

Response to the Editor

Dear Editor,

We appreciate the opportunity to revise our manuscript and would like to express our gratitude for the constructive feedback provided by the reviewers. This response letter is structured into four sections. The first section is addressed to the editor and provides general comments on the revision process. The second and third sections respond to the general comments from Reviewer 1 and Reviewer 2, respectively. The fourth section is dedicated to addressing the specific comments raised by Reviewer 1. We have carefully considered all suggestions and have made substantial modifications on the paper to enhance the clarity, methodological rigor, and overall contribution of our study. Below, we provide a detailed point-by-point response to each comment.

1) General Comments on the Review Process

We sincerely appreciate the insightful feedback provided by the reviewers. Their detailed and constructive comments allowed us to recognize that the initial version of our manuscript presented some conceptual and structural ambiguities. In response, we have undertaken a major revision to refine and clarify our work.

A key outcome of this revision was the recognition that the section focusing on the spatial distribution of drought occurrence was detracting from the core message of the study. Consequently, this section has been removed to enhance the manuscript's clarity and focus. The revised version now concentrates on the methodological framework inspired by the dispersion analysis of COVID-19, as this aspect received greater attention and interest from the reviewers.

Beyond this refinement, we have incorporated additional reflections and methodological advancements into the manuscript. Specifically, in addition to the original curves, that we had to reformulate their names, we have introduced a dynamic phase analysis of drought events, categorizing them into expansion, persistence, and contraction stages. To further evaluate the transitions between these phases, we applied a transition matrix approach, which provides valuable insights into the evolution of droughts and their implications for decision-making.

Furthermore, based on observed drought events, we have developed a typology of drought evolution patterns. This classification system offers an additional contribution to decision-makers that can now better understand how events in their region are expected to evolve and the design of mitigation strategies tailored to the most probable drought evolution patterns.

We believe that these revisions have significantly strengthened the manuscript, aligning it more closely with the journal's scope and ensuring that the study provides clear and actionable insights for drought monitoring and management.

2) Response to General Reviewer 1 Comments

We are grateful for the thorough and constructive feedback provided by Reviewer 1. The comments allowed us to significantly refine and clarify the manuscript, leading to a substantial revision of both the methodological framework and the presentation of results. Below, we detail the major issues raised and the corresponding revisions made.

- **Language:**
The reviewer noted grammatical errors and poorly structured sentences. Given that most of the text in the revised manuscript is new, we conducted a comprehensive English language review to ensure clarity, coherence, and grammatical accuracy.
- **Materials and Methods:**
The reviewer pointed out that the study area was not sufficiently presented and that the methodology lacked clarity. In response, we have restructured the methodology section to provide a clearer description of the study area and methods. Additionally, we incorporated a flowchart to enhance the comprehension of the methodological steps.
- **Results:**
Several figures had critical flaws, including missing labels and incorrect values. Additionally, some analyses, such as the 4D analysis, were not adequately introduced in the methods, and the concept of correlation was misapplied. We have carefully revised all figures, replaced some analyses, and removed figures that were no longer relevant to the refined scope of the study.
- **Discussion:**
The reviewer observed that the results lacked proper discussion and identified a duplicated paragraph. To address this, we have integrated the discussion of results alongside their presentation, ensuring a clear narrative that highlights the practical implications and informational gains provided by the proposed methodology.
- **Novelty:**
The reviewer questioned the novelty of using growth curves and growth rates, arguing that they do not provide a significant technical gain over classical approaches such as accumulated severity and total affected area. In response, we made a significant effort to better articulate the technical

advantages of our approach. The newly proposed typology improves the characterization of drought behavior in a given region, enabling better preparedness for expected drought dynamics. Additionally, the transition matrix analysis allows decision-makers to gain confidence in the reliability of the information derived from the dynamic evolution of droughts.

- **Applicability for Decision-Makers:**

The reviewer requested further demonstration of how the proposed tool enhances drought prediction and mitigation. To address this, we incorporated an in-depth discussion on how the tool supports proactive drought management by facilitating region-specific action planning. For instance, in the study area, where droughts tend to expand and contract rapidly while maintaining prolonged persistence, a swift response in both the initiation and termination of mitigation measures is crucial. The revised manuscript now explicitly connects these insights to actionable decision-making strategies.

3) Response to Specific Reviewer 1 Comments

We sincerely appreciate reviewer 1 (RC1) detailed and constructive feedback. Below, we provide a point-by-point response to the specific comments raised, outlining the revisions made to the manuscript.

- **"The CRU TS v4.05 time series has been available since 1901, but we chose only to use data from the mid-20th century onwards as the region did not have many rain gauges at the beginning of the century and the dataset interpolation may add noise for the grid analysis."**

Response: The reviewer correctly pointed out that the phrase "has been available since 1901" could be more accurately stated as "provides data for the period starting in 1901." We have made this change, and the revised paragraph now reads:

"Monthly precipitation data were sourced from the CRU TS v4.05 dataset, which has a spatial resolution of $0.5^\circ \times 0.5^\circ$ and covers the period from 1950 to 2018 (Harris et al., 2020). Although the CRU TS v4.05 time series extends back to 1901, we opted to use data from 1950 onward due to the limited availability of rain gauge records in the study region during the early 20th century, which could introduce uncertainties in data interpolation."

