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"Effects of Climate Change on the Estimation of Intensity-Duration-Frequency (IDF) curves for Thessaloniki, Greece"

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Climate Change

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Human activities

↓

Increase of greenhouse gas emissions

↓

Globally climate change
(rising temperatures and changing rainfall patterns)

↓

Increasing incidences of weather-induced disasters
(floods, droughts, wild fires, strong winds, heat-cold waves)

Climate Change prediction

Climate Models
(simulation of the earth's behaviour with mathematical descriptions of the climate system and interaction between components.

↓

Global Climate Models (GCMs)
(Large spatial revolution)

↓

Regional Climate Models (RCMs)
(Finer spatial and temporal revolution)

↓

Temporal-Spatial Downscaling Methods
(climate simulations at appropriate temporal scale for the simulation of runoff by computational hydraulic models)

- Olofsson M. (2007). *"Climate Change and Urban Drainage. Future precipitation and hydraulic impact"*.
- Nguyen et al. (2010) .

Objective of the research

How extreme rainfall events will be modified in the future for the region of Thessaloniki (Greece)?

- Description & application of a Temporal Downscaling Method on a RCMs data for Thessaloniki
- Construction of Intensity-Duration-Frequency (**IDF**) Curves for current and future climates
- Assessment of future changes in rainfall depths and intensities for Thessaloniki

IDF curves

Straight lines on a logarithmic plot that represent pairs of rainfall intensity-Duration-Return period for different return periods

IDF curves

- Based on historic rainfall records
- Temporal rainfall pattern (design storm) estimation

Design Storms

- Runoff models input
- Runoff hydrographs computation

Urban Drainage modeling

- Hydrological models uncertainty reduction
- Design of efficient and sustainable drainage systems

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Methodology

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The Generalized Extreme Value (GEV) distribution

- Extreme rainfall annual series modelling

The Temporal downscaling GEV distribution

- Description of the relationships between daily and sub-daily extreme precipitations for current and future climate (Nguyen et al., 2002)

The Generalized Extreme Value (GEV) distribution

The cumulative distribution function, F(x), for the GEV distribution is given as

$$F(x) = exp\left[\{ -[\left(1+\frac{\xi(x-\mu)}{\sigma}\right)]^{-\frac{1}{\xi}}\right]\} \qquad \xi \neq 0$$

where μ, σ and ξ are the location, scale and shape parameters, respectively. Here, the three parameters are estimated by the method of L-moments.

Nguyen et al. 2002 showed that the k-th order of Non-Central Moments (NCM), can be expressed as

$$m_k = \sum_{i=0}^{k} \binom{k}{i} (-1)^i \left(-\frac{\sigma}{\xi}\right)^i \left(\mu - \frac{\sigma}{\xi}\right)^{k-i} \Gamma(1-i\xi) \;,$$ where Γ(.) is the gamma function.

The quantiles for each return period *T* can be calculated as:

$$X_T = \mu - \frac{\sigma}{\xi}\{1 - [-\ln(1-p)]^{-\xi}\}$$

where p is the probability of exceedance, related to the return period *T*: $p = \frac{1}{T}$

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The scaling GEV model

Nguyen et al. (2002)

if $f(x)$ is scaling then there exists a function $C(\lambda)$ such that

$$f(x) = C(\lambda) f(\lambda x)$$

Nguyen et al. (2002) proved that

$$C(\lambda) = \lambda^{-\beta}$$

and β is a constant.

$$f(x) = x^{\beta} f(1)$$

The relationship between the non-central moment (NCM) of order *k*, m_k, and the variable *x*, can be expressed as:

$$m_k = E\{f^k(x)\} = \alpha(k) x^{\beta(k)}$$

where $\alpha(k) = E\{f^k(1)\}$ and $\beta(k) = \beta k$

The scaling GEV model

a simple scaling model for two different time scales t and λ t (λ≤1) :

Nguyen et al. (2002)

I. The shape parameter, ***ξ*** **,** is supposed to be **constant with duration !**
II. The statistical properties of short-duration extreme rainfalls derivation **uses the larger-duration properties !**

$$\xi(\lambda t) = \xi(t)$$

$$\mu(\lambda t) = \lambda^{\beta} \mu(t)$$

$$\sigma(\lambda t) = \lambda^{\beta} \sigma(t)$$

$$X_T(\lambda t) = \lambda^{\beta} X_T(t)$$

Present study

I. The shape parameter**, *ξ* , is supposed to change with duration !**
II. The GEV distribution parameters computation is made **directly from the three NCMs, after the implementation of the downscaling scheme !**

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1. Evaluation of the performance of the downscaling method

