Revision of manuscript **egusphere-2025-621**
"Gridded Intensity-Duration-Frequency (IDF) curves: understanding precipitation extremes in a drying climate"
Responses to Reviewer 03

Cristóbal Soto-Escobar, Mauricio Zambrano-Bigiarini,
Violeta Tolorza, and René Garreaud

August 27, 2025

We would first like to express our sincere gratitude to the handling editor, Prof. Thomas Kjeldsen, and to the three anonymous reviewers for their valuable comments and suggestions, which have helped us to substantially improve the quality and clarity of our manuscript.

We hereby submit our detailed responses to the comments provided by Reviewer 03 regarding our article entitled "*Developing Intensity–Duration–Frequency (IDF) curves using sub-daily gridded and in situ datasets: characterising precipitation extremes in a drying climate*".

The main revisions introduced in the manuscript are as follows:

1. **New title**: following a comment made by Reviewer 01, the title of the manuscript was changed from "*Gridded Intensity-Duration-Frequency (IDF) curves: understanding precipitation extremes in a drying climate*" to "*Developing Intensity-Duration-Frequency (IDF) curves using sub-daily gridded and in situ datasets: characterising precipitation extremes in a drying climate*".

2. **Incorporation of reviewers' suggestions**: We implemented several of the proposed improvements, with the aim of enhancing clarity without unnecessarily increasing the manuscript length.

3. **Revisions to figures to improve clarity and conciseness and reduce redundancy**:

    - Figure 3: Number of subplots reduced from 25 to 5.
    - Figure 5: Combines the previous Figures 5 and 7, retaining only the most representative results.
    - Figure 6: Merges the previous Figures 6 and 8, reducing the number of subplots from 40 to 8.
    - Figure 8: Integrates the previous Figures 9 and 10, decreasing the total number of subplots from 16 to 8.
    - New Figure 7: Introduced to present a scatter plot comparing intensities derived from stationary and non-stationary models.

4. **Expanded bibliography**: Additional references have been included, following the reviewers' suggestions as well as our own evaluation, to strengthen the scientific context of the study.

5. **Updated supplementary material**: The supplementary files were revised to include metadata of the rain gauge network and several new figures. Furthermore, some material originally in the supplementary section has been incorporated into the main manuscript to improve accessibility of key information. The new supplementary material can be found on `https://doi.org/10.5281/zenodo.16956066`.

In the following sections, we provide a point-by-point response to all comments raised by Reviewer 03. We hope that our detailed explanations will satisfactorily address all concerns.

REVIEWER 3

R3C0: The authors describe a study focused on IDF curves for the climate of Chili, researching whether the assumption of stationarity is valid for IDF parameter estimation in a changing climate. I found it an interesting, detailed paper with a thorough methodology to research assumptions that may have implications for extreme value analysis. In that level of detail is at the same time the weak part of the paper: sometimes there is too much detail (e.g. Figure 1 is so extremely high resolution that it crashed my printer), but at other parts some more information is needed or there is quite some repetition. I find the lack of a dedicated Discussion Section also rather limiting since it makes the Results section less straightforward. The work is sound overall, but the structuring and writing could use some extra work – I'm recommending Major Revisions because of that reason.

We thank you for this comment and apologise for the inconvenience you have had with the printout of the original manuscript. We have reduced the overall weight of Figure 1 without significantly affecting its quality (and now the manuscript can be printed without problems), we have merged several figures, and improved many parts of the text to avoid repetition and add more details, based on all the comments of the three reviewers. Therefore, we believe the revised manuscript does not require a structural change, as separating the Results and Discussion would inevitably lead to repeating parts of the Results in the Discussion section, unnecessarily increasing the length of the article.

R3C1: Please be careful with the overabundance of abbreviations and acronyms – and at least be consistent when using them. Especially the shortening of Precipitation to P, and then later on using a parameter p in the Gumbell distribution in equation 6 and accompanying text can get quite confusing (also because the word precipitation is fully written out in other sentences). Given the heavy statistical nature of this text, I'd suggest to keep the abbreviations in that field and the product names (GEV, IMERG etc) as they are normally shortened like that, but keep the use of abbreviating regular words to a minimum.

