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HyetosR: An R package for temporal stochastic simulation of rainfall at fine time scales

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1. Abstract

A complete software package for the temporal stochastic simulation of rainfall process at fine time scales is developed in the **R programming environment**. This includes several functions for sequential simulation or disaggregation.

Specifically, it uses the **Bartlett-Lewis rectangular pulses rainfall model** for rainfall generation and proven **disaggregation techniques** which adjust the finer scale (hourly) values in order to obtain the required coarser scale (daily) value, without affecting the stochastic structure implied by the model. Additionally, a **repetition scheme** is incorporated in order to improve the Bartlett-Lewis model performance, without significant increase of computational time.

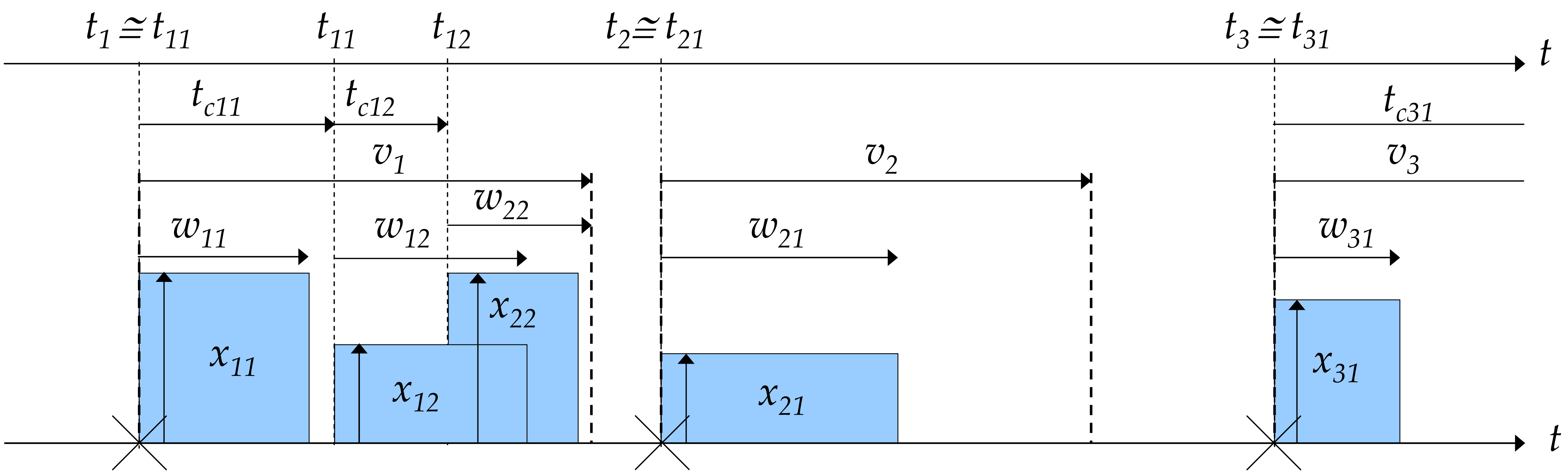
Finally, the package includes an enhanced version of the **evolutionary annealing-simplex optimization method** for the estimation of Bartlett-Lewis parameters. Multiple calibration criteria are introduced, in order to reproduce the statistical characteristics of rainfall at **various time scales**.

This upgraded version of the original Hyetos program (Koutsoyiannis & Onof, 2000) operates on several modes and combinations thereof (depending on data availability), with many options and graphical capabilities. The package, under the name **HyetosR**, is **available free** in http://itia.ntua.gr/en/softinfo/3/.

This presentation is available on-line at http://itia.ntua.gr/en/docinfo/1200/

2. Rainfall generation via Bartlett-Lewis model

- Model assumptions (original version; Rodriguez-Iturbe *et al.*, 1987):
  - **Storm origins**, t_i, occur in a Poisson process, with rate λ
  - **Cell origins**, t_{ij}, occur in a Poisson process, with rate β
  - **Cell arrivals** terminate after v_i, exponentially distributed (parameter γ)
  - **Cell durations**, w_{ij}, exponentially distributed (parameter η)
  - **Cell intensities**, x_{ij}, either exponentially or gamma distributed
- In the modified version (Rodriguez-Iturbe *et al.*, 1988; Onof & Wheater, 1994), η is assumed gamma distributed, with scale parameter v and shape parameter a, and varies for each storm event, such as the ratios β/η and γ/η remain constant.



3. Disaggregation model

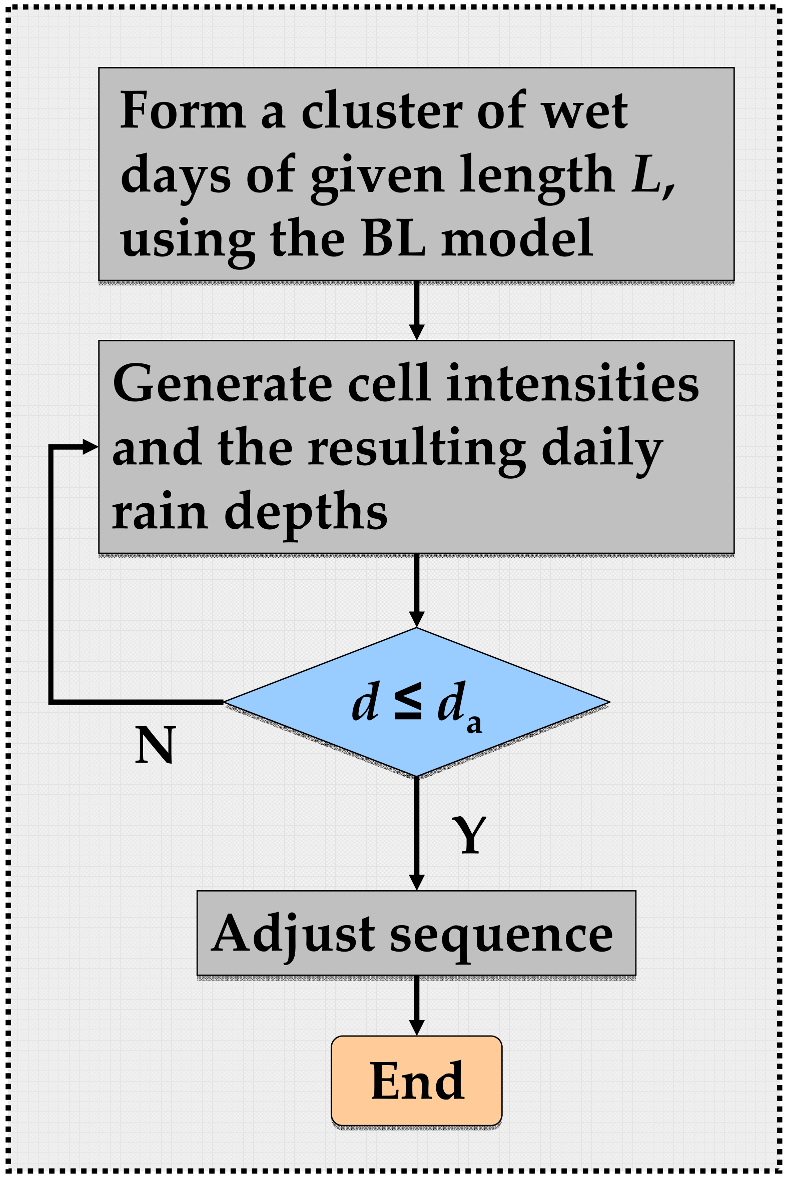
- Different sequences of wet days (separated by at least one dry day) can be assumed independent. This reduces computational time rapidly.
- The BL model runs separately for each cluster of L wet days, forming a sequence of storms and cells.
- For each cluster, a departure is calculated by:

$$d = \left[\sum_{t=1}^{L} \ln \left(\frac{Z_t + c}{\tilde{Z}_t + c} \right)^2 \right]^{1/2}$$

where $\tilde{Z}_t$ is the daily sum of simulated fine-scale data and Z_t is the known total rainfall depth.

- Several runs are performed, until d becomes lower than an acceptable limit d_a.
- The chosen sequence is adjusted to become fully consistent with the given sequence, according to the proportional adjusting procedure:

$$X_i = \tilde{X}_i \left(Z \Big/ \sum_{i=1}^{24} \tilde{X}_i \right)$$



- In the case of very long clusters, the cluster is subdivided into sub-clusters, each treated independently; for details see Koutsoyiannis & Onof, 2001.

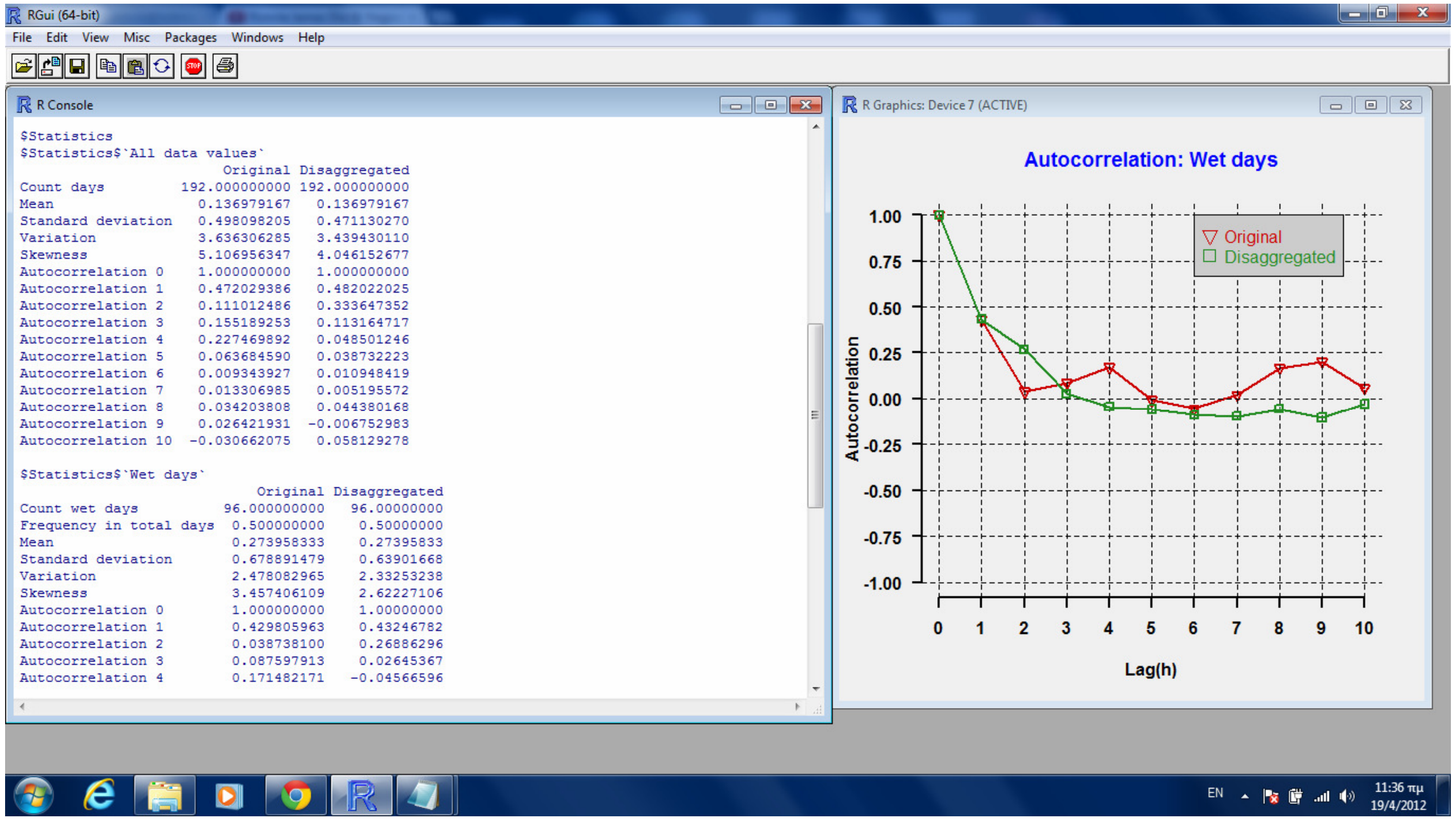
4. Parameter estimation

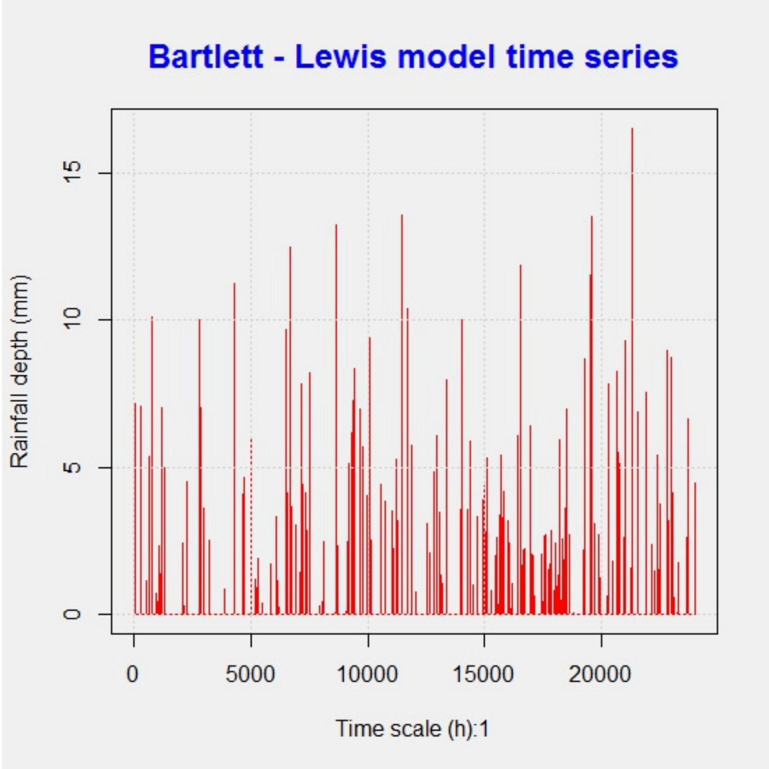
- The modified version of the BL model contains 6 or 7 parameters.
- For given parameter values, some of the most important theoretical statistical characteristics of rainfall (mean, variance, covariance, probability dry) can be analytically computed.
- On the other hand, the inverse procedure (i.e. the estimation of model parameters for given statistical characteristics) has no analytical solution.
- This is handled through calibration, seeking to minimize the “distance” between the theoretical and the observed statistics.
- The calibration problem is inherently multiobjective, although it is typically treated as single-objective.
- In the formulation of the objective function, a number of questions arise:
  - Which are the statistical characteristics to preserve and for which time scales?
  - Which distance metric is the most consistent, for the specific statistical parameter?
  - How are the different metrics combined (e.g. in terms of weighting coefficients) to provide a unique performance measure, i.e. a scalar objective function?