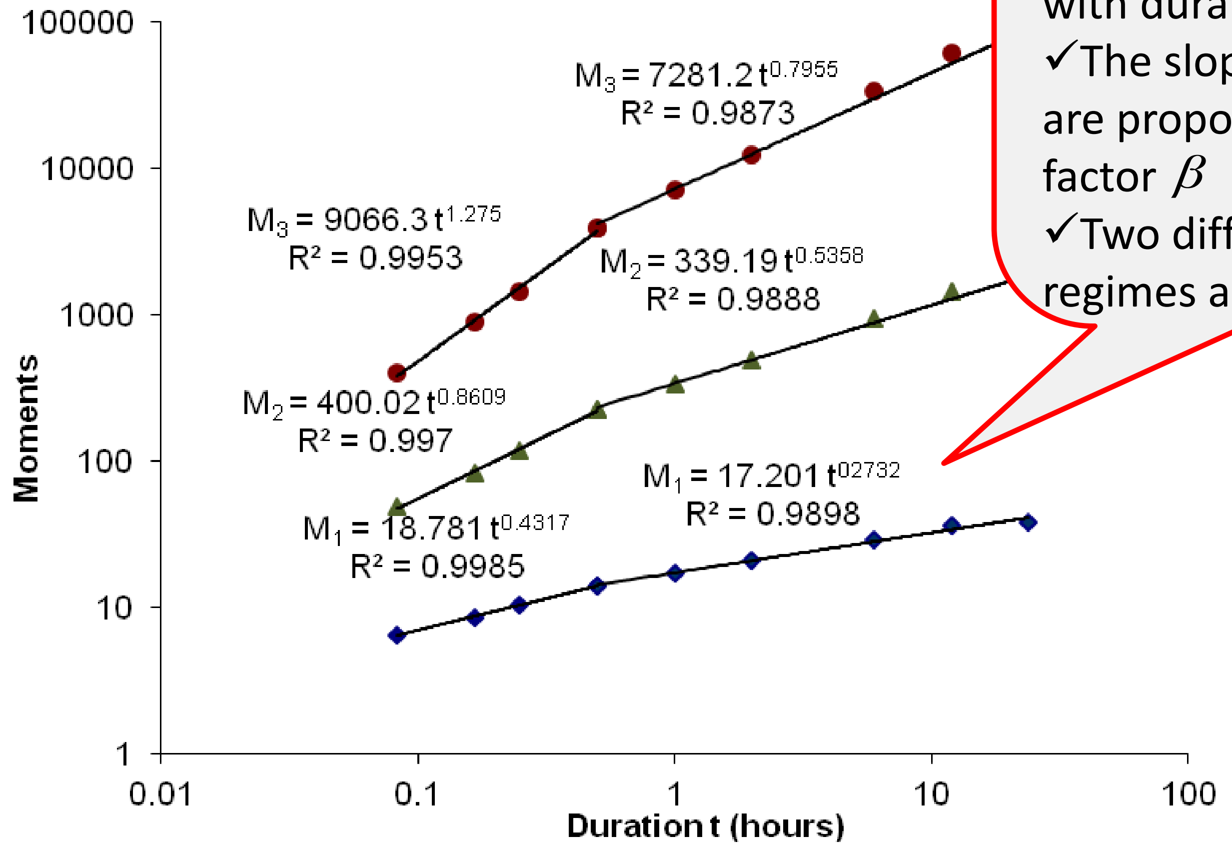
Observed Annual Maximum Precipitation (AMP) data

- Represent the annual maximum rainfall depth on a daily or sub-daily basis.
- Are available for 9 durations (5, 10, 15, 30 minutes; 1, 2, 6, 12, 24 hours).
- Cover 25 continuing years (1963-1987).
- Are provided by the HNMS for Thessaloniki Airport Station.

Procedure

1. **Investigation of the scaling behaviour of AMP series by constructing the log-log plots of the first three rainfall NCMs against duration.**
2. **Detection of the the linearity of the scaling exponent *β(k)* with the moment order *k*.**
3. **comparison between the observed and the estimated (by downscaling) distributions of rainfall depths.**

The log-log plot of NCMs of AMPs versus duration for Macedonia Airport station.



- ✓The log-linearity of the NCMs of AMPs indicates the power law depedency of the statistical moments with duration.
- ✓The slopes in the plot are proportional to a factor β
- ✓Two different scaling regimes are evident.

Observed and estimated distributions of maximum 5-minute rainfalls for Macedonia Airport station.

