Replies to reviewer (CC1)

3rd-Apr-2026

Journal: EGUsphere (Copernicus Publications)
Manuscript ID: Egusphere-2025-3715
Title: "*Interannual relative contributions of climatic drivers and Black Carbon to glacier area retreat in Central Chile, 2000–2020*".
Autors: Karina Vallejos, Lina Castro, Álvaro Ossandon, Raúl Flores, and Felipe McCracken

We sincerely thank you for your constructive and insightful comments, which have substantially improved the quality and clarity of the manuscript.

Below, we provide a point-by-point response to each comment.

All changes introduced in the revised manuscript are indicated by page and line numbers.

Suggestions by Reviewer
This study focuses on the analysis of melting of the Paloma Oeste Glacier (POG) and the Bello Glacier (BG) in the Maipo River basin, central Chile. It finds that the surface changes of both glaciers are more sensitive to black carbon concentration and the Niño 3.4 index than to precipitation, PDO, or temperature. Additionally, POG shows a more significant retreat due to its higher black carbon concentration, while the impact of climatic factors on glacier retreat exceeds that of black carbon during drought periods. Overall, the structure is coherent and the analysis is reasonable. However, one big question for this paper is: How does the author define "anthropogenic influence"? Is black carbon (BC) intended to serve as an indicator of anthropogenic activities in this region? It is argued that the paper's arguments can only be meaningfully discussed if the author provides a clear definition of this term. Without such a definition, BC cannot reasonably be regarded as the sole indicator of anthropogenic activities affecting glacier melting. **Citation**: https://doi.org/10.5194/egusphere-2025-3715-CC1
Answers from authors
We thank the reviewer for this important comment. We agree that 'anthropogenic influence' is a broad term. To avoid ambiguity, we have revised the manuscript to explicitly define the term: within the scope of this study, 'anthropogenic influence' refers to the deposition of light-absorbing impurities from human activities that reduce snow/ice albedo and enhance melt. Black Carbon (BC) is used as the primary operational proxy for this local particulate deposition. We justify the use of BC because of its well-documented physical effect on albedo—being considered the second most important contributor to global warming after CO_2 (Bond et al., 2013)—and the availability of retrospective deposition fields. We also clarify in the Methods that other anthropogenic factors (e.g., mineral dust from mining, SO_2-derived aerosols, local land-use changes) may contribute but are outside the direct scope of the present analysis. These limitations are now discussed in the revised manuscript (Introduction; P4, L99-111 and Section 2.2; P7, L175-185). **The specific changes are detailed below:** * **Introduction** (P4, L99-111): "The climatic variables used as predictors included the number of days with average temperatures below 0 °C (hereafter DTb), annual accumulated precipitation over the hydrological year, and the macroclimatic indices PDO and Niño 3.4. In this study, "anthropogenic influence" refers to the impact of locally emitted combustion aerosols, represented by the deposition of black carbon (BC) on the snow surface, which reduces snow albedo and enhances melt (Flanner et al., 2007; Shi et al., 2022). In this context, the anthropogenic variable considered was surface-deposited BC, an operational indicator of the anthropogenic aerosol forcing relevant to snow and glacier melt in our analysis. This approach recognizes that BC is a well-established tracer of anthropogenic combustion processes, including transport, residential heating, mining, and industrial activities (Ramanathan and Carmichael, 2008; Gramsch et al.,

2020). It is also one of the most effective light-absorbing impurities affecting snow and ice surfaces (Warren and Wiscombe, 1980; Flanner et al., 2007). Moreover, BC has been identified as the second most important anthropogenic climate forcing agent after carbon dioxide (Bond et al., 2013), and its deposition on glacier surfaces has been shown to significantly accelerate melt rates in mountain cryospheric environments, including the central Andes (Ming et al., 2009; Cereceda-Balic et al., 2022; Shi et al., 2022).”

