Geoscientific Model Development

STORM: A simple, flexible, and parsimonious stochastic rainfall generator for simulating climate and climate change
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**Synopsis**

This paper presents STORM, a stochastic rainfall model using probability density functions of storms characteristics to generate synthetic individual storms over a grid. The model is flexible and the user has the possibility to perform case-control experiments by shifting the observed PDFs or adding an underlying trend to storm characteristics. The model has wide applications in the context of climate change.

**Major comments**

Generating synthetic time series of rainfall on a grid over short time steps is a very ambitious work. This is not an easy task and authors made a huge effort to develop STORM. I was impressed. Regarding the form, the paper is very well-written and the figures are of high quality. I recommend this paper for publication after a few clarifications but I am sure that authors will address my concerns easily enough.

My main criticism is the lack of information on how the PDFs (storm area and storm center location) are derived from observed data. Some information are disseminated throughout the text (sections 2, 3 and 6) but the reader would like to know all the details as soon as possible in one single paragraph. My first question as a potential user is: how am I supposed to derive these PDFs from my network of rain-gauges? Authors have made a number of assumptions to define storm center and storm area and this warrants more clarification and justification.

Figure 1 This is a very nice figure but the reader needs more information. Panel b) why did you use a GEV fit? Sounds like a Gamma distribution would be a better fit although I may be wrong. Same question regarding the other panels. How did you select the distribution that best fits the data? An objective approach would be to compare different distributions using AIC or some sort of model selection criterion.

Figure 1c I find the term center confusing. To me, the center refers to the centroid. Please clarify.

Figure 1e Do you have an explanation for the stabilization of rainfall intensity between $10^1$ and $10^2$ minutes?

Figure 1f Please add a legend (if possible). Is the green curve indicating the 90th percentile as seen in Figure 1e?

The first component I was expecting to see in this figure is the storm frequency. Isn't it required to initialize STORM? Also, what about the diurnal cycle of rainfall events? Intense storms (and rainfall in general) are strongly locked onto the diurnal cycle. I was surprised to see no mention of the diurnal cycle of rainfall in the text.

Page 7 Line 22 Yes, but this issue is also expected in the other bins, right? I guess this also depends on the traveling speed of the storm and the temporal resolution of the observed data used to derive the PDF.

Page 8 Line 24 Rainfall does vary with elevation but this variation also depends on wind direction (windward vs leeward sides). How does STORM deal with that? Authors acknowledge that a more explicit method is needed (I guess authors will investigate this point in further studies) but a couple more sentences would be welcome. For example, would it be possible to derive a PDF of intensity and duration based on a metric reflecting collectively orography, mean wind direction and mean wind speed? This is very relevant, especially when working at the watershed scale. Taking into account leeward vs windward effects would greatly improve STORM.

**Minor comments**

Page 1 Line 20 "We explain the how" should read "We explain how..."?

Page 2 Line 5 I am not sure that "spatial resolutions" is the most appropriate wording here. Rain-gauges are point measurements and are generally thought to provide information at the finest possible scale. The problem is rather their spatial representativeness, their limited coverage and low density. Also, another issue with most rainfall datasets is their coarse (typically daily) resolutions of measurements.

Page 2 Line 4-15 Could be relevant to mention radar datasets in this paragraph that may overcome some of these limitations.

Page 2 Line 8 Another general criticism is that most GCM are unable to simulate the diurnal cycle of rainfall extremes correctly but also basic features such as rainfall intermittency (Trenberth et al. 2017).

Trenberth, K. E., Zhang, Y., & Gehne, M. (2017). Intermittency in Precipitation: Duration, Frequency, Intensity, and Amounts Using Hourly Data. Journal of Hydrometeorology, 18(5), 13931412. https://doi.org/10.1175/JHM-D-16-0263.1

Page 2 Line 14-15 I don't understand why this information is challenging to summarize over longer periods? Please clarify.

Page 3 Line 11 Why decadal? It would be useful to provide some information regarding the computational demands of STORM for a specific case study (e.g. the small watershed in SE Arizona).

Page 3 Line 19 What is exactly the storm center location? Is this the centroid of the storm or the rain gauge with the highest intensity?

Page 3 Line 20 How do you define storm duration? Is this the consecutive numbers of wet time steps or do you allow for a few dry time steps within the wet spell?

Page 3 Line 5-6 Can this be done using monthly PDFs? This would enable STORM to simulate rainfall more realistically for example in regions where the intensity is strongly modulated on sub-seasonal timescales (e.g., monsoonal regions). Some papers have shown that rainfall intensity is the highest during the onset of the monsoon when the soils are dry and when there is enough moisture to trigger deep moist convection.

Page 4 Line 32-33 The temporal resolution of the simulated rainfall depends on the temporal resolution of the historical data used to initialize STORM, right?

Page 5 Line 6 Unclear. Why the median? Shouldn't it be the sum?

Page 5 Line 7 "...PDFS for THIS THIS paper..."

Page 8 Line 6 is this the maximum seasonal/annual $P_I$?

Page 8 Line 19 Why did you constrain your attention to the first/last 3 curves? What about using a linear relation between the curve number and the probability of selection (e.g. curve 5 would have a lower probability of selection than curve 8)?

Figure 3 Very nice figure. I would suggest replacing the curve number by the percentile. This would be more informative for the reader. Also, what is the range of the OG1-lowest elevation group?

Figure 5 Please indicate on this figure the record length of observations (blue dots).

Page 11 Line 21 and Page 12 Line 4 "...a new PDF of for...". Is that right?

Page 12 First paragraph Can you clarify whether or not it is possible to add a trend in storminess without altering $P_{total}$. The user can be interested in simulating climate conditions where storms are getting more intense but less frequent without modifying $P_{total}$.

Figure 9 Authors acknowledge that STORM tends to overpredict storm total as well as annual P. Indeed, the amplitude of simulated values in much larger than that of observations. Can authors provide an explanation? The Monte-Carlo resampling procedure and the use of a large number of N-year simulations should produce distributions similar to the observed ones. This needs clarification.

Figure 10 Is this showing the grid point co-located with the Walnut Gulch watershed? It would be neat to add 2 subplots showing the decline in $P_I$ and the increase in $P_{total}$ seen in high-resolution observed data.

Page 18 Line 4-13 Another interesting application of STORM would be to characterize the network density needed to detect changes in short-duration rainfall extremes that are generally very localized in space (and thus often missed by surface stations). Given that daily (and longer) duration extremes are generally associated with larger systems, their detection from surface rain-gauges should be easier. If we progressively increase rainfall intensity in STORM, it could be interesting to sample a few fixed grid cells as hypothetical surface stations and see whether trends (or other statistics) emerge in short (minutes to hours) or long-duration (daily to multi-days) rainfall extremes first (see Kendon et al. 2018 and Barbero et al. 2017). This may provide insights on the network density needed to detect changes in rainfall characteristics.

Kendon, E. J., Blenkinsop, S., & Fowler, H. J. (2018). When will we detect changes in short-duration precipitation extremes? Journal of Climate. https://doi.org/10.1175/JCLI-D-17-0435.1

Barbero, R., Fowler, H. J., Lenderink, G., & Blenkinsop, S. (2017). Is the intensification of precipitation extremes with global warming better detected at hourly than daily resolutions? Geophysical Research Letters, 44(2). https://doi.org/10.1002/2016GL071917

Page 20 Line 3-6 The density of rain-gauges is expected to affect the PDF of storm areas but also that of storm gradient.