Response to: 'Comment on essd-2026-18', Anonymous Referee #2, 26 May 2026

ESSD-2026-18: Matus, F., Paredes, M., Lagos-Zúñiga, M., Garcés, A., Pinto, D., Aguilar, G., and Montserrat, S.: Extreme Precipitation Events: A Comprehensive Catalog for Northern Chile (17.5° S to 30.0° S), Earth Syst. Sci. Data Discuss. [preprint], https://doi.org/10.5194/essd-2026-18, in review, 2026.

Dear Reviewer,

We sincerely thank you for the thorough and detailed review of our manuscript. Your comments have been very valuable in strengthening the methodology, presentation, and overall clarity of this work. We have carefully analyzed all the remarks and revised the manuscript accordingly. Below, we address each comment.

General Comments:

Reviewer: This manuscript presents a catalog of seasonal extreme precipitation events in northern Chile (17.5°S–30.0°S) from 1979 to 2019. By integrating data from CR2METv2.5, ERA5 IVT, MODIS snow cover, and a landslide/debris flow inventory, the study conducts a systematic analysis of event types, snowline elevation, and applications in disaster management. The dataset is regionally valuable and potentially useful for studies of extreme precipitation, moisture transport, snowline variability, and hydro-geomorphic hazards in arid and semi-arid mountain environments.

However, the manuscript does not yet provide sufficient detail regarding event selection, classification criteria, dataset structure, quality control, and uncertainty assessment. Some key classifications rely on subjective interpretation, and the inferences regarding applications to debris flows appear somewhat over-stretched. We recommend a major revision before considering acceptance.

Authors: We thank the reviewer for the positive assessment of the catalog's regional value and for identifying the key areas requiring improvement. We have addressed each of the raised concerns as follows:

- Event selection and classification criteria: Section 3 has been expanded to detail the spatial and temporal criteria for event identification, and the classification workflow based on systematic visual inspection of precipitation and IVT fields is now explicitly documented, including the exclusion criteria for omitted events.
- Dataset structure: a new appendix (A1–A4) describing file formats, variables, coordinate systems, and relationships between files has been added to the manuscript, along with a Jupyter Notebook provided as Supplementary Material illustrating how to load, filter, and visualize catalog events.
- Quality control: a comparison between CR2MET and weather station observations is included in the Supplementary Material, and the rationale for selecting CR2METv2.5 over alternative products is now discussed in the data section.

- Uncertainty assessment: Figure 6 has been expanded with scatterplots comparing empirical and MODIS-derived snowline, and Table 2 now shows RMSE and R^2 metrics, and the conclusions now include an explicit limitations section covering daily resolution, classification uncertainty, snowline estimation errors, and the incomplete hazard inventory.
- Debris flow applications: the scope has been framed more carefully as a first-order demonstration of the catalog's applicability rather than a comprehensive hazard analysis.

Further details on each of these aspects are provided in the specific responses below

Reviewer: The manuscript states that they selected the maximum daily precipitation event for each season, but they did not fully explain the specific definition of "extreme events". Does this mean that there is one extreme event per grid cell each year? Why was it defined this way? The description is very vague. Furthermore, this criterion ignores event duration, accumulated precipitation, and spatial extent, all of which are critical for hazard triggering.

Authors: This observation about extreme events identification has also been pointed by Referee #1, which indicates that this section was not as clear as we previously thought. Because of that, we have revised Section 3 to provide a more detailed and explicit description of the event selection methodology, addressing the concerns regarding the definition of extreme events, the spatial and temporal criteria employed, and their limitations.

"To identify extreme precipitation events, we analyzed precipitation at the grid-cell level rather than using spatially averaged values, capturing the localized signals relevant for small-scale hydrometeorological hazards. In a study region characterized by extreme aridity, precipitation events are infrequent and typically short-lived, often of convective origin, making the daily timescale sufficient to capture each storm as a discrete occurrence without risk of merging distinct events. Furthermore, area-based metrics tend to favor large-scale, low-magnitude events that cover extensive areas but are less sensitive to localized high-intensity storms. By selecting the grid cell (~25 km^2) with the highest daily precipitation for each year, season, and latitudinal band, we ensured that these localized extremes were captured. This is particularly relevant for the study area since high-intensity precipitation is a primary trigger for floods and debris flows, whose initiation is governed by rainfall intensity, duration, and antecedent conditions (Berti et al., 2020; Nikolopoulos et al., 2017).

The date of this highest value was then used to extract the full spatial precipitation field for that day, hereafter referred to as the maximum seasonal precipitation event for that band. This approach ensures that each event corresponds to a single coherent day of precipitation while targeting the most intense occurrence in the record. All selected events present in the catalog were also visually inspected to verify that the identified precipitation fields corresponded to coherent storm structures, with affected areas approximately greater than 250 km^2, which is consistent with the spatial scale of convective precipitation (around 100 km in one direction; Houze, 2004).

The analysis was conducted at daily resolution, which is the finest temporal scale available from the CR2METv2.5, with a 0.05° per 0.05° spatial resolution (~25 km^2 per grid cell). Although sub-daily rainfall characteristics are also relevant for debris flow initiation (Berti et al., 2020; Zhang et al., 2020), daily precipitation maxima provide a robust first-order indicator of extreme forcing in arid environments where sediment availability is generally unlimited and transport capacity is primarily controlled by rainfall magnitude and geomorphic connectivity (Aguilar et al., 2020)."

Reviewer: Due to the sparse network of stations and complex topography in the mountainous regions of northern Chile, this catalog—which is primarily based on daily-resolution grid data from CR2METv2.5 and ERA5—may underestimate localized short-duration heavy precipitation. ERA5 also has resolution limitations in its IVT representation near complex terrain. It is recommended that the authors conduct cross-validation using station observations, historical events, or other precipitation products.

