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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.

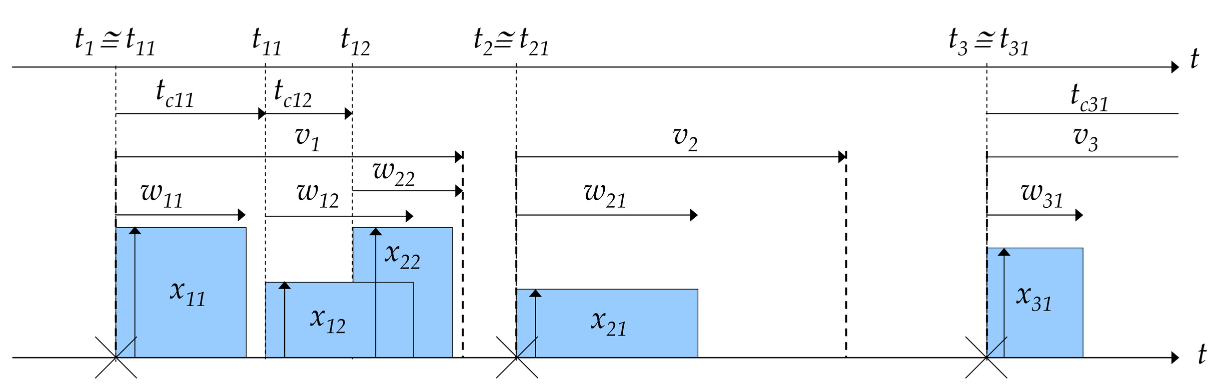
Finally, the package includes an enhanced version of the **evolutionary annealing-simplex optimization method** for the estimation of Bartlett-Lewis parameters. Multiple calibration criteria are introduced, in order to reproduce the statistical characteristics of rainfall at **various time scales**.

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.



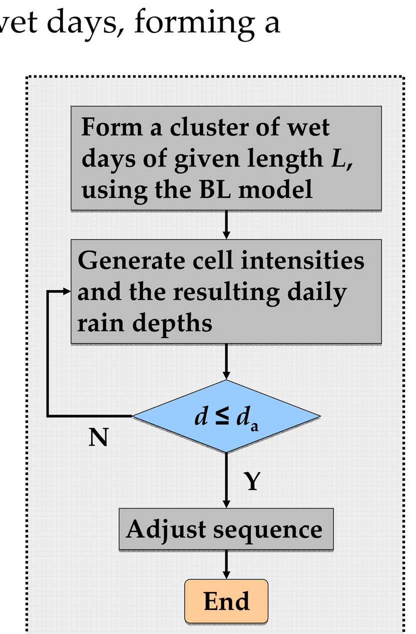
3. Disaggregation model

- 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:

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



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

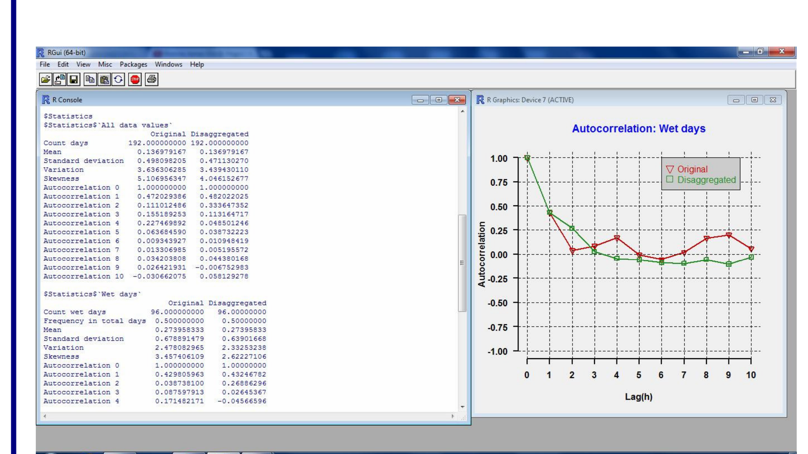
4. Parameter estimation

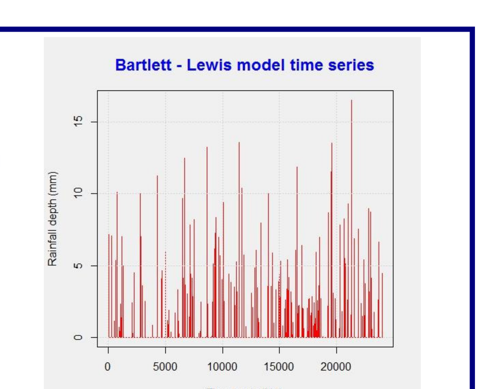
- The modified version of the BL model contains 6 or 7 parameters.
- For given parameter values, some of the most important theoretical statistical characteristics of rainfall (mean, variance, covariance, probability dry) can be analytically computed.
- On the other hand, the inverse procedure (i.e. 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.