- Additional uncertainties are due to the highly non-convex response surface, which makes essential to use advanced optimization algorithms to obtain a robust parameter set, with reasonable computational effort.
- Usually, a huge number of almost equivalent local optima exist.

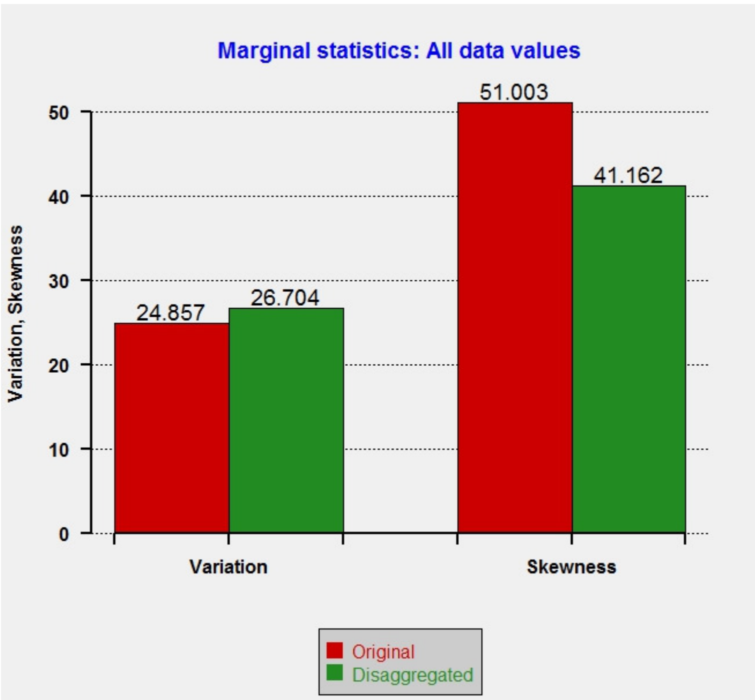
5. Software implementation in R

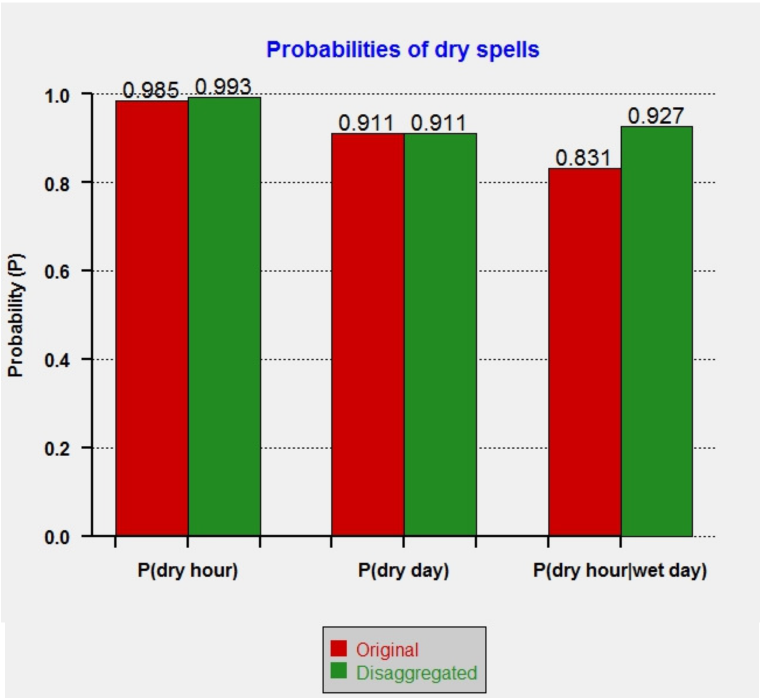
- The model is implemented in **R** programming language, under the name **HyetosR** (http://itia.ntua.gr/en/softinfo/3/).
- R is an open source programming language and software environment for interactive data analysis, statistical computation and graphics.
- HyetosR operates on several modes and combinations thereof (depending on data availability), and includes the following functions:
  - **DisagSimul.test** (with hourly input): The initial daily sequence either is generated by the BL model or is read from a file. The program disaggregates it, producing the corresponding synthetic hourly series (the entire model performance is tested).
  - **DisagSimul** (with daily input): Similar to DisagSimul.test function but the input file contains only daily data (no means for testing).
  - **SequentialSimul** (with or without hourly input): The synthetic rainfall series is generated using the BL model, at the chosen time scale, without performing any disaggregation.
  - **eas**: The evolutionary annealing-simplex optimization method is employed for the estimation of BL model parameters through calibration.
- The platform allows the user to formulate all aspects of the calibration problem (objective function, parameter bounds, population size, etc.).