Authors: We acknowledge that CR2METv2.5, as a gridded product based on weather data, can inherit limitations from the underlying station network, particularly in the hyperarid north where weather station density is sparse. However, CR2MET is currently the best available gridded precipitation product developed for Continental Chile at this spatial and temporal resolution, which is why it is widely used by the regional research community (i.e. national water balance across Chile by DGA, 2017; Álvarez-Garreton et al., 2019; Amann et al., 2022; Anderson et al., 2021; Araya et al., 2023; Ayala et al., 2025; Baez-Villanueva et al., 2021, 2024; Boisier et al., 2025; Garreaud et al., 2025; Muñoz-Castro et al., 2026; Núñez-Hidalgo et al., 2025; Stehr et al., 2025). The gridded product CR2MET has been compared to other meteorological products in Segovia et al. (2025, pre-print), where the Far and Near North area (equivalent to our study area) showed a higher probability of detection for most storm events than other gridded products WRF-SAAG (Dominguez et al., 2024) and RF-MEP (Baez-Villanueva et al., 2020), and a percentage correct of almost 100% for storm events above 20 mm. In order to make this paper self-contained, we have added a Supplementary Material section in the revised manuscript (that will also be added as a new Material in the Zenodo Database) where we compare the identified events in the catalog with the observed daily precipitation of the weather stations with high data confidence to check magnitude, occurrence and some other statistics, but this is also part of the CR2MET original methodology.

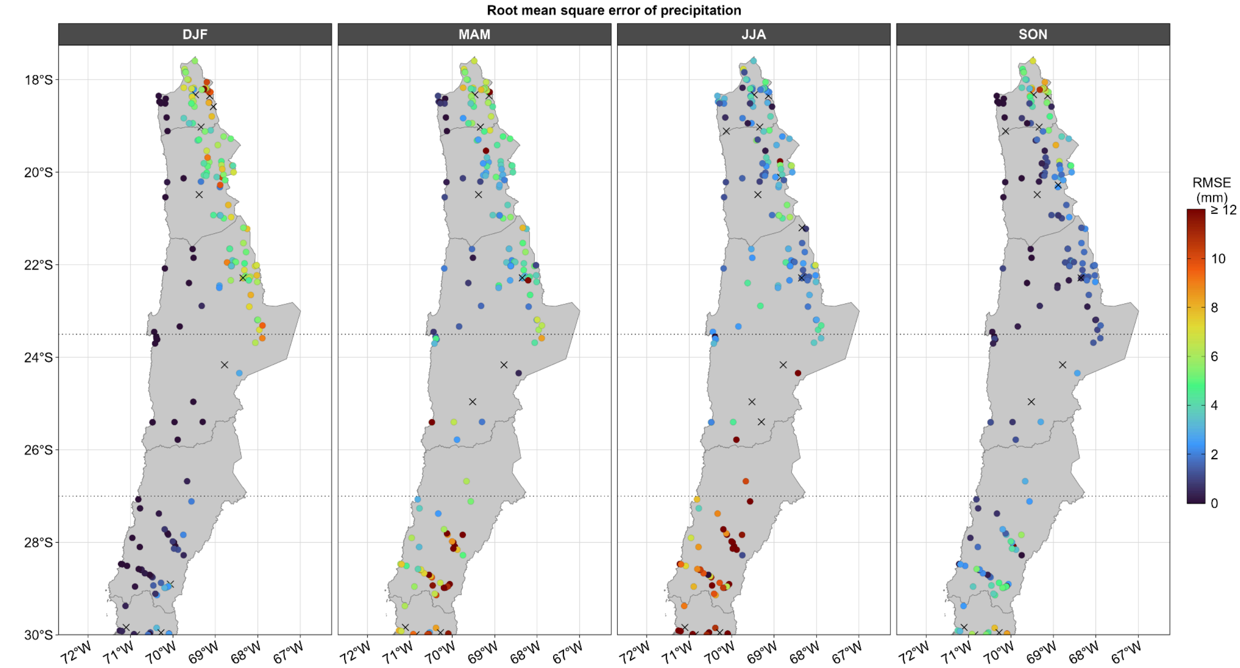


Figure depicting the root mean square error between the daily precipitation reported by CR2METv2.5 and weather stations.

Regarding the use of the ERA5 reanalysis, it is the standard product used for IVT analysis in this region, consistent with previous studies (e.g., Rondanelli et al., 2019; Rutllant et al., 2023; Bozkurt et al., 2016). Furthermore, the classification of extreme events is based on spatial precipitation patterns and IVT structures rather than absolute magnitudes, meaning that systematic biases in the gridded products do not invalidate the identified categories or patterns identified for the events presented in the catalogue. We additionally highlight that ERA5 reanalysis fields are used as predictant to estimate precipitation in CR2METv2.5, and therefore, the precipitation fields are consistent temporally with the dynamic fluxes of the reanalysis.

Alvarez-Garreton, C., Lara, A., Boisier, J. P., & Galleguillos, M. (2019). The Impacts of Native Forests and Forest Plantations on Water Supply in Chile. Forests, 10(6), 473. https://doi.org/10.3390/f10060473

Amann, B., Bertrand, S., Alvarez-Garreton, C., & Reid, B. (2022). Seasonal Variations in Fjord Sediment Grain Size: A Pre-requisite for Hydrological and Climate Reconstructions in Partially Glacierized Watersheds (Baker River, Patagonia). Journal of Geophysical Research: Earth Surface, 127(2), e2021JF006391. https://doi.org/10.1029/2021JF006391

Anderson, T. G., Christie, D. A., Chávez, R. O., Olea, M., & Anchukaitis, K. J. (2021). Spatiotemporal Peatland Productivity and Climate Relationships Across the Western South American Altiplano. Journal of Geophysical Research: Biogeosciences, 126(6), e2020JG005994. https://doi.org/10.1029/2020JG005994

Araya, D., Mendoza, P. A., Muñoz-Castro, E., & McPhee, J. (2023). Towards robust seasonal streamflow forecasts in mountainous catchments: Impact of calibration metric selection in hydrological modeling. Hydrology and Earth System Sciences, 27(24), 4385–4408. https://doi.org/10.5194/hess-27-4385-2023

Ayala, Á., Muñoz-Castro, E., Farinotti, D., Farías-Barahona, D., Mendoza, P. A., MacDonell, S., McPhee, J., Vargas, X., & Pellicciotti, F. (2025). Less water from glaciers during future megadroughts in the Southern Andes. Communications Earth & Environment, 6(1), 860. https://doi.org/10.1038/s43247-025-02845-6

Baez-Villanueva, O. M., Zambrano-Bigiarini, M., Mendoza, P. A., McNamara, I., Beck, H. E., Thurner, J., Nauditt, A., Ribbe, L., & Thinh, N. X. (2021). On the selection of precipitation products for the regionalisation of hydrological model parameters. Hydrology and Earth System Sciences, 25(11), 5805–5837. https://doi.org/10.5194/hess-25-5805-2021

