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NP2.05/ Scaling, multifractals and nonlinear variability in geophysics: Stochastic rainfall modelling: Scaling/non-scaling approaches and disaggregation

A computer program for temporal rainfall disaggregation using adjusting procedures

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Parts of the presentation

1. Introduction – Usefulness of a temporal rainfall disaggregation model
2. Theoretical background, model structure, model implementation
3. Description of the program
4. Case studies and model performance

Usefulness of a temporal rainfall disaggregation model

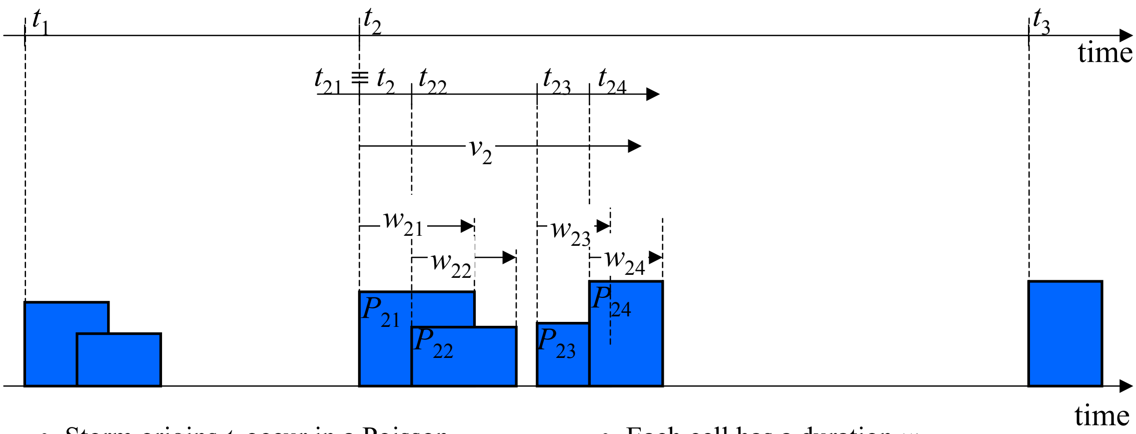
- **Enhancement of data records:** Disaggregation of widely available daily rainfall measurements into hourly records (often unavailable and frequently required by hydrological models).
- **Climate change studies:** Use of output from General Circulation Models (forecasts for different climate change scenarios), generally provided at a coarse time-scale (e.g. monthly) to hydrological applications that require a finer time scale.
- **Flood studies:** Synthesis of one or more detailed storm hyetograph (more severe than the observed ones) with known total characteristics (duration, depth).
- **Simulation studies:** Study of a hydrological system using multiple (rather than the single observed) sequences of rainfall series all having some common cumulative properties.

General idea

- Instead of designing and implementing a special model for rainfall disaggregation, it is preferable to **use an existing typical rainfall simulation model** and seek for an appropriate technique for performing disaggregation.
- As an appropriate rainfall model, the **Bartlett-Lewis model rectangular pulses** was chosen due to its wide applicability and experience in calibrating and applying it to several climates.
- Techniques for **disaggregation by adjusting**, i.e., for modifying a fine scale (lower-level, such as hourly) time series, generated by a specific stochastic model, so as to be consistent with a given coarser scale (higher-level, such as daily) time series, and simultaneously not affecting the stochastic structure implied by the model, have been studied by Koutsoyiannis (1994) and Koutsoyiannis and Manetas (1996).

