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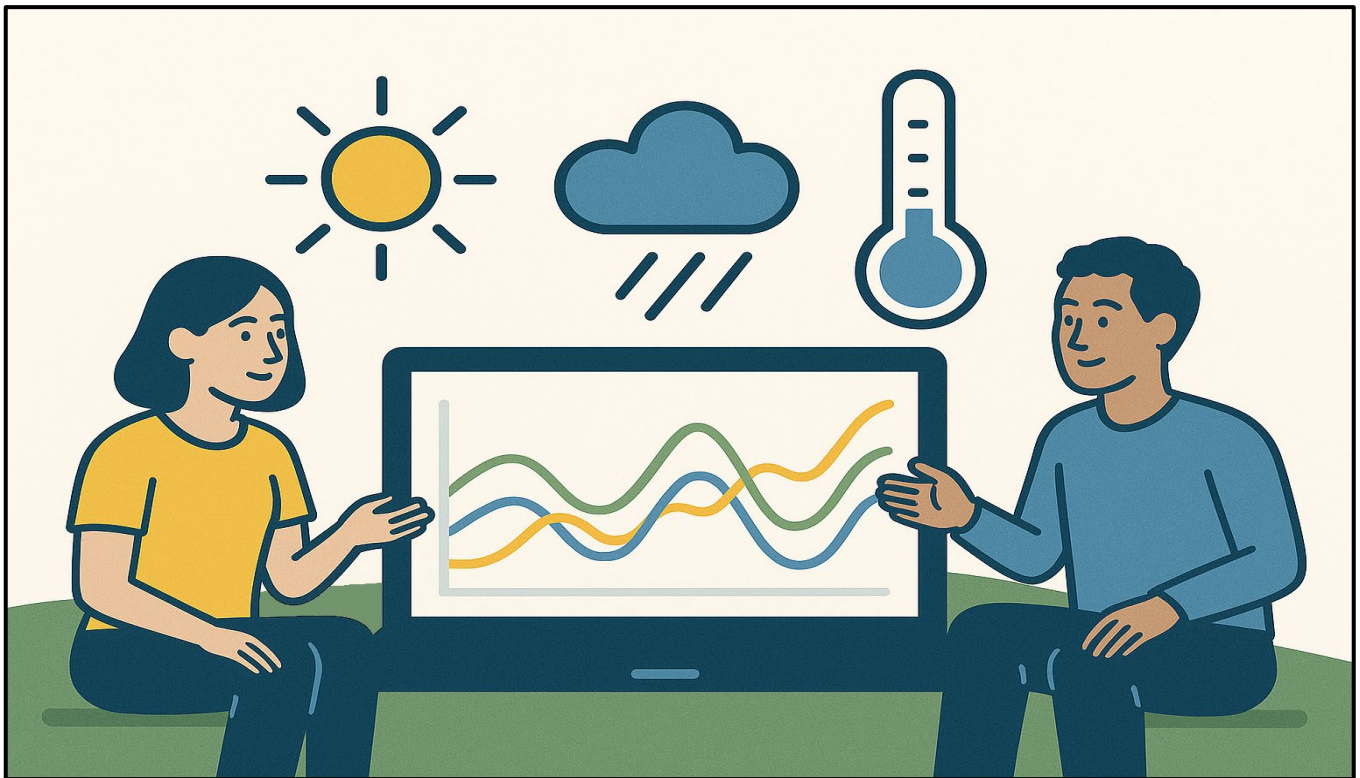
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A Collaborative Stochastic Weather Generator for Climate Impacts Assessment

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14. ABSTRACT The wxgenR project developed a modern, open-source stochastic weather generator to support Reclamation's climate change adaptation and planning studies. wxgenR integrates seasonality directly into daily precipitation and temperature simulation, improving representation of key hydroclimate patterns such as monsoons and snowmelt timing. The tool uses a non-homogeneous Markov chain framework with seasonal covariates and is implemented as an R package, publicly released on CRAN. Validation at multiple U.S. sites demonstrated strong performance in reproducing precipitation and temperature statistics. The methods, algorithms, and validation results are documented in the attached peer-reviewed manuscript (Woodson et al. 2025). This report provides background context, outlines Reclamation applications, and documents data archiving and dissemination activities for project closeout.					
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Cover Image – Two people sit next to laptop displaying weather generator traces. Pictographs of weather phenomena are seen overhead (David Woodson/Bureau of Reclamation).

A Collaborative Stochastic Weather Generator for Climate Impacts Assessment

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A Collaborative Stochastic Weather Generator for Climate Impacts Assessment

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Externally reviewed by peer-reviewed journal SoftwareX and peer-review comments and responses are included in an appendix

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Acronyms and Abbreviations

AMSL	above mean sea level
CONUS	contiguous United States
CRAN	Comprehensive R Archive Network
GCM	global climate model
GHCN	Global Historical Climatology Network
S&T	Science and Technology
SWG	stochastic weather generator
RCT	representative climate trace
Reclamation	Bureau of Reclamation

Contents

	Page
Executive Summary	ES-1
1.0 Introduction.....	1
2.0 Background.....	1
3.0 Research Outcomes and Work Products.....	4
4.0 Resources	6
5.0 References.....	7

Figures

- 1.—GHCN weather stations used to train and validate *wxgenR*. Labels indicate city, state, country, GHCN identification code, and elevation in feet above mean sea level (AMSL). ... 3
- 2.—Overview of *wxgenR* setup and operation with options for multisite simulation and shuffle to preserve spatial covariability, and simulation of temperature extrema—maximum and minimum temperatures..... 5

Appendices

- A *wxgenR*: An R package for stochastic weather generation with seasonality
- B Peer review comments and responses from Software X

Executive Summary

The wxgenR project developed a modern, flexible, and open-source stochastic weather generator designed to support Reclamation's climate change adaptation and planning studies. Traditional weather generators often rely on stationary transition probabilities and lack explicit representation of seasonality, limiting their ability to represent intra-annual variability such as monsoon dynamics or changing snowmelt timing.

wxgenR addresses this gap by incorporating seasonal variability into the generation of daily precipitation and temperature. Implemented as an R package and publicly released on CRAN, wxgenR uses a non-homogeneous Markov chain for precipitation occurrence with seasonally parameterized distributions for precipitation amounts and temperature.

The project involved algorithm design, software development, and validation across nine stations spanning diverse U.S. hydroclimates. The package demonstrated strong skill in reproducing seasonal precipitation statistics, wet/dry spell lengths, and cross-correlations between temperature and precipitation. wxgenR has been applied in pilot studies (e.g., Lower Santa Cruz Basin) and is positioned for broader use in basin modeling, scenario development, and climate planning.

1.0 Introduction

Reclamation's water management planning increasingly requires large ensembles of daily weather sequences that realistically capture observed hydroclimate variability while allowing for systematic exploration of potential future changes. Daily precipitation and temperature series are key inputs for hydrologic models and scenario planning.

Traditional stochastic weather generators have played an important role in such efforts but often lack mechanisms to represent seasonal variations in wet and dry spells, temperature distributions, or precipitation intensity. This limitation is particularly significant in regions where seasonal timing controls water availability, such as snow-dominated basins or monsoon-influenced watersheds.

The wxgenR project was initiated under the Science and Technology Program to develop, implement, and validate a stochastic weather generator that incorporates seasonality and can be readily applied within Reclamation's climate adaptation workflows.

The primary **objective** of the wxgenR project was to develop and validate a stochastic weather generator that:

- Incorporates **seasonal variability** in precipitation and temperature generation,
- Is computationally **efficient and reproducible**,
- Can be applied across **diverse hydroclimate regimes**, and
- Is packaged as **open-source software** for broad adoption.

A secondary objective was to provide documentation, examples, and training materials to facilitate integration into Reclamation workflows.

2.0 Background

Stochastic weather generators (SWGs) have long been used in a variety of fields, including hydrology, climatology, ecology, and agronomy (Birt et al. 2010; Chandler 2020; Farhani et al. 2022; Fortin et al. 2022; Ji et al. 2024; Schlabing et al. 2014; Zaniolo et al. 2024). SWGs simulate atmospheric variables (e.g., precipitation, temperature, solar radiation, wind, etc.) by replicating the space-time features of natural weather phenomenon described by these variables while largely preserving the distributional characteristics of the observed data. The probabilistic nature of SWG simulations makes them a valuable tool in risk assessment (e.g., planning for floods and droughts). SWGs have also been used to simulate altered weather paradigms in climate change studies based on either global climate model (GCM) projections or scenario modelling including GCM downscaling (Kilsby et al. 2007; Wilks 1992). Additionally, SWGs are attractive due to their computational efficiency in comparison to physically based models such as numerical weather prediction models.

