Temporal downscaling of monthly to daily meteorology using a weather generator and based on a global observational dataset

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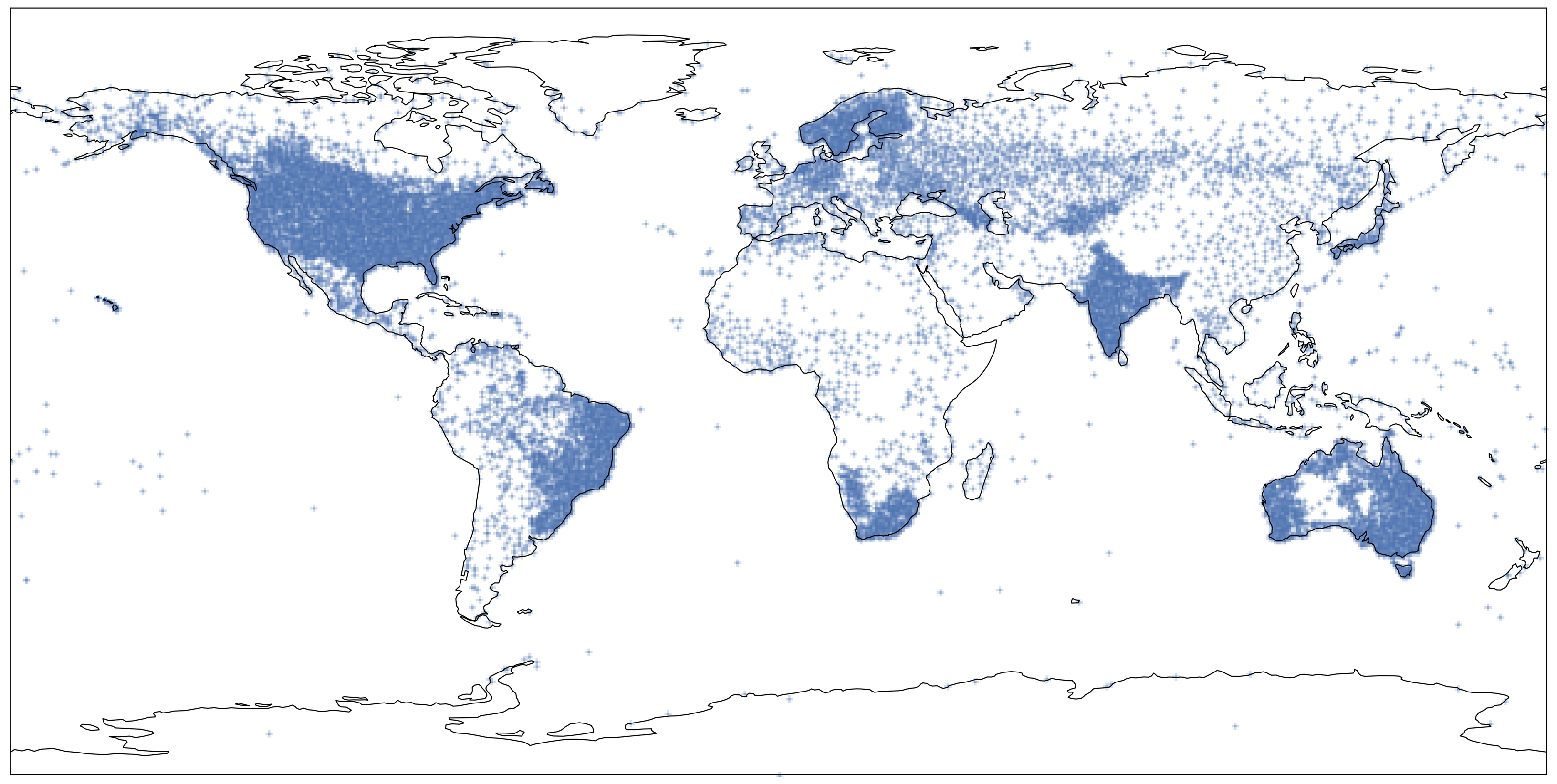
Abstract

Accurate modelling of large-scale vegetation dynamics, hydrology, and other environmental processes requires meteorological forcing on daily timescales. While meteorological data with high temporal resolution is becoming increasingly available, simulations for the future or distant past are limited by lack of data and poor performance of climate models, e.g., in simulating daily precipitation. To overcome these limitations, we may temporally downscale monthly summary data to a daily time step using a weather generator. Parameterisation of such statistical models has traditionally been based on a limited number of observations. Recent developments in the archiving, distribution, and analysis of "big data" datasets provide new opportunities for the parameterisation of a temporal downscaling model that is applicable over a wide range of climates.