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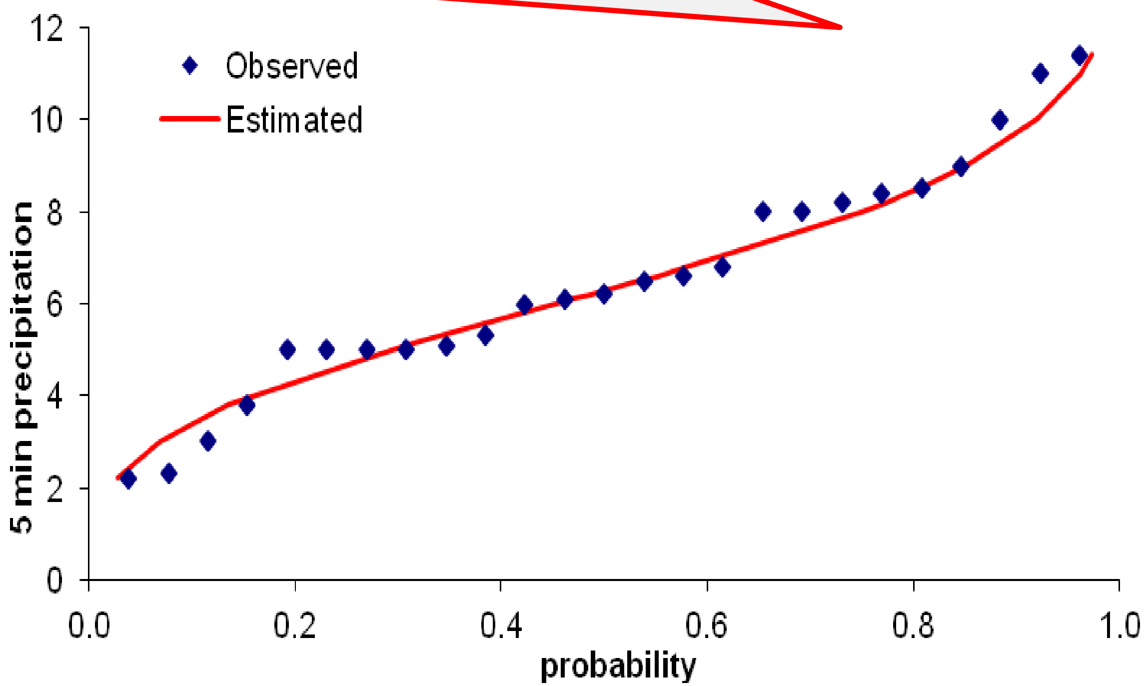
✓The estimated GEV distribution presents a satisfying level of agreement with the observations.
✓A smaller value of the related square error between the observed and estimated data is achieved, compared to using a model with a constant shape parameter for all different durations.



2. Derivation of IDF curves

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Future climate data for the region of Thessaloniki

—Represent the annual maximum rainfall depth on a daily basis.
—Are available for 1 duration (24 hours).
—Concern current (1950-2000) and future (2001-2100) climate.
—Are provided by the KNMI-RACMO2 climate model .

Procedure

1. **Estimation of the GEV distribution parameters for each duration of the rainfall process, utilizing the three NCMs of the daily rainfall predictions for current and future climate and considering the scaling coefficient *β(k)* to be kept constant for both simulation periods.**
2. **Computation of the sub-daily AMP quantiles for the current and future time periods, following the estimation of the GEV parameters for all sub-daily durations.**

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Derivation of IDF curves

Intensity-Duration-Frequency relationships for extreme precipitations for different durations and return periods are derived for current and future climates respectively, using the following relationship

$$i = \frac{a \times T^{c}}{t^{(1\text{-}b)}}$$

where i is the rainfall intensity (mm/h), t the rainfall duration (hours), T the return period (years) and *a, b,* c constants.

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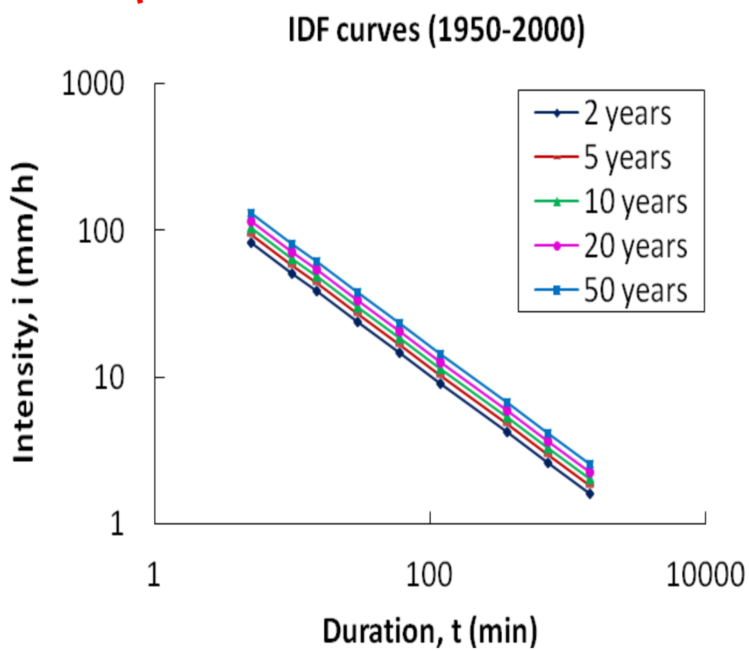