Thank you very much for this suggestion. We kept the abbreviations in the statistical field and the product names (e.g., GEV, IMERG), but greatly reduced the usage of abbreviations in regular words.

R3C2: In 4.1, and the definition of the bias correction factor S, the authors implicitly assume the rain gauges to be the absolute truth, without discussing the measurement accuracy of rain gauges. This needs some further discussion in my opinion: the type of rain gauge also isn't mentioned, whereas the technique of measuring precipitation has a direct relation with the inherent error in the resulting measurement. For instance, tipping bucket gauges tend to underestimate large rainfall intensities. To this end, section 2.2.1 could be more expanded with more metadata about the rain gauges, but also the selection criteria: the authors remove over 400 stations due to "anomalously large precipitation values" , which seems strange to me if the research is about IDF curves which try to predict extremes. Why discard the whole station and not just filter instead? From figure 3 it seems like for some climatic regions the data density is very sparse as a result which would make me question the validity of the found relations. Please include selection criteria, what exactly qualifies as an anomaly versus an actual extreme event, and some discussion on the effect of rain gauge quality on the work in this paper.

Thank you for your valuable observations and comments. In response, we have added a new supplementary CSV file containing detailed information on the metadata and precipitation amounts recorded by each rain gauge.

With regard to the instrumentation, precise information on the type of rain gauges used at all stations was not initially available. To address this, we contacted the institutions that provided the data. They confirmed that most stations are equipped with tipping-bucket rain gauges. While it is acknowledged that this type of instrument can underestimate high precipitation intensities; particularly during short-duration, high-intensity events; their reliability, low cost, and ease of maintenance explain their widespread use in operational monitoring networks.

Furthermore, we have included a new section S1.1 in the supplementary material, which documents errors detected at 400 stations due to "*anomalously large precipitation values*". These errors were systematic, deviating markedly from both neighbouring station records and climatological expectations. Such patterns pointed to recurring instrumentation issues or recording errors at stations belonging to the AGROMET network. We reported these problems to the institution. Although the anomalies affected 400 stations, their records only began in 2010 and gradually increased over time. Consequently, only a small subset of stations from this network was ultimately retained for the study.

It is important to stress that excluding these stations was essential to ensure the robustness and reliability of the final IDF curve estimates. Although the focus of this work is the quantification of extremes, incorporating clearly erroneous or systematically biased data would have introduced significant distortions into the statistical analysis. This precaution is consistent with the guidance in the literature, particularly Koutsoyiannis (2004a,b), who emphasises the importance of distinguishing true extreme events from data errors.

- Koutsoyiannis, D. (2004a). Statistics of extremes and estimation of extreme rainfall: I. Theoretical investigation. Hydrological sciences journal, 49(4). doi: 10.1623/hysj.49.4.575.54430.
- Koutsoyiannis, D. (2004b). Statistics of extremes and estimation of extreme rainfall: II. Empirical investigation of long rainfall records. Hydrological Sciences Journal, 49(4). doi: 10.1623/hysj.49.4.591.54424.

R3C3: Section 2.2.2 could be more concise, it feels like a lot of repetition. Especially the IMERG7 section, which includes a massive summation of changes that feels like it could be copy-pasted from the technical documentation. That level of detail is unnecessary, same as the mention of a sixth dataset that wasn't used – a discussion point at best, not it distracts from the actual methodology.

We thank Reviewer 3 for this valuable comment. In response, we have substantially reduced the description of precipitation datasets in Section 2.2.2, particularly that of IMERG07B and ERA5-Land.

With respect to PDIR-Now, Nguyen et al. (2020) described this product as promising for representing extreme precipitation events and subdaily precipitation, noting that:

"*an evaluation is carried out to examine the performance of PDIR-Now in capturing two extreme events, Hurricane Harvey and a cluster of summer thunderstorms that occurred over the Netherlands, where it is shown that PDIR-Now adequately represents spatial precipitation patterns as well as sub-daily precipitation rates*".

However, in our study area in the Southern Hemisphere, these positive conclusions did not hold. We believe it is important to mention this discrepancy to alert future users to carefully assess the spatial patterns of this product before applying it in their analyses.

