# Rainfall Downscaling Conditional on Upper-air Variables: Assessing Rainfall Statistics in a Changing Climate

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## 1. Introduction

Precipitation is one of the least well reproduced hydrologic variables by both Global Climate Models (GCMs) and Regional Climate Models (RCMs). This is especially the case at a regional level (where hydrologic risks are assessed) and at small temporal scales (e.g. daily) used to run hydrologic models.

In an effort to remedy those shortcomings and assess the effect of climate change on rainfall statistics at hydrologically relevant scales, Langousis and Kaleris (2014) developed a statistical framework for simulation of daily rainfall intensities conditional on upper air variables. The developed downscaling scheme conditions rainfall simulation solely on a vector of atmospheric predictors, properly selected to reflect the relative influence of upper-air variables on ground-level rainfall statistics.

In this study, we use the developed downscaling scheme to generate synthetic Mean Areal Precipitation (MAP) series for an intermediate-sized catchment in Italy; i.e. the **Flumendosa catchment** (see **Figure 1**). Conditional simulation is done using atmospheric data from: a) the ERA-Interim archive, and b) the ECHAM5/MPI model outputs of the ENSEMBLES project (http://ensembleseu.metoffice.com) for the A1B climatic scenario.

The selected GCM/RCM model combination has been identified as the best performing one for Flumendosa catchment, both in terms of rainfall and temperature; see Deidda *et al.* (2013). The statistics of the synthetic time series are compared to those of the historical rainfall record, and to those obtained from the ERA-Interim and ECHAM5/MPI rainfall products. The last two are statistically corrected to account for biases relative to the historical time series.

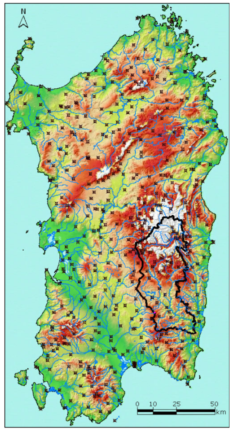

**Figure 1**: Flumendosa catchment in Sardinia, Italy. Points indicate rainfall measuring locations

## 2. Methodological framework

**Step 1:** Use ERA-Interim atmospheric products and ground-level rainfall measurements, to **identify the most influential atmospheric predictors** to condition rainfall simulation; see Langousis and Kaleris (2014).

***vector of atm. predictors*** ⇨ $\mathbf{X} = [Z_{700hPa}, VO_{500hPa}, D_{300hPa}, SP]$

*geopotential*, *rel. vorticity*, *divergence*, *surface pressure*

**Step 2:** For the set of atmospheric predictors identified in **step 1**, use ERA-Interim atmospheric data and ground-level rainfall measurements to **calibrate** the stochastic **downscaling scheme**.

**Step 3: Establish a statistical linkage** between ERA-Interim upper-air atmospheric forecasts and climate model results.

➡ **Q-Q correct** the series of atmospheric predictors of the ECHAM5/MPI **climate model, to match** the marginal distributions of the corresponding **ERA-Interim** atmospheric data.

**Step 4:** Use the ERA-Interim upper-air atmospheric forecasts, the Q-Q corrected ECHAM5/MPI climate model atmospheric data from **step 3**, and the calibrated downscaling scheme from **step 2**, to **stochastically generate synthetic rainfall series**.

**Step 5: Q-Q correct** the ERA-Interim and ECHAM5/MPI climate model **rainfall products, to match** the marginal statistics of ground-level **rainfall measurements**.

***Compare*** ⇨
- *historical* rainfall series
- *synthetic* series from **step 4**
- *bias corrected rainfall products* from **step 5**

## 3. Case study: The Flumendosa catchment in Sardinia, Italy

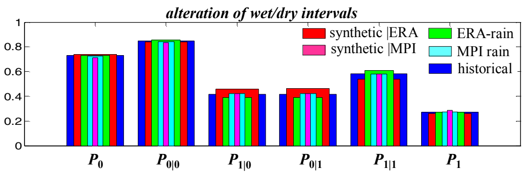


**Figure 2**: Comparison of the probabilities $P_0 := P[I_t = 0]$, $P_{0|0} := P[I_t > 0 | I_{t-1} = 0]$, $P_{1|0} := P[I_t = 0 | I_{t-1} > 0]$, $P_{1|1} := P[I_t > 0 | I_{t-1} > 0]$, and $P_1 := P[I_t > 0]$ as obtained from the historical, synthetic (conditional on ERA and MPI upper-air variables using the methodology in Section 2), and Q-Q corrected ERA and MPI rainfall series, for the period from 01 October 1979 – 30 September 2008.

