A Continental Stochastic Precipitation Generator

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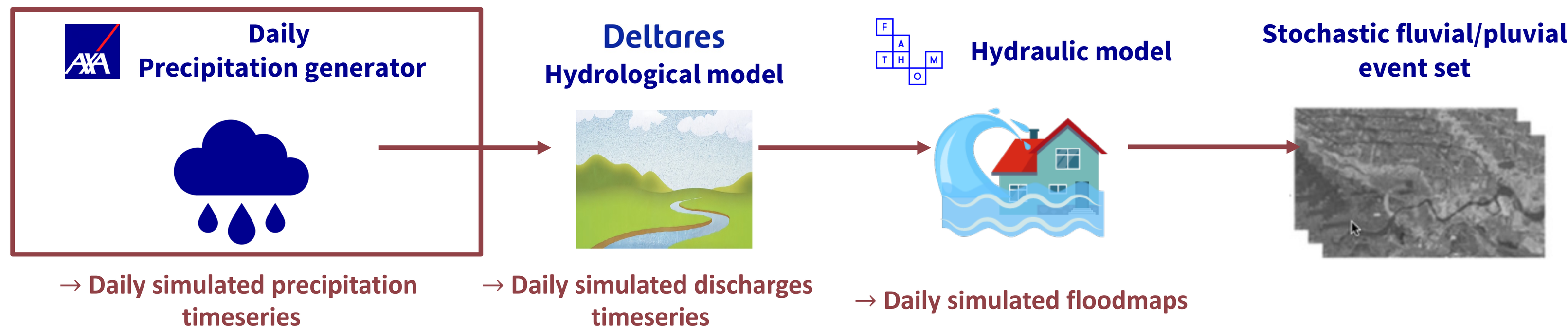
Building a pan-European Flood risk model

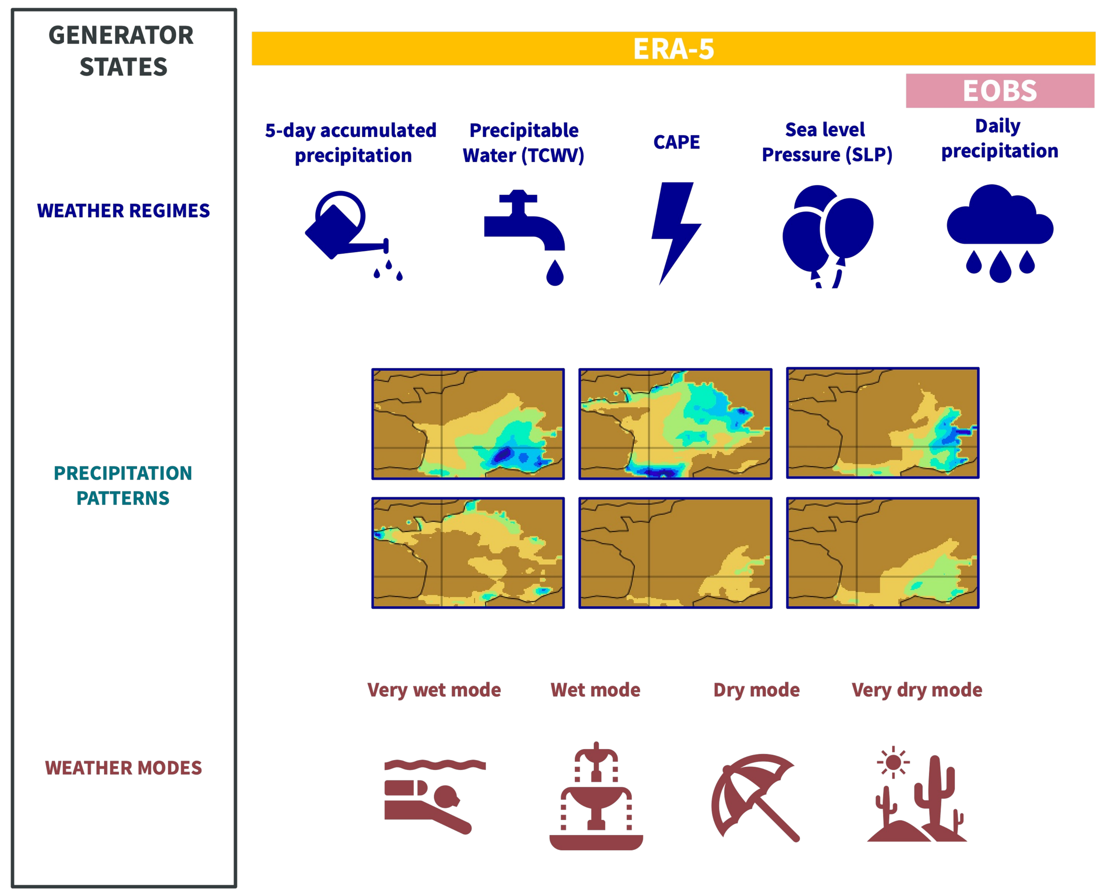


A time-reshuffling stochastic weather generator

AXA proposes a novel continental-scale generator of precipitation. Its main features are:

