discussion about the PDO has been removed. As encouraged by the referee, the PDO has been replaced by Nino3 index in the Figure 11 of the current version.

Anonymous referee #1 comment:

2321.21:"temperature reanalysis data present a slight, but not statistically significant, positive trend" 2321.24:"we observed that the highest summer temperature anomalies (2003 and 2006) are associated with the positive annual mass balances observed on Pascua-Lama ice-bodies." 2322.3:"However, if the trend of rising summer temperatures is confirmed in the next decades, the increase in melting at glacier surface could increase the mass loss and consequently the rate of glacier retreat in this region." These three statements seem to contradict each other. If there is no statistically significant trend, what trend is there to follow? And if highest temperature anomalies are associated with higher positive mass balance, why an increase in temperature in the next paragraph will bring about mass losses?

Authors reply:

The last sentence (2322.3) has been removed as it was confusive and conjectural.

Anonymous referee #1 comment:

2322.24 It would be fair to stress in the conclusions that the comparison with Echaurren is based on a very short time-series.

Authors reply:

It has been done. This point of the conclusion is now: "Although based on a short time-series, the mass balance record of Echaurren Glacier shows notable similarities to mass balance of Guanaco Glacier"

Anonymous referee #1 comment:

2324.1: Favier et al. (2009) Please give the correct title of the final published paper

Authors reply:

Done.

Anonymous referee #1 comment:

Figure 4 is too small, it is illegible in print form.

Authors reply:

The size of this figure (now Fig. 6) has been modified.

Anonymous referee #1 comment:

Figure 7. Please revise area loss after calculating total area percentage. Please consider a comparison with ENSO index, and specially El Niño 3 rather than PDO

Authors reply:

This has been done.

Anonymous referee #1 comment:

Please add a figure with map or sketch of ablation stakes distribution

Authors reply:

The location of ablation stakes on glaciers Esperanza, Toro 1, Toro 2 and Guanaco has been added on the new map: Figure 3 A and B (see a previous answer).

Interactive comment on The Cryosphere Discuss., 4, 2307, 2010.

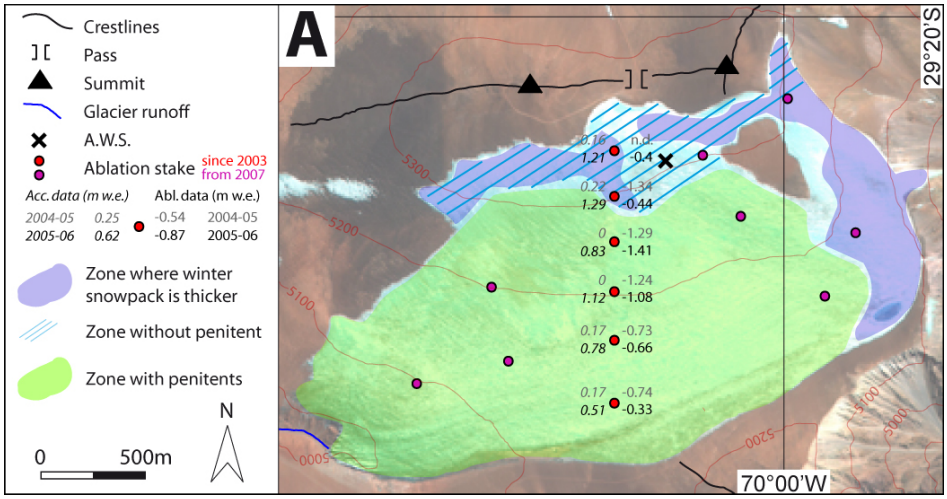

Fig. 1.

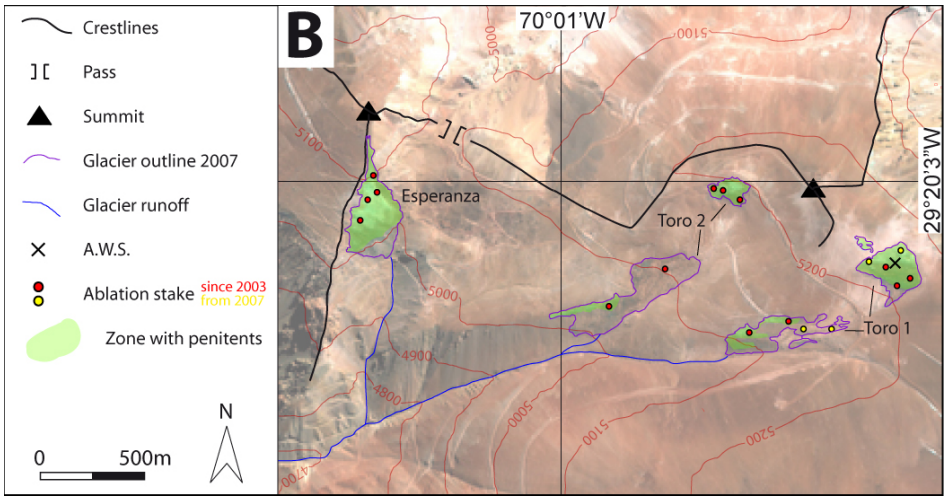
Crestlines
Pass
Summit
Glacier outline 2007
Glacier runoff
A.W.S.
Ablation stake since 2003 from 2007
Zone with penitents
N
0
500m
B
70°01'W
29°20'3"W
Esperanza
Toro 2
Toro 1
5100
5000
4900
4800
5200

Fig. 2.

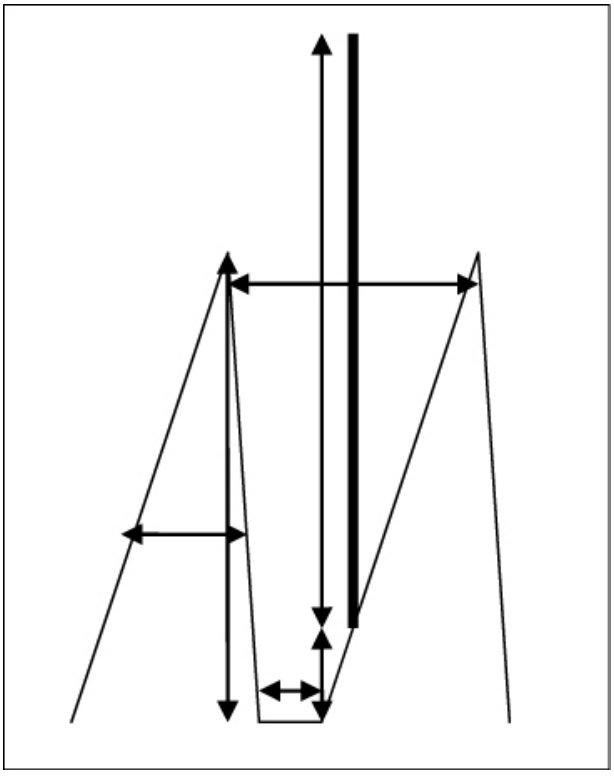

Fig. 3.