Synopsis of the Bartlett-Lewis (BL) Point Process Model

(Rodriguez-Iturbe Et Al., 1987, 1988)



- Storm origins t_i occur in a Poisson process (rate λ)
- Cell origins t_{ij} arrive in a Poisson process (rate β)
- Cell arrivals terminate after a time v_i exponentially distributed (parameter γ)
- Each cell has a duration w_{ij} exponentially distributed (parameter η)
- Each cell has a uniform intensity P_{ij} with a specified distribution

Synopsis of adjusting procedures (Koutsoyiannis and Manetas, 1996)

- **Proportional adjusting procedure**

$$X_s = \tilde{X}_s \left(Z \Big/ \sum_{j=1}^{k} \tilde{X}_j \right) \qquad (s = 1, \ldots, k)$$

  - The simplest in application
  - Exact for complete preservation of distributions of independent variables with two parameter gamma distribution and common scale parameters
  - Good approximation for dependent variables with gamma distribution
  - Does not generate negative values

- **Linear adjusting procedure**

$$X_s = \tilde{X}_s + \lambda_s \left(Z - \sum_{j=1}^{k} \tilde{X}_j \right) \qquad (s = 1, \ldots, k)$$

  - Exact for complete preservation of distributions for Gaussian variables
  - Exact in preserving second order moments of (dependent or independent) variables with any distribution.
  - Can explicitly assure preservation of correlations with lower-level variables of different higher-level periods
  - Can result in negative values (which are then corrected using repetitions)

- **Power adjusting procedure**

$$X_s = \tilde{X}_s \left(Z \Big/ \sum_{j=1}^{k} \tilde{X}_j \right)^{\lambda_s / \eta_s} \qquad (s = 1, \ldots, k)$$

  - Approximate apart from special cases (e.g. when coincides with proportional procedure)
  - Needs repetitions
  - Does not result in negative values
  - For stationary processes is identical to the proportional procedure.

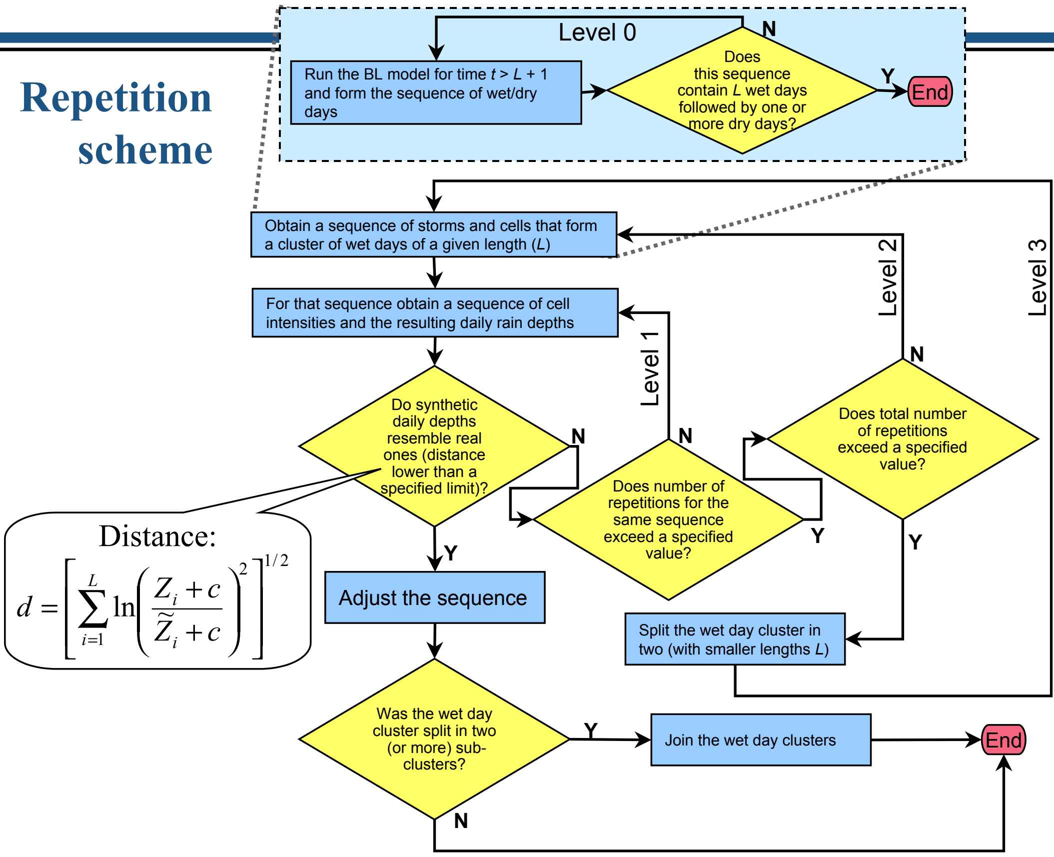
Notes on the choice of the appropriate adjusting procedure