The earliest SWGs simulated weather at a single site, modelling precipitation states (wet or dry) as a Markov process (Richardson 1981; Katz 1977; Stern and Coe 1984), then simulating precipitation amounts and temperature with various parametric approaches including use of specific probability distributions or time-series models. Parametric multi-site weather generators were subsequently developed by Wilks (Wilks 1998), Khalili et al. (Khalili et al. 2009), Baigorria and Jones (Baigorria and Jones 2010), Shamir et al. (Shamir et al. 2019), Shamir and Halper (Shamir and Halper 2019), among others. However, these parametric multi-site SWGs can easily become cumbersome as they require the use of a large number of parameters to maintain spatial dependence across sites (Mehrotra et al. 2006). Generalized linear models (GLMs) can simulate weather between stations when coupled with spatial models (Verdin et al. 2015; Kleiber et al. 2013; 2012) or by incorporating covariates like ocean-atmosphere indices and seasonal precipitation and temperature characteristics (Asong et al. 2016; Furrer and Katz 2007; 2008; Verdin et al. 2018). Bayesian SWGs provide a probability distribution for each model parameter (Verdin et al. 2019; Cano et al. 2004; Legasa and Gutiérrez 2020). Nonparametric and semiparametric SWGs emerged as an attractive alternative to parametric approaches, both for single (Rajagopalan and Lall 1999) and multiple sites (Sharif and Burn 2007; Buishand and Brandsma 2001; Beersma and Buishand 2003; Yates et al. 2003; Apipattanavis et al. 2007) due to their robust performance and ability to model inherent non-linearities in weather data, and to implicitly maintain spatial covariance across sites. Motivated by the need and the importance of stakeholder participation in climate impact studies to account for concomitant changes in precipitation occurrence, precipitation amounts, temperature, and seasonality of these hydroclimatic variables (Bearup et al. 2021; Gangopadhyay et al. 2019; Gupta et al. 2023; Halper et al. 2022), we have developed a weather generator R (R Core Team 2024) package, *wxgenR* (Gangopadhyay et al. 2025), that accommodates such information change. In developing *wxgenR*, we considered the role of stakeholders in any climate-informed decision-making process, and this is a foundational premise in the use of the tool. Stakeholders commonly have information of future climate projections that is locally relevant but does not capture the uncertainty associated with a range of possible climate futures and thus may miss possible impacts of concern.

For climate impact studies, the weather generator, *wxgenR*, requires as input a representative climate trace (RCT), which consists of daily precipitation, mean temperature (also referenced as average temperature in this presentation), and a season identifier at a minimum. Optionally, *wxgenR* can also simulate daily maximum and minimum temperatures when these two variables are included as inputs (figure 1). Details of simulating maximum and minimum temperatures are provided in the Supplementary Material of the paper. Here we focus our presentation on the simulation of daily precipitation and mean temperature.

The RCT may be based on available climate information such as GCMs, regional climate models, national climate assessments, local climate impact studies, and, ideally, should be developed through a stakeholder-driven collaborative process. Using a single RCT, *wxgenR* resamples the precipitation, mean temperature and seasonality information prescribed in this trace to develop an ensemble of daily precipitation and mean temperature time series that represents a range of possible magnitudes, daily patterns, and seasonality that preserves the statistical properties (e.g., moments, spell statistics, etc.) of the given RCT. Yates et al. (Yates et

al. 2003) provides an algorithm to develop RCTs from historical observations of precipitation and temperature with prescribed change information for these hydroclimate variables. Fatichi et al (Fatichi et al. 2011) provides a methodology for calculating and applying change factors estimated from multi-model ensemble of GCM realizations. In addition, ensemble-informed climate scenario development approaches such as the hybrid delta ensemble method (Elsner et al. 2010; Hamlet et al. 2013) can be used to develop a set of RCTs representing a range of future climatic conditions (e.g., hot-dry, warm-wet, etc.) which can then be used individually in *wxgenR* to develop daily weather sequences of precipitation and mean temperature corresponding to the respective future climate. *wxgenR* is accessible through the Comprehensive R Archive Network (CRAN).

wxgenR was tested at nine weather stations from the Global Historical Climatology Network (GHCN) distributed across the contiguous United States (CONUS). The stations were selected for their geographic diversity such that *wxgenR* could be tested under a variety of hydroclimatic regimes (figure 1).

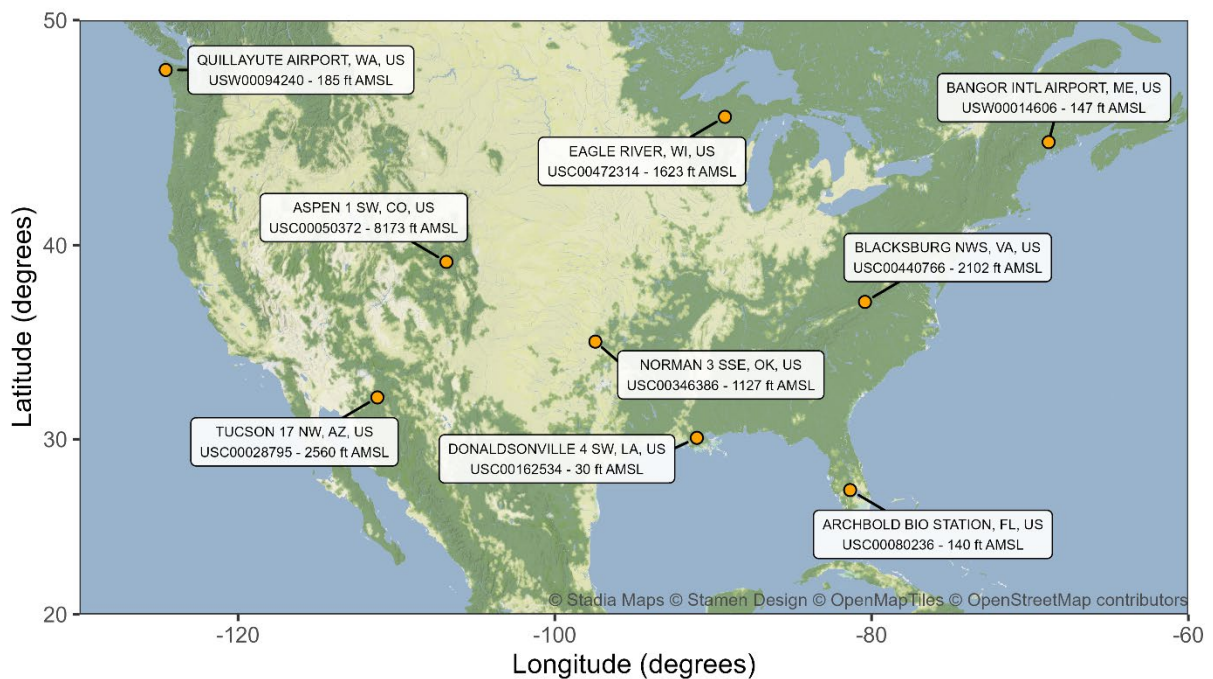


Figure 1.—GHCN weather stations used to train and validate *wxgenR*. Labels indicate city, state, country, GHCN identification code, and elevation in feet above mean sea level (AMSL).

The significant contributions for *wxgenR* are listed below:

- Seasonality integration—*wxgenR* accounts for seasonal shifts in weather patterns, enabling studies on phenomena like earlier snowmelt or prolonged dry spells.
- Customizable simulations—the package supports user-defined parameters, such as simulation length, seasonal definitions, and perturbation of precipitation/temperature, making it flexible for diverse applications.
- Validation—tested using data from nine weather stations across the United States, *wxgenR* demonstrates strong performance in capturing statistical moments, seasonal variability, and wet/dry spell lengths.
- Multisite and multivariate weather generation—*wxgenR* can simulate daily precipitation, average, maximum and minimum temperatures for multiple sites, and preserves the spatial covariability across these sites (see, Supplementary Material for details and case study). Guidance for generating additional hydroclimate variables, such as solar radiation, is also provided in the Supplementary Material.
- Broad applicability—by accommodating both point and basin-average data, *wxgenR* is suitable for applications in hydrology, ecology, and disaster risk management. It is particularly useful for regions where historical weather data is limited or where climate model projections need validation.
- Accessibility and transparency—*wxgenR* is openly available on CRAN, with extensive documentation and supporting examples.