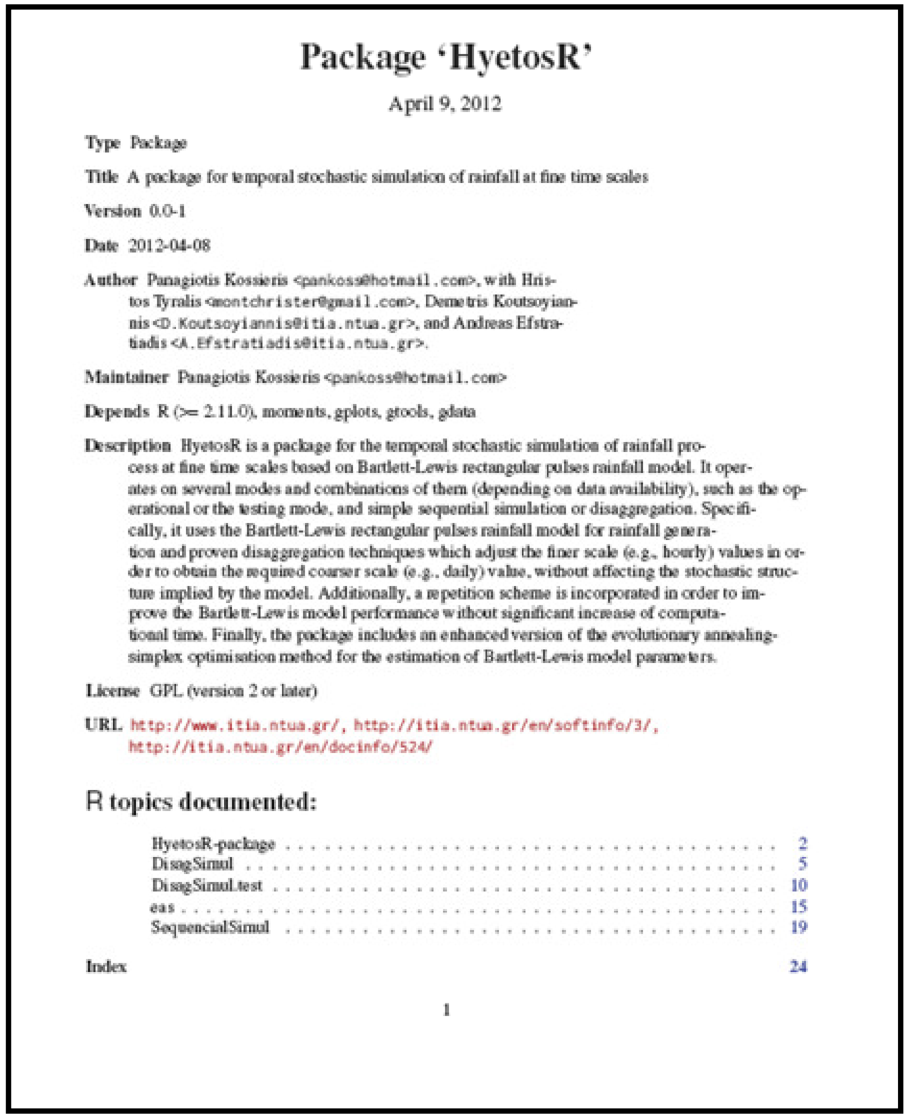
6. Characteristic features











Package 'HyetosR'

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Type Package

Title A package for temporal stochastic simulation of rainfall at fine time scales

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Maintainer Panagiotis Kossieris <pankoss@hotmail.com>

Depends R (>= 2.11.0), moments, gplots, gtools, gdata

Description HyetosR is a package for the temporal stochastic simulation of rainfall process at fine time scales based on Bartlett-Lewis rectangular pulses rainfall model. It operates on several modes and combinations of them (depending on data availability), such as the operational or the testing mode, and simple sequential simulation or disaggregation. Specifically, it uses the Bartlett-Lewis rectangular pulses rainfall model for rainfall generation and proven disaggregation techniques which adjust the finer scale (e.g., hourly) values in order to obtain the required coarser scale (e.g., daily) value, without affecting the stochastic structure implied by the model. Additionally, a repetition scheme is incorporated in order to improve the Bartlett-Lewis model performance without significant increase of computational time. Finally, the package includes an enhanced version of the evolutionary annealing-simplex optimisation method for the estimation of Bartlett-Lewis model parameters.

License GPL (version 2 or later)

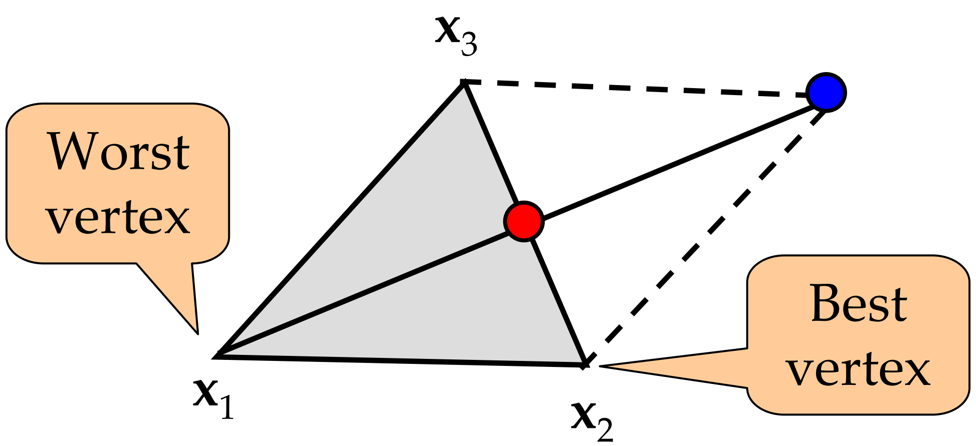
URL http://www.itia.ntua.gr/, http://itia.ntua.gr/en/softinfo/3/, http://itia.ntua.gr/en/docinfo/524/