- Stationary process (power procedure identical to proportional one).
- Large proportion of zeros (e.g., up to 90% within rainy days).
- Approximately gamma distributed nonzero depths.
- Not very strong autocorrelation.
- Under these conditions, the proportional procedure is chosen.
- Main source of bias: the variable number of nonzero intervals within any period.
- Repetitions are required to reduce bias and better preserve the autocorrelations and skewness.
- Main potential problem: computer time consuming.

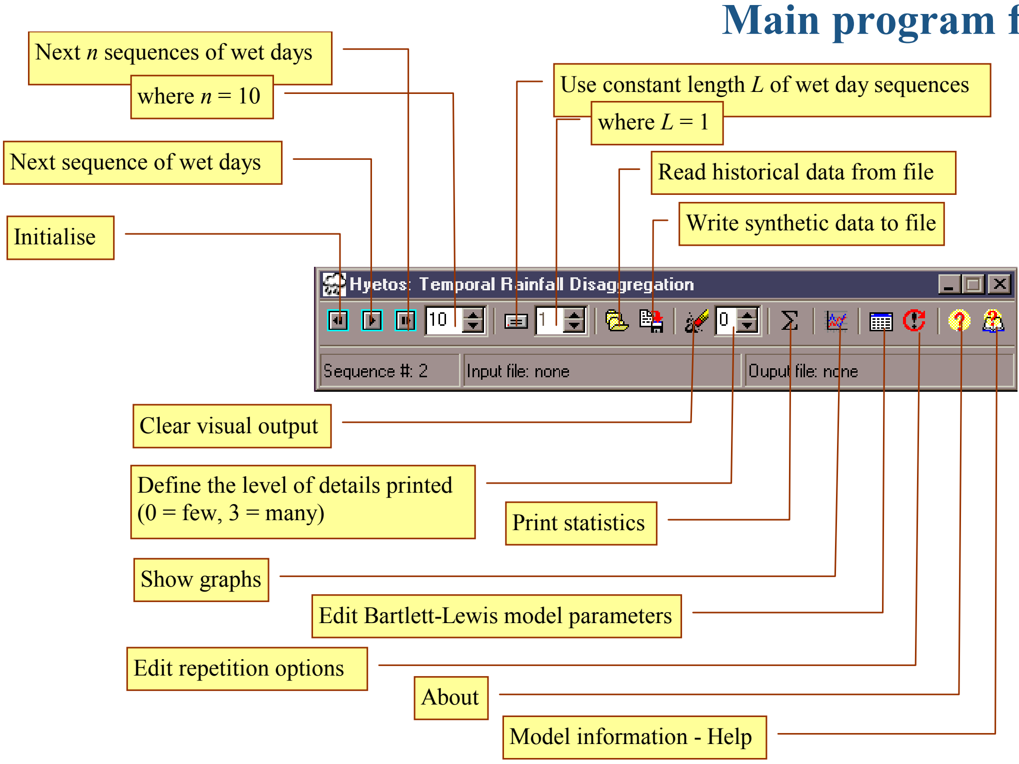
Implementation of the BL model

- Different clusters of rain days (separated by at least one dry day) may be assumed independent. This empirical observation is consistent with the BL model, which assumes Poisson arrivals of storms.
- This allows different treatment of each cluster of rain days, which reduces computational time rapidly.
- Conclusively, the BL model runs separately for each cluster of rain days. Several runs are performed for each cluster, until the departure of daily sum from the given daily rainfall becomes lower than an acceptable limit.
- In case of a very long sequence of wet days, it is practically impossible to get a sequence of wet days with departure of daily sum from the given daily rainfall lower than the specified limit. In these cases the sequence is subdivided into sub-sequences, each treated independently of the others.
- Further processing consists of application of the adjusting procedure to achieve full consistency with the given sequence of daily depths.