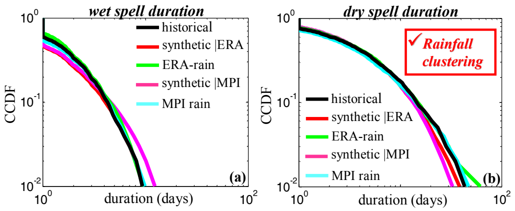


**Figure 3**: Comparison of the empirical complementary cumulative distribution functions (CCDFs) of the duration of: (a) wet spells, and (b) dry spells for the series in **Figure 2**.

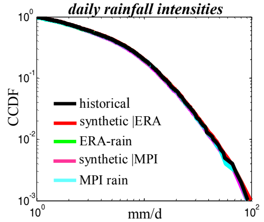


**Figure 4**: Comparison of the empirical complementary cumulative distribution functions (CCDFs) of daily rainfall intensities in the historical, synthetic (conditional on ERA and MPI upper-air variables using the methodology in Section 2), and Q-Q corrected ERA and MPI rainfall series, for the period from 01 October 1979 – 30 September 2008.

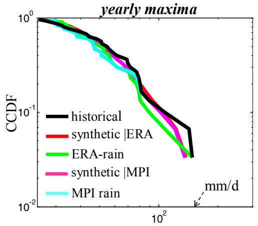


**Figure 5**: Comparison of the empirical complementary cumulative distribution functions (CCDFs) of daily rainfall maxima in a year, as obtained from the historical, synthetic (conditional on ERA and MPI upper-air variables using the methodology in Section 2), and Q-Q corrected ERA and MPI rainfall series, for the period from 01 October 1979 – 30 September 2008.

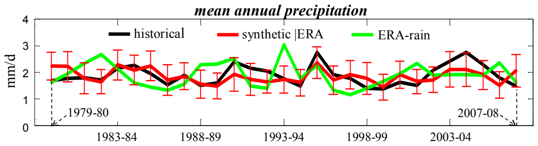


**Figure 6:** Mean annual precipitation in different hydrologic years, as obtained from the historical rainfall record (black line), the ensemble of 100 rainfall simulations conditional on ERA upper-air atmospheric forecasts for the period 01 October 1979 - 30 September 2008 (red line), and the Q-Q corrected ERA-Interim rainfall series (green line). Vertical bars denote the 95% confidence intervals of the simulations.

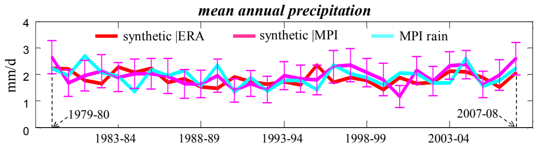


**Figure 7:** Mean annual precipitation in different hydrologic years, as obtained from: a) the Q-Q corrected MPI rainfall products (cyan line), b) 100 rainfall simulations conditional on the Q-Q corrected MPI upper air predictors (magenta line; see step 3 in Section 2), and c) the ensemble of 100 rainfall simulations conditional on ERA upper-air atmospheric forecasts for the period 01 October 1979 - 30 September 2008 (red line).

## 4. Conclusions and future developments

- ✓ The downscaling scheme reproduces the historical rainfall statistics from a limited number of ERA reanalysis atmospheric products; see red lines in **Figures 2-6**.
- ✓ The downscaling scheme is statistically valid at the 95% conf. level.
  - ➡ Historical statistics fall inside the 95% confidence intervals of rainfall simulations (see black and red lines in **Figure 6**)
- ✓ The synthetic simulations (red line in **Figure 6**) are closer to the observed values (black line) than the bias corrected ERA rainfall products (green line).
- ✓ The downscaling scheme outperforms the Q-Q corrected ERA rainfall products in modelling rainfall extremes (see **Figure 5**).
- ✓ Upper-air atmospheric predictors provide an efficient basis to model the rainfall process.
- ✓ The bias corrected ECHAM5/MPI climate model atmospheric products, lead to synthetic rainfall series (cyan lines in **Figures 2-7**) that match the statistics of the simulated series conditional on ERA atmospheric forecasts (red lines in **Figures 2-7**).

⇨ ***Use the rainfall downscaling scheme to:***

- ✓ **generate ensemble realizations** for different climatic periods.
- ✓ **run uncertainty analyses**, without the need of climate model ensembles. ⇨ *avoid epistemic uncertainties associated with the relative performances of the models.*

## References

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