Baez-Villanueva, O. M., Zambrano-Bigiarini, M., Miralles, D. G., Beck, H. E., Siegmund, J. F., Alvarez-Garreton, C., Verbist, K., Garreaud, R., Boisier, J. P., & Galleguillos, M. (2024). On the timescale of drought indices for monitoring streamflow drought considering catchment hydrological regimes. Hydrology and Earth System Sciences, 28(6), 1415–1439. https://doi.org/10.5194/hess-28-1415-2024

Boisier, J. P., Alvarez-Garreton, C., Marinao, R., & Galleguillos, M. (2025). Increasing water stress in Chile revealed by novel datasets of water availability, land use and water use. Hydrology and Earth System Sciences, 29(20), 5185–5212. https://doi.org/10.5194/hess-29-5185-2025

Garreaud, R., Boisier, J. P., Alvarez-Garreton, C., Christie, D. A., Carrasco-Escaff, T., Vergara, I., Chávez, R. O., Aldunce, P., Camus, P., Suazo-Álvarez, M., Masiokas, M., Castro, G., Muñoz, A., Zambrano-Bigiarini, M., Fuster, R., & Godoy, L. (2025). Hyperdroughts in central Chile: Drivers, impacts, and projections. Hydrology and Earth System Sciences, 29(20), 5347–5369. https://doi.org/10.5194/hess-29-5347-2025

Muñoz-Castro, E., Anderson, B. J., Astagneau, P. C., Swain, D. L., Mendoza, P. A., & Brunner, M. I. (2026). How well do hydrological models simulate streamflow extremes and drought-to-flood transitions? Hydrology and Earth System Sciences, 30(3), 825–848. https://doi.org/10.5194/hess-30-825-2026

Núñez-Hidalgo, I., Pfeiffer, M., & Gaxiola, A. (2025). Long-term dynamics of soil water erosion in Chile: Interactions between climate variability and land-cover change. CATENA, 259, 109377. https://doi.org/10.1016/j.catena.2025.109377

Stehr, A., Benavente, C., and Orellana, F.: Influence of Hydro-climatic Factors on Streamflow Patterns in Chilean Catchments, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2025-5318, 2025.

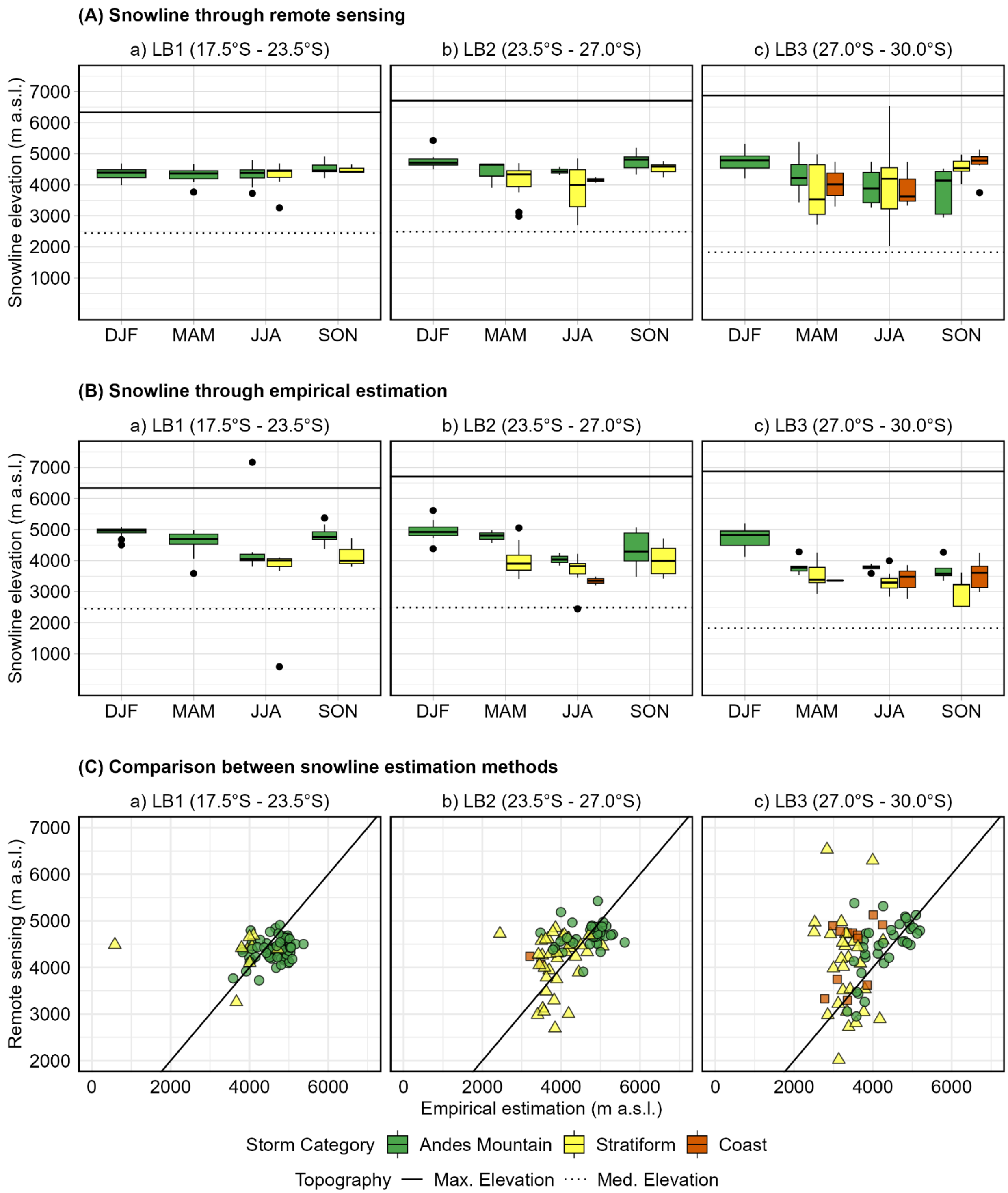
Reviewer: The categories Andes Mountain, Coast, Stratiform, and their subcategories are central to the paper, but their definitions remain qualitative. The authors should provide quantitative criteria based on precipitation location, precipitation fraction by geomorphic zone, precipitation centroid, IVT direction, IVT convergence, or moisture-source contribution. If expert judgement was used, the workflow and classification uncertainty should be documented.

