Interpreting extreme climate impacts from large ensemble simulations are they *unseen* or *unrealistic*?

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Large-ensemble climate model simulations can provide **deeper understanding** of the characteristics and causes of extreme events than historical observations, thanks to their **larger sample size**.

The use of large-ensemble simulations to deepen understanding of climate-related risks hinges on the **realism** of the simulations.

Takeaway challenges

- Complexity of appreciating the **adequacy of model properties**
- Differences between simulated and observed distributions **cannot statistically be explained** under natural variability and uncertain observations
- There is **high sensitivity** of the simulations outside observed variability to the **bias adjustment** method, but use of such adjustments are often **simply required** to meet the needs of impact models
- For the most extreme floods, which may have unique driving mechanisms, **single event analyses can provide insightful information** in addition to the general, averaged, relationship between floods and teleconnections
- **Sensitivity of results** to the event definition, model and reference data, evaluation metrics, applied solution (such as bias correction), statistical methods, and framing (Kelder et al., 2022)

Don't hesitate to get in touch if you are also keen to improve our preparedness to high-impact events!

Link to the paper

References:

[1]Thompson, V., Dunstone, N.J., Scaife, A.A., Smith, D.M., Slingo, J.M., Brown, S., Belcher, S.E., 2017. High risk of unprecedented UK rainfall in the current climate. Nature communications 8, 107.

[2]Kelder, T., Marjoribanks, T.I., Slater, L.J., Prudhomme, C., Wilby, R.L., Wagemann, J., Dunstone, N., 2022. An open workflow to gain insights about low-likelihood high-impact weather events from initialized predictions. Meteorological Applications 29, e2065. https://doi.org/10.1002/MET.2065

[3]Van der Wiel, K., Wanders, N., Selten, F.M., Bierkens, M.F.P., 2019. Added Value of Large Ensemble Simulations for Assessing Extreme River Discharge in a 2 °C Warmer World. Geophysical Research Letters 46, 2093–2102. https://doi.org/10.1029/2019GL081967

[4]Bevacqua, E., Suarez-Gutierrez, L., Jézéquel, A., Lehner, F., Vrac, M., Yiou, P., Zscheischler, J., 2023. Advancing research on compound weather and climate events via large ensemble model simulations. Nat Commun 14, 2145. https://doi.org/10.1038/s41467-023-37847-5

[5]Gessner, C., Fischer, E.M., Beyerle, U., Knutti, R., 2021. Very rare heat extremes: quantifying and understanding using ensemble re-initialization. Journal of Climate 1–46. https://doi.org/10.1175/JCLI-D-20-0916.1

[6]Yiou, P., 2014. AnaWEGE: A weather generator based on analogues of atmospheric circulation. Geoscientific Model Development 7, 531–543. https://doi.org/10.5194/GMD-7-531-2014

Exceptional events are hard to characterize

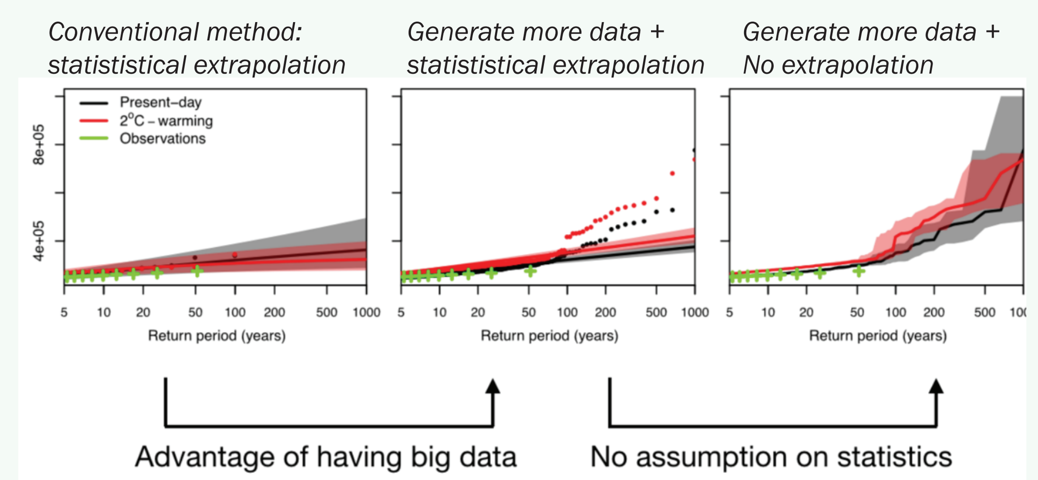
2009 floods in the Amazon: worst in >100 years

Only two years later it happened again!

Image by Jochen Schöngart / National Institute for Amazon Research.

de Andrade, M.M.N. et al. (2017). Flood Risk Mapping in the Amazon.