- Time reshuffling synthetic gridded rainfall daily timeseries (10km resolution) generated by re-sequencing historical multisite timeseries (E-OBS) to derive unobserved events
- Applications to cross-country risk assessment under current and future climate scenarios. Europe serves as a case-study to demonstrate and assess its performance in terms of hazard modelling and extrapolation to unobserved extreme local and regional events.
- The model is calibrated using the ERA5 reanalysis and precipitation timeseries are obtained by reshuffling EOBS data

Data and methods



The generator defines **monthly** weather regimes, and tracks local persistence effects in the precipitation patterns, and alternating wet/dry sequences to reproduce the observed statistics of durations of wet and dry spells. As described, the reshuffling is conditioned by:

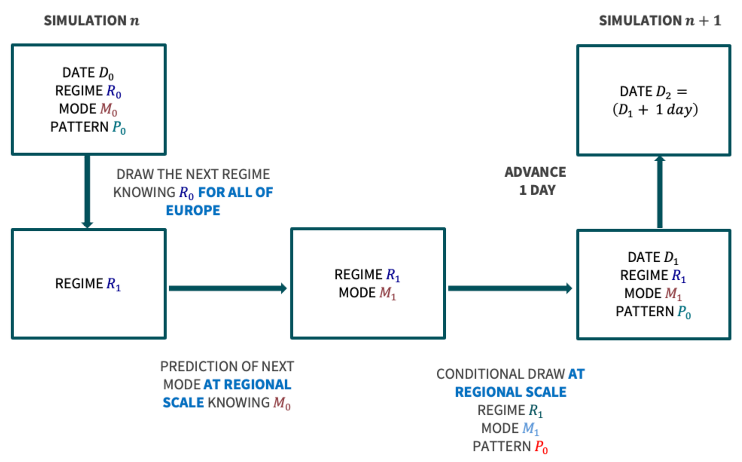
- **Weather Regimes (WR).** Historical data is clustered at the **European scale** into weather regimes based on multiple variables that trigger the physical processes leading to precipitation. This clustering is done at the scale of Europe.
- **Spatial Precipitation Patterns (PP).** Daily precipitation fields are classified using the same technique to identify similar spatial patterns at a **regional scale**.
- **Modes.** Dry and wet sequences of precipitation are identified at **regional scale**, and a threshold is set based on the historical distribution.

Historical dates defined by the daily **state** defined as the triplet (WR, PP, mode). The dates are reshuffled in arbitrary long sequences

Weather regimes: quantization of rainfall-prone situations

Our model relies on the assumption that precipitation-prone atmospheric conditions over Europe can be classified as weather regimes (WRs). WRs define discrete representations of recurrent atmospheric states, characterizing peaks of the probability density function of the states of the atmosphere in a certain phase space (Michelangeli et al., 1995). Their use simplifies to a great extent the complexity of mid-latitude dynamics, but beyond their usefulness and applicability to weather forecasting, there is strong evidence that WRs are more than a mere statistical classification of the state of the atmosphere and that they are physically meaningful (Hochman et al., 2021). Transitions matrices can then be constructed between regimes (Vautard et al., 1990).

The WRs and PP are identified through a clustering approach using **Self-Organizing Maps** based on daily data from the ERA-5 reanalysis and the **final sequences are constructed from the daily E-OBS precipitation observations** (Copernicus Climate Change Service, 2020) which present a finer spatial resolution (10km). The different modes characterizing wetness are defined regionally using quantiles of the precipitation distribution.