R topics documented:

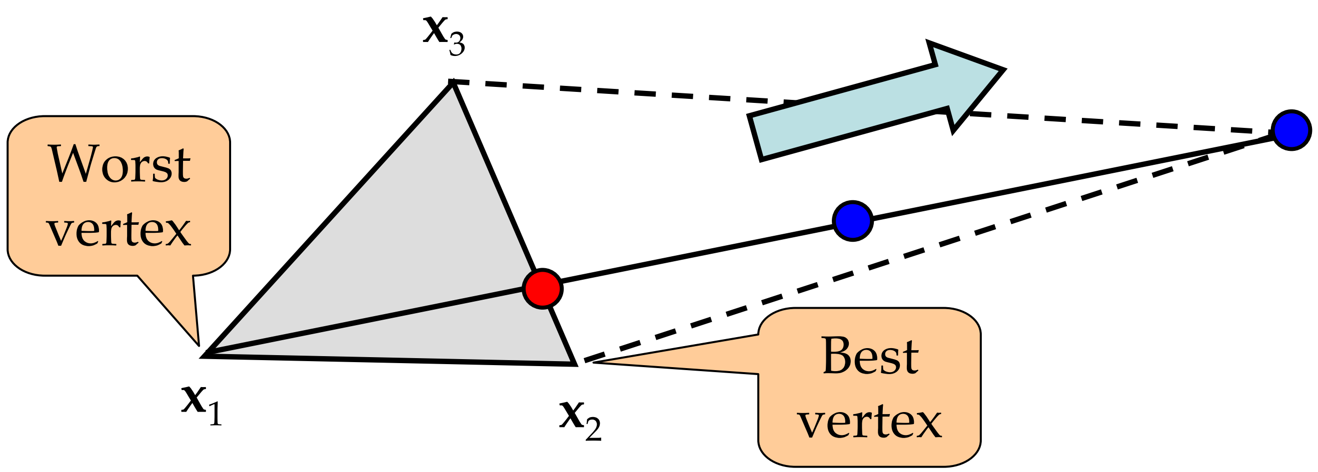
1

7. Evolutionary annealing-simplex (version 3.0)

- Evolution is based either on simplex transformations or mutations.
- All evaluations are based on probabilistic criteria, since a stochastic term is added to the objective function, relative to a "temperature" metric.
- "Temperature" is gradually decreased, on the basis of an adaptive annealing cooling schedule, which controls the degree of randomness within evolution.
- "Uphill" transitions are also allowed to escape from local minima.
- The major difference to the version by Efstratiadis & Koutsoyiannis (2002) involves the reflection step, which is now implemented through a weighted centroid (proxy of the gradient) instead of the geometrical one.
- This change made the algorithm even an order of magnitude faster!
- The EAS package is also implemented in **R** (http://itia.ntua.gr/en/softinfo/29/).



Reflection of the simplex through its centroid, according to the original Nelder-Mead (1965) procedure



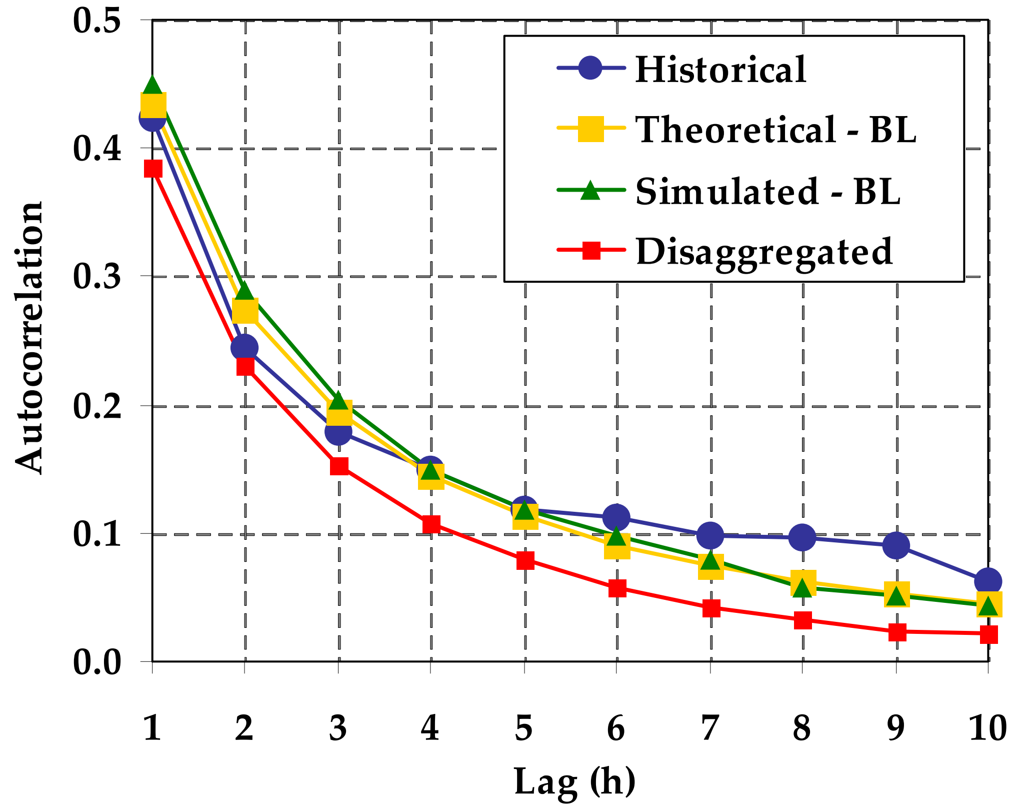
Reflection of the simplex through a weighted centroid and multiple expansions towards the direction of the function improvement