Authors: We have addressed this comment by revising Section 3 to explicitly document the classification workflow and criteria. By expert criteria, the method relies on systematic visual inspection of precipitation and IVT fields, which we now state directly in the text. We opted for this approach over quantitative thresholds because the heterogeneity of events across bands and seasons makes fixed criteria difficult to apply without introducing misclassifications. We recognize that this introduces classification uncertainty; however, the fact that compositing events within each category yields coherent and physically interpretable synoptic patterns provides confidence that the classification captures real structural differences between event types.

"Once identified, extreme precipitation events within the three defined LBs were classified based on two criteria: the spatial distribution of precipitation within the latitudinal band and the associated IVT pattern. Events with precipitation concentrated along or near the coastline were classified as "Coast", events with precipitation spread across most of the band as "Stratiform", and events with precipitation concentrated over the Andes as "Andes Mountain". The "Andes Mountain" category was further subdivided based on the latitudinal position of precipitation along the cordillera ("North", "South", or "Along Andes") and the IVT structure ("Convergence" or "Westerly IVT"). Classification was performed through systematic visual inspection of precipitation and IVT fields, as illustrated in Figures 3 and 4. While this approach is qualitative, its internal consistency is supported by the coherent synoptic patterns that emerge when compositing events within each category (Figures 7-9). All extreme precipitation events identified from 1979 to 2019 fall under defined main categories; however, not all subcategories appear in every season. Events were excluded when the seasonal maximum precipitation within the latitudinal band was confined to isolated border grid cells or exhibited negligible magnitude, indicating no coherent precipitation signal. This determination was made through visual inspection of each event's spatial precipitation field, discarding those covering fewer than approximately 10 grid cells, equivalent to roughly 250 km² at the 0.05° (~5 km) resolution of CR2METv2.5. These events are labeled as Omitted in the catalog (20 out of 492 band-season-year combinations), and remain accessible in the dataset for transparency."

Reviewer: The use of both empirical and MODIS-based methods for estimating the snowline is a key component of this dataset. However, in certain seasons and latitudinal zones, there are significant discrepancies between these two methods, with differences sometimes reaching hundreds of meters or even exceeding 1,000 meters. This has important implications for runoff generation and the interpretation of debris flows. Therefore, the authors should quantify method-related biases, root mean square error (RMSE), seasonal dependence, and classification dependence.

Authors: We thank the reviewer for this observation. The submission only showed the snowline estimation differences between both methodologies in Figure 6 and Table 2, in which only Table 2 has statistical information. According to the suggestion, we have modified Figure 6 to contain a new row of facets depicting both snow line estimation methodology as scatterplots (where the X-axis is the empirical estimation, and Y-axis is the remote snowline estimation obtained from MODIS). The scatterplots also include a 1:1 diagonal line.



We have also modified Table 2 to contain the root mean square error (RMSE) and coefficient of determination (R^2) calculated from the empirical and remote sensing methodologies for the events occurring between 2000 and 2019. These metrics are shown according to all observed combinations of latitudinal band, storm category, and season.

Table 2. Mean and standard deviation of the snowline (m.a.s.l.) estimated by both methods for each latitudinal band, season, and storm category for the extreme precipitations events during 2000–2019 and 1979–2019. RMSE and R^2 were calculated based on the 2000 – 2019 data for both methodologies.

Band	Season	Storm category	Remote Sensing (2000 – 2019)	Empirical estimation (2000 – 2019)	Empirical estimation (1979 – 2019)	RMSE	R^2
LB1	DJF	Andes Mountain	4376 ± 201.5	4931 ± 144.8	4874 ± 186.4	587.4	0.074
	MAM	Andes Mountain	4327 ± 209.6	4633 ± 334.0	4637 ± 320.4	397.1	0.394
	JJA	Andes Mountain	4318 ± 283.7	4288 ± 877.0	3903 ± 1046.7	840.5	0.029
		Stratiform	4261 ± 475.1	3489 ± 1289.7	3630 ± 958.5	1525.0	0.011
	SON	Andes Mountain	4526 ± 198.2	4792 ± 270.1	4787 ± 219.9	426.7	0.004
		Stratiform	4490 ± 141.2	4173 ± 484.1	4296 ± 395.7	551.9	0.143
LB2	DJF	Andes Mountain	4741 ± 209.4	4960 ± 256.6	4886 ± 233.9	396.1	0.001
	MAM	Andes Mountain	4410 ± 435.3	4782 ± 211.1	4742 ± 306.5	425.5	0.856
		Stratiform	4174 ± 500.3	3999 ± 431.1	4019 ± 357.7	507.2	0.205
	JJA	Andes Mountain	4442 ± 126.2	4039 ± 201.5	4005 ± 177.6	425.9	0.314
		Stratiform	3873 ± 714.1	3708 ± 451.6	3682 ± 379.8	899.6	0.043
		Coast	4153 ± 123.0	3347 ± 200.8	3296 ± 409.9	837.9 (*)	(*)
	SON	Andes Mountain	4745 ± 260.1	4392 ± 539.5	4317 ± 471.9	643.4	0.023
		Stratiform	4529 ± 189.2	4010 ± 493.4	3895 ± 416.5	709.5	0.004

Reviewer: The Data Availability section provides only the Zenodo DOI, which is insufficient to describe the data product. We recommend adding a data description table that lists the filenames, formats, variables, units, spatial resolution, time range, missing value coding, coordinate system, event IDs, the meanings of classification labels, and the relationships between files. It would be best to include a simple example of how to read the data, illustrating how to filter by a specific latitude band, season, and event type.

Authors: We thank the reviewer for this suggestion. We have improved the data documentation by including a Supplementary Material section and expanding the README file from the Zenodo repository. This README file contains detailed descriptions of filenames, formats, variables, units, spatial resolution, time range, coordinate system, classification labels, and the relationships between files. Additionally, we have included a brief summary in the Appendix (A1-4) to provide the dataset contents and structure directly.