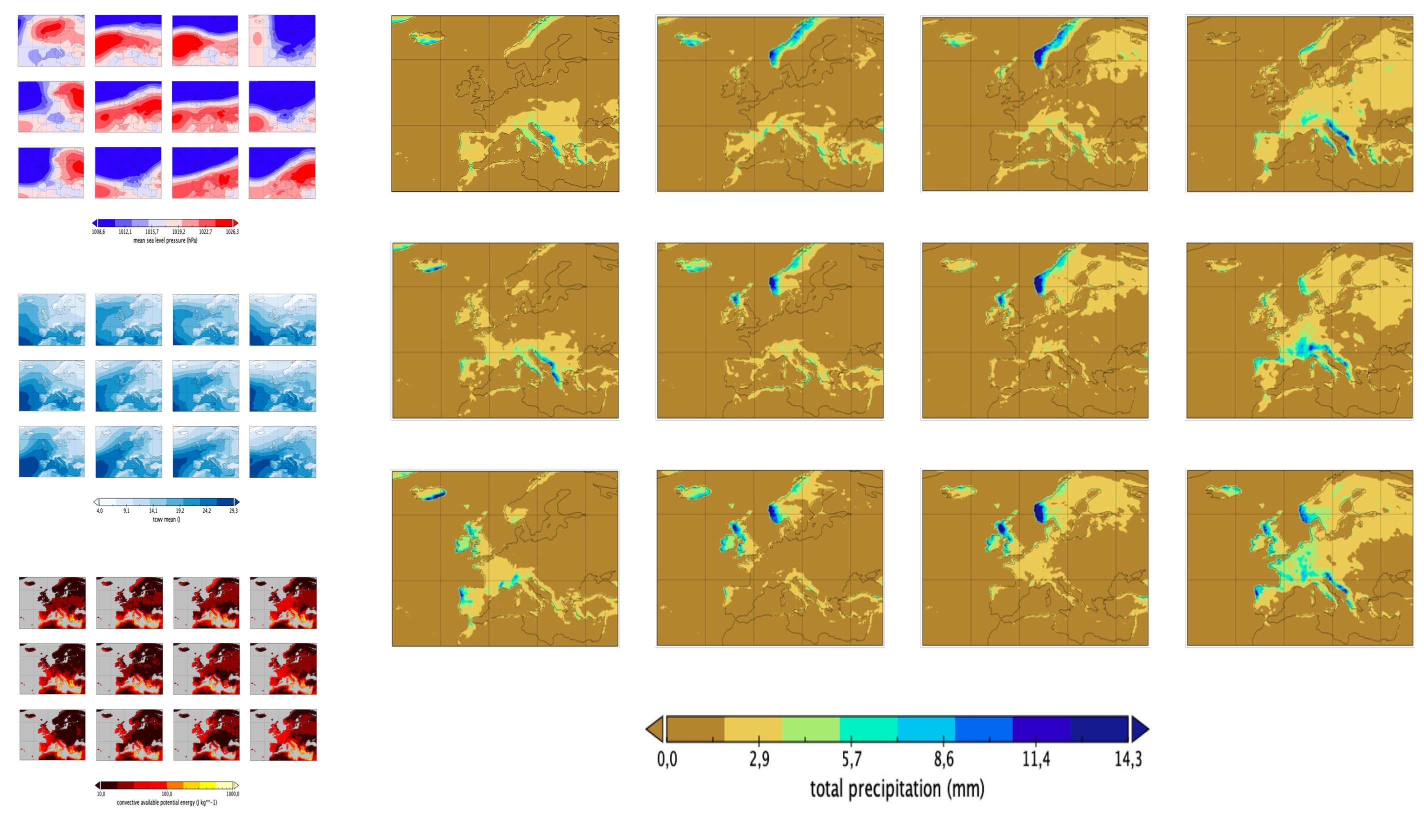
Generating unobserved sequences of rainfall

Unobserved precipitation sequences are generated through a Markov chain based on the three parameters described above. Typically, 10 000-year simulations are generated. This sampling scheme is executed over the seven geographic zones. To preserve spatial meteorological conditions throughout Europe we choose a driver zone between the seven geographic zones that divide Europe. We sample a weather regime based on the driver zone's previous weather regime for a given day of the simulation and based on historical observations of weather regime evolution between two consecutive days.

At the end of the sampling process the day following the selected one is chosen to introduce some decay in the state described by the model and represent the passing of time.