3.0 Research Outcomes and Work Products

wxgenR allows users to generate ensembles of precipitation and temperature with custom-defined simulation length, ensemble size, seasonality definitions, sampling window length as well as optional perturbation of precipitation and/or temperature (figure 2). *wxgenR* can be applied to point- or basin-average type data. *wxgenR* can be applied to either multi-site data or select gridded data (e.g., grid cells representative of stations, elevation bands, etc.); such multi-site applications would require post-processing to maintain the spatial coherence between sites. The Schaake Shuffle (Clark et al. 2004), and the Iman and Conover (Iman and Conover 1982) algorithms are post-processing techniques which can be used to introduce/preserve correlations in a multivariate dataset. However, there are algorithmic differences between these two methods, and Li and Babovic (Li and Babovic 2019) provides a detailed comparison of these two algorithms. The Iman and Conover (Iman and Conover 1982) shuffling algorithm used here performs well in preserving the Spearman Rank correlation between stations but assumes stationarity of the observational record which may require adjustments for climate change applications. Refer to the Supplementary Material for details on how the Iman and Conover (Iman and Conover 1982) method is implemented into *wxgenR* for multisite simulation which maintains spatial covariability among simulated variables.

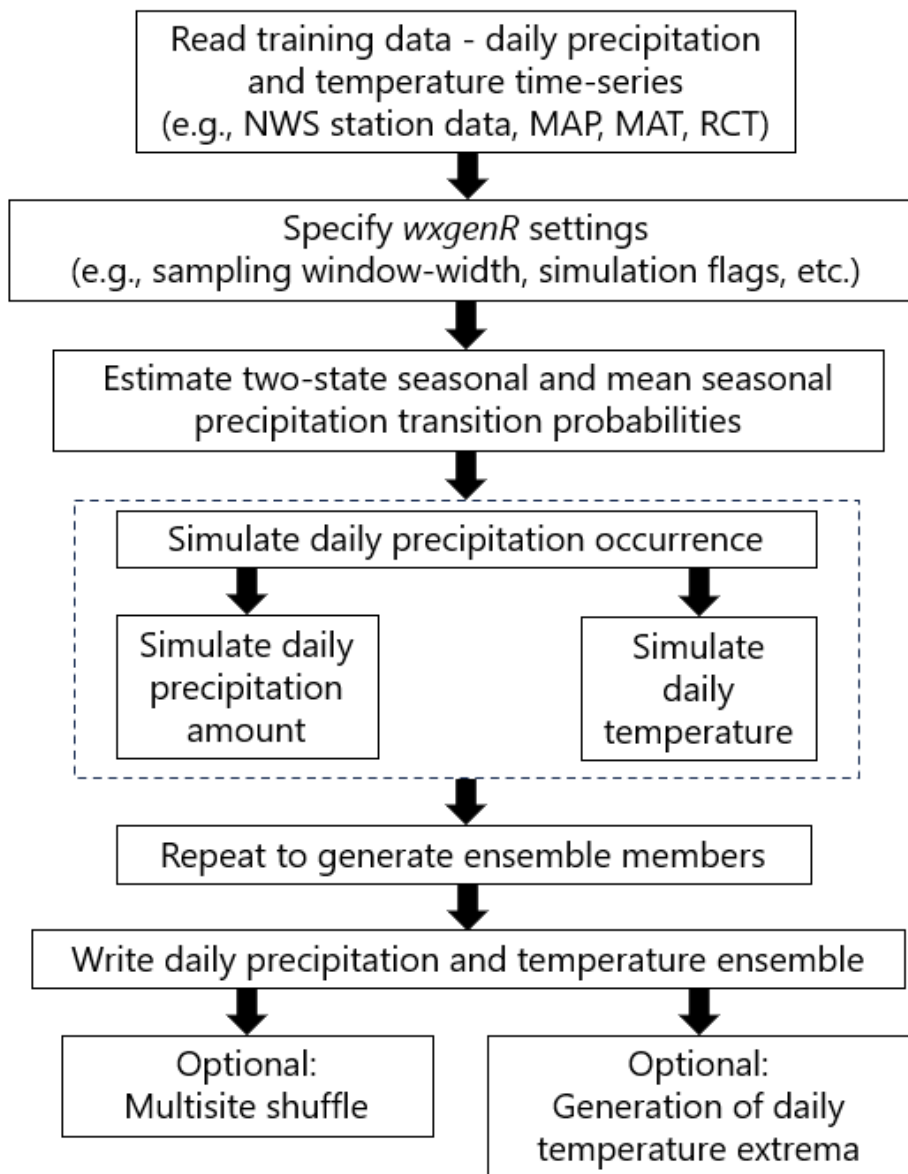


Figure 2.—Overview of *wxgenR* setup and operation with options for multisite simulation and shuffle to preserve spatial covariability, and simulation of temperature extrema—maximum and minimum temperatures.

wxgenR can be used in any of the traditional realms where weather generators have been used. The main motivation behind the development and use of *wxgenR* has thus far been for climate change analyses (e.g., the Lower Santa Cruz River Basin Study [Bearup et al. 2021]), wherein *wxgenR* is used to widen the envelope of uncertainty surrounding a single representative climate model trace. *wxgenR* may also be used in a similar context with perturbed historical data for scenario planning; for example, historical data may be perturbed with warm/hot/dry/wet scenarios and potentially shifted seasonal delineations as well (e.g., an earlier spring onset). In

these climate change impact applications, *wxgenR* is perhaps an alternative, complementary approach to the traditional approach of climate model downscaling and bias-correction. Finally, *wxgenR* is widely available in an easy-to-use R package. Between its original release on 2023-09-14 and 2025-09-30, *wxgenR* had been downloaded 7,683 times.

4.0 Resources

Presentations:

Woodson, David, Subhrendu Gangopadhyay, Lindsay Bearup, et al. 2025. *wxgenR*: A Collaborative Stochastic Weather Generator Incorporating Seasonality for Climate Impacts Assessment. 105th Annual AMS Meeting 2025, *American Meteorological Society Meeting Abstracts* Volume 105 (January): 452429.

Publications:

Woodson, David, Subhrendu Gangopadhyay, Lindsay Bearup, et al. 2025. *wxgenR*: An R Package for Stochastic Weather Generation with Seasonality. *SoftwareX* 31 (September): 102209. <https://doi.org/10.1016/j.softx.2025.102209>.

Online Resources:

All code and documentation for *wxgenR* are publicly available through CRAN and GitHub:

- CRAN: <https://cran.r-project.org/package=wxgenR>
- GitHub: <https://github.com/dwoodson-usbr/wxgenR>

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Appendix A

wxgenR: An R Package for Stochastic Weather Generation with Seasonality

wxgenR: An R Package for Stochastic Weather Generation with Seasonality

A journal article containing methods, data and results relevant to the weather generator, wxgenR, is published in Software X. Follow the doi link below to access the article and supplementary material.

Woodson, David, Subhrendu Gangopadhyay, Lindsay Bearup, et al. 2025. wxgenR: An R Package for Stochastic Weather Generation with Seasonality. *SoftwareX* 31 (September): 102209. <https://doi.org/10.1016/j.softx.2025.102209>

Appendix B

Peer Review Comments and Response from SoftwareX

Response to Reviewer Comments

Manuscript title: *wxgenR*: An R package for stochastic weather generation with seasonality

Authors: David Woodson, Subhrendu Gangopadhyay, Lindsay Bearup,
Andrew Verdin, Eylon Shamir, Eve Halper, and Marketa McGuire

We would like to first thank the two anonymous reviewers for their time and valuable comments that have helped us to significantly improve the manuscript and expand the functionalities of our R package *wxgenR*.

We considered all issues mentioned in the reviewers' comments carefully and provided a point-by-point response to each of the reviewer comments here.

Reviewer comments and remarks are presented using italicized font text, and our response to each comment is discussed using regular font text. We have also made minor formatting edits for a few of the comments for completeness and consistency in the presentation, and to help with the readability in preparing our responses.

We first provide response to the comments from Reviewer #1 followed by response to comments from Reviewer #2.

Reviewer #1

The paper introduces wxgenR, an R package designed for stochastic weather generation that incorporates seasonal variability in precipitation and temperature. The package addresses the needs in climate change adaptation and hydroclimate modeling, providing users with an accessible tool for generating weather data ensembles under various scenarios.

Thank you for this excellent summary of the manuscript.