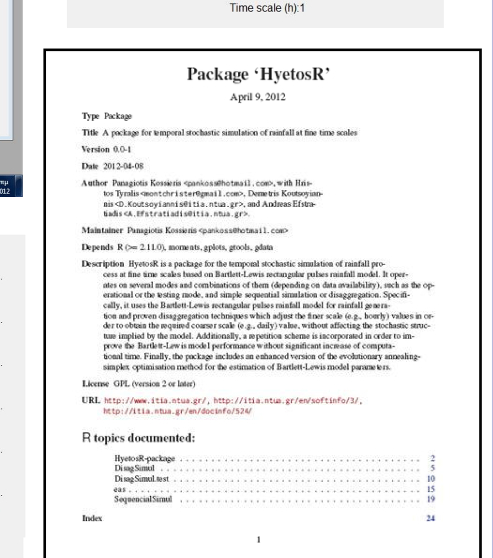
5. Software implementation in R

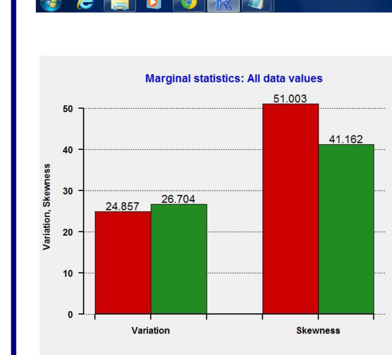
- The model is implemented in **R** programming language, under the name **HyetosR** (http://itia.ntua.gr/en/softinfo/3/).
- R is an open source programming language and software environment for interactive data analysis, statistical computation and graphics.
- HyetosR operates on several modes and combinations 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.).