To balance our perspective with the reviewer's suggestion, we have now reduced the description of this product to only two lines in the revised manuscript:

" *The sixth dataset, Precipitation Estimation from Remotely Sensed Information Using Artificial Neural Networks–Dynamic Infrared Rain Rate (PDIR-Now, Nguyen et al., 2020), was ultimately not included in this manuscript (see details in supplementary material S2; Soto-Escobar et al., 2025)* ".

R3C4: Figure 3 (as well as 8) has 25 subplots which makes it nearly impossible to digest. Consider which panels need to be included to support the main text, and move the rest or the full image to the supplementary material. In general, given the comparison between stationary and non-stationary Imax distributions, it would be interesting to see some more in-depth analysis and scatterplots of comparing the distribution statistics, rather than just showing spatial maps which mainly seem to be dominated by Chile's climatological gradient (at first glance at least).

We appreciate your comment. In response, we have made a significant effort to redesign and streamline most of the figures for improved clarity and conciseness. Specifically:

- Figure 3: the number of subplots was reduced from 25 to 5 (see response to R1C10).
- Figure 5: now combines the previous Figures 5 and 7, retaining only the most representative results.
- Figure 6: merges the previous Figures 6 and 8, reducing two figures into one and the number of subplots from 40 to 8.
- Figure 8: now integrates the previous Figures 9 and 10, decreasing the total number of subplots from 16 to 8 (see response to R2C0).

In addition, we created a new Figure 7, which presents a scatter plot comparing the intensities derived from the stationary and non-stationary models. For completeness, we include the updated figure and the associated text below.

" *To further assess the statistical similarity between stationary and non-stationary models, Figure 7 presents scatter plots of the estimated values for each product and region. The strong clustering of points along the 1:1 line across all panels indicates a high degree of agreement between the two approaches throughout the full distribution of annual maxima. A slight tendency for I_{max} from the non-stationary model to be lower, particularly for the most extreme values, supports the systematic negative differences identified in the boxplot analysis (Figure 6). IMERGv07B, ERA5, and ERA5-Land exhibit particularly high consistency between the modelling approaches, with minimal scatter. By contrast, IMERGv06B and CMORPH-CDR display greater variability, especially in regions characterised by more intense precipitation, such as the Near North and Far South. Despite these discrepancies, the differences introduced by the modelling assumption remain small relative to the magnitude of the I_{max} extremes. Overall, the scatter plots confirm that the observed differences are systematic across the entire value range and not driven by spatial climatological gradients. They complement the boxplot results and highlight that non-stationary modelling generally introduces only minor adjustments to extreme precipitation estimates for most datasets and regions* ".