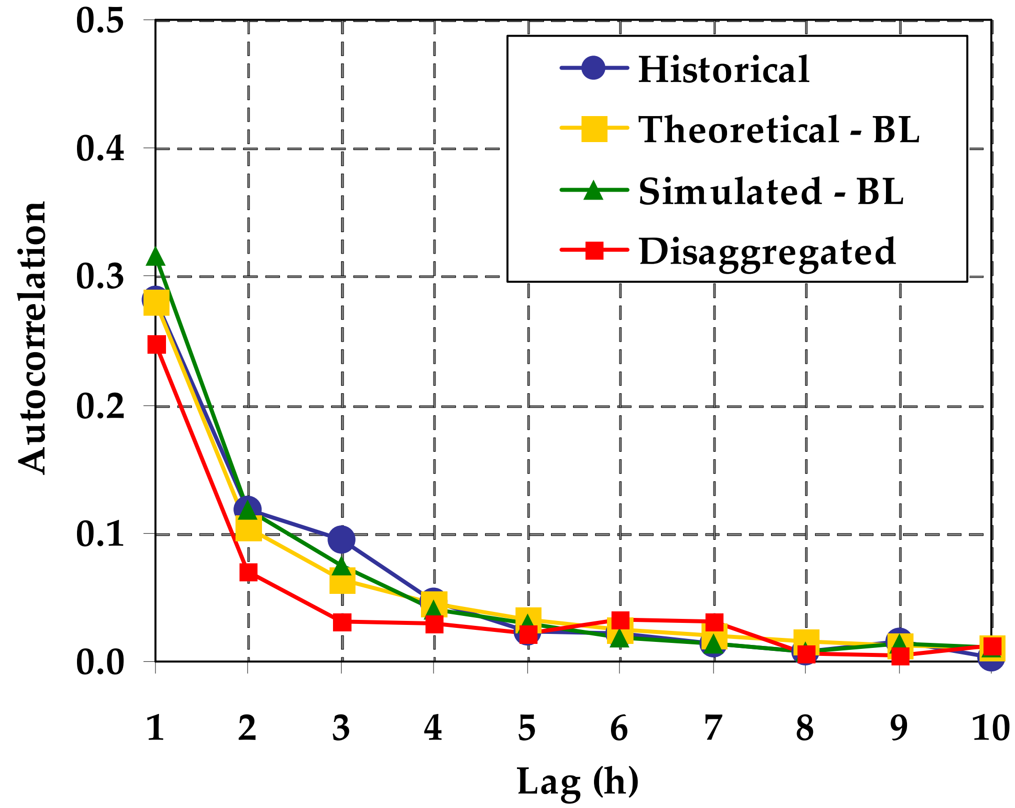
8. Case study: Simulation of Athens rainfall

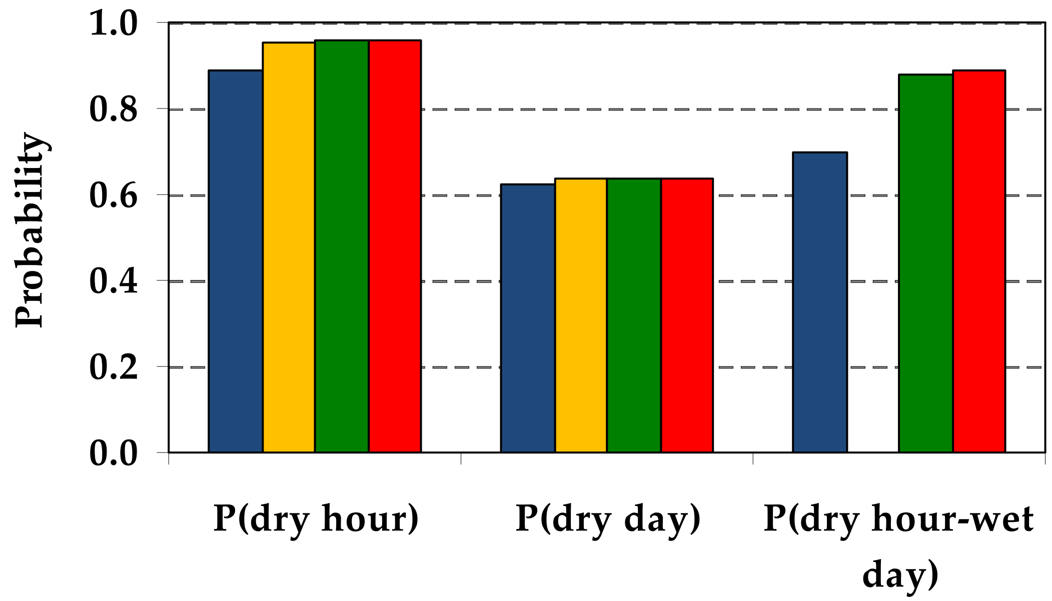
- As test case, we used the hourly data sets from the National Observatory of Athens (1940-90), for two months with different characteristics (January, June).
- Model parameters were calibrated on theoretical mean, standard deviation and probability dry for 1 and 24 h, and theoretical autocovariance for 1 hour.
- The model run for 1000 years, to generate synthetic hourly rainfall data.
- The statistical characteristics of the synthetic time series were extracted and compared to the historical ones.

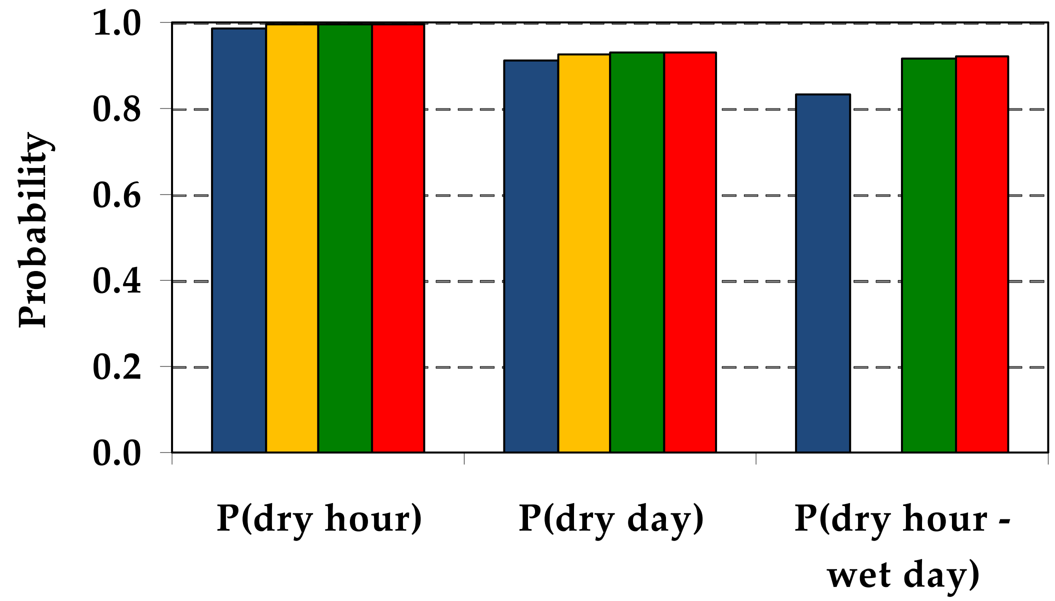
	Historical	Theoretical	Simulated – BL	Disaggregated	
Average (mm)	0.063	0.063	0.063	0.063	**Hourly statistics, January**
Standard deviation (mm)	0.439	0.436	0.431	0.472	
Coefficient of skewness	16.024	–	13.566	15.637	
Average (mm)	1.502	1.512	1.503	–	**Daily statistics, January**
Standard deviation (mm)	4.361	4.133	4.107	–	
Coefficient of skewness	5.386	–	5.986	–	
Average (mm)	0.016	0.016	0.015	0.015	**Hourly statistics, June**
Standard deviation (mm)	0.391	0.391	0.371	0.397	
Coefficient of skewness	51.312	–	51.782	54.470	
Average (mm)	0.375	0.384	0.362	–	**Daily statistics, June**
Standard deviation (mm)	2.852	2.793	2.736	–	
Coefficient of skewness	11.949	–	24.873	–	