A glimpse through the weather regimes classifier

Self-Organizing Maps of weather regimes for the month of November



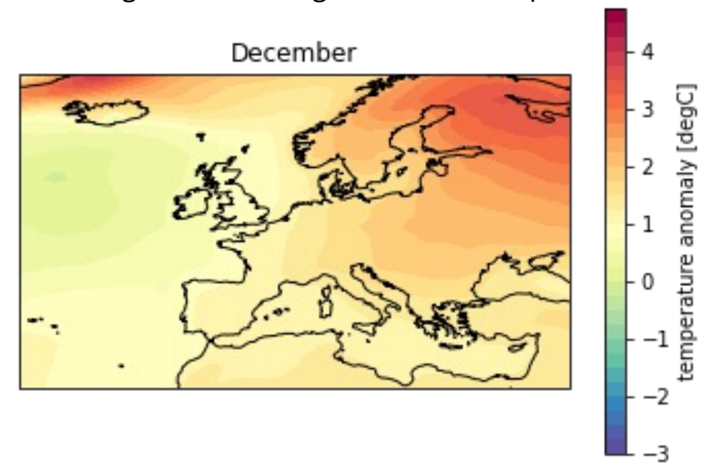
Self-Organizing Maps: a visual approach to the definition of weather regimes

SOMs (Kohonen, 2013) have been extensively used in the definition of archetypal weather regimes (Hewitson and Crane, 2002). Days presenting similar meteorological characteristics are grouped into clusters defined monthly to preserve seasonality, using a self-organising map (SOM). WRs are arranged on a grid where similar patterns are adjacent nodes.

Evidence has been given that the sea level pressure (**SLP**) is an atmospheric driver of precipitation in Europe, especially during the winter (Lavers et al., 2013). Total Column Water Vapour (**TCWV**), is intuitively introduced as an indicator of the reservoir of water available for precipitation. This quantity represents the total quantity of water vapour at a given point, expressed as the height of an equivalent column of liquid water. Convective Available Potential Energy (**CAPE**) is introduced as a proxy parameter for atmospheric instability.

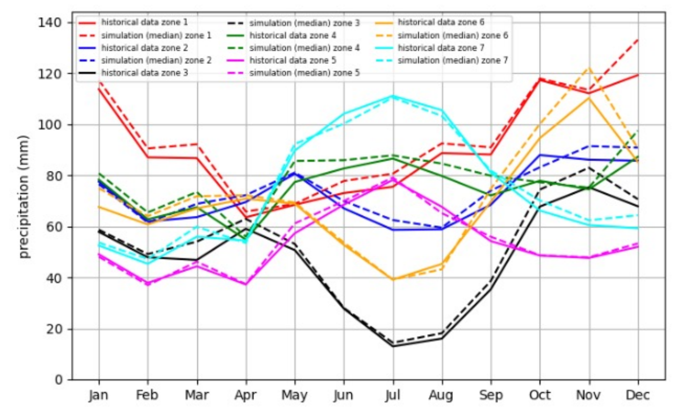
Incorporating Climate Change

2°C global warming level over Europe



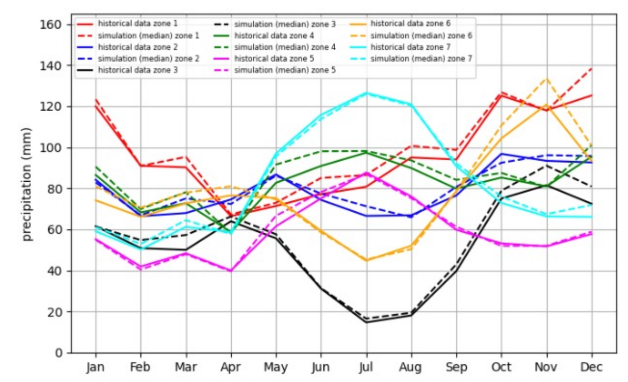
Reference : baseline (median)

Monthly average cumulated over each zone



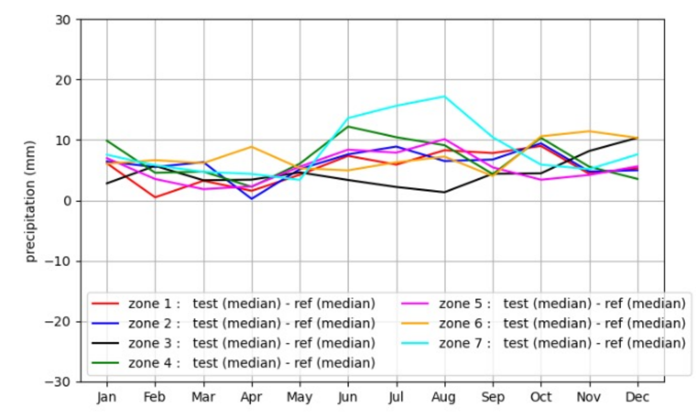
Test : GWL 2°C (SSP2-RCP4.5) (median)

