RMAWGEN: A software project for a daily Multi-Site Weather Generator with R
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Abstract
Among the pre-existing approaches in literature, the R package RMAWGEN aims to generate future daily weather conditions by using the theory of vector auto-regressive models (VAR). The VAR model is used here because it is able to maintain the temporal and spatial correlations among the variables. In particular, historical time series of daily maximum and minimum temperature and precipitation are used to calibrate the parameters of a VAR model, which is stored as an object whose class inherits the varest S3 class defined in the package vars (Pfaff, 2008). Therefore the VAR model, coupled with monthly mean weather variables downscaled by Global Climate Model predictions, can generate several stochastic daily scenarios.

What is a VAR?

A set of \( K \) random variables can be described by a Vector Auto-Regressive Model (VAR(\( K,p \))) as follows:

\[
x_t = A_1 \cdot x_{t-1} + \ldots + A_p \cdot x_{t-p} + C \cdot d_t + u_t
\]

where \( x_t \) is a \( K \)-dimensional vector representing the set of weather variables generated at day \( t \) by the model, called “endogenous” variables, \( d_t \) is a set of known \( K \)-dimensional processes, whose components are called “exogenous” variables, \( A_i \) is a coefficient matrix \( K \times K \) for \( i = 1, \ldots, p \), \( C \) is a coefficient matrix for the exogenous variable and \( u_t \) is the VAR residual, i.e. \( K \)-dimensional stochastic process, \( x_t \) and \( u_t \) are usually normalized to have a null mean \( u_t \) is a Standard White Noise (Luetkepohl, 2007, def. 3.1), i.e. a continuous random process with zero mean and \( u_t \) independent for each \( t \neq s \), consequently it has a time-invariant nonsingular covariance matrix. In RMAWGEN, the VAR model is saved as a varest S4 object which contains varest S3 object. The VAR models work correctly if the variable \( x_t \) is normally distributed. This requires a normalization procedure of the meteorological variable, which can be resumed as follows:

\[
x_t = G_m(x_t) \quad z_t = G_m^{-1}(x_t)
\]

Discussion and Future developments

- RMAWGEN fairly reproduces generated time series of daily temperature statistically coherent with the observed ones (even if some problems should be investigated further).
- RMAWGEN is quite flexible: thanks to Gaussianization (see Fig. 1), it can work with different probability distributions of weather variables.
- RMAWGEN contains also a stochastic daily precipitation generator (which will be improved and upgraded soon) based on VAR models. The use of VAR, as varest or varest2 objects, allows the introduction of exogenous variables: this enables the generation of daily weather variables simultaneously at several sites.
- RMAWGEN was conceived to generate daily time series of temperature and precipitation for ecological and phenological modeling and is open to customized implementations.

Application: Calibration for Daily Minimum and Maximum Temperature (Trentino Dataset)

Figure 2: Time Series at T0090

Figure 3: Q-Q (quantile-quantile) plot at T0090 Station: Maximum (left) and Minimum (middle) Temperature and Daily Thermal Range (right)

The observed and simulated time-series (provided by trentino dataset, Eccel =[, 2012] (see Fig. 2) are reported under different values of \( p \) (auto-regression order) and with or without GPCA (see Table 1). Q-Q plots show a satisfactory fitting between observations and simulations, as expected (see Fig. 3). However, the tests of acceptance of the VAR model, carried out on residuals, are successful only in case of GPCA. Unfortunately, heteroskedasticity of the residuals cannot be verified by the tests Is it significant for climatology applications? Further validation of the model was successfully done by analyzing some Climate Indices and here presented by Di Piazza A et al, Use of a Weather Generator for analysis of projections of future climate changes and its validation with climate change indices, 298-EGU2012-5404.

Table 1: Test on whiteness of residuals

<table>
<thead>
<tr>
<th>p</th>
<th>1</th>
<th>p = 10</th>
<th>p = 1 (with GPCA)</th>
<th>p = 10 (best AIC)(with GPCA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acronym</td>
<td>P01</td>
<td>P10</td>
<td>P01GPCA</td>
<td>P10GPCA</td>
</tr>
<tr>
<td>Normality Test</td>
<td>NO</td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Seriality Test</td>
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<td>NO</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>Heteroskedasticity Test</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
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</tbody>
</table>

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