Key contributions of the package and paper

- *Seasonality Integration: wxgenR accounts for seasonal shifts in weather patterns, enabling studies on phenomena like earlier snowmelt or prolonged dry spells.*
- *Customizable Simulations: The package supports user-defined parameters, such as simulation length, seasonal definitions, and perturbation of precipitation/temperature, making it flexible for diverse applications.*
- *Validation: Tested using data from nine weather stations across the United States, wxgenR demonstrates strong performance in capturing statistical moments, seasonal variability, and wet/dry spell lengths.*

We are in complete agreement with the Reviewer on the key contributions of the package and the paper. Of the three key contributions noted by the Reviewer, the standout contribution in our view is the focus on seasonality. To the best of our knowledge, the ability to incorporate changing seasons to simulate “what-if” climate change scenario conditions make this tool unique. In terms of customization capabilities of wxgenR, we attempted to incorporate our collective lessons learned having conducted several large-scale water resources planning studies and keeping the user in mind—the parameters that are generally important to the user in applying a tool such as weather generators. We also wanted to validate the applicability of wxgenR by testing its performance across a broad range of hydroclimatic conditions throughout the Continental United States (CONUS). As the Reviewer has correctly noted, we tested wxgenR using data from nine weather stations across CONUS, and wxgenR demonstrated strong performance in capturing statistical moments, seasonal variability, and wet-dry spell lengths.

In addition (please refer to subsequent comment and response), we have now added multisite functionality and the ability to simulate multiple variables in wxgenR. We illustrate this new functionality through a standalone case study which is included in the Supplementary Material of the manuscript.

Strengths of the contribution

- *Innovative Methodology: wxgenR combines stochastic resampling and statistical modeling with a focus on seasonality, addressing limitations in traditional weather generators. The ability to perturb data for “what-if” scenarios make it a valuable tool for climate change impact studies.*
- *Broad Applicability: By accommodating both point and basin-average data, wxgenR is suitable for applications in hydrology, ecology, and disaster risk management. It is particularly useful for regions where historical weather data is limited or where climate model projections need validation.*
- *Accessibility and Transparency: wxgenR is openly available on CRAN, with extensive documentation and examples provided.*

We are in complete agreement with the Reviewer on the strengths of this contribution. The *wxgenR* methodology is data-driven and combines stochastic resampling and statistical modeling with a focus on seasonality addressing the limitations in traditional weather generators. Our goal was to develop a tool with the user/stakeholder in mind where for example, representative climate traces (RCTs; refer to text in the paper for description) can be developed collaboratively by prescribing user-defined parameters for a broad range of impact assessment studies. Subsequently, RCTs are used by *wxgenR* to simulate a weather ensemble for input to impact assessment models. To that end, we appreciate the recognition by the Reviewer in the broad applicability of *wxgenR* to support impact assessments in diverse fields such as hydrology, ecology, and disaster risk management. Last but not the least, as the methodology supporting *wxgenR* was developed through federally funded projects, we generally need to have the tool accessible and available for public use. We have published *wxgenR* through the peer-reviewed CRAN (The Comprehensive R Archive Network) archive along with extensive documentation and example applications for this R package. We believe that by implementing all the recommended changes from the reviewers and achieving acceptance of this revised manuscript by the Journal, we will fulfill our vision for *wxgenR*'s comprehensive documentation, which includes the methodology (stochastic resampling and statistical modeling) as well as the application and validation of this R package.

Weaknesses

- *Limited Multisite Functionality: While wxgenR can simulate individual sites, its lack of inherent multisite spatial coherence is a limitation for studies requiring geographically linked weather patterns. The suggested use of the Schaake Shuffle for spatial correlation is a post-processing step, which may complicate workflows for end-users. Copula-based approaches may provide an alternative. See for example: X. Li, V. Babovic, 2019, Multi-site multivariate downscaling of global climate model outputs: An integrated framework combining quantile mapping, stochastic weather generator and empirical copula approaches. Climate Dynamics, 52, 5775–5799.*

Thank you for the comment and pointing out *wxgenR*'s multisite functionality limitation and motivating us to include this functionality in our R package. We have now added multisite functionality to *wxgenR* as a post-processing step following the generation of correlated daily weather variables at individual sites. We have implemented this functionality following the concepts of the Schaake Shuffle methodology (Clark, et al., 2004)¹ and work of Iman and Conover (1982)². We have added functions to the updated *wxgenR* R package and demonstrate this update through a standalone case study application for the Boulder County area in Colorado, USA. This case study application, presented in the manuscript's Supplementary Material, illustrates generation of multiple daily weather variables (precipitation, average temperature, maximum and minimum temperatures; also see comment below in the section—Suggestions for Improvement) and preservation of correlation and cross-correlation of these weather variables across the multiple sites in this study area.

¹ Clark, M., Gangopadhyay, S., Hay, L., Rajagopalan, B., and Wilby, R. (2004). The Schaake Shuffle: A Method for Reconstructing Space–Time Variability in Forecasted Precipitation and Temperature Fields. *Journal of Hydrometeorology*, 5, 243–262, [https://doi.org/10.1175/1525-7541\(2004\)005<0243:TSSAMF>2.0.CO;2](https://doi.org/10.1175/1525-7541(2004)005<0243:TSSAMF>2.0.CO;2).

² Iman, R. L., and Conover, W. J. (1982). A distribution-free approach to inducing rank correlation among input variables. *Communication in Statistics-Simulation and Computation*, 11(3), 311–334, <https://doi.org/10.1080/03610918208812265>.

Integrating the multisite weather generation functionality within *wxgenR* will alleviate workflow complications for the end-users and addresses a concern you had raised. We fully agree that other approaches such as ones based on copulas (e.g., Li and Babovic, 2019) are applicable, and we have noted the same in the revision. However, given the general non-parametric resampling framework used in *wxgenR* we elected to use a distribution-free approach, i.e., the concepts described in Clark et al. (2004), and Iman and Conover (1982) to implement multisite functionality. Our case study application validates a satisfactory level of performance of this distribution-free implementation of multisite weather generation in *wxgenR*.

We found this recommendation of yours to be extremely helpful, and we certainly consider including this multisite weather generation functionality as a major improvement to *wxgenR* and for it to be a versatile tool to support impact assessments in diverse fields.

- *Sensitivity to Data Quality: wxgenR's performance is heavily reliant on the quality and completeness of input data. Its robustness in handling noisy or incomplete datasets could be elaborated further.*

We fully agree that *wxgenR*'s performance is heavily reliant on the quality and completeness of input data. For that matter, we would generalize that this statement is valid for any weather generator and is independent of methodological choices (e.g., parametric or non-parametric) used in the simulation to generate weather ensembles. Even though this R package can numerically handle missing data, in designing *wxgenR* we made a choice that the users of this R package will be developing complete time series which will then form the input (training data) for *wxgenR*. Again, the expectation is to use complete weather time series datasets which users are anticipated to complete as a preprocessing step before applying *wxgenR*. We did not want to include, to some extent arbitrary, data filling methods such as random imputation or linear interpolation to fill-in missing values of a daily weather time series. Such approaches we believe could lead to improper applications of *wxgenR*. We want the end-user to have control and understanding of the *wxgenR* training dataset (input), and not for the tool to be a so called "plug-and-play" black-box.

We acknowledge your comment and have included highlights of the above discussion in the revision and contemplate this elaboration and rationale to be adequate for addressing the issue of reliance on the quality and completeness of input datasets.

- *Evaluation Gaps: The study focuses on temperature and precipitation but does not explore other key atmospheric variables like solar radiation or wind, which are critical for many applications. The performance under extreme weather conditions (e.g., floods or droughts) is not explicitly assessed.*

We have now added functionality to *wxgenR* for developing traces (realizations) of daily maximum and minimum temperatures in addition to daily precipitation and average temperature. To develop traces of daily maximum and minimum temperatures, these two variables must now be included as part of the training dataset (input) used by *wxgenR* in stochastic resampling and statistical modeling. Daily average temperature is derived from daily maximum and minimum temperatures—(daily maximum temperature + daily minimum temperature)/2. Then the *wxgenR* algorithm (described in Section 2.1 of the manuscript) is applied to develop traces of daily precipitation and average temperature. Next, maximum temperature is estimated using quantile mapping from monthly CDFs (cumulative distribution functions) of average and maximum temperatures developed from the training dataset. For example, to estimate maximum temperature for January 1st of a given trace, we use the January CDFs of maximum temperature and average temperature. These CDFs are built using all the available daily data for a given month. Say, if

30-years of weather data were used in the training dataset, 30×31 (total number of days in January) = 930 average and maximum temperature values (assumes the dataset to be serially complete) will be utilized in developing the respective monthly CDFs. After estimating the maximum temperature for the day (e.g., January 1st), minimum temperature is calculated utilizing the average temperature relationship presented above. The development of monthly CDFs is implemented within *wxgenR*.