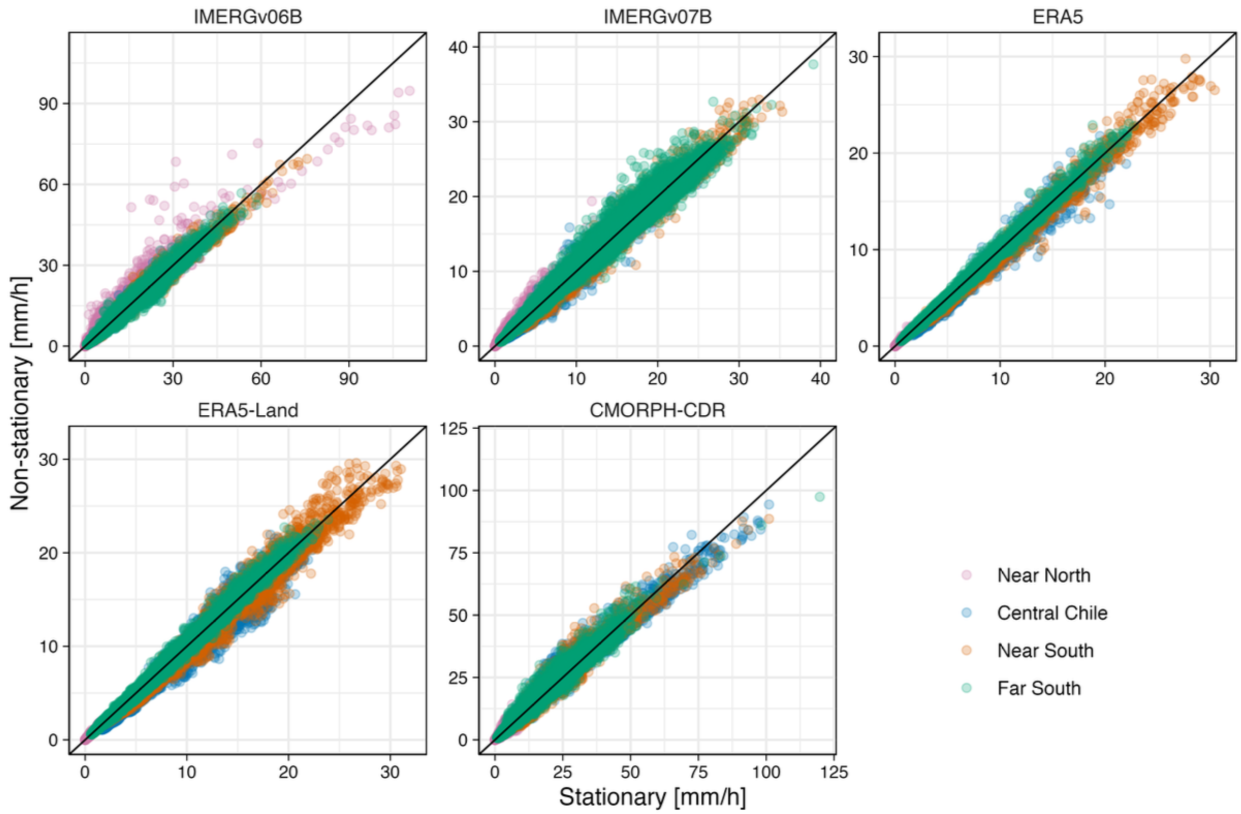

Figure 7. Scatterplots comparing I_{max} derived from stationary and non-stationary model for each product and all durations. Points are colored by climatic macrozone, and the 1:1 line indicates perfect agreement between both approaches.

R3C5: Section 4.6 draws heavily on the supporting material figures which is not ideal, and also has several references to other work in it already – perhaps this is better suited for a Discussion section (which is lacking at the moment, and interspersed with the Results), since this particular section uses only the ERA dataset and is therefore rather limited compared to the other Results.

Thank you very much for your comment. We have done our best to reduce to a minimum the redirection of the reader to the supplementary material in Section 4.6, as described in the following paragraphs.

The new Figure 8 integrates the previous Figures 9 and 10, decreasing the total number of subplots from 16 to 8 (see also response to R3C4 and R2C0). We believe this figure is a good representation of the overall result of this section, redirecting only to the interested reader to the two sections of the supplementary material:

" *For each grid cell of ERA5 and ERA5-Land, we compared the* I_{max} *values estimated with 40 and 20 years of data using both stationary and non-stationary approaches for return periods of 2, 5, 10, 25, 50, and 100 years. Figure 9 focuses on the case of* $T = 50$ *years, summarising the differences* $I_{max,40years} - I_{max,20years}$ *for both approaches. The results show median differences close to 0 mm* h^{-1}*, interquartile ranges within [-1, 1] mm* h^{-1}*, and maximum differences within [-4, 4] mm* h^{-1} *across all durations and macroclimatic zones. Readers interested in other return periods can find similar results in supplementary material S9.1 and S9.2 .*"