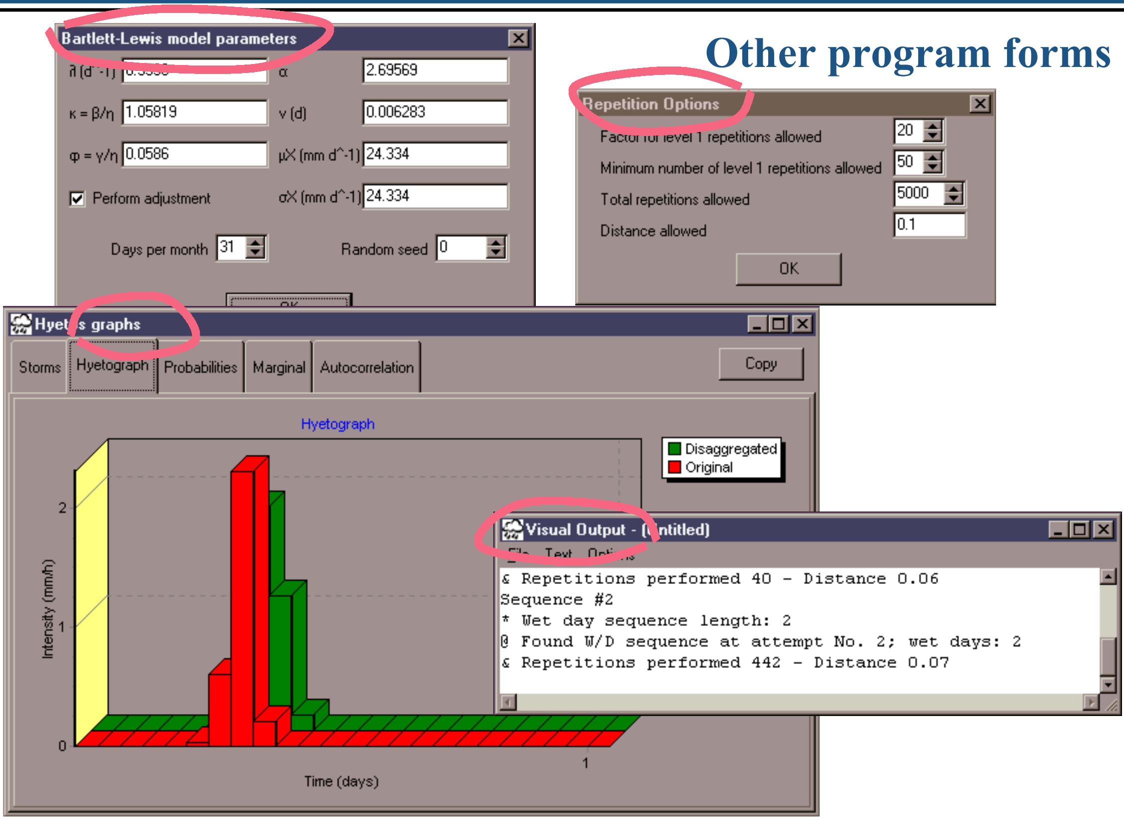
Repetition scheme



Main program form



Other program forms



Modes of program operation

1. **Disaggregation test mode** (without input; default mode). An initial sequence of storms is generated using the Bartlett-Lewis model with the given parameters and then aggregated into hourly and daily scale. The daily sequence is disaggregated, thus producing another synthetic hourly series. (Mode appropriate for testing the disaggregation model itself).
2. **Full test mode** (with hourly input). The daily sequence is read from a file rather than generated (Mode appropriate for testing the entire model performance including the appropriateness of the Bartlett-Lewis model and its parameters, and the disaggregation model).
3. **Operational mode** (with daily input). Similar to Full test mode but the input file contains no hourly data but only daily (Usual case for the model application – no means for testing).
4. **Rainfall model test mode** (with hourly input). Similar to the Full test mode but with synthetic data not disaggregated but generated from the Bartlett-Lewis model with the given parameters. (Mode appropriate for testing the BL model).
5. **Simple rainfall generation mode** (without input and without disaggregation). Similar to the Rainfall model test mode but with no input provided. (Mode appropriate for testing the BL model).