* **Section 2.2** (P7, L175-185): “The selection of climatic and anthropogenic variables as potential drivers of glacier ablation was guided by previous studies conducted in the region (Gramsch et al., 2020; CerecedaBalic et al., 2020; Cordero et al., 2022). The selected variables include climate indicators (precipitation and temperature) and measures of climate variability (Niño 3.4 and the Pacific Decadal Oscillation, PDO). To represent local anthropogenic forcing, we selected surface-deposited Black Carbon (BC) from CAMS as an operational proxy. This choice is based on (1) the strong physical effect of BC on snow and ice albedo and melt, and (2) the availability of retrospective, spatially resolved deposition fields that allow interannual comparison. Accordingly, BC is used here as a tracer of anthropogenic particulate deposition affecting glacier surface energy balance, while other anthropogenic drivers may influence glacier retreat; their explicit quantification falls outside the scope of the present analysis. A detailed description of all data sources used in this study is provided in Table S1 in the Supplementary Material. The time series of these variables were analyzed for the hydrological years 2000 to 2020, with the hydrological year in Chile running from April 1 to March 31 of the following year.”

References

- Bond, T. C., Doherty, S. J., Fahey, D. W., Forster, P. M., Berntsen, T., Deangelo, B. J., Flanner, M. G., Ghan, S., Kärcher, B., Koch, D., Kinne, S., Kondo, Y., Quinn, P. K., Sarofim, M. C., Schultz, M. G., Schulz, M., Venkataraman, C., Zhang, H., Zhang, S., Bellouin, N., Guttikunda, S. K., Hopke, P. K., Jacobson, M. Z., Kaiser, J. W., Klimont, Z., Lohmann, U., Schwarz, J. P., Shindell, D., Storelvmo, T., Warren, S. G., and Zender, C. S.: Bounding the role of black carbon in the climate system: A scientific assessment, Journal of Geophysical Research Atmospheres, 118, https://doi.org/10.1002/jgrd.50171, 2013.
- Gramsch, E., Muñoz, A., Langner, J., Morales, L., Soto, C., Pérez, P., and Rubio, M. A.: Black carbon transport between Santiago de Chile and glaciers in the Andes Mountains, Atmospheric Environment, 232, https://doi.org/10.1016/j.atmosenv.2020.117546, 2020.
- Ming, J., Xiao, C., Cachier, H., Qin, D., Qin, X., Li, Z., and Pu, J.: Black Carbon (BC) in the snow of glaciers in west China and its potential effects on albedos, Atmospheric Research, 92, 114–123, https://doi.org/10.1016/j.atmosres.2008.09.007, 2009.
- Cereceda-Balic, F., Ruggeri, M. F., Vidal, V., Ruiz, L., and Fu, J. S.: Understanding the role of anthropogenic emissions in glaciers retreat in the central Andes of Chile, Environmental Research, 214, https://doi.org/10.1016/j.envres.2022.113756, 2022.
- Cereceda-Balic, F., Vidal, V., Ruggeri, M. F., and González, H. E.: Black carbon pollution in snow and its impact on albedo near the Chilean stations on the Antarctic peninsula: First results, Science of the Total Environment, 743, https://doi.org/10.1016/j.scitotenv.2020.140801, 2020.
- Cordero, R. R., Rowe, P. M., Damiani, A., MacDonell, S., Carrasco, J., Feron, S., et al.: Black carbon in the Southern Andean snowpack, Environmental Research Letters, 17, 044 026, https://doi.org/10.1088/1748-9326/ac5df0, 2022.
- Flanner, M. G., Zender, C. S., Randerson, J. T., & Rasch, P. J. (2007). Present-day climate forcing and response from black carbon in snow. Journal of Geophysical Research: Atmospheres, 112, D11202. https://doi.org/10.1029/2006JD008003
- Shi, T., Chen, Y., Xing, Y., Niu, X., Wu, D., Cui, J., Zhou, Y., Pu, W., & Wang, X. (2022). Assessment of the combined radiative effects of black carbon in the atmosphere and snowpack in the Northern Hemisphere constrained by surface observations. *Environmental Science: Atmospheres, 2*, 702–713. https://doi.org/10.1039/D2EA00005A
- Ramanathan, V., & Carmichael, G. (2008). Global and regional climate changes due to black carbon. Nature Geoscience, 1(4), 221–227. https://doi.org/10.1038/ngeo156
- Warren, S. G., & Wiscombe, W. J. (1980). A model for the spectral albedo of snow. I: Pure snow. Journal of the Atmospheric Sciences, 37, 2712–2733.