Here we parameterise a WGEN-type weather generator using more than 50 million individual daily meteorological observations, from over 10'000 stations covering all continents, based on the Global Historical Climatology Network (GHCN) and Synoptic Cloud Reports (EECRA) databases. Using the resulting "universal" parameterisation and driven by monthly summaries, we downscale mean temperature (minimum and maximum), cloud cover, and total precipitation, to daily estimates. We apply a hybrid gamma-generalized pareto distribution to calculate daily precipitation amounts, which overcomes much of the inability of earlier weather generators to simulate high amounts of daily precipitation. Our globally parameterised weather generator has numerous applications, including vegetation and crop modelling for paleoenvironmental studies.

Methods

GHCN and cloud parameterisation stations



Global meteorological datasets

- Synoptic Cloud Reports (EECRA) databases (Hahn and Warren, 1999): 9000 stations for cloudiness and temperature
- Global Historical Climatology Network-daily (GHCN-daily) (Menne et. al, 2012): 100'000 stations for precipitation and temperature
- Select 1 GHCN station per 0.5° x 0.5° grid cell (15'800 GHCN with 3'100 EECRA stations)

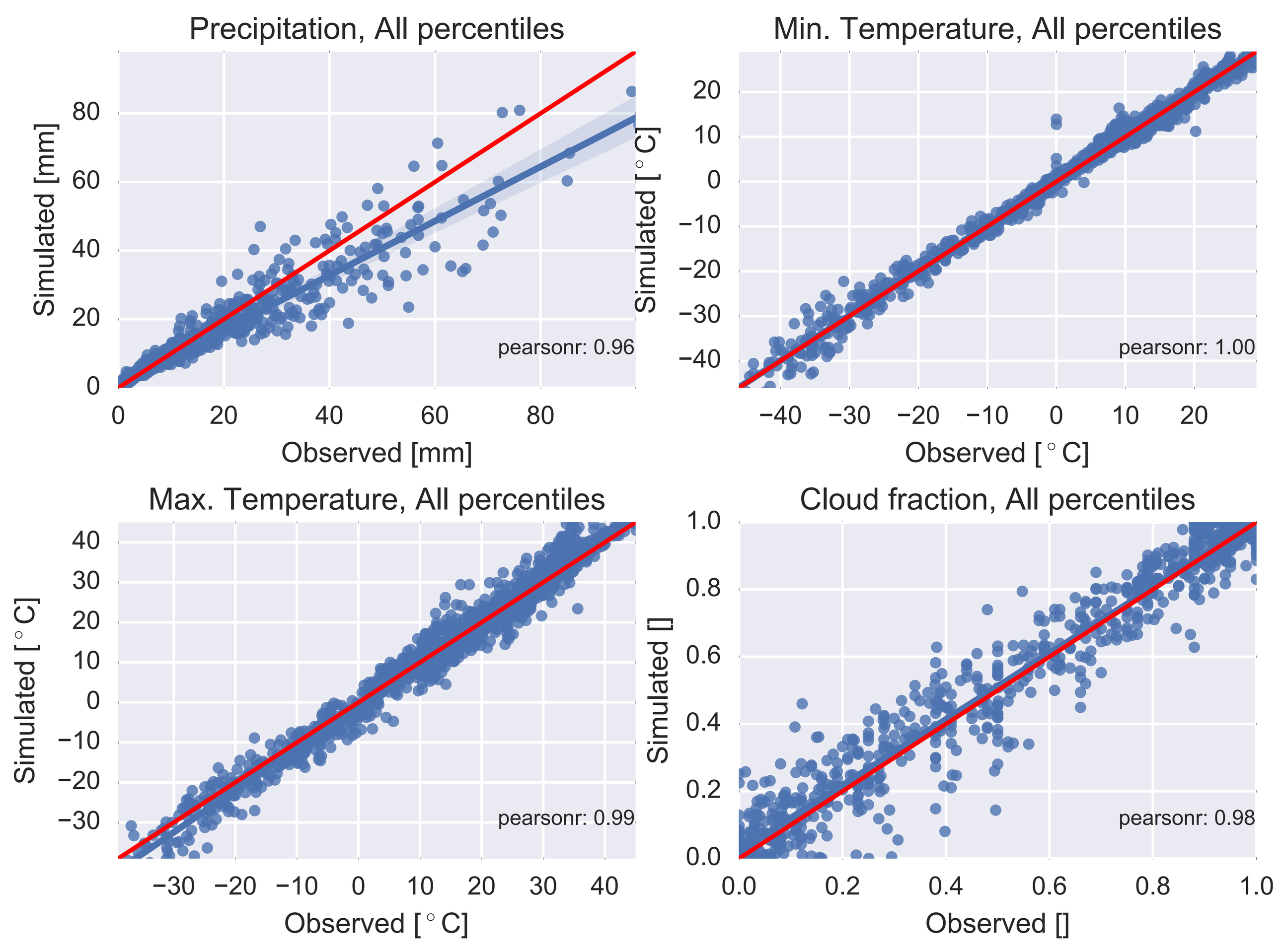
Monthly Model Input

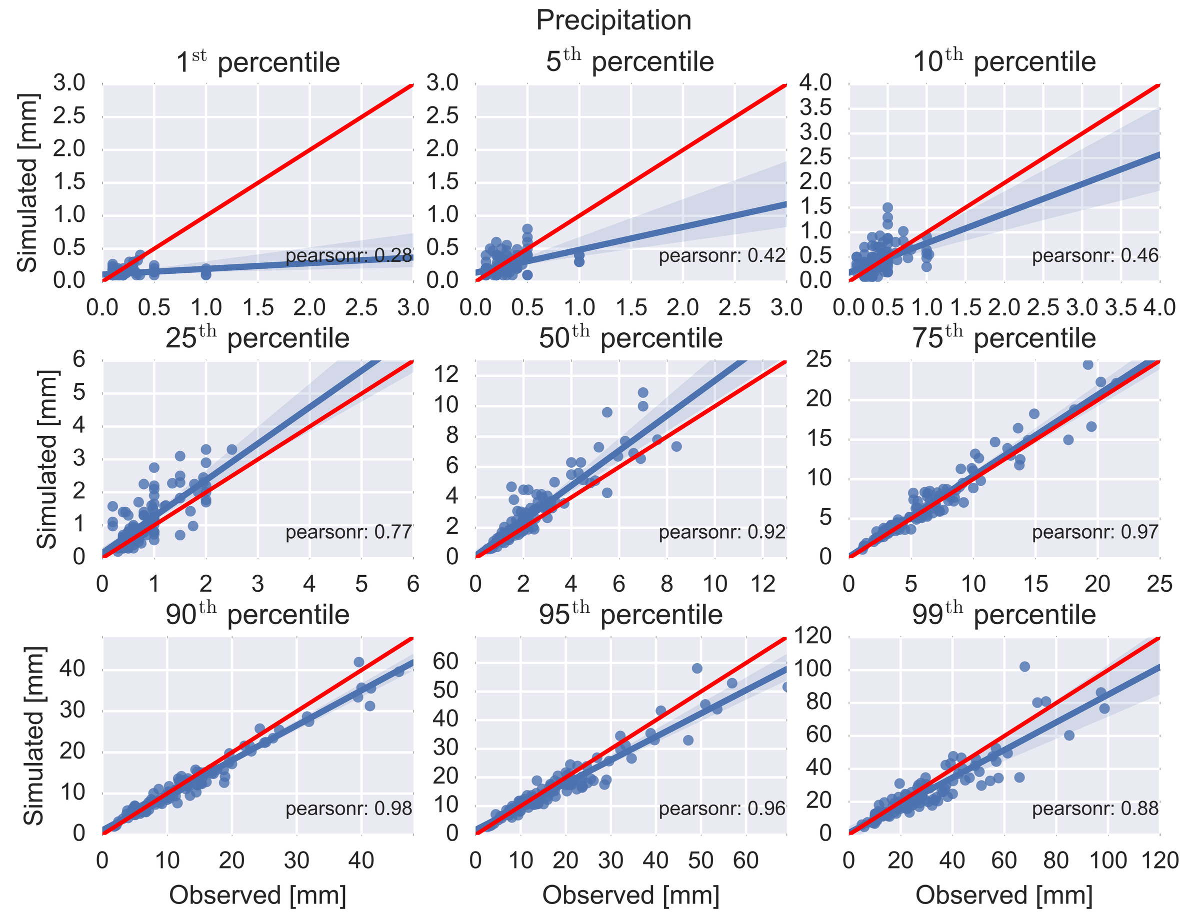
- Total precipitation
- Number of days with measurable precipitation (wet days)
- Mean daily minimum and maximum temperature
- Mean cloud fraction

Weather Generator (based on Richardson et al., 1981)

1. Estimate the wet or dry state of the day based upon the number of wet days. If not a wet day, continue (rejection sampling to ensure simulated number of wet days is ±1 day of input)
2. For wet days, calculate gamma scale parameter from monthly precipitation and estimate the precipitation amount with the hybrid Gamma-GP distribution
3. Adjust the mean and SD of temperature and cloud fraction based upon the wet or dry state
4. Calculate daily temperature and cloud fraction including cross correlation using a gaussian random variable to simulate noise

Results





To evaluate the model, we extracted daily meteorological records from 500 globally-distributed weather stations that were excluded from the parameterisation. We calculated monthly summaries from these daily data and used the resulting monthly data to drive our weather generator. The result was a simulated daily timeseries we compared to the original observations.