How to characterize exceptional weather events statistically



Analysis of extreme high discharge in the Amazon River. Left: GEV-fits based on 100 years of data. Middle: GEV-fits based on 2000 years of data. Right: Empirical distribution estimate based on sampling of 2000 years of data.
Van der Wiel et al., 2019 [3]

We can find exceptional weather events within model worlds

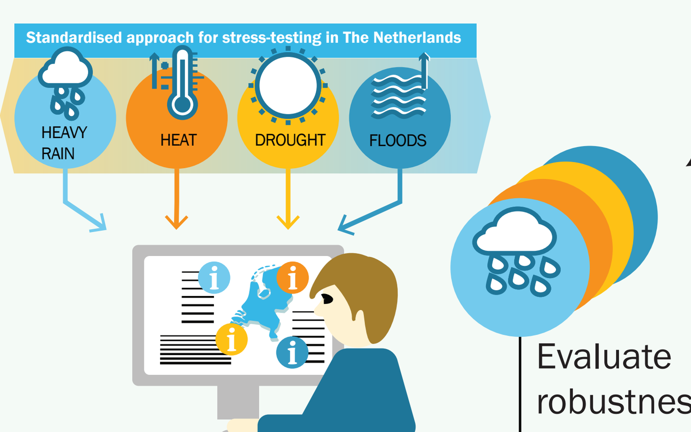
With a surge of open workflows and open data, numerous approaches have become available to 'generate more data' and study high-impact events

- UNSEEN [1,2]
- SMILE [3,4]
- Ensemble boosting [5]
- Weather generators [6]

As we are crunching our models, we see exceptional weather events occuring across the world

How to make our scientific knowledge land in practice?

- Building confidence in our simulations through thorough evaluation
- Combining multiple lines of evidence
- Co-designing information with practitioners



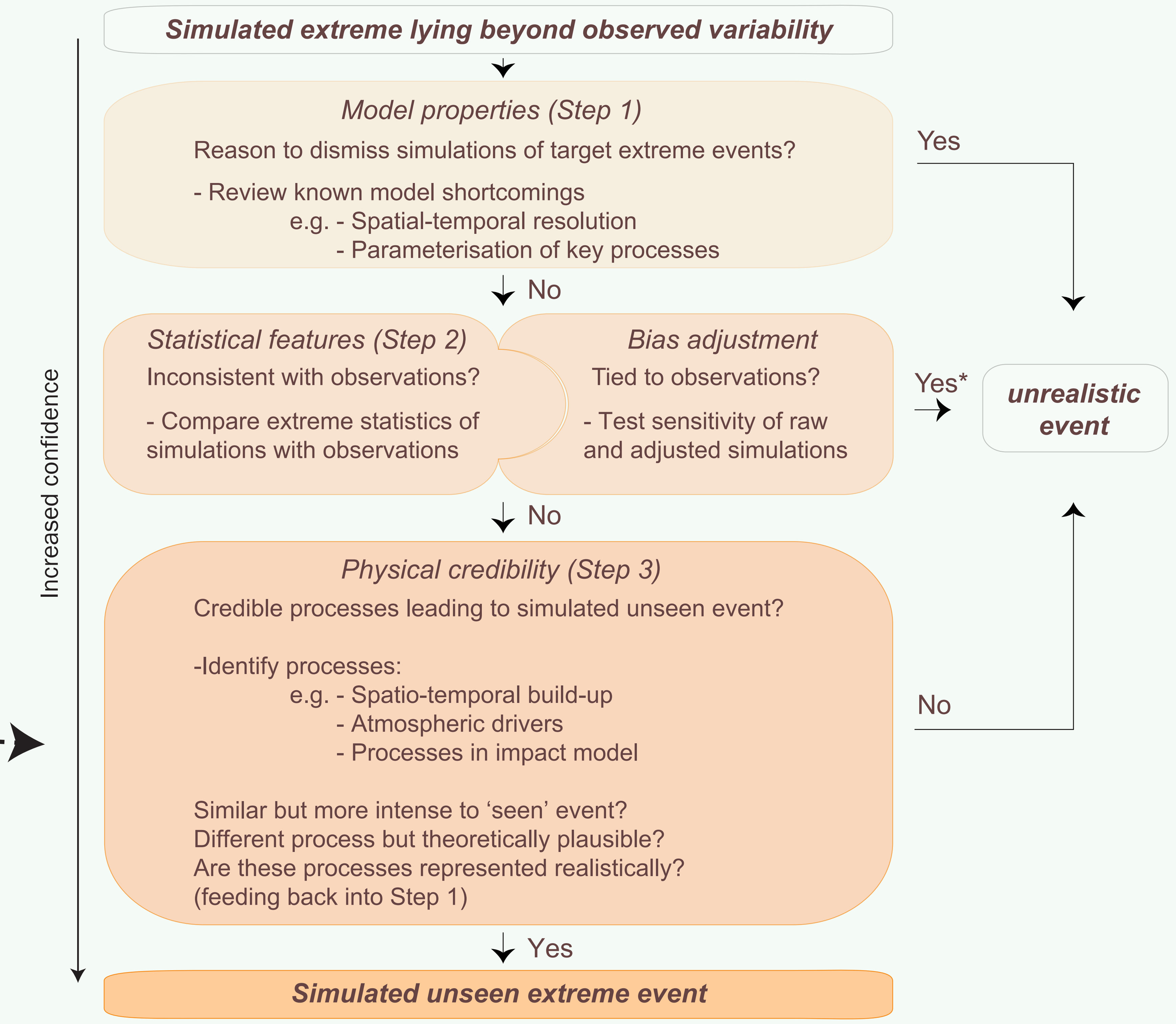
For example, through additional assessments of ***high-impact events***