9. Reproduction of autocorrelation functions and characteristic probabilities





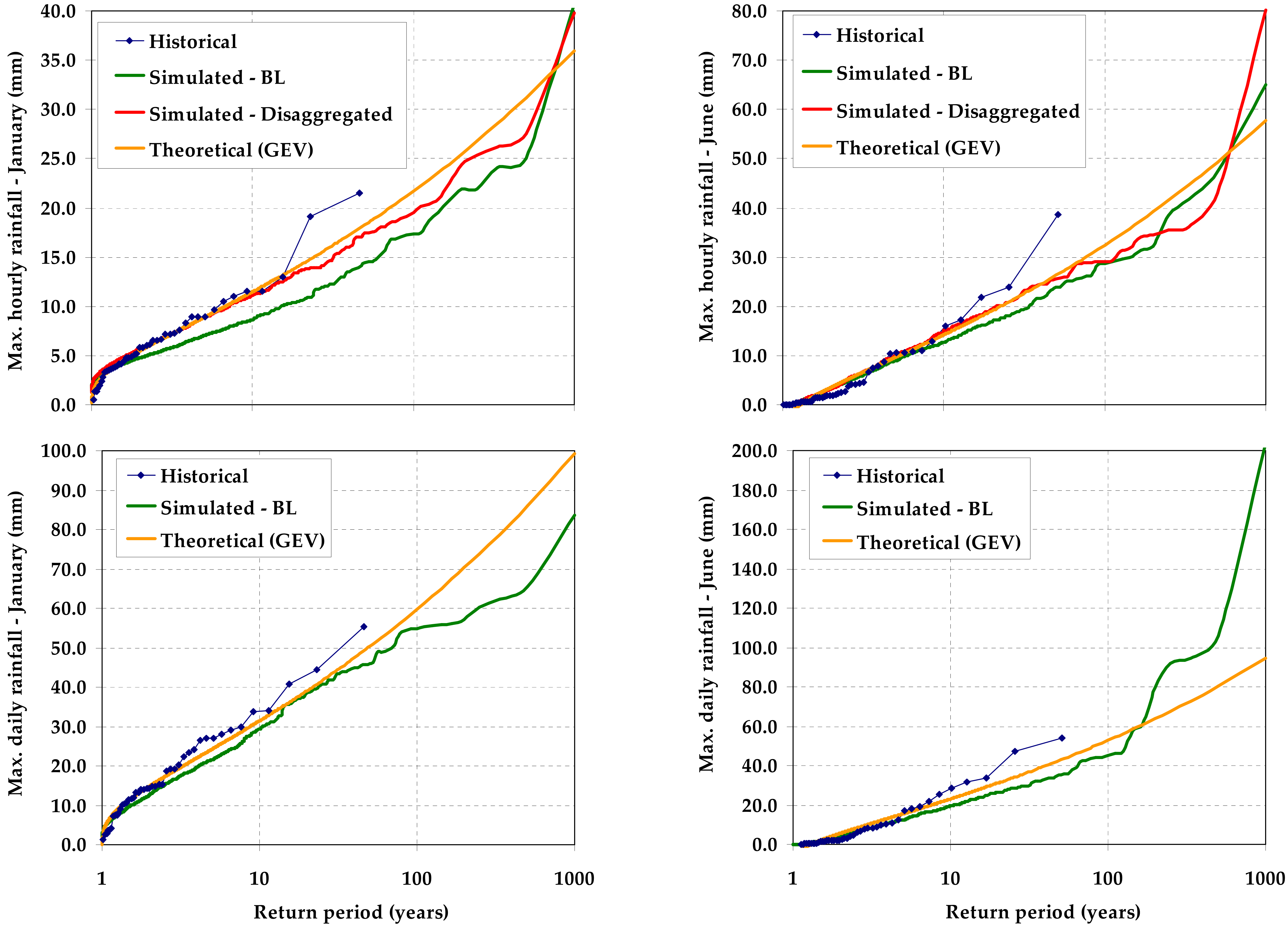




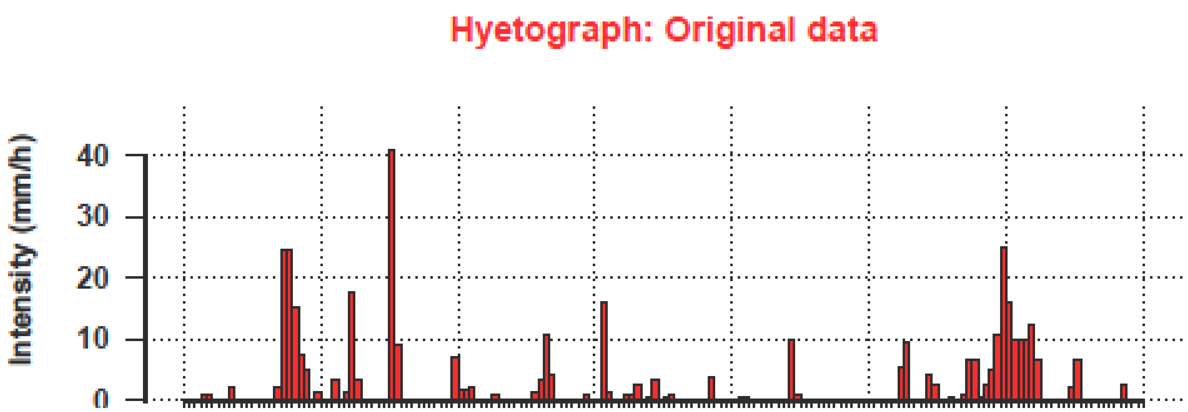
January

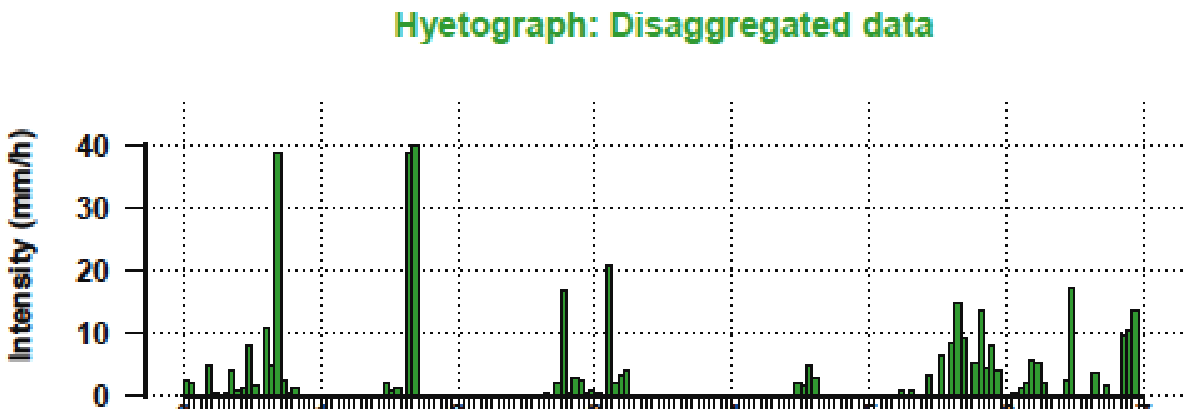
June

10. Reproduction of distributions of extremes

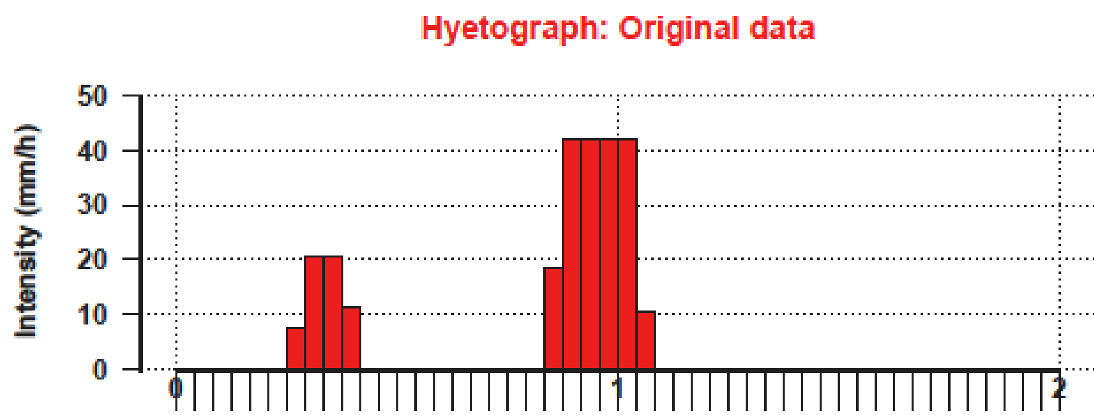


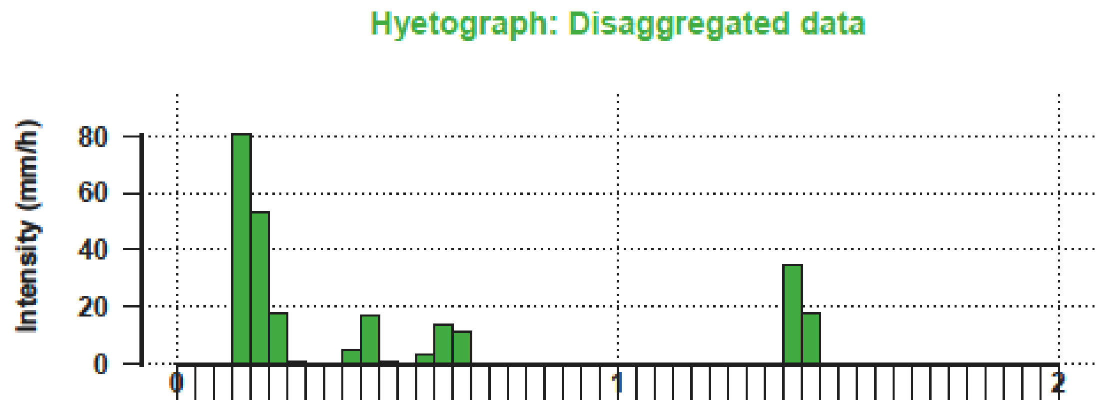
11. Characteristic synthetic rainfall events





Total duration = 7 days, maximum daily rainfall depth = 83.5 mm





Total duration = 1.5 days, maximum daily rainfall depth = 203.6 mm

*Most extreme **January** rainfall event (top: simulated by the BL model; down: disaggregated)*

*Most extreme **June** rainfall event (top: simulated by the BL model; down: disaggregated)*

12. Conclusions

- The HyetosR program is a fully operational program, used for reconstructing past hourly rainfall on the basis of known daily data (through disaggregation), or for generating synthetic rainfall data at fine time scales.
- In our case study, the model reproduced almost all the essential statistical characteristics of the observed data, at both the daily and hourly time scales; it also reproduced the hourly autocorrelations and the dry probabilities.
- The stochastic approach is validated by comparing the empirical pdf of the synthetic extremes to a theoretical distribution (i.e. the GEV, with $\kappa = 0.15$).
- The empirical pdf of disaggregated extremes fits well the GEV model; thus HyetosR is appropriate for generating design storms in flood studies.
- Further improvement of the parameter estimation problem, towards a multiobjective calibration framework, is possible.

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