

Review for egosphere

Title: Unseasonal atmospheric river drives anomalous summer snow accumulation on glaciers of the subtropical Andes

Authors: Bravo, Cisternas, Viale, Paredes, Bozkurt, García-Lee.

PAPER SUMMARY AND RECOMMENDATION

Bravo et al. analyse the impact of an unseasonal atmospheric river (AR) on the annual mass balance of Olivares Alfa Glacier, subtropical Andes of Chile. The AR occurred at the end of January 2021 and resulted in a strong precipitation event over central Chile, which is very rare to occur during the austral summer. The authors conducted their analyses using remote sensing products, meteorological observations, and energy and mass balance models. They found that the event produced an accumulation of 164 mm w.e. (measured near the glacier tongue) and lowered the altitude of the 0°C isotherm from typical summer values of 4000-4500 m a.s.l. to 3000-3500 m a.s.l., as well as lowering the snowline to elevations of about 2500 m a.s.l. The authors propose that the annual mass balance of Olivares Alfa Glacier was close to neutral because of the AR and other factors. A statistical analysis based on results for previous seasons indicate that without the event the annual balance of Olivares Alfa would have been negative (between -0.5 and -2.5 m w.e., approximately).

This is the second version of an article that I already revised with positive comments. I had three major comments. I am satisfied with the responses provided by the authors except for a few details that need more clarification in the article. I also have a second round of suggested text changes to improve clarity and flow.

UPDATE ON MY MAJOR COMMENTS

1. How rare was this event on glaciers?

Thanks for the new analyses. The exceptional occurrence of the event is now much more evident.

2. Mechanisms that explain the mass balance change

In the revised version, the authors state that (496-498) “It is important to remark that the impact is not solely from the event itself. Two small accumulation events in February and March (Fig. 7b), combined with relatively low air temperature during these months (Fig. S5) reduced the ablation rates towards the end of the hydrological year (Fig 7c)”.

I appreciate that the authors have extended the possible causes that explain the near-neutral mass balance to causes other than the accumulation from the AR. Please add a similar (maybe shorter) statement in the Conclusions and Abstract. I don’t want to reduce the impacts of your findings, but I find these considerations very important.

Moreover, I think it must be clear in the article that, although the event was remarkable and with large impacts across Central Chile, the snow accumulation during the event (0.16 m w.e.) was relatively small in comparison to the typical annual ablation (between 1 and 4 m, Figure 7c). This is why I think that apart from the accumulation (which I agree is remarkable for summer), the increase in surface albedo due to the fresh snow, plus the small events that came later, plus the low temperatures are all responsible for the neutral mass balance.

3. Hypothetical scenario (“no event”)

Thanks for explaining this exercise more in detail. I see now more clearly what the analysis was, but I think that the methods require a few more clarifications:

212-216: “To further evaluate the impact of this unseasonal precipitation event, we **also simulated** the 2020/21 hydrological year's mass balance under a hypothetical scenario without the AR's influence, removing the accumulation attributed to the summer-2021 AR. To complete the last two months of the 2020/21 hydrological year, the mass balance time series from previous similar years (i.e., **those years with negative mass balance until the end of January**) were decomposed to extract the trend for each year (Box et al., 2015). Then, the 2020-2021 mass balance series was detrended, and **the average, maximum, and minimum trends** derived from previous years, were applied to the analysed hydrological year to hypothesize a scenario range without the occurrence of the AR.”

- “we also simulated”: To be fair, you didn't perform new simulations, you use the results from previous years. Please rephrase as it now suggests that you used COSIPY to perform new simulations.
- “those years with negative mass balance until the end of January”: How many years are those, only three? Please mention them explicitly.
- “the average, maximum, and minimum trends”: Figure 8 shows values of “sigma”, is that a standard deviation calculated from only three curves? Did you use standard deviation or a minimum and maximum?

MINOR COMMENTS

- Use of the word “rate”

The article uses the word “rate” many times, but I think that it is sometimes superfluous and in other times misleading. Please check the use of this word throughout the article. It seems that many times the authors refer to precipitation totals and not really “a rate”, in the sense that can be understood as an hourly or daily rate. I would say that the important feature of the article was the amount of precipitation and not really a rate, or do the authors refer to a particular hourly or daily rate?

- Figure 6

Do these fluxes correspond to the location of the AWS or are averaged over the entire glacier? My guess is that they correspond to the location of the AWS because the snow seems to disappear very quickly. If that is the case, then please reword the caption to: “Glacier energy balance fluxes estimated by COSIPY at the location of the AWS.”