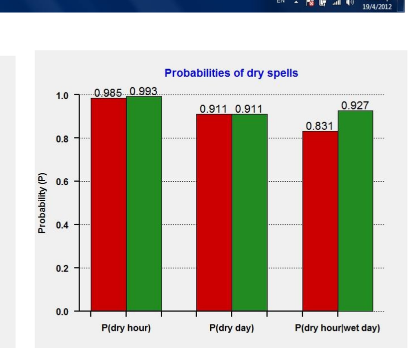
6. Characteristic features





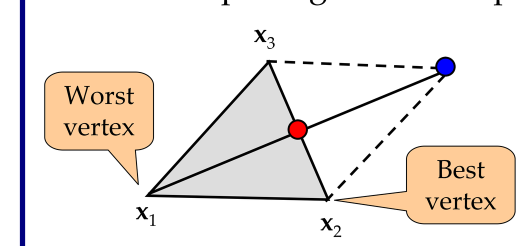




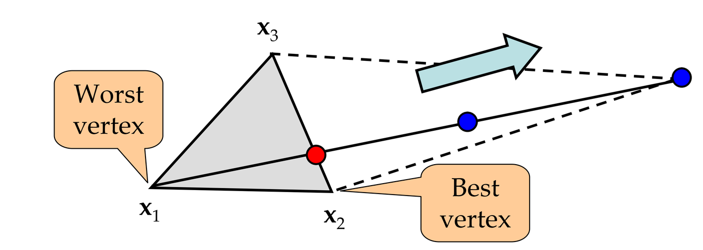


7. Evolutionary annealing-simplex (version 3.0)

- 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



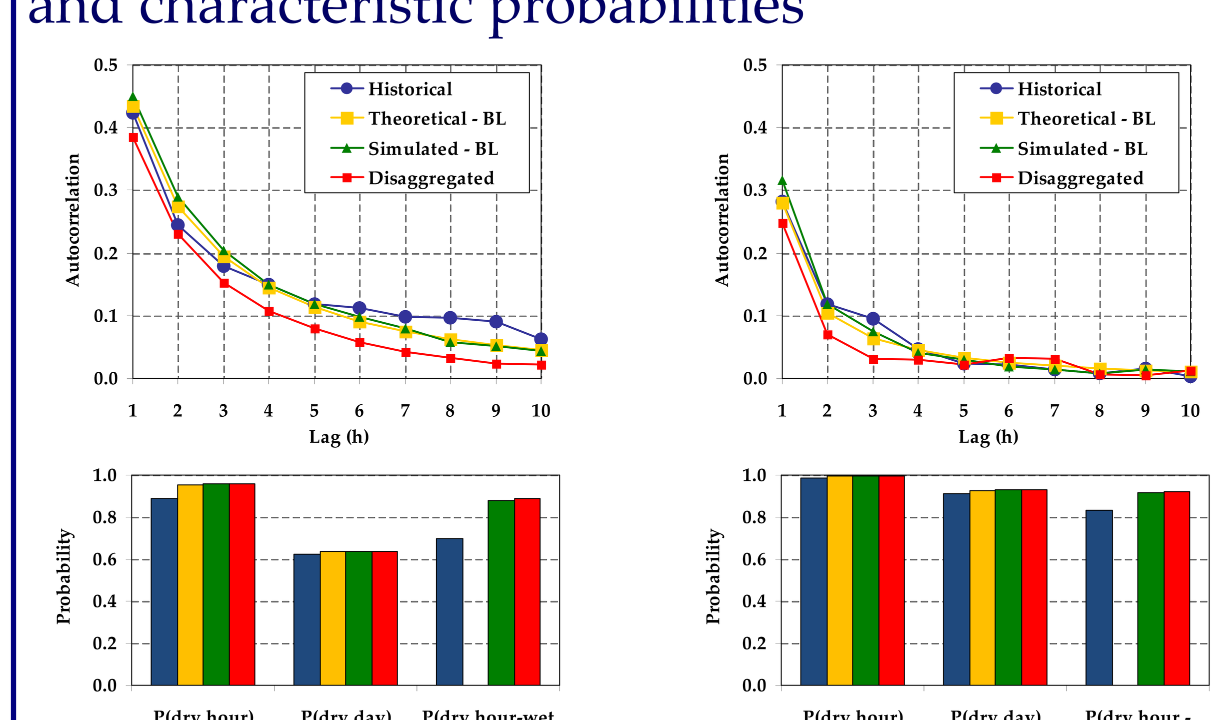
Reflection of the simplex through a weighted centroid and multiple expansions towards the direction of the function improvement

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.

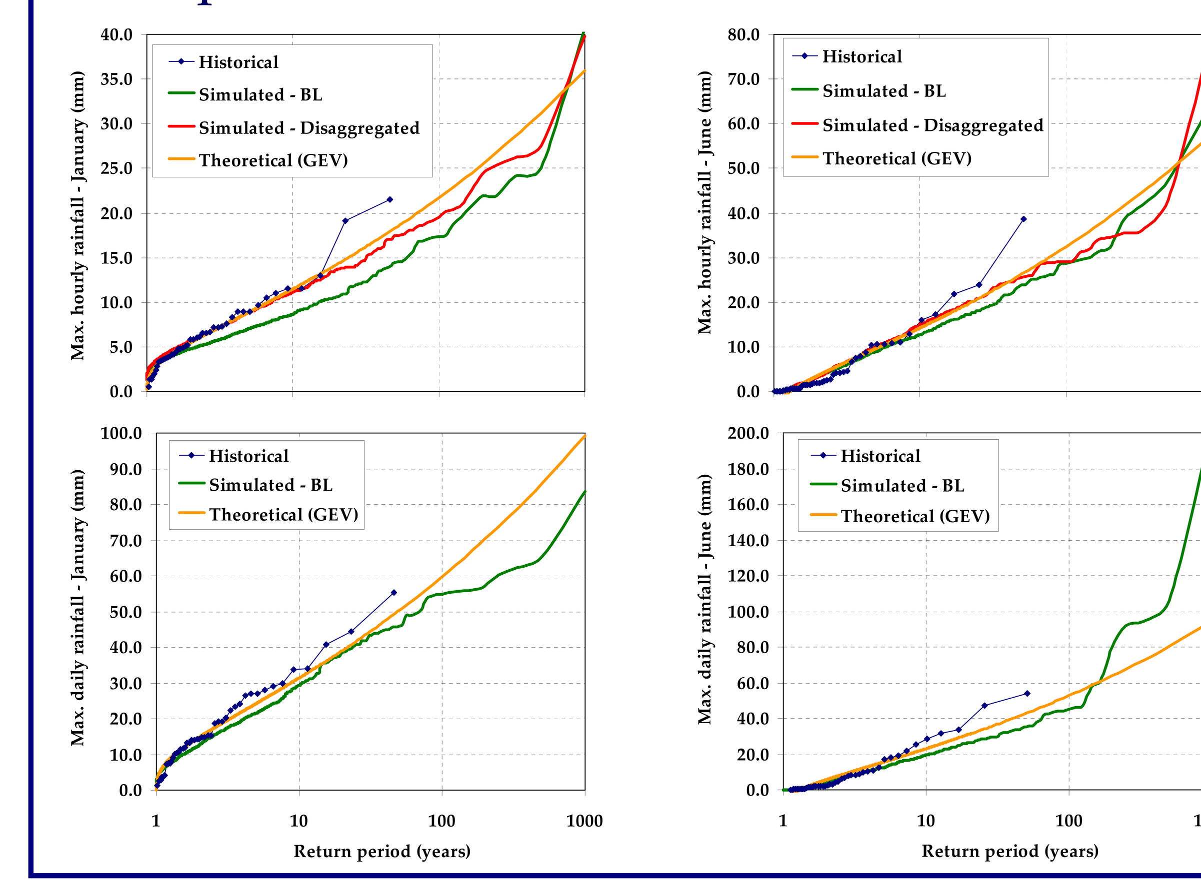
	Historical	Theoretical	Simulated – BL	Disaggregated	
Average (mm)	0.063	0.063	0.063	0.063	**Hourly statistics, January**
Standard deviation (mm)	0.439	0.436	0.431	0.472	
Coefficient of skewness	16.024	–	13.566	15.637	
Average (mm)	1.502	1.512	1.503	–	**Daily statistics, January**
Standard deviation (mm)	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