"*The repository contains: (1) a CSV file listing all extreme precipitation events with their associated meteorological descriptors, including latitudinal band, date, season, storm category, maximum daily precipitation (mm/day), mean temperature (°C), freezing level and snowline elevations (m a.s.l.) estimated through both empirical and MODIS-based methods; (2) NetCDF files with daily precipitation fields from CR2METv2.5 and vertically integrated water vapor transport (IVT) components derived from ERA5 for each cataloged event; and (3) a NetCDF file* *with post-processed MODIS snow cover maps for events from 2001 onward. A detailed description of the file structure, variable definitions, and coordinate systems is provided in the Supplementary Material (Appendix A1-3). Illustrative figures depicting CR2METv2.5 daily precipitation performance according to weather stations are available as Supplementary Material (also described in Appendix A4).*"

Reviewer: The conclusion currently focuses primarily on restating results and describing applications. It is recommended to clearly summarize the total number of events in the dataset, key variables, primary added value, applicable scenarios, scenarios where the dataset is not applicable, and future directions for expansion.

Authors: We have revised the conclusion section to include a quantitative summary of the catalog, its key variables, applicable and non-applicable scenarios, and future directions for expansion.

"*Together, these applications form a cohesive narrative: the catalog bridges atmospheric dynamics to geomorphic impacts, transforming theoretical classifications into practical frameworks for disaster risk reduction. In total, the catalog comprises 472 band-specific extreme precipitation events corresponding to 408 unique storm dates across the period 1979–2019. Of these, 59 storms affected multiple latitudinal bands simultaneously, with 33 exhibiting different precipitation categories across bands, reflecting how the same synoptic system can manifest distinct spatial patterns depending on latitude.*

Of the cataloged events, 292 were classified as Andes Mountain, 161 as Stratiform, and 19 as Coast, each characterized by date, storm category, maximum daily precipitation (3.3–111.5 mm/day), mean temperature (−2.9 to 15.1°C), freezing level, and empirical snowline elevation, and MODIS-derived snowline elevation when available (237 events from 2001 onward). It should be noted that the catalog captures the most intense daily event per season and band, and therefore does not account for sub-daily rainfall characteristics, multi-day accumulation, or antecedent conditions, which are also relevant for debris flow initiation. Additionally, the event classification relies on systematic visual inspection rather than quantitative thresholds, empirical snowline estimates for events prior to 2000 carry larger uncertainties due to the absence of MODIS observations, and the comparison with the debris flow inventory is constrained by the incomplete nature of the historical record. Future work includes extending the catalog beyond 2019, incorporating sub-daily precipitation products as they become available at adequate spatial resolution, and expanding the analysis toward central Chile where different precipitation regimes prevail. By contextualizing extreme rainfall within both meteorological and societal contexts, this work advances preparedness in Chile's complex climatic and topographic setting."

Line-by-line comments

1. The term "Comprehensive Catalog" in the title is strong. The abstract should state the total number of events, included variables, and data-product structure to justify this wording.

Authors: We have revised the abstract to include the total number of cataloged events, the key variables, and the data-product structure. The revised abstract reads as follows:

"This study presents a comprehensive catalog of the extremest seasonal rainfall events of northern Chile between 1979 and 2019. We analyzed its meteorological patterns across three latitudinal bands (17.5ºS–23.5ºS, 23.5ºS–27ºS, and 27ºS–30ºS) using daily precipitation and mean daily temperature from the CR2METv2.5 product, and vertically integrated water vapor transport data (IVT) from the ERA5 reanalysis. These events were classified into three main precipitation categories: Stratiform, Coast, and Andes Mountain. The Andes Mountain category was further subdivided into five subcategories based on IVT patterns and precipitation spatial distribution: North Andes, South Andes, Along Andes, Convergence, and Westerly IVT. In total, the catalog comprises 472 extreme precipitation events corresponding to 408 unique storm dates, each characterized by date, precipitation category, maximum precipitation within the latitudinal band, average storm temperature, and snow line elevation determined through empirical methods and remote sensing from daily MODIS imagery. The dataset is available as a CSV catalog with additional NetCDF files containing gridded precipitation, IVT, and MODIS snow cover fields for each event. To test the applicability of this catalog, we characterized extreme events composite results for the Austral summer between 27ºS–30ºS (latitudinal band 3), showing that events within each category yield coherent synoptic patterns. Additionally, we contrasted our catalog with an existing national landslide inventory of 548 events in the study area, finding that just six cataloged storms (all classified as Stratiform) account for 203 debris flow events (37%), indicating the March 2015 and May 2017 storms were alone responsible for 168 of them. We also estimated the approximate debris flow volumes for the March 2015 Atacama event using a transport-capacity approach, showing reasonable agreement for deposits larger than 4000 m^3. These findings enhance our understanding of extreme precipitation events in Chile and provide a valuable resource for storyline analysis and precipitation pattern identification."

2. The abstract states that composite analysis was performed for austral summer events in LB3, but it does not clearly state the main finding or scientific implication. A concise result statement should be added.

Authors: We have added a concluding statement at the end of Section 5.1 that summarizes the main findings of the composite analysis and its scientific implications.

"These results demonstrate that, despite the qualitative nature of the classification, compositing events within each category yields coherent and physically consistent synoptic patterns. In particular, the "Convergence" composites highlight the contribution of water vapor transport from east of the Andes in enhancing extreme precipitation events in the region, suggesting that this moisture source may play a significant role in modulating event intensity. The extent to which this eastern contribution is necessary for the development of extreme events warrants further investigation."

3. The abstract mentions comparison with a landslide/debris-flow inventory, but does not report the key finding. The authors should state how many events were matched or what this comparison demonstrates.

Authors: We have revised the abstract to include the main finding of the comparison with the debris flow inventory. The revised sentence now states the proportion of recorded debris flows associated with cataloged storms (Abstract shown in previous comments)

4. The abstract uses “Coastal,” while the main text uses “Coast.” Please use consistent terminology throughout the entire manuscript.

Authors: We have revised the abstract and corrected the inconsistencies. We use “Coast” as the definitive terminology (Abstract shown in previous comments).

5. The introduction provides a fairly comprehensive overview of extreme precipitation and debris flow risks, but does not specifically address the shortcomings of existing event catalogs or databases.

Authors: We have revised the introduction to explicitly address the absence of systematic catalogs in the region. In particular, we now highlight that while individual events and regional climatologies have been studied, no structured record exists that compiles extreme precipitation events together with their synoptic characteristics across multiple decades, bands, and seasons.