46: citations?

46-48: This knowledge gap contradicts what you asserted in the previous sentence, maybe reword?

48: significance -> magnitude and frequency

144: Historical satellite images -> from 1955? Those would be aerial and not satellite.

248: Citations for this sentence?

252: Is the fact that the AR in January 2021 is a Category 1 somehow unexpected? In the Introduction you mention that Category 1 are mainly beneficial.

446: Why the conditions can't be generalised?

481-482: I don't agree with this sentence. I think that the cold conditions that prevailed during the rest of the summer would have prevented the mass balance to be so negative as in the other years.

FIGURES AND TABLES

Figure 4: Can you indicate the event period here?

Figure S1: Please change the red colour of the ERA5 longwave radiation. It is difficult to distinguish from the black lines.

Table 2: Define the event period in the caption

SUGGESTED TEXT CHANGES

22: glaciers -> basin?

33: Glaciers are highly sensitive to climatic variations and stand as...

34: Glacier mass balance is a metric that is central to their behaviour and is a critical ...

36: Long-term observations, over what period?

37: Delete "However"

37: Embedded in this overall negative mass balance trend there is a large interannual variability in atmospheric conditions that is transferred to the annual mass balance of glaciers.

40: I suggest to reword starting with "The atmospheric interannual variability in the subtropical Andes of Chile and Argentina (between 32S and 36S)..."

42: the Southern Annular Mode....

43: delete "of the subtropical Andes"

44: sometimes -> can

45: modulating annual mass balance -> driving general trends in glacier mass balance

46: modulate -> impact

56: Delete "Notably"

58: Delete "semi-arid"? it is a bit confusing jumping from semi-arid to sub-tropical

59: "about 50%"?

61: "on mid-latitude glaciers" and delete "mid-latitude glaciers" at the end of the sentence.

63: dynamics -> mass balance

65: Suggest rearranging: "...showed that the days with the most intense ablation and largest accumulation rates at Brewster Glacier..."

71: Suggest rearranging to eliminate the commas, maybe: "Conversely, ARs can trigger substantial snow accumulation events on glaciers located above the 0C isotherm."?

73: "mid-latitudes, but can also exert a ..."

80: notably contributing to glacier albedo changes -> largely increasing the albedo

82: in -> on

83 semi-arid -> sub-tropical? Or define both regions? I would try to stick to one only.

85: dynamics -> mass balance

90: enhances -> can help to enhance

90: Central Andes? This could be confusing too.

91-93: Please check the wording and rearrange for a better readability. Viale et al (2018) is cited at the beginning and again at the end.

94: Delete “For example”, this is the main event of the article

96: During the event, precipitation in central-southern Chile exceeded...

100: Join both paragraphs

104: marking the first study analysing the impact of an AR on the mass balance of glaciers in the sub-tropical Andes.

106: contextualise the extraordinariness -> describe the exceptional characteristics

106: unusually large precipitation

133: sanitization -> sanitation?

133: The basin contains...

134-135: Our analyses focused on the the Olivares River sub-basin (coordinates here), which hosts...

136: These glaciers have experienced the largest ice loss... (“most significant” is not technically correct)

141: they have shown -> their surfaces have shown a trend towards darkening since ...

142: We simulate the energy and mass balance of the Olivares....

145: continuous -> larger

146: delete all after “2013”, or why does the loss of area directly indicate fragmentation?

151: why “extend”? maybe “build a catalogue”? This is the first time that a catalogue is mentioned in the article.

151: “a catalogue of the summertime AR in the Andes”

152: rate or total? Or did the event have a high daily or hourly precipitation rate?

153: “we identify AR conditions on the grid points of the ERA5 reanalysis data representing the coast of Central Chile in the 1941-2023 period”.

160: “of at least Category 1 conditions that occurred”?

163: Please check the verb tenses of all the sections. It seems that this section is in present tense, but the next section is written in Past tense.

163: of AR -> the AR

164: delete “on”

165: the available 83-year period

173: Firstly, we estimate if glaciers in the Maipo River Basin were ...”

174: “For this, we utilised...”

180: Delete “Furthermore”

183: “1a) to estimate the freezing level.”

183-184: “The freezing level was estimated using a linear regression...”

185: “accuracy and reliability” of what?

193: Please provide the simulation period at some point at the beginning of the paragraph.