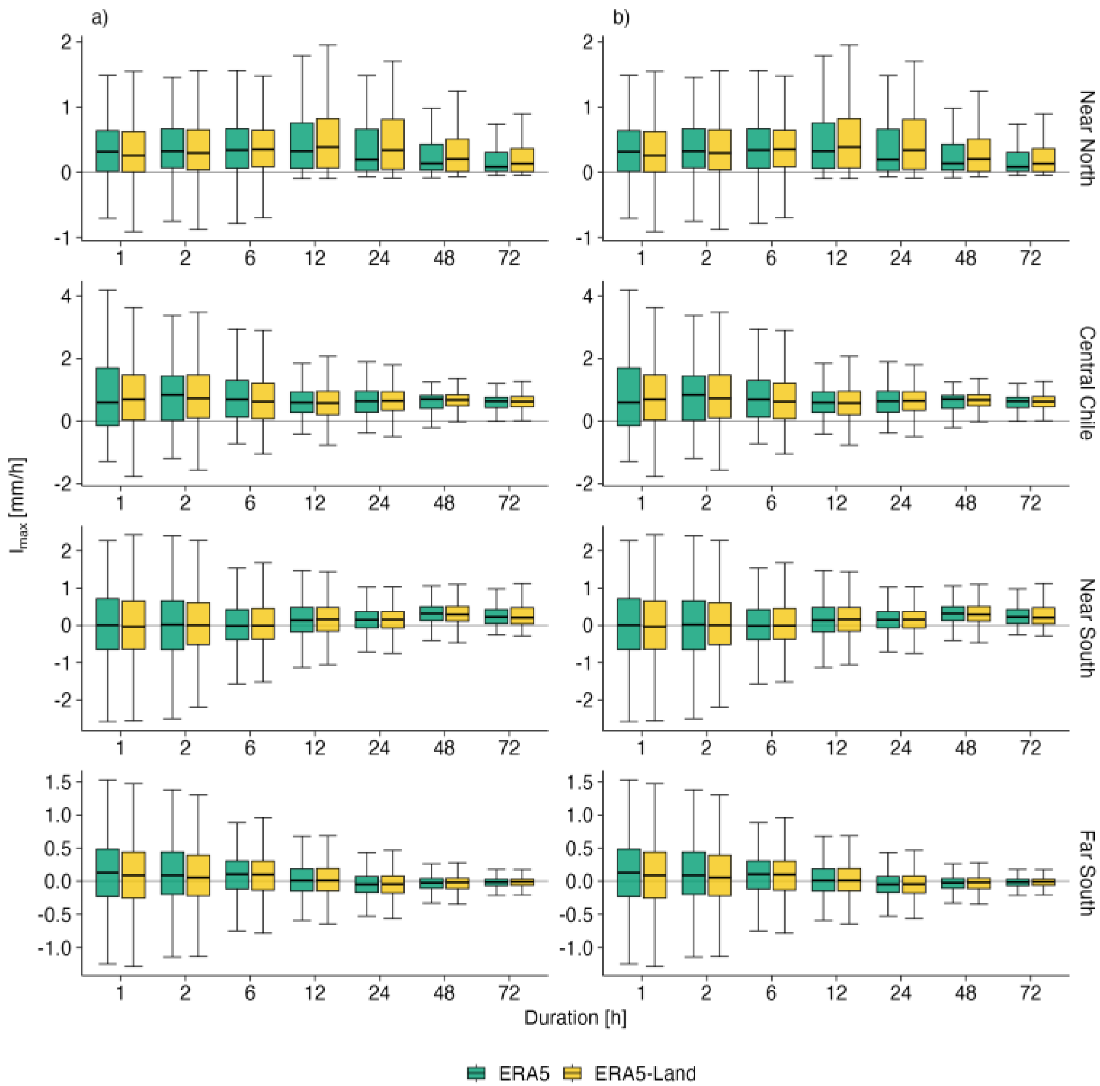

Figure 8. Panel of boxplots summarising differences between I_{max} derived from stationary and non-stationary models, estimated using data series of 40 and 20 years ($I_{max,40years} - I_{max,20years}$), for ERA5 (green colour) and ERA5-Land (yellow colour), considering a 50-years return period and durations of 1, 2, 6, 12, 24, 48, and 72 hours. From top to bottom, each panel corresponds to a different macroclimatic area. Column a) shows results obtained using the stationary model, while column b) shows results from the non-stationary model.