With the ability of *wxgenR* now to simulate daily maximum and minimum temperatures, this R package is well-poised to develop other key atmospheric variables such as solar radiation. Given that several algorithms exist to develop solar radiation using inputs of daily precipitation, maximum and minimum temperatures, we direct end-users to select an appropriate algorithm to calculate key atmospheric variables, e.g., solar radiation. To that end, we would like to suggest the following peer-reviewed publications—Kimball et al. (1997)³, Thornton and Running (1999)⁴, and Thornton et al. (1997)⁵, and select an applicable algorithm to estimate, dew point temperature, humidity and solar radiation. Our rationale for developing *wxgenR* was to provide functionalities to generate the minimum number of essential daily weather variables (precipitation, average, maximum and minimum temperatures) and for the end-user to subsequently apply a relevant algorithm (refer to, Kimball et al., 1997; Thornton and Running, 1999; Thornton et al., 1997) to estimate key atmospheric variables such as solar radiation, among others.

With all our hydrologic modeling including climate impacts assessments with hydrology models we use historical wind fields (e.g., observed or derived from reanalysis models). This is because changes in wind events especially extreme wind events are poorly understood due to climate model limitations in doing realistic wind field simulations (e.g., Chapter 3 Fifth National Climate Assessment—USGCRP (2023)⁶; Rahimi et al, 2024⁷). With *wxgenR* our goal was to develop a minimum albeit essential daily weather variables.

Following on your extremely helpful recommendation, we recognized the importance of including the functionality of generating daily maximum and minimum temperatures (in addition to daily precipitation and average temperature), and then for the end-user to derive other key atmospheric variables—e.g., dew point temperature, humidity and solar radiation, using published algorithms. We also want to justify this rationale and approach to ensure that all the simulated hydroclimate variables are intrinsically physically consistent. We acknowledge that selection of the daily wind fields is somewhat prescriptive and follows from an implicit assumption that cross-correlation coefficients between wind speed and other

³ Kimball, J. S., Running, S. W., and Nemani, R. R. (1997). An improved method for estimating surface humidity from daily minimum temperature. *Agriculture and Forest Meteorology*, 85, 87–98, [https://doi.org/10.1016/S0168-1923\(96\)02366-0](https://doi.org/10.1016/S0168-1923(96)02366-0).

⁴ Thornton, P. E., and Running, S. W. (1999). An improved algorithm for estimating incident daily solar radiation from measurements of temperature, humidity, and precipitation. *Agricultural and Forest Meteorology*, 93, 211–228, [https://doi.org/10.1016/S0168-1923\(98\)00126-9](https://doi.org/10.1016/S0168-1923(98)00126-9).

⁵ Thornton, P. E., Running, S. W., and White, M. A. (1997). Generating surfaces of daily meteorological variables over large regions of complex terrain. *Journal of Hydrology*, 190, 214–251, [https://doi.org/10.1016/S0022-1694\(96\)03128-9](https://doi.org/10.1016/S0022-1694(96)03128-9).

⁶ USGCRP (U.S. Global Change Research Program) (2023). *Fifth National Climate Assessment*. Eds. Crimmins, A.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, B.C. Stewart, and T.K. Maycock, <https://doi.org/10.7930/NCA5.2023>.

⁷ Rahimi, S., Huang, L., Norris, J., Hall, A., Goldenson, N., Krantz, W., et al. (2024). An overview of the Western United States Dynamically Downscaled Dataset (WUS-D3). *Geoscientific Model Development*, 17, 2265–2286, <https://doi.org/10.5194/gmd-17-2265-2024>.

hydrometeorological variables are small (Ivanov et al., 2007⁸). However, Fatichi et al. (2011)⁹ notes that, “wind speed exhibits a marked daily cycle in some locations and therefore the assumption of independence may need to be questioned.” Additional publications, for example, which describes a parametric model for wind speed generation is the one by Parlange and Katz (2000)¹⁰, which is an extension of the Richardson (1981)¹¹ model to include two additional variables—daily mean wind speed and dewpoint temperature. We could explore incorporating methods presented across the various publications that consider wind field generation in a future update to *wxgenR*, but from our experience, we find our current practice of using historical (or reanalysis) wind field data to be sufficient for now. However, your comment does provide us impetus to explore wind field generation as a future research topic for consideration.

Finally, to respond to your comment, “*The performance under extreme weather conditions (e.g., floods or droughts) is not explicitly assessed.*”, we have now included statistics for maximum and average, wet-dry spell lengths comparing training and simulated datasets for daily precipitation for each station in the Supplementary Material of the manuscript. These spell length statistics along with statistics such as maximum daily precipitation provides evidence that *wxgenR* can satisfactorily simulate extreme weather conditions which can result in flood or certain drought (dry spell length) conditions. These spell statistics serve as indicators and are the drivers for extreme events. To explicitly simulate flood or drought events would require water balance calculations using a hydrologic model and we see that to be beyond the current scope of the weather generator tool development effort. We conclude that we have adequately demonstrated the satisfactory performance of *wxgenR* with a wide-range of statistical measures covering multi-order moments (mean, standard deviation and coefficient of skewness), seasonal variability (relevant monthly statistics), spell characteristics, at-site and multi-site correlation and cross-correlation variability. The at-site and multi-site correlation and cross-correlation variability is presented in the case study described in the Supplementary Material of the manuscript.

⁸ Ivanov, V. Y., Bras, R. L., and Curtis, D. C. (2007). A weather generator for hydrological, ecological, and agricultural applications. *Water Resources Research*, 43, W10406, <https://doi.org/10.1029/2006WR005364>.

⁹ Fatichi, S., Ivanov, V. Y., and Caporali, E. (2011). Simulation of future climate scenarios with a weather generator. *Advances in Water Resources*, 34, 448-467, <https://doi.org/10.1016/j.advwatres.2010.12.013>.

¹⁰ Parlange, M. B., and Katz, R. W. (2000). An extended version of the Richardson model for simulating daily weather variables. *Journal of Applied Meteorology*, 39, 610–622, <https://doi.org/10.1175/1520-0450-39.5.610>.

¹¹ Richardson, C. W. (1981). Stochastic simulation of daily precipitation, temperature, and solar radiation. *Water Resources Research*, 17, 182–190, <https://doi.org/10.1029/WR017i001p00182>.

- *Unclear Comparison with Alternatives: A detailed comparison with existing stochastic weather generators would clarify wxgenR's relative strengths and weaknesses. See for example: S. Fatichi, et al., 2011, Simulation of future climate scenarios with a weather generator. Advances in Water Resources, 34(4), 448–467.*

We have not compared our weather generator (*wxgenR*) with alternative weather generators. We do fully acknowledge this could be a very useful exercise, but to do such comparisons in a comprehensive and meaningful manner will require establishing community model comparison protocols such as the ones used in, for example, MOPEX (Model Parameter Estimation Experiment; Duan et al., 2006¹²) or HEPEX (Hydrologic Ensemble Prediction Experiment; Schaake et al., 2006¹³), among others. Without a comprehensive weather generator model comparison protocol including use of benchmark datasets and QA/QC (Quality Assurance/Quality Control) of existing stochastic weather generator codes, we feel, any comparison will lack the necessary rigor, will be inadequate and generally not meaningful. *wxgenR* is another tool in the weather generator toolbox, but as you have adeptly recognized its strength lies in the ability to focus on seasonality. We want to reiterate, the ability to incorporate changing seasons to simulate “what-if” climate change scenario conditions make this tool unique. Furthermore, we maintain transparency of our code through the peer-reviewed CRAN software publication process of R packages where the tool has passed the QA/QC requirements of CRAN, and the code is publicly accessible for use and critical reviews.

Our validation statistics also demonstrate that *wxgenR* can satisfactorily simulate daily weather variables—precipitation, average, maximum, and minimum temperatures, and with the addition of multisite functionality, at-site and multi-site correlation and cross-correlation variability at daily and monthly (seasonal) time scales. Following your recommendation, updating *wxgenR* with multisite functionality and including capabilities to simulate daily maximum and minimum temperatures alleviates any major weaknesses in the *wxgenR* tool from its original submission. In revising the manuscript, we also provide directions for end-users on the available literature relevant to simulating additional key atmospheric variables such as solar radiation, dew point temperature and humidity including hydrologic practices followed by many of the authors of this research (e.g., use of historical daily wind fields in hydrologic modeling).