In all modes the Bartlett-Lewis model can be implemented either in its original or modified version with a number of parameters from 5 to 7.

Case studies and model performance: Raingauges, climate regimes and BL model parameters

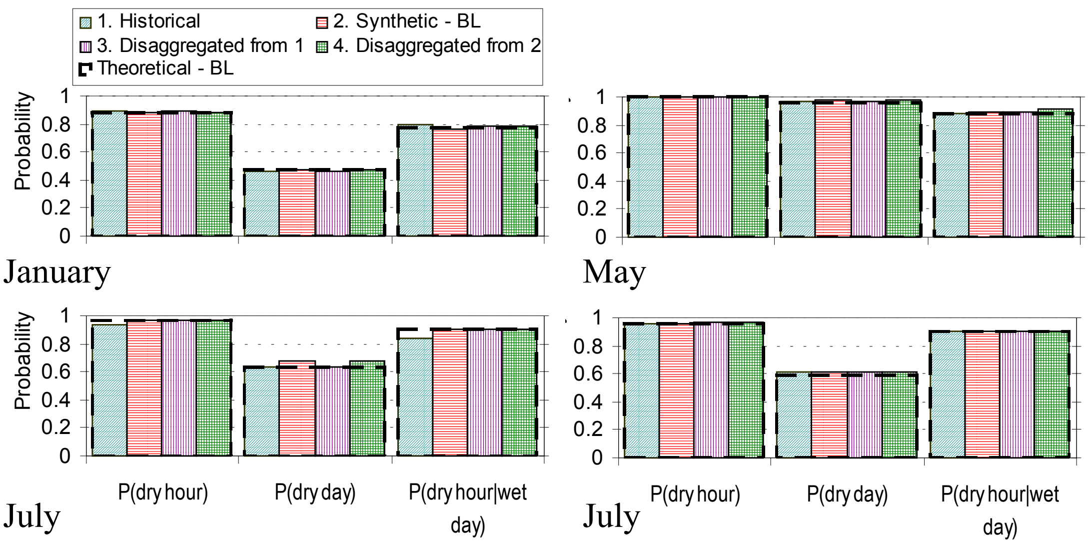
Raingauge		Heathrow airport		Walnut Gulch Gauge 13	
	Climate conditions	Wet throughout the year		Semiarid with a wet season	
Month		**January**	**July**	**May**	**July**
	Climate conditions	(The wettest month)	(The driest month)	(The driest month)	(The wettest month)
Record length (yr)		39	39	36	36
Monthly rainfall	Mean (mm)	50.04	50.96	3.62	84.22
	Standard deviation (mm)	23.09	28.39	5.31	39.85
Daily rainfall	Mean (mm)	1.61	1.64	0.12	2.72
	Standard deviation (mm)	3.05	4.79	0.92	6.21
Hourly rainfall depth	Mean (mm)	0.067	0.068	0.005	0.113
	Standard deviation (mm)	0.305	0.580	0.124	0.956
Proportion dry	Daily	0.466	0.630	0.966	0.613
	Hourly	0.891	0.939	0.996	0.961
Parameters of BL model	α	5.675	3.038	17.624	96.612
	κ	0.5551	0.5509	0.0726	0.1983
	φ	0.1011	0.1037	0.0120	0.1261
	λ (d^{-1})	0.6386	0.4405	0.0352	0.4977
	μ_X (d^{-1})	20.33	118.56	357.21	270.34
	ν (d)	0.0896	0.0102	0.0220	0.7506