Also, we believe the inclusion of the new Figure 9 is a good representation of the overall spatial patterns of the differences in the location and scale parameters of the stationary Gumbel distribution, redirecting only to the interested reader to supplementary material S6.1, as described in the following reduced text about this point:

" *Figure 9 presents representative maps of the percentage differences in the location and scale parameters of the stationary Gumbel distribution for ERA5-Land, comparing estimates obtained with 20 years (2001–2021) and 40 years (1981–2021) of data. The differences were computed by subtracting the 20-year parameter estimates from the 40-year estimates and then normalising by the 40-year values. The results show generally minor differences in the location parameter (–10% to 10%) across the study area for both ERA5 and ERA5-Land, with the exception of the coastal area of the Coquimbo region (26–30° S), where differences reach up to –40%. By contrast, the scale parameter exhibits larger differences (–40% to 40%) throughout the domain. These include a clear spatial pattern* *of higher values for the 20-year period in most of the Near North (26.0–32.2° S) and Central Chile (32.2–36.2° S), and a more heterogeneous "salt and pepper" pattern in the South (36.4–43.7° S) and Far South (43.7–56.5° SS) macrozones. Readers interested in the raw maps of the Gumbel parameters for the stationary model can find them in supplementary material S6.1. "*

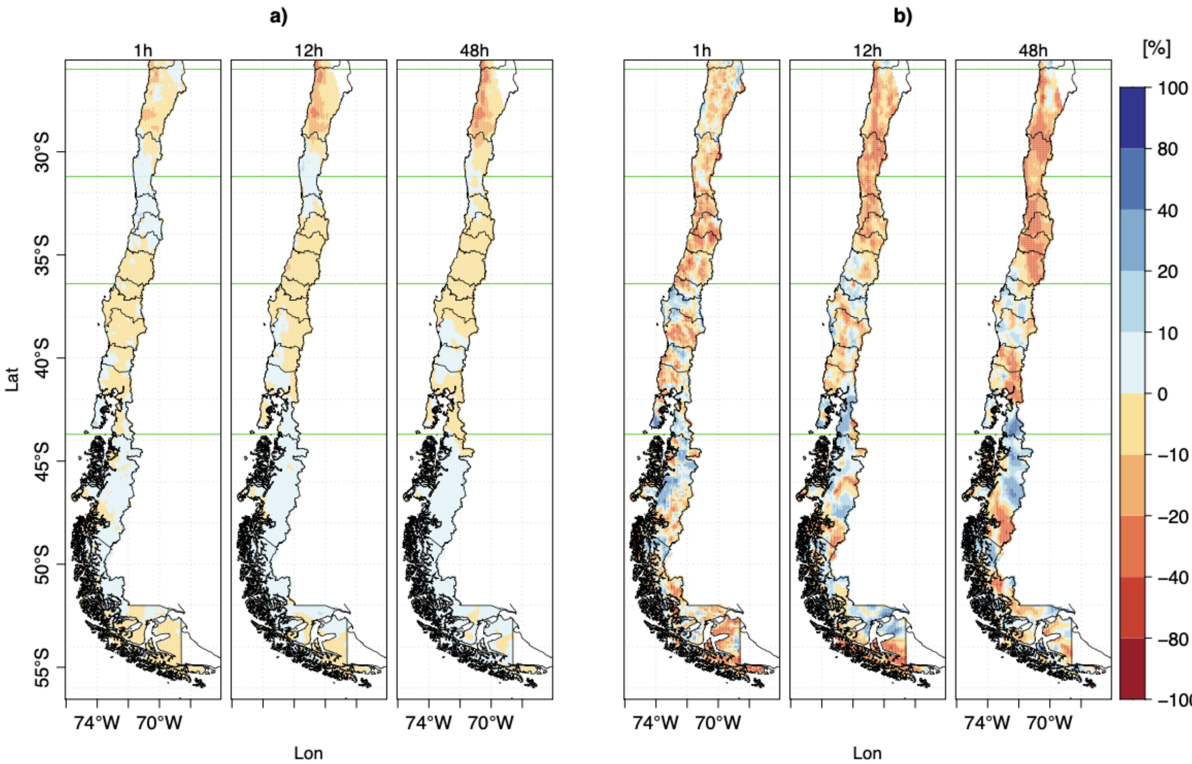

Figure 9. Maps displaying, in panel (a), the percentage difference in the Location parameter between the periods 1981–2021 and 2001–2021 for the ERA5-Land dataset, and in panel (b), the percentage difference in the Scale parameter between the same periods for the ERA5 dataset. Results are shown for durations of 1, 12, and 48 hours.