For temperature and cloud fraction, the model does an excellent job of downscaling monthly input to daily timeseries that are very similar to the original data.

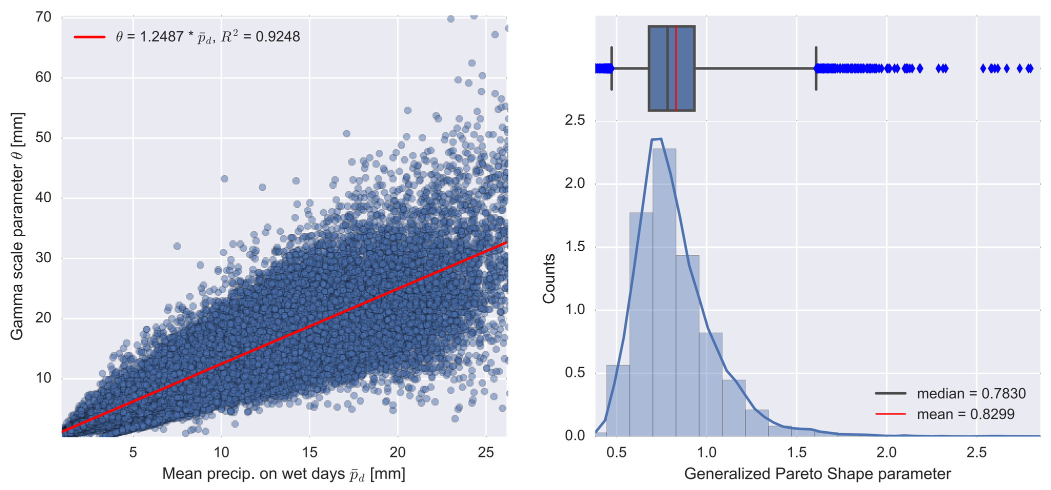
For precipitation, comparison of the percentiles shows good correlation except for the low percentiles possibly do due to the 0.1 mm precision of the input data.

A Kolmogorov-Smirnoff test to compare observed and simulated distributions of precipitation amount shows no significant difference between simulation and original data at about 87% of the stations.

The heavy tail of the generalized pareto (GP) distribution that is part of the in the hybrid Gamma-GP distribution we used to simulate precipitation amount helps us better capture the infrequent but very high precipitation events observed at some stations.

Parameterisation

Precipitation



Fit hybrid Gamma-GP distribution (Furrer and Katz, 2008) to the data and estimate the parameters

Gamma distribution:

$$f(x) = \begin{cases} \frac{x^{\alpha-1}\exp^{-\frac{x}{\theta}}}{\theta^{\alpha}\Gamma(\alpha)} & \text{for } x > 0 \\ 0 & \text{for } x = 0 \end{cases}$$

Generalised Pareto (GP) distribution:

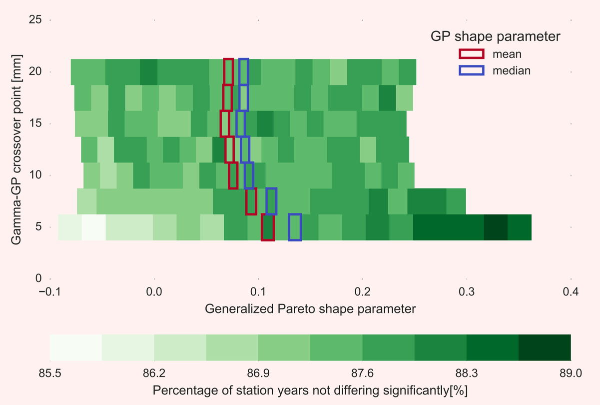
$$g(x) = \frac{1}{\sigma}\left(1 + \frac{\xi\,(x-\mu)}{\sigma}\right)^{-\frac{1}{\xi}-1}$$

Hybrid Gamma-GP distribution (μ = 10 mm):