195: not only turbulent fluxes, I guess, but the full energy and mass balance

196: “To cover the complete simulation period, we derived data before 2016 from the ERA5 reanalysis, after going...”

198: “incoming shortwave and longwave radiation”

202: delimitations -> outlines?

203: “The model distributes...” This fits better somewhere in the previous paragraph.

206: “annual approach” is not a very clear term, maybe is better just explain?

207: no-snow starting -> snow-free initial

208: “The analysed model outputs”

208: total -> glacier total

210: was made with that of previous...

212: Please start here a new paragraph

232: Please check the use of the word “rate”

233: “costal grid points of Central Chile”

234: rarity -> low frequency?

236: the total number of AR events during all seasons reached 687

239: delete “nearby”

241: Move “Valenzuela et al. (2022)...” sentence to the end of the paragraph.

250: at Lagunitas station

265: “ERA5 reanalysis”

267: 19 AR summertime (DJF) events

275: usually being

277: it -> this value

279: January 2021 -> Maybe more like December 2020?

286: the 0C isotherm altitude

287: isotherm altitude estimates

289: minimum altitude of the 0C

290: “Around this time, ... were accumulating snow.”

293: at the glacier lowest elevations

294: up -> down?

294: “decreased to altitudes similar to those observed in the previous day”

296: “On the days after”, How many?

298: radiosonde-derived

302: Time series of the 0C isotherm (left axis) and hourly precipitation (right axis) during the event

304: Bars indicate

304: correspond

307: indicate that the

309: Latent heat fluxes are predominantly negative (λ), indicating that...

312: daily mean value?

315: in the magnitude of both the net shortwave and longwave

319: decrease of the surface temperature

321: why does the persistent cloud cover reduce the temperature gradient?

326: remove “according to...”?

328: remove “and the accumulation and ablation”

329: May-March?

330: with the mass balance of 2019/20

330: The mass balance in 2018/19 was

330: while the mass balance in 2016/17

331: with a positive value

331: maybe add “cumulative” somewhere, to make sure that you don’t refer only to April values. Also, it would be better to say that is “the trend” that is interrupted, I think.

336: The mass balance in 2020/21 shows

339: earlier than

345: please reword, the glacier experienced the mass loss, not the years.

347: a sensitivity -> a hypothetical

348: delete “negatively”

352: Cumulative glacier mass balance, or why “mean”? is that a spatial average?

352: delete all “mean”

353: are -> indicate, represent

357: Hypothetical glacier mass balance

362: using a constant lapse rate for air temperature is not realistic.

364: The explanation of the snow albedo parameterization should be in “Methods”

364: ice albedo is assumed as spatially uniform and spatially constant.

365: the ice albedo parameterization

367: of the glacier surface

368: ... penitentes – spiky...- has been noted on the Olivares River sub-basin glaciers.

370: “Indeed”, repetition

372: context of a severe drought

375: the relative impact

377-378: What do you think that no direct measurements of energy balance fluxes are available? The other studies use probably the same type of data (AWSs)

387: those from previous studies

388: such as varying periods, elevation,

391: Geodetic mass balance of Olivares Alfa Glacier for the last 20 years has been negative.

393: Can you add the uncertainty of the Hugonnet estimates? I guess it is quite a lot for such a short period

397: Mention somewhere that the monitoring of Echaurren is done in-situ using the glaciological method

397: Not only is reported to WGMS, but is also the reference glacier for the Southern Andes

406: snow accumulation on

408-410: Can you reword using less commas? It would help the flow of the reading

410: The maximum IVT value? Or the mean?

412: the long duration

413: rate of snow accumulation -> snow accumulation values compared to previous summers

416: determine the occurrence of snow accumulation on glaciers

435: summer snow accumulation is not unusual. To illustrate this, ...

441: “after the event”, for how long?

42: , even at the elevation of ...

443: the glacier surface

445: However, these conditions...

47: GEONOR sensor

451-453: Please check the sentence structure

459: of incoming longwave radiation

459: they represent an energy sink

461-464: Please reword. It is not very clear.

475-475: Same here. Please consider splitting the sentence.

480: The mass balance would have been

485: Maybe delete “during 1991-2021”, it confuses a bit the sentence

485: Delete “rate”

501: orographic summertime precipitation

503: delete “in the subtropical Andes”

508: has -> had

511-512: The reduction in the magnitude of energy sinks did not compensate for the decrease in energy inputs.

519-521: Please reword, not very clear with so many commas.

521: accumulations -> accumulation

527-530: Check the verb tenses (all in present)