Note: BL model parameters were estimated using the generalised method of moments

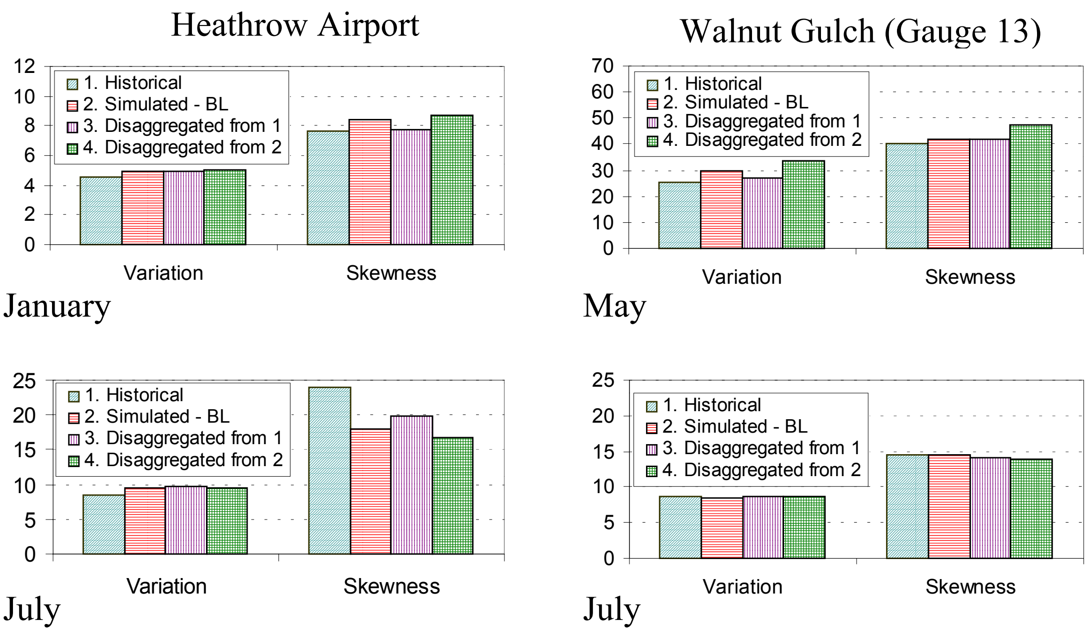
Preservation of dry/wet probabilities

Heathrow Airport

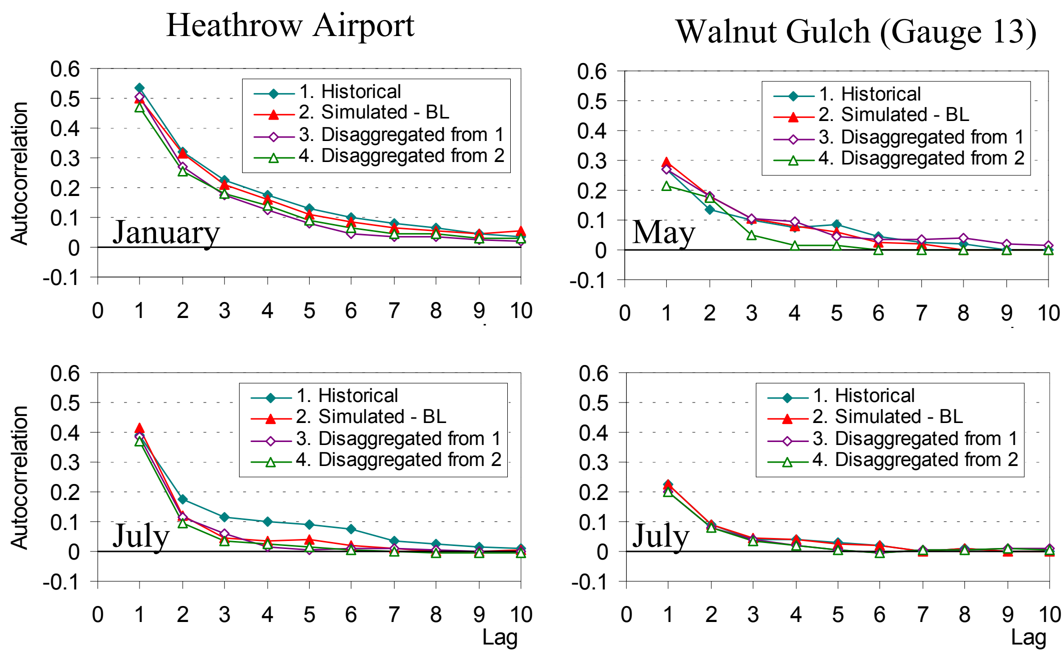
Walnut Gulch (Gauge 13)