- **"How many stations are sufficient to avoid noise in dataset interpolation?"**

Response: It is difficult to precisely quantify the number of stations required to eliminate interpolation noise. However, the fewer the stations, the greater the uncertainty, as precipitation patterns from distant locations may be imposed on regions with insufficient data. Given our understanding

of the study area and the historical distribution of meteorological stations, we believe that by the 1950s, the density of stations was adequate to provide reliable information for grid-based analysis.

- **"The first step for drought spatio-temporal definition is data processing is the first step."**

Response: Corrected for clarity.

- **"(e.g. hydrological" (incomplete sentence).**

Response: Corrected.

- **"Run theory (reference)?"**

Response: The missing reference was added: *Run theory (Yevjevich, 1967)*.

- **"Drought duration was not chosen to be analyzed since it is present in all the other three drought characteristics."**

Response: This sentence was removed from the text, as we no longer consider it essential for conveying our message. The original intention was to highlight that drought duration could not be treated as a standalone characteristic because our proposed methodology already incorporates temporal evolution in the analysis of severity and affected area.

- **"The growth rate is the first derivative (of what)?"**

Response: To clarify, we revised the terminology of the curves. What was previously referred to as the *growth rate* is now termed the *state curve*. The revised section now reads:

"Each drought characteristic, in this study the affected area and severity, was used to compute the three-curve model:

1. **Growth Curve:** Cumulative drought characteristic (integral of the State Curve).
2. **State Curve:** Drought characteristic.
3. **Dynamic Curve:** Change in the State Curve (first derivative of the State Curve)."

- **"What is the utility of the centroid curve/rate/acceleration? The drought-affected area might grow while the centroid remains stationary. Also, a mild drought signal might move around within the study area."**

Response: This comment prompted us to reassess the necessity of including centroid-related analyses. We concluded that the centroid did not provide significant added value in explaining drought dynamics. Consequently, we removed this variable from the analysis, focusing instead on the most informative indicators—affected area and severity.

- **"By 'dangerous,' do you mean 'hazardous'?"**
Response: Yes, we have replaced *dangerous* with *hazardous* to align with appropriate scientific terminology.
- **"Consider showing Figure 2A as a separate figure."**
Response: We created a separate figure specifically to illustrate the spatio-temporal evolution obtained from the 3D analysis.
- **"The study area (this is the first mention of a 'study area.' By convention, it should be presented in the methods section)."**
Response: A dedicated *Study Area* subsection has been added to the methodology section, providing a clear description of the location where the proposed framework was applied.
- **"A 4D analysis (of what)?"**
Response: This section of the study was removed.
- **"Correlation (no correlation is presented; this is a pairplot)."**
Response: This section was removed.
- **"The area overlap criteria did not result in any changes in the definition of drought events. (That is a rather surprising result. Do you have any justification or discussion to contribute?)"**
Response: This section was removed.

4) Response to General Reviewer 2 Comments

We sincerely appreciate the thoughtful and detailed feedback provided by Reviewer 2. The comments prompted substantial revisions, leading to a more refined and focused manuscript. Below, we outline the key concerns raised and the corresponding modifications implemented in response.

- **Methodological Limitations – Use of a Single Drought Index (SPI):**
The reviewer highlighted that evaluating drought events solely through the Standardized Precipitation Index (SPI) oversimplifies the phenomenon by neglecting key local aspects, particularly water availability. We acknowledge this limitation and agree that a multi-index approach could provide a more comprehensive representation of drought conditions. However, the primary goal of our study is to propose a methodological framework that enhances the information available to decision-makers rather than to provide an exhaustive drought characterization. The methodology we present is inherently flexible and can be adapted to incorporate other drought indices, such as the Standardized Precipitation Evapotranspiration Index (SPEI) or hydrological drought indicators. To

reflect this, we have explicitly mentioned this methodological limitation in the revised manuscript and suggested future research avenues that could explore the integration of additional indices.

- **Use of the Drought Centroid:**

The reviewer questioned the relevance of tracking the drought centroid, suggesting that this metric would be more valuable if it demonstrated spatial causality in precipitation deficits. Upon further reflection, we recognize that the initial version of the manuscript did not fully establish a causal relationship between centroid movement and drought propagation. Given this, and in an effort to streamline the manuscript's focus, we have decided to remove this analysis from the revised version. This change allows us to concentrate on the methodological aspects that provide decision-makers with clearer and more actionable insights.

- **Clarity and Textual Coherence:**

The reviewer pointed out issues related to writing quality, including weak structure, short sentences, and limited textual cohesion. As mentioned in our response to Reviewer 1, the majority of the manuscript has been rewritten, and we have conducted a thorough English language revision to improve clarity, coherence, and readability. We hope that these improvements effectively address the linguistic concerns raised in the initial review.

- **Discussion – Connection to Study Findings:**

The reviewer noted that a substantial portion of the discussion repeated well-known meteorological dynamics of the study region without sufficiently linking them to the study's findings. To address this, we have integrated the discussion directly into the results section. This restructuring allows us to explain the findings in a way that immediately clarifies their practical implications, ensuring that each result is contextualized within the broader objective of enhancing drought monitoring and decision-making.

These revisions have strengthened the manuscript by enhancing methodological transparency, focusing on the most informative analyses, and improving overall readability. We greatly appreciate the reviewer's insights, which have significantly contributed to refining our study's impact and clarity.

The new version of the paper is attached as supplement to this comment. We greatly appreciate the opportunity to refine our study based on the reviewers', and we hope that the revised manuscript meets the expectations of the journal.

Sincerely,
João Dehon de Araújo Pontes Filho
On behalf of all authors