“While considerable progress has been made in understanding extreme weather events in northern Chile, critical gaps still exist regarding the dominant mesoscale features and the areas they affect. In particular, the meteorological mechanisms and water vapor sources driving extreme rainfall events in this region, which contribute to a complex and heterogeneous precipitation landscape, remain unclear. Despite the increasing focus on extreme climate events and their impacts, no systematic catalog exists that compiles and organizes extreme precipitation events together with their synoptic characteristics, water vapor transport patterns, and snowline conditions across multiple decades, latitudinal bands, and seasons. Key questions arise: What are the precise meteorological conditions that lead to extreme rainfall events in different latitudinal bands of northern Chile? How do integrated water vapor transport patterns contribute to these phenomena? Addressing these questions requires a structured record of extreme events that enables composite analysis, pattern identification, and hazard assessment.”

6. The three latitudinal bands are said to be based on precipitation climatology, event frequency, and intensity, but the specific boundaries at 23.5°S and 27°S require clearer justification.

Authors: We have revised the description of the latitudinal bands in Section 2 to provide a clearer justification for the selected boundaries. In addition to the precipitation climatology and station density already stated, we now describe the distinct precipitation regimes that characterize each band — from SAMS-dominated convective activity in the north to mid-latitude frontal systems in the south —that were considered in defining the chosen boundaries.

"To facilitate the isolation of precipitation events from different weather systems, the region is divided into three distinct areas based on the climatological characterization of Chilean precipitation and the synoptic patterns associated with precipitation events (described in Aceituno et al., 2021). The criteria considered latitude, meteorological station density, the spatial distribution of precipitation climatology, and the frequency and intensity of precipitation events. The latitudinal band 1 (LB1, 17.5°S–23.5°S, see Figure 1) is dominated by austral summer convective precipitation linked to the SAMS, the latitudinal band 2 (LB2, 23.5°S–27°S) represents a transitional zone where both summer convective and winter synoptic systems can produce extreme events, and the latitudinal band 3 (LB3, 27°S–30°S) is increasingly influenced by mid-latitude frontal systems, cut-off lows, and atmospheric rivers."

We have also added this information after Figure 1:

"It is important to note that, since single meteorological events can occur in large spatial extent, some extreme events from the catalog will not be constrained to a single latitudinal band as the same storm date can appear across multiple bands, which can be potentially portrayed as different precipitation categories."

7. Figure 1 shows topography and seasonal precipitation composites, but the sample size for each composite is not indicated. Please add event numbers in the caption or text.

Authors: We revised and incorporated the required information into Figure 1 caption.

"Climate and elevation features in northern Chile. (a) Topography (km a.s.l.); Panels (b) through (e) show the composite of maximum precipitation events (mm/day) for each season (1979-2019, 41 events per season). Dashed lines delimit the three latitudinal bands (LB1, LB2, LB3). Black contours indicate the 1 and 5 mm/day thresholds; white contours indicate 20 mm/day."

8. Explain why the CR2METv2.5 precipitation product was chosen over station observations, the ERA5 precipitation product, or satellite products. The data section should discuss the product's advantages, applicability, and limitations.

Authors: CR2MET was selected because it is the best available gridded precipitation product for Chile, offering daily resolution at 0.05° spatial coverage from 1979 to 2019. It integrates both ERA5 fields and station observations through logistic regression for precipitation occurrence and multiple linear regression using topographic features (Boisier et al., 2018), making it a more suitable product for complex terrain than ERA5 precipitation alone, which at 0.25° resolution cannot resolve the sharp topographic gradients of northern Chile. Station observations alone were not used because of the sparse and uneven gauge network in the hyperarid north, which limits spatial representativeness. Satellite precipitation products, while offering broader spatial coverage, have shorter temporal records and known biases in arid mountainous regions (e.g., Chen et al. 2020; Maggioni et al., 2016). We acknowledge that CR2MET inherits limitations from its underlying inputs, particularly in areas with low station density, and any systematic biases are inherited by the catalog:

"This product was selected because it combines station observations and reanalysis data at a spatial resolution (0.05°) suitable for resolving the sharp topographic gradients of northern Chile, while providing consistent daily coverage over the full study period. However, CR2MET inherits limitations from the sparse station network in the hyperarid north, and any systematic biases in the product are carried into the catalog."

Chen, C., Z. Li, Y. Song, Z. Duan, K. Mo, Z. Wang, and Q. Chen, 2020: Performance of Multiple Satellite Precipitation Estimates over a Typical Arid Mountainous Area of China: Spatiotemporal Patterns and Extremes. J. Hydrometeor., 21, 533–550, https://doi.org/10.1175/JHM-D-19-0167.1.

Maggioni, V., P. C. Meyers, and M. D. Robinson, 2016: A Review of Merged High-Resolution Satellite Precipitation Product Accuracy during the Tropical Rainfall Measuring Mission (TRMM) Era. J. Hydrometeor., 17, 1101–1117, https://doi.org/10.1175/JHM-D-15-0190.1.

9. CR2MET may be weakly constrained by stations in arid and mountainous northern Chile. The authors should discuss its reliability for extreme precipitation in the study area or explicitly acknowledge this uncertainty.

Authors: Revised and incorporated in previous comment. Furthermore, we have explicitly recognized this limitation in the Data and Methods section.

"...However, CR2MET inherits limitations from the sparse station network in the hyperarid north, and any systematic biases in the product are carried into the catalog."

10. Line 104-108: ERA5 IVT is analyzed at 20 UTC to capture afternoon convective activity, but not all extreme events necessarily peak at that time. The authors should explain whether other time steps or daily mean IVT were tested.

Authors: We prioritized 20 UTC due to the afternoon convective activity (e.g., Garreaud and Wallace, 1997) which would be smooth or reduced in daily means or other time steps. ARs or fronts, or synoptic-scale events, have relatively persistent IVT signals, making the choice of time steps less critical for these categories. We added to the conclusion that:

"*(...) Finally, the existence of this catalog also opens the door to future studies that delve deeper into the atmospheric dynamics and thermodynamics at different temporal resolutions, analyzing the evolution of each event over time and complementing it with other sources of information such as in situ observations, satellite swaths, and radiosondes, among others.*"

Garreaud, R., and J. M. Wallace, 1997: The Diurnal March of Convective Cloudiness over the Americas. Mon. Wea. Rev., 125, 3157–3171, https://doi.org/10.1175/1520-0493(1997)125<3157:TDMOCC>2.0.CO;2.