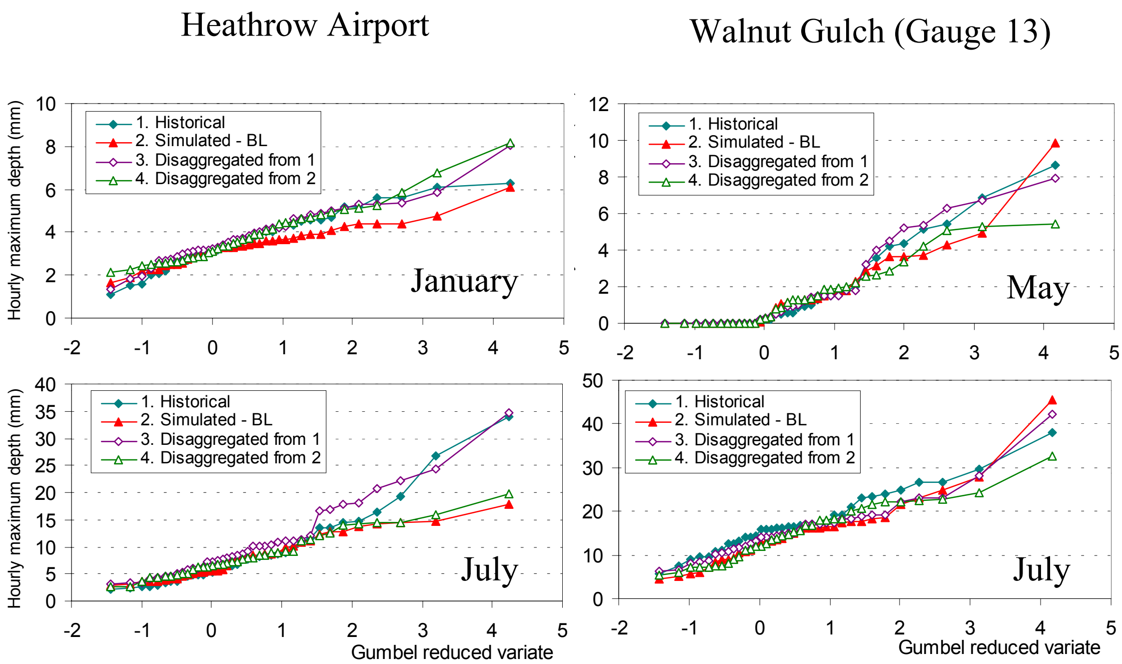
Preservation of marginal moments



Preservation of autocorrelations



Distribution of hourly maximum depths



Concluding remarks

- The modelling framework used combines the strengths of a standard stochastic rainfall model, such as the Bartlett-Lewis model, and a disaggregation model. The combination is done by means of the disaggregation by adjustment techniques.
- The model is implemented in a user-friendly program in Windows environment, offering several means for user interaction and visualisation. The program can works in several modes appropriate for operational use and model testing.
- The case study verifies the good performance of the model in preserving second order properties of the process and dry/wet probabilities. In addition, properties that are not explicitly maintained by the model such as skewness coefficients and distributions of maxima are very well approximated.