Monthly average cumulated over each zone



Difference : GWL 2°C - baseline

Monthly average cumulated over each zone



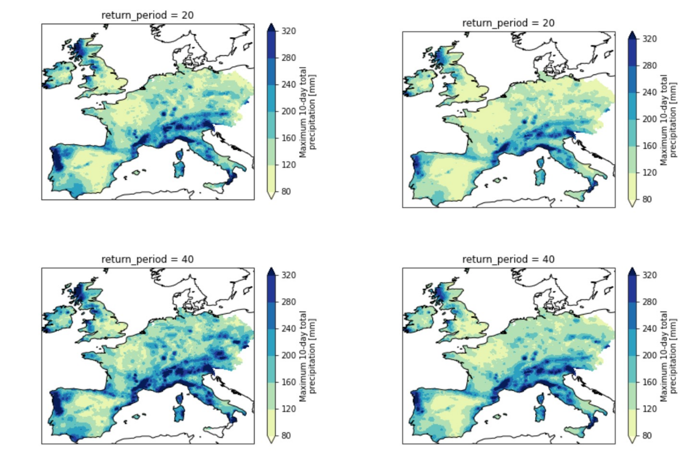
Delta-temperature: introducing Clausius-Clapeyron

Using the Clausius-Clapeyron relationship (+1°C implies a +6.5% change in humidity) we update the variables used to define the weather states in the generator, except for **SLP**

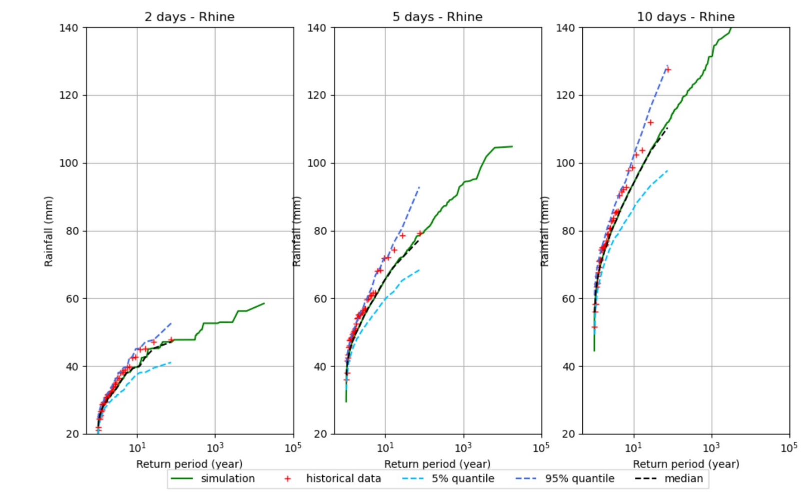
To that end, gridded temperature anomalies for various global warming levels (ranging from +1.5°C to +4°C) are used to locally upscale the precipitation, TCWV and CAPE (below 37°C, Romps et al. 2016)

This delta-temperature approach is simple but robust as it alleviates the issue of precipitation representation in GCMs.