11. Line 109: The definition of "maximum seasonal precipitation event" remains unclear. Please clarify whether one event is selected per band-season-year based on grid-cell maximum, regional maximum, or area-mean precipitation.

Authors: This comment was addressed previously in the response to Specific Line Comment 6. The corresponding modifications have been incorporated into the Data and Methods section.

Line 115: The manuscript states that negligible or atypical events were excluded, but no thresholds or numbers are provided. Please report the exclusion criteria and the number of excluded events by band and season.

Authors: We revised and incorporated the required information, the manuscripts now state:

"*...All extreme precipitation events identified from 1979 to 2019 fall under defined main categories; however, not all subcategories appear in every season. Events were excluded when the seasonal maximum precipitation within the latitudinal band was confined to isolated border grid cells or exhibited negligible magnitude, indicating no coherent precipitation signal. This determination was made through visual inspection of each event's spatial precipitation field, discarding those covering fewer than approximately 10 grid cells, equivalent to roughly 250 km^2 at the 0.05° resolution of CR2METv2.5. These events are labeled as "Omitted" in the catalog (20 out of 492 band-season-year combinations), and remain accessible in the dataset for transparency.*"

12. The criteria for Andes Mountain, Coast, and Stratiform events should be quantified, for example using precipitation centroid, elevation-band distribution, coastal/mountain precipitation fraction, or spatial coverage.

Authors: We discussed this issue in our response to the previous comment on classification criteria. We have revised Section 3 to explicitly document the classification workflow. Events were classified through systematic visual inspection of precipitation and IVT fields based on two criteria: the spatial distribution of precipitation within the latitudinal band and the associated IVT pattern. We acknowledge that the classification is qualitative, and have added a statement in the text noting that its internal consistency is supported by the coherent synoptic patterns emerging from the composite analysis.

13. Figures 3 and 4 show classification examples, but it is unclear whether these are typical, random, or borderline cases. Please clarify the selection rationale.

Authors: The events shown in Figures 3 and 4 were selected as representative examples that display typical precipitation and IVT patterns for each category. We have clarified this in the figure captions.

"Representative examples of precipitation patterns (mm) for the extreme precipitation events identified in the catalog, selected to display typical patterns for each category. (...)"

14. Several instances of “*W esterly IV T*” contain unintended spaces. Please correct them to “*Westerly IVT*”.

Authors: Revised and corrected.

15. Figure 6 shows differences between the two snowline methods, but the interpretation remains descriptive. A boxplot or scatterplot of empirical minus MODIS snowline estimates would be useful.

Authors: We have added a scatterplot per latitudinal band inside Figure 6, as shown in a previous answer to the reviewer. Table 2 was updated to show the RMSE and R^2 values between both methodologies during 2000 - 2019.

16. MODIS covers only 2000–2019, whereas the catalog spans 1979–2019. The reliability and limitations of snowline estimates for 1979–1999 should be stated more clearly.

Authors: This limitation is addressed in Section 4.2, where we discuss the differences between empirical and MODIS-derived snowline estimates and explicitly note that these differences may have important consequences for years prior to 2000, when only empirical estimations are available. Additionally, Table 2 reports empirical snowline statistics separately for 2000–2019 and 1979–2019, allowing users to assess the reliability of pre-MODIS estimates.

“The main statistics for each method in the period 2000--2019 are presented in Table 2, where it can be seen that the empirical estimation tend to produce higher snowline estimations than remote sensing in LB1, and during austral summer and fall in LB2, however, to higher latitudes this method presented lower estimations around 200 m. These differences may have important consequences for extreme flows and landslide estimations, especially during years prior to 2000, where only empirical estimations could be made because of remote sensing data availability. Because of this, the use of empirical methods, including in-situ and upper-air observations, may help complement the analysis”

17. Section 5.1 presents composite maps of precipitation, geopotential height, and IVT for the LB3 summer Convergence category, but no significance testing (e.g., t-test or Monte Carlo simulation) is provided.

Authors: We acknowledge that no significance testing was applied to the composite analysis. As a data paper, the primary contribution of this manuscript is the catalog itself, rather than a dynamical analysis of the identified events. Section 5.1 is therefore intended as a demonstration of one possible application of the catalog, illustrating how users can leverage the classified events to construct composites and identify synoptic patterns. In this context, the coherence of the emerging patterns provides sufficient qualitative support for the classification's internal consistency. A rigorous statistical assessment of the composites, including significance testing, falls within the scope of future studies that build upon the catalog.

18. Section 5.2 compares the catalog with the SERNAGEOMIN inventory, but the matching rule is insufficiently described. Please specify whether matching is based on the same day, a multi-day window, or storm episodes.

Authors: The event matching between inventories was reviewed case-by-case by us according to debris-flow event's date or date range reported by SERNAGEOMIN. When the SERNAGEOMIN inventory reports a specific date for the debris-flow event, we considered this particular event in our analysis if our catalog also presented an extreme precipitation event on the same day in the same latitudinal band. Some debris-flow events in the SERNAGEOMIN inventory lack an exact date of occurrence and thus have a date range instead; for these debris-flow events, we checked whether a storm reported in our catalog took place within the reported date range inside the same latitudinal band. If the exact date or reported date range did not match with any extreme seasonal events reported in our catalog, that debris-flow event was not considered in the analysis.

In order to clarify this in the text, we have added this sentence in Section 5.2:

"We contrasted the 548 debris-flow events located in the study area against the storm catalog, checking whether those events had the same date of occurrence as an extreme storm in the catalog or, in the case of some debris-flow events lack an exact date, if an extreme storm took place within the date range reported by the SERNAGEOMIN inventory. We found that 203 events (37%) are associated with six storms from the catalog (Table 3): one in LB1, three in LB2, and four in LB3 (two storms overlap Bands 2 and 3). All storms were stratiform. Most events occurred in Band 3 (170), particularly during two key storms in the MAM season: March 25, 2015 (97 events) and May 12, 2017 (71 events)."

19. The statement that six storms account for 37% of debris-flow events should be framed cautiously. It indicates that the catalog captures some high-impact storms, not that it represents all hazard-triggering rainfall.