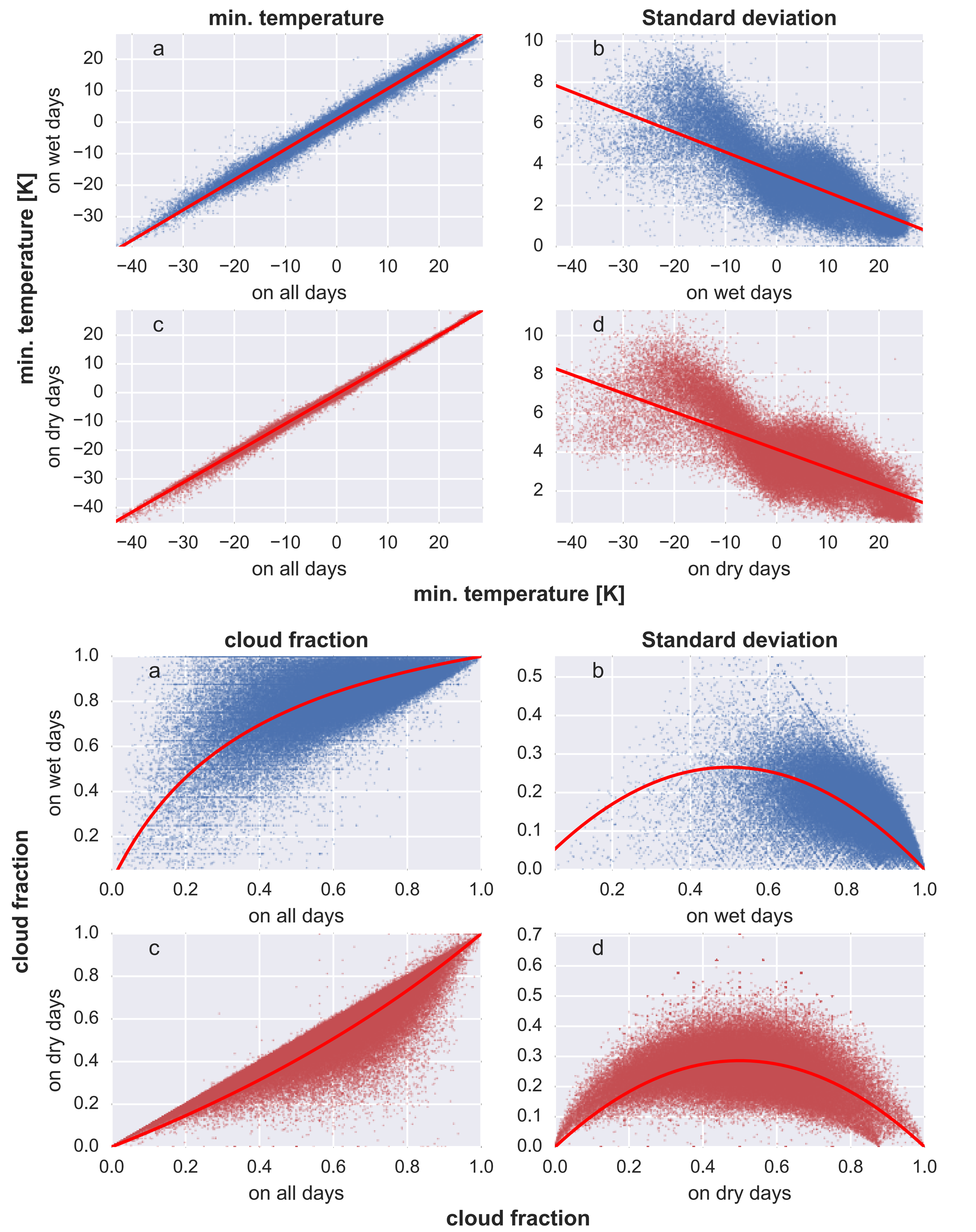
$$h(x) = \begin{cases} f(x) & \text{for } x \leq \mu \\ (1 - F(\mu))\, g(x) & \text{for } x > 0 \end{cases}$$

The hybrid Gamma-GP distribution has two very uncertain parameters that are difficult to estimate within the weather generator: the crossover point μ from Gamma to GP distribution and the GP shape parameter.

In a sensitivity analysis we varied those two parameters. The threshold from 5 to 20mm and the GP shape parameter within the standard deviation. There were however only minor impacts on the final outcome. For all combinations the amount of station years without significant difference were between 85 an 89%.



Temperature and cloud cover



Conclusions

Our weather generator model uses a global dataset of precipitation, temperature and cloudiness to downscale monthly to daily data. Our results show that some simple relationships are applicable on the whole globe and can be used to within a reasonable accuracy for the estimation of the weather distribution throughout a month.

Compared to the Gamma distribution the applied hybrid Gamma-GP distribution improves the model results due to its heavy tail. Although it introduces two new parameters, the quality of the results seem to be fairly independent of the exact values.

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