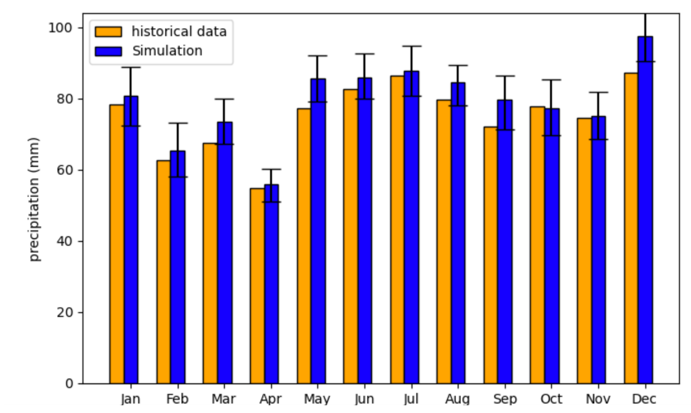
Results

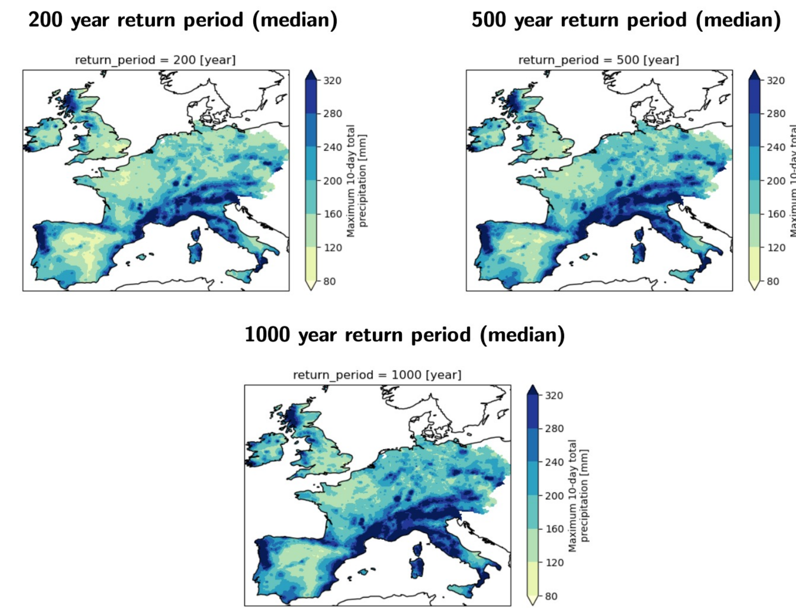


Cumulated precipitation over Rhine



Monthly average over Germany

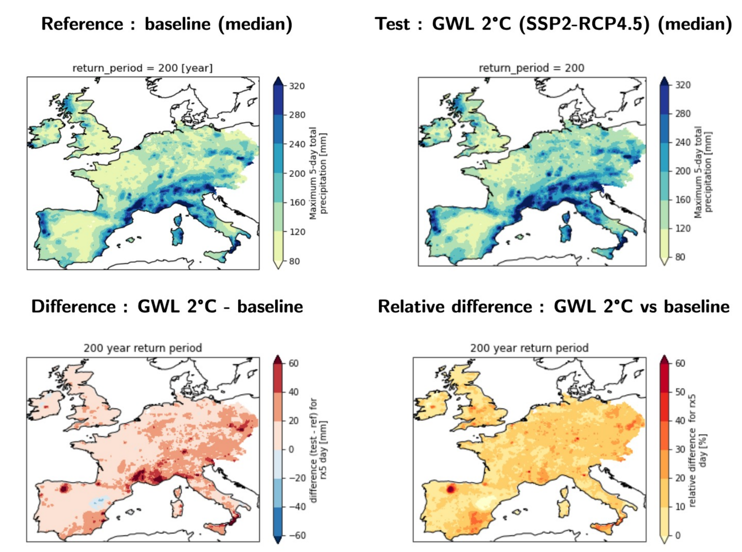




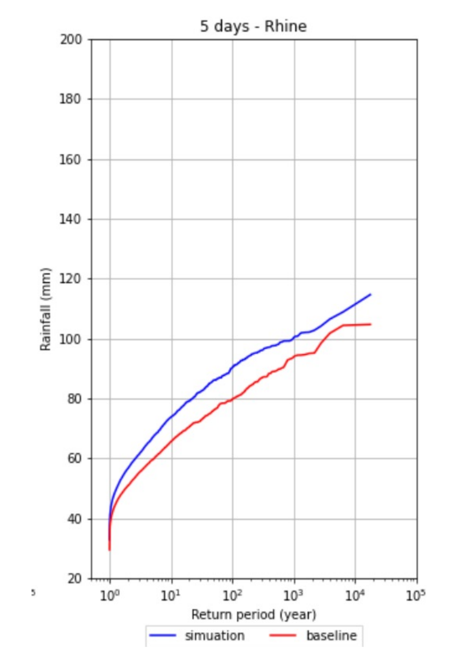
Modelled precipitation for a synthetic 10,000y timeseries

The model is used to generate 10,000 simulation years . We present here a comparison between the E-OBS observations and the median of simulated 42y samples of the simulated timeseries. The model shows overall good representation of the historical observations and their seasonality. Return periods of 2, 5 and 10d accumulated rainfall can then be extrapolated and maps can be produced showing extreme rainfall affecting the Mediterranean region.

Return period of cumulated precipitation over Europe : 5 days window - 200 years return period



2°C global warming level



Projected rainfall extremes under a +2°C global warming level

The simple delta-temperature approach allows the exploration of extreme scenarios under various climate change hypotheses. The model projects an increase of extreme (200y RP) rainfalls in the South of France and south of Spain, and an overall increase of precipitations across Europe.

Selected references

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