Authors: The text includes a disclaimer stating that the SERNAGEOMIN inventory does not contain all the events that occur in reality: *"It is important to note that this inventory does not aim to document all events that have occurred. Instead, it focuses on events identified during periods of emergency or when an official threat was declared by authorities. Consequently, there is a gap between the events that actually occurred and those recorded in the inventory."*

In addition, it is mentioned that the catalog does not include all the storms that triggered debris flows: *"These findings show that those six storms in the catalog account for an important portion of the debris flow in the study area (37%), but not all. This discrepancy may be explained by the nature of rainfall-triggered debris flows, which result in either minor affected areas or in different intensities and durations that were not captured by the adopted criteria of our study (Berti et al., 2020; Zhang et al., 2020; Nikolopoulos et al., 2017). Short-duration, high-intensity events may not be identified as significant in the catalog because the analysis considers only the total daily precipitation of each event."*

20. The conclusions should more directly summarize the data contribution, including total event number, variable list, category counts, and reuse scenarios.

Authors: We have revised the conclusions to include a quantitative summary of the catalog, as described in our response to a similar comment from Reviewer 1. The revised text now reports the total number of events (472 band-specific entries corresponding to 408 unique storm dates), the category distribution, the key variables and their ranges, multi-band event statistics, applicable and non-applicable scenarios, and future directions for expansion.

"*Based on a comprehensive analysis of the selected maximum seasonal daily precipitation events across three latitudinal bands, we defined several storm categories that describe their main characteristics. These categories were based in systematical visual classification of the geographical region of precipitation and the pattern of water vapor transport they exhibit. On average, three distinct patterns for extreme events were found in each band and season, with the most common variations falling into the categories Coast, Stratiform, and Andes Mountain. In the category Andes Mountain, it was found that in certain seasons it could be further subdivided into North Andes, South Andes, and Along Andes (along the Andes Cordillera), depending on the area of the mountain range where precipitation occurs.*

Furthermore, we used the catalog and analyzed the composites for all the categories generated and, considering only the circulation and IVT, two general categories were identified encompassing all extreme events in different seasons and bands: (1) convergence of water vapor transport (Convergence); and (2) IVT from the Pacific (Westerly IVT). An exception arose in the Along Andes pattern during summer in the LB3, where events exhibited a bimodal synoptic pattern. In this case, approximately half of the events were associated with Convergence and the other half with Westerly IVT. Therefore, the Along Andes category for this specific band and season was further subdivided into Convergence and Westerly IVT to represent the dual nature of the underlying mechanisms accurately.

As an example, the IVT convergence covers the results shown in Figure 9. It is also important to note that significant variations are observed between events classified into these two categories, including variability in the depth of development, circulation intensity, and IVT. These differences in atmospheric circulation and water vapor transport, combined with fluctuations in atmospheric moisture availability, contribute to the formation of a wide range of observed precipitation patterns. These factors also determine the extent to which these events can influence a specific latitudinal band.

The catalog's utility extends beyond classification, enabling actionable insights for hazard management. First, composite analysis provides meteorological storylines—recurring synoptic scenarios like Convergence or Westerly IVT—that explain how extreme rainfall develops. These storylines are critical for early warning systems, as they link observable atmospheric patterns to high-impact precipitation. Second, the correlation of cataloged storms with 37% of historical debris flows (e.g., the March 2015 MAM event, which triggered 97 mass movements) *underscores the catalog's value in identifying high-risk storms that disproportionately threaten Andean communities. Third, the coarse estimation of debris-flow volumes via transport-capacity models (Figure 10) translates precipitation magnitudes into sediment-yield approximations, providing a first-order proxy for infrastructure planning and mitigation. Finally, the existence of this catalog also opens the door to future studies that delve deeper into the atmospheric dynamics and thermodynamics at different temporal resolutions, analyzing the evolution of each event over time and complementing it with other sources of information such as in situ observations, satellite swaths, and radiosondes, among others.*

Together, these applications form a cohesive narrative: the catalog bridges atmospheric dynamics to geomorphic impacts, transforming theoretical classifications into practical frameworks for disaster risk reduction. In total, the catalog comprises 472 band-specific extreme precipitation events corresponding to 408 unique storm dates across the period 1979–2019. Of these, 59 storms affected multiple latitudinal bands simultaneously, with 33 exhibiting different precipitation categories across bands, reflecting how the same synoptic system can manifest distinct spatial patterns depending on latitude. Of the cataloged events, 292 were classified as Andes Mountain, 161 as Stratiform, and 19 as Coast, each characterized by date, storm category, maximum daily precipitation (3.3–111.5 mm/day), mean temperature (−2.9 to 15.1°C), freezing level and empirical snowline elevation, and MODIS-derived snowline elevation when available (237 events from 2001 onward).

It should be noted that the catalog captures the most intense daily event per season and band, and therefore does not account for sub-daily rainfall characteristics, multi-day accumulation, or antecedent conditions, which are also relevant for debris flow initiation. Additionally, the event classification relies on systematic visual inspection rather than quantitative thresholds, which introduces classification uncertainty acknowledged throughout the manuscript. Empirical snowline estimates for events prior to 2000 carry larger uncertainties due to the absence of MODIS observations. Finally, the comparison with the debris flow inventory is constrained by the incomplete nature of the historical record, which does not capture all events that occurred in the study area.

Future work includes extending the catalog beyond 2019, incorporating sub-daily precipitation products as they become available at adequate spatial resolution, and expanding the analysis toward central Chile where different precipitation regimes prevail. By contextualizing extreme rainfall within both meteorological and societal contexts, this work advances preparedness in Chile's complex climatic and topographic setting."

21. The conclusions should explicitly state key limitations, including daily rainfall resolution, classification uncertainty, snowline-estimation errors, and incomplete hazard inventories.

Authors: We revised and corrected the conclusions, adding a section that states limitations.

"*It should be noted that the catalog captures the most intense daily event per season and band, and therefore does not account for sub-daily rainfall characteristics, multi-day accumulation, or antecedent conditions, which are also relevant for debris flow initiation. Additionally, the event* *classification relies on systematic visual inspection rather than quantitative thresholds, which introduces classification uncertainty acknowledged throughout the manuscript. Empirical snowline estimates for events prior to 2000 carry larger uncertainties due to the absence of MODIS observations. Finally, the comparison with the debris flow inventory is constrained by the incomplete nature of the historical record, which does not capture all events that occurred in the study area.*"