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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.

**Anonymous Referee #1**

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This paper presents several years of glacier mass balance studies in Northern Chile. The authors identify a climatic setting common to a large region of the Cordillera and attempt establishing a a link between the Pacific Decadal Oscillation and glacier mass balance. The link with ENSO or PDO is worth investigating, as it may provide a useful predictive tool. This would be valid not only for glacier mass balance but also for snow precipitation and later infiltration and runoff that will affect water availability in a very dry region.

There is a general lack of glaciological studies in the Andes, and therefore new contributions should be welcome. The paper under discussion adds valuable data, collected



over six years, both in summer and winter. It describes a rather well monitored site, which is complemented by additional precipitation data. Readers in other latitudes may no be aware of how rare these data are for the Andes Cordillera. However some conclusions are rather speculative and the presentation needs some clarification.

**General points**:

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.

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.

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.

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? 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

**Specific points**:

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%.

2308.22: What is the "Arid diagonal"?

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

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

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

2309.25: Please specify "ice flow" also in 2310.10



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.

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.

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.

2310.20: "All these ice-bodies are comprised of cold ice and are thought to be cold-based throughout;"
2314.13: "(i) ablation occurs by both melting and sublimation;"
2314.23: "melt water from diurnal fusion refreezes during the night and superimposed ice is accreted to glacier ice and snow."

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.

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? Are the laboratory settings comparable to your field site?

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. "border" instead of boder.

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?

2318.16: See 2308.11

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.

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 is really driven by, or simply correlated?



2321.21:"temperature reanalysis data present a slight, but not statistically significant, positive trend"
2321.24:"we observed that the highest summer 25 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?

2322.20 44% See main point 2.

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

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

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

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.

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

**References**

Bergeron, V., Berger, C., and Betterton, M. D.: Controlled irradiative formation of penitents, Phys. Rev. Lett., 96(9), 098502, doi:10.1103/PhysRevLett.96.098502, 2006.

Escobar, F. and Aceituno, P.: Influencia del fenómeno ENSO sobre la precipitación nival en el sector andino de Chile Central durante el invierno austral, Bull. Inst. Fr.

Etudes Andines, 27(3), 753–759, 1998.

Ginot, P., Kull, C., U. Schotterer, U., Schwikowski, M and Gäggeler, H. W. 2005. Glacier mass balance reconstruction by sublimation induced enrichment of chemical species on Cerro Tapado (Chilean Andes). Climate of the Past 2(1): 22-30.

LaChapelle, E. 1959. Errors In Ablation Measurements From Settlement And Sub-Surface Melting. Journal of Glaciology 3(26): 458-467.

Masiokas, M., Rivera, A., Espizua, L. E., Villalba, R., Delgado, S. and Aravena, JC. 2009. Glacier fluctuations in extratropical South America during the past 1000 y.ears. Palaeogeography, Palaeoclimatology, Palaeoecology 281(3-4): 242-268

Pelto, M. S. 2000. The impact of sampling density on glacier mass balance determination. Hydrological Processes 14(18): 3215–3225

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