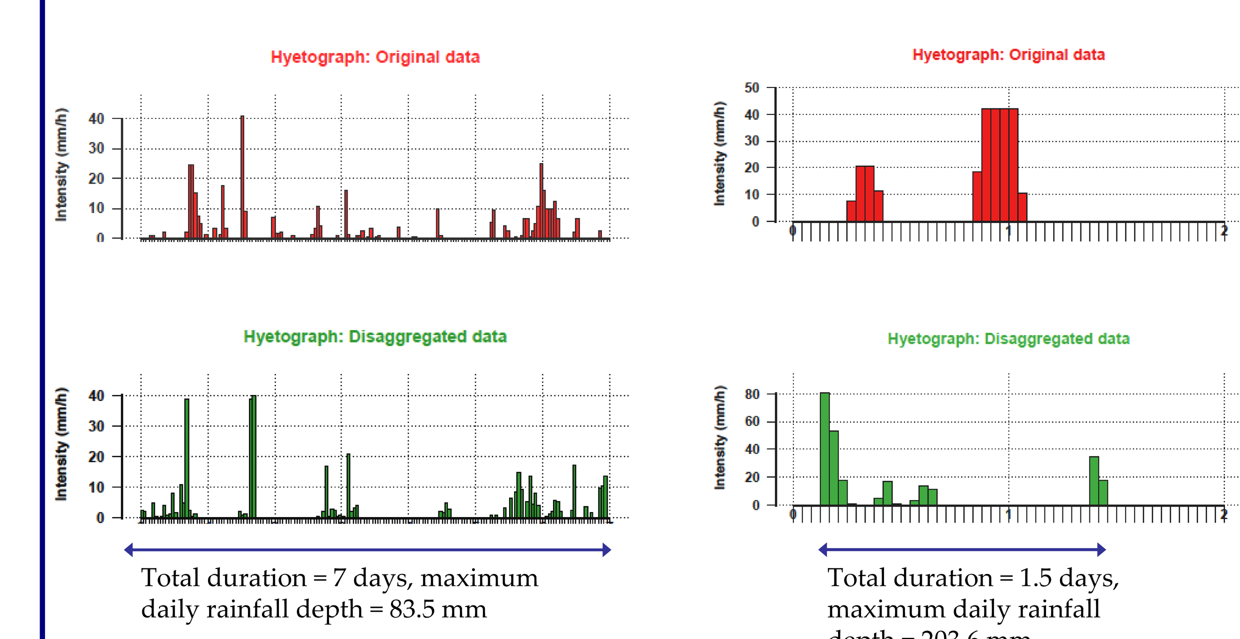


January **June**

10. Reproduction of distributions of extremes



11. Characteristic synthetic rainfall events



*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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