We are quite confident that you will understand our reasoning for not conducting a detailed comparison with existing stochastic weather generators without established data and model code handling protocols. Additionally, we believe we have effectively followed your recommendations to enhance *wxgenR* by incorporating multisite and multivariate functionality, and we have significantly demonstrated its successful performance through a range of relevant statistical measures.

¹² Duan, Q., Schaake, J., Andréassian, V., Franks, S., Goteti, G., Gupta, H. V., et al. (2006). Model Parameter Estimation Experiment (MOPEX): An overview of science strategy and major results from the second and third workshops. *Journal of Hydrology*, 320, 3–17, <https://doi.org/10.1016/j.jhydrol.2005.07.031>.

¹³ Schaake, J., Franz, K., Bradley, A., and Buizza, R. (2006). The Hydrologic Ensemble Prediction Experiment (HEPEX). *Hydrology and Earth System Sciences Discussion*, 3, 3321–3332, <https://doi.org/10.5194/hessd-3-3321-2006>.

Suggestions for Improvement

- *Expand Multisite Capabilities: Incorporate built-in functionalities for spatially correlated multisite simulations to broaden the package's applicability.*

Thank you for this valuable suggestion. We have now incorporated built-in functionality in *wxgenR* to perform spatially correlated multisite multivariate simulation and we have provided discussion of the same in our responses in the sections above. We see these expanded functionalities to sufficiently broaden the applicability of our R package *wxgenR*.

- *Enhance Validation: Include additional metrics to evaluate performance during extreme weather events, which are increasingly relevant in climate studies. See for example: J. Chadalawada, V. Babovic, 2019, Review and comparison of performance indices for automatic model induction. Journal of Hydroinformatics, 21(1), 13–31.*

Thank you for this valuable suggestion. We have now included maximum and average wet-dry spell length statistics and results of maximum daily precipitation simulation in the content of the Supplementary Material of the manuscript. These spell length statistics along with statistics such as maximum daily precipitation provides evidence that *wxgenR* can satisfactorily simulate extreme weather conditions which can result in flood or certain drought conditions. These spell statistics serve as indicators and are the drivers for extreme events. We do not explicitly simulate flood or drought events using any hydrologic model and we see that to be beyond the current scope of the weather generator tool development effort. We acknowledge that further analysis of extreme events using hydrology models with *wxgenR* simulated weather ensembles will be a useful addition in a future research application.

- *Support for Additional Variables: Extend wxgenR to simulate variables like wind speed or solar radiation, making it more versatile.*

Thank you for this valuable suggestion. We have now incorporated built-in functionality in *wxgenR* to generate daily maximum and minimum temperatures in addition to daily precipitation and average temperature, which were the only two variables that *wxgenR* simulated in our first submission. Our rationale for developing *wxgenR* was to provide functionalities to generate the minimum number of essential daily weather variables (precipitation, average, maximum and minimum temperatures) and we direct end-users to subsequently apply relevant published algorithms to estimate key atmospheric variables such as solar radiation, dew point temperature and humidity including hydrologic practices followed by many of the authors of this research, specifically, use of historical daily wind fields in hydrologic modeling. We have considered your valuable suggestion but want to justify our rationale with the *wxgenR* simulation approach to develop essential daily weather variables which are generated to be internally consistent (see Section 2.1 of the main manuscript), and use of subsequent algorithms to simulate additional atmospheric variables (e.g., solar radiation, etc.). Such an approach ensures that all the simulated hydroclimate variables are intrinsically physically consistent which should be a necessary condition for all weather generators.

- *Comparison with Existing Tools: Provide a comparative analysis with alternative weather generators to demonstrate wxgenR's unique contributions.*

We have not compared our weather generator (*wxgenR*) with alternative weather generators. We do fully acknowledge this could be a very useful exercise, but we are of the opinion that to do a comprehensive meaningful comparison would require use of established model comparison protocols. We are not aware of any such protocol to compare stochastic weather generators. We would like to reiterate, that we feel largely confident that you will agree with our rationale in not conducting a detailed comparison with existing stochastic weather generators without established data and model code handling protocols. We have followed your recommendations in improving *wxgenR* by including additional multisite and multivariate functionality, and substantially demonstrate its performance successfully using pertinent statistical measures and verification metrics. As far as a unique contribution, we would like to emphasize, the ability to incorporate changing seasons to simulate “what-if” climate change scenario conditions make *wxgenR* a unique tool by addressing the limitations in traditional weather generators.

If a protocol is developed by the atmospheric science and hydrologic modeling community (e.g., like MOPEX, HEPEX, etc.) to compare stochastic weather generators with benchmark datasets including QA/QC protocols for the weather generator codes and reporting of results, it will provide the necessary platform for *wxgenR* to do a meaningful comparative analysis. Once again, we are quite confident that you will understand our reasoning for not conducting a comparative analysis; however, we are open to pursuing this as a future community collaboration effort.

Conclusion

wxgenR is potentially useful tool that makes proposes some advancements in stochastic weather generation by integrating seasonality and providing flexible simulation options. It has potential for use in climate impact assessments and resource planning. Addressing its limitations, particularly in multisite coherence and evaluation under extreme conditions, could further enhance its utility and adoption in diverse research domains.

We most certainly appreciate your valuable insights and comments. You will see that we have carefully considered all your comments and suggestions to address the limitations of *wxgenR* from the first submission. To that end, *wxgenR* has now been updated to include multisite and multivariate functionality including intrinsic preservation of physical consistency of the generated daily weather variables and spatial coherence in multisite application. We also clearly demonstrate *wxgenR*'s performance with respect to wet-dry spell characteristics and in its ability to successfully simulate daily maximum precipitation events. Even though we do not explicitly use any hydrology model, these spell statistics serve as indicators and drive extreme events which *wxgenR* is able to satisfactorily replicate.

As you rightly point out and we completely agree, the design of *wxgenR* is flexible and we have attempted to incorporate our collective lessons learned from several large-scale water resources planning studies and keeping the user in mind to be able to intuitively parameterize the weather generator and to develop the requisite training datasets which serve as the primary input for *wxgenR*.

We believe that with the incorporation and thorough validation of your suggested updates, *wxgenR* will be a valuable tool across various research domains. This package meets the needs of climate change adaptation and hydroclimate modeling, offering users an accessible means to generate weather data ensembles under different scenarios.

Reviewer #2

This manuscript introduces wxgenR, a novel weather generator designed for simulating daily rainfall and temperature. The manuscript is generally well-written, and the results appear credible. However, I have the following concerns:

- *The precipitation model presented in the study combines a first-order Markov chain for precipitation occurrence with a resampling-based method for precipitation intensity. These components, individually, are not new and have been applied in prior weather generators. I recommend that the authors provide a more thorough review of existing weather generation models in the literature. Additionally, it would be beneficial for the authors to clearly articulate the specific contributions of this study relative to existing approaches, thereby clarifying the novel aspects of their work.*

We agree with the Reviewer that the first-order Markov chain method for simulating precipitation occurrence followed by a resampling approach have been used in prior weather generators (e.g., Richardson, 1981; Yates et al., 2003¹⁴). However, we are not aware of a weather generator that has explicitly incorporated seasonality into these approaches. In fact, this was a key motivation for us to develop *wxgenR*—ability to generate weather ensemble accounting for seasonality shifts from a changing climate. The development of *wxgenR* was initiated by a hydroclimate analysis using areal average precipitation and temperature from the Lower Santa Cruz River Basin in Arizona, USA, to understand hydrologic impacts from shifts in seasonality, specifically, shifts in the North American Monsoon seasonality in this monsoon-dominated region (Bearup et al., 2021¹⁵). Following your recommendation, we have expanded the literature review in the manuscript, and we have described the specific contributions of this study and its novel aspects. The specific contributions we have described are listed below and are compiled from comments and suggestions provided to us by other reviewers of the manuscript, and our responses.

- Seasonality Integration: *wxgenR* accounts for seasonal shifts in weather patterns, enabling studies on phenomena like earlier snowmelt or prolonged dry spells.
- Customizable Simulations: The package supports user-defined parameters, such as simulation length, seasonal definitions (e.g., Bearup et al., 2021), and perturbation of precipitation/temperature, making it flexible for diverse applications.
- Validation: Tested using data from nine weather stations across the United States, *wxgenR* demonstrates strong performance in capturing statistical moments, seasonal variability, and wet/dry spell lengths.