Evaluate robustness to 'blind spots'

Plans
Adaptation options

Robust plans
Robust adaptation options

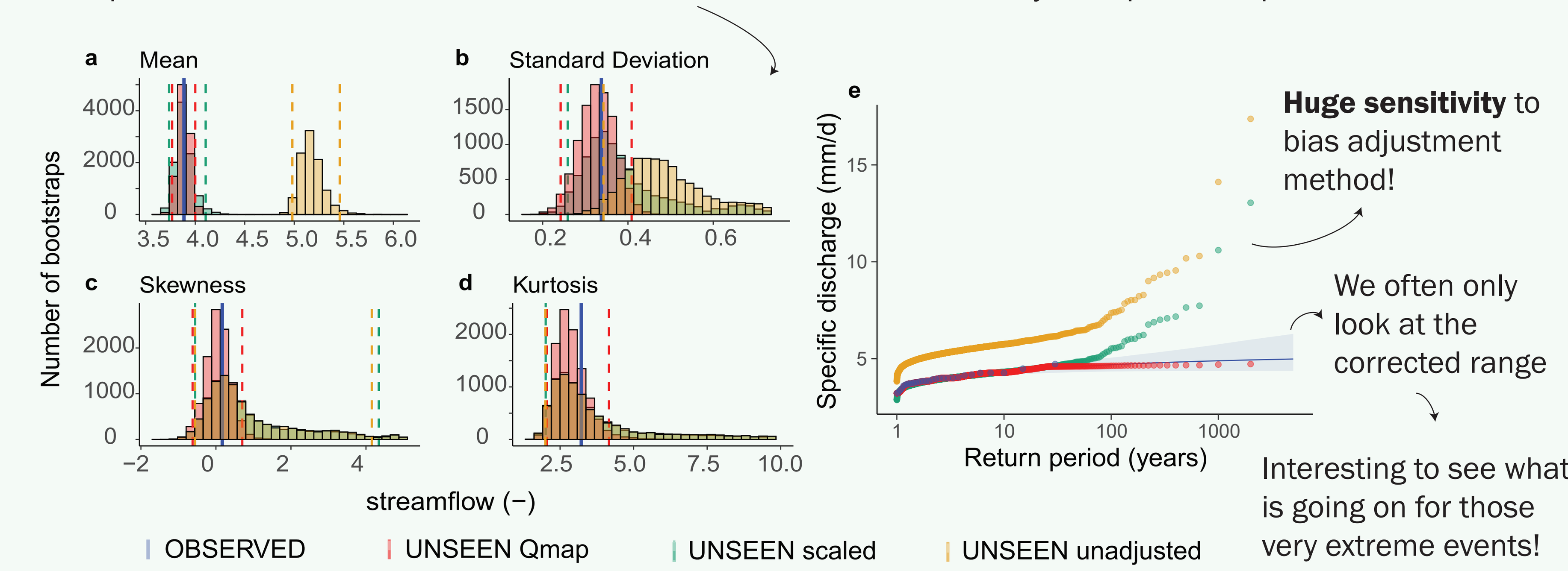
A three-step procedure for evaluating climate model extremes



* Acknowledging that the evaluation and correction of unseen extremes are restricted by the brevity of observed records, one may wish to further assess the physical credibility if the simulations are inconsistent with observations

Example of the three-step procedure applied to Amazon floods

- Step 1. Spatial resolution of 1x1° and daily temporal resolution is coarse, but no **reason to dismiss** monthly flood simulations over the Amazon a priori.
- Step 2. Simulations show a **skewed distribution** that could be caused by infrequent compound behaviour



a-d) The distribution characteristics of annual maximum streamflow before (orange) and after applying quantile mapping (red) and scaling (green) are compared to observations (blue). Histograms show the distributions bootstrapped to the length of the observed record and dashed lines indicate the 95% confidence intervals. **e**) Extreme value distribution for the historical record (blue) alongside the UNSEEN streamflow large ensemble, both before (orange circles) and after applying quantile mapping (Qmap, red) or a scaling factor (green circles).

- Step 3. Identifying the driver of the largest simulated Amazon flood showed southern tributaries are driven by a rare error in the correction of precipitation. **Thus, these events are in this case deemed unrealistic.**