¹⁴ Yates, D., Gangopadhyay, S., Rajagopalan, B., and Strzepek, K. (2003). A technique for generating regional climate scenarios using a nearest-neighbor algorithm. *Water Resources Research*, 39(7), 1199, <https://doi.org/10.1029/2002WR001769>.

¹⁵ Bearup, L., Gangopadhyay, S., and Mikkelson, K. (2021). Lower Santa Cruz River Basin Study Hydroclimate Analysis. *Bureau of Reclamation-Technical Service Center*, Technical Memorandum No. ENV-2020-056, 94 p. https://www.usbr.gov/lc/phoenix/programs/lscrbasin/LSCRBS_Hydroclimate_2021.pdf.

- Broad Applicability: By accommodating both point and basin-average data, *wxgenR* is suitable for applications in hydrology, ecology, and disaster risk management. It is particularly useful for regions where historical weather data is limited or where climate model projections need validation.
- Accessibility and Transparency: *wxgenR* is openly available on CRAN, with extensive documentation and examples provided.

Of the key contributions listed above, the standout contribution in our view is the focus on seasonality. To the best of our knowledge, the ability to incorporate changing seasons to simulate “what-if” climate change scenario conditions make this tool unique. In terms of customization capabilities of *wxgenR*, we attempted to incorporate our collective lessons learned having conducted several large-scale water resources planning studies and keeping the user in mind—the parameters that are generally important to the user in applying a tool such as weather generators. We also wanted to validate the applicability of *wxgenR* by testing its performance across a broad range of hydroclimatic conditions throughout the Continental United States (CONUS). We have tested *wxgenR* using data from nine weather stations across CONUS, and *wxgenR* demonstrated strong performance in capturing statistical moments, seasonal variability, and wet-dry spell lengths (please see response to the next comment).

We have now added multisite functionality and the ability to simulate multiple variables in *wxgenR*. So, *wxgenR* is now capable of simulating daily weather variables which includes, precipitation, average temperature, maximum and minimum temperatures for multiple sites and preserves the spatial covariability across the sites. We illustrate this new functionality through a standalone case study (Boulder County area in Colorado, USA) which is included in the Supplementary Material of the manuscript.

- *The evaluation of the weather generator appears somewhat preliminary. While the authors state that the model is capable of reproducing statistical moments (e.g., mean, standard deviation, skewness) as well as wet and dry spell lengths, these results are not presented in the manuscript. To strengthen the validation of their approach, I suggest that the authors include these specific results, providing further evidence of the model’s performance.*

We believe we have done quite a thorough evaluation of the weather generator but agree with you that we did not show all the pertinent statistics that we had evaluated. In the revised manuscript’s Supplementary Material, we have included statistics of daily precipitation and temperature simulations including seasonal (monthly) aggregations of the same, and the spell statistics—maximum and average wet-dry spell lengths. Furthermore, since *wxgenR* now includes added multisite and multivariate functionality, we have also included statistics demonstrating the satisfactory performance of the tool in preserving at-site and multi-site correlation and cross-correlation variability amongst daily precipitation, average temperature, maximum and minimum temperatures.

We are confident that you will consider our presentation of the evaluation results in the Supplementary Material of the manuscript to be thorough and comprehensive.

Response to Reviewer Comments—2nd Revision

Manuscript title: *wxgenR*: An R package for stochastic weather generation with seasonality

Authors: David Woodson, Subhrendu Gangopadhyay, Lindsay Bearup,
Andrew Verdin, Eylon Shamir, Eve Halper, and Marketa McGuire

We would again like to thank the two anonymous reviewers for their time and valuable comments that have helped us to significantly improve the manuscript and expand the functionalities of our R package *wxgenR*.

We considered all issues mentioned in the reviewers' comments carefully including suggestions for revision and provided a point-by-point response to each of the reviewer comments here.

Reviewer comments and remarks are presented using italicized font text, and our response to each comment is discussed using regular font text. We have also made minor formatting edits for a few of the comments for completeness and consistency in the presentation, and to help with the readability in preparing our responses.

We first provide response to the comments from Reviewer #1 followed by response to comments from Reviewer #2.

Reviewer #1

Thank you for your recommendations, and we have now addressed the comments you have brought to our attention through this revision.

- *Comparative Analysis with Existing Tools—Although the authors explain their choice not to undertake detailed comparisons with other weather generators, a brief qualitative comparison or conceptual positioning within existing tools would still enhance readers’ understanding of wxgenR’s unique value. Recommendation: Add a concise section comparing major functionalities and limitations against established tools to highlight the unique contributions more clearly.*

Following your recommendation, we have now added a new section, “Text S8. Discussion on comparison of wxgenR with existing weather generators”, in the Supplementary Material in which we present a brief qualitative comparison with a few established weather generators to conceptually position wxgenR’s unique value and conclude the section by providing a discussion as to what would be necessary to conduct a comprehensive comparison across multiple weather generators.

- *Simulation of Additional Variables—While the manuscript now addresses temperature maxima and minima, it lacks built-in functionalities for other critical atmospheric variables (e.g., wind, solar radiation), which are significant for comprehensive climate impact studies. Recommendation: Discuss clearly the reasons behind limiting the package to precipitation and temperature and suggest clearly defined methods or integrations for calculating other atmospheric variables externally.*

Thank you for the comment. As we have noted in the manuscript, wxgenR development was initiated by a hydroclimate analysis using areal average precipitation and temperature from the Lower Santa Cruz River Basin in Arizona, where representing monsoon moisture and changes therein is important for water supply planning. This was a basin-scale water supply planning study, and the input variables of interest for hydrologic modeling were, daily precipitation, average temperature and seasonality of the North American monsoon (see reference [35] in the main manuscript for details of this study). This need motivated the design of wxgenR, and we focused on the primary daily weather variables—precipitation and average temperature. At the same time, we also recognized, it will be useful, more generally for our water resources planning studies with hydrologic models to additionally have simulated daily maximum and minimum temperatures. Your comments from the first revision provided us the impetus to include capability within wxgenR to also be able to simulate daily maximum and minimum temperatures and to add the functionality of multisite simulation of these four daily weather fields—precipitation, average, maximum and minimum temperatures. You will also note from the discussion presented in the text section S5 that we use historical/reanalysis wind fields in our hydrology models for climate impacts assessments; and we anticipate continuing this practice at least for the foreseeable future. One of the primary hydrology models we use for our water resources planning studies is the macro-scale hydrology model, VIC (Variable Infiltration

Capacity)¹. For simulating daily runoff in water balance mode, VIC requires, at a minimum, four daily meteorological inputs—precipitation, maximum and minimum temperatures, and wind speed; other required inputs are related to topography, soil texture and land-cover. The VIC model infrastructure has evolved over the years² but functionally, it still can use these four meteorological variables to calculate fields such as solar radiation and other atmospheric variables (e.g., humidity) using algorithms which we have referenced in section S5. These algorithms are part of the Mountain Microclimate Simulation Model (MTCLIM) which has been used as a forcing preprocessor by the VIC model at least up to VIC version 4. Bohn et al. (2013)³ provides an evaluation of MTCLIM and related algorithms for ecological and hydrological modeling. More recently, these algorithms can be accessed through an open-source standalone Python package, MetSim (Bennett et al., 2020)⁴ for estimation and disaggregation of meteorological data. So, for an external tool to estimate other key atmospheric variables we can recommend the Python package, MetSim. The algorithms used in MetSim to simulate key atmospheric variables are described in the references presented in this section, i.e., section text S5. Using the *wxgenR* simulations of daily precipitation, maximum and minimum temperatures, MetSim can also be used to develop sub-daily values of precipitation, temperature, shortwave radiation, vapor pressure, air pressure, relative humidity, specific humidity, longwave radiation, cloud cover fraction and wind speed (only if given as an input; refer to discussions earlier in this section, i.e., section text S5 for specifying wind data).

We have now added this discussion to text section S5 of the Supplementary Material.

- *Extreme Weather Events Validation—Although wet/dry spells and extreme precipitation statistics have been provided, explicit evaluation or demonstration using real extreme events (floods or droughts), or clear thresholds could strengthen the software's credibility for critical applications. Recommendation: Provide or suggest a more explicit framework for assessing extreme conditions using additional hydrologic modeling if not directly within wxgenR itself.*

We recognize the significance of this comment; however, proposing any explicit framework that involves hydrologic modeling is beyond the scope of the current development and verification effort of this weather generator tool. We would like to reiterate that we have demonstrated *wxgenR*'s overall strong performance to replicate wet/dry spell length statistics including simulation of maximum daily total precipitation. These spell length statistics along with the

¹ Liang, X., Lettenmaier, D. P., Wood, E. F., Burges, S. J. (1994). A simple hydrologically based model of land surface water and energy fluxes for general circulation models. *Journal of Geophysical Research: Atmospheres*, 99, 14415–14428. <https://doi.org/10.1029/94JD00483>.

² Home page for the Variable Infiltration Capacity (VIC) Macroscale Hydrologic Model, <https://vic.readthedocs.io/en/master/>.

³ Bohn, T. J., Livneh, B., Oyler, J. W., Running, S. W., Nijssen, B., and Lettenmaier, D. P. (2013). Global evaluation of MTCLIM and related algorithms for forcing of ecological and hydrological models. *Agricultural and Forest Meteorology*, 176, 38–49, <https://doi.org/10.1016/j.agrformet.2013.03.003>.

⁴ Bennett, A. R., Hamman, J. J., and Nijssen, B. (2020). MetSim: A Python package for estimation and disaggregation of meteorological data. *Journal of Open Source Software*, 5(47), 2042, <https://doi.org/10.21105/joss.02042>.

statistics of maximum daily precipitation provides evidence that *wxgenR* can satisfactorily simulate extreme weather conditions.

Typically, water resources studies have specific study goals, and use modeling tool chains (e.g., hydrology models, water demand forecasting models, and water resources system models among others) to meet these goals. With the use of many such modeling tools (e.g., hydrology models, water demand forecasting models, etc.) input data requirements are quite diverse, and we do point to the study in the Lower Santa Cruz River Basin in Arizona as a case study (see reference [35] in the main manuscript and Gupta et al. (2023)⁵) where wide-ranging water resources management decisions focused on environmental conservation, water supply, and flood control were made using simulations from a “weather generator”—the foundation for *wxgenR*. We would like to refer readers to this study and references listed in the publications here for a framework relevant to water resources decision making such as the ones listed above.

We have excerpted the discussion presented in the paragraphs above in text section S6 of the Supplementary Material.

- *Sensitivity and Uncertainty Analysis*—*The manuscript could benefit from a clear discussion or analysis regarding model sensitivity to input data quality, particularly in handling incomplete or noisy datasets. Recommendation: Include a brief sensitivity analysis, or guidelines clearly defining quality thresholds for input data.*

In text section S7 of the Supplementary Material we have now added the following content (text in quotes) for a guideline to the discussion from the first revision.

“*wxgenR* allows an adaptive window width functionality which is most likely to be invoked in regions with long dry seasons (arid/semi-arid regions), specifying a small initial value of the variable *wwidth* (see Table 3 in main manuscript), or if the number of years in the training data is relatively short. As a general guideline, having a serially complete 30 years of daily training data would provide a representative dataset for the *wxgenR* algorithms.”

However, we want to reiterate that, the expectation is to use serially complete weather time series datasets which users are anticipated to complete as a preprocessing step before applying *wxgenR* even though the package can numerically handle missing input values of daily precipitation and temperature. We did not want to include, to some extent arbitrary, data filling methods such as random imputation or linear interpolation to fill-in missing values of a daily weather time series. Such approaches we believe could lead to improper applications of *wxgenR*. We want the end-user to have control and understanding of the *wxgenR* input dataset, and not for the tool to be a so called “plug-and-play” black-box.

We recon these guidelines to be adequate and the discussions lay out a clear expectation from end-users of the package.

⁵ Gupta, N., Bearup, L., Jacobs, K., Halper, E., Castro, C., Hsin-I, C., and Fonseca, J. (2023). Stakeholder-Informed Hydroclimate Scenario Modeling in the Lower Santa Cruz River Basin for Water Resource Management. *Water*, 15(10), 1884, <https://doi.org/10.3390/w15101884>.

Minor Recommendations

- *Consider improving the visual clarity and explanatory power of figures/tables.*

Thank you for your comment. After reviewing the figures and tables in the manuscript, including the Supplementary Material, we determined that they effectively convey the information and descriptions presented in the text. Therefore, no changes were made to the figures and tables.

- *Ensure clarity in figure captions, helping readers interpret the visuals without extensive reference to the text.*

Thank you for your comment. We reviewed the figure captions in the main manuscript and found that they do not extensively reference the text. However, in the Supplementary Material, we have included cross-references in the figure captions and added notes below some of them for clarity. We believe this stylistic approach enhances the readability of the Table of Figures, which is included at the beginning of the Supplementary Material. Therefore, no changes were made to the figure captions.

Thank you once again for your valuable comments, which have greatly contributed to the improvement of the manuscript, as well as for your overall recommendation of the paper. We are confident that you will find our responses to all your comments to be thorough and comprehensive. We appreciate your recognition of the manuscript's value and its potential to advance climate adaptation research, particularly because of its accessibility, methodological rigor, and practical relevance.

Reviewer #2

The revised manuscript has addressed most of my concerns, but there are still some issues listed as below:

Thank you for your kind acknowledgement that we were able to address most of your concerns in the first revision, and we have now addressed the issues you have brought to our attention through this revision.

- *Lines 6-7 in section 4 of the revised manuscript (with changes marked), the statement “The Schaake Shuffle [50], developed based on the work of Iman and Conover [51], is one such post-processing technique that uses rank ordering to shuffle simulated weather based on observations within a sampling window.” is not true. The Schaake Shuffle algorithm was not developed based on the work of Iman and Conover, and these two algorithms are quite different. For a detailed comparison of these two algorithms, please see the following reference—Li, X., & Babovic, V. (2019). A new scheme for multivariate, multisite weather generator with inter-variable, inter-site dependence and inter-annual variability based on empirical copula approach. *Climate Dynamics*, 52(3), 2247-2267.*

Thank you for your comment, and sorry for any confusion from the attribution. Our intent simply was to note that the Schaake Shuffle and the Iman and Conover method are both nonparametric techniques which can be used to introduce/preserve correlations in a multivariate dataset through post-processing. You are correct in pointing out the algorithmic differences between these two methods. We have now revised the text in the manuscript to reflect the change and included the Li and Babovic (2019) reference which provides a detailed comparison of these two algorithms.

- *To show the performance of the post-processing technique, it is better to show its capability in reconstructing the multi-site and multi-variable correlations using metrics such as inter-site and inter-variable correlations. This is more convincing than showing the perturbed simulated timeseries in Figure S2–S5.*

We present results (boxplots) of multi-site and multi-variable correlations with the metrics of inter-site and inter-variable correlations before and after multisite shuffling in Figures S7–S16 for the two Boulder County (Boulder, Colorado, USA) case study stations—station 1 and station 2; metadata for the stations are given in Table S1. Listed below are the figure captions which summarize the correlation statistics we have calculated.

- Figure S7. Spearman rank correlation between station 1 daily total precipitation and station 2 daily total precipitation calculated by month for observations and simulations before and after multisite shuffling.
- Figure S8. As in Figure S7 but for station 1 daily average temperature and station 2 daily average temperature.
- Figure S9. As in Figure S7 but for station 1 daily maximum temperature and station 2 daily maximum temperature.
- Figure S10. As in Figure S7 but for station 1 daily minimum temperature and station 2 daily minimum temperature.

- Figure S11. As in Figure 7 but for station 1 daily total precipitation and station 2 daily average temperature.
- Figure S12. As in Figure 7 but for station 1 daily total precipitation and station 2 daily maximum temperature.
- Figure S13. As in Figure S7 but for station 1 daily total precipitation and station 2 daily minimum temperature.
- Figure S14. As in Figure S7 but for station 1 daily average temperature and station 2 daily maximum temperature.
- Figure S15. As in Figure S7 but for station 1 daily average temperature and station 2 daily minimum temperature.
- Figure S16. As in Figure S7 but for station 1 daily maximum temperature and station 2 daily minimum temperature.

These figures (Figure S7 through Figure S16) show the Spearman Rank Correlation calculated between variables at stations 1 and 2 for observations, unshuffled- and shuffled- simulations. Boxplots are comprised of correlation values calculated separately by year and trace (i.e., each data point in a January boxplot is the January correlation for a different year and, if from simulated data, a different trace). For example, Figure S7 shows Spearman correlation by month calculated on daily precipitation at station 1 and daily precipitation at station 2. During most months, particularly the high precipitation months, shuffling increases the correlation between stations 1 and 2 to match closely with the observed correlation and reduces the range relative to unshuffled correlation. Similarly, for correlation calculated on temperature variables, shuffling either increases or decreases correlation to better match observed correlation values.

Thank you again for your valuable comments which have helped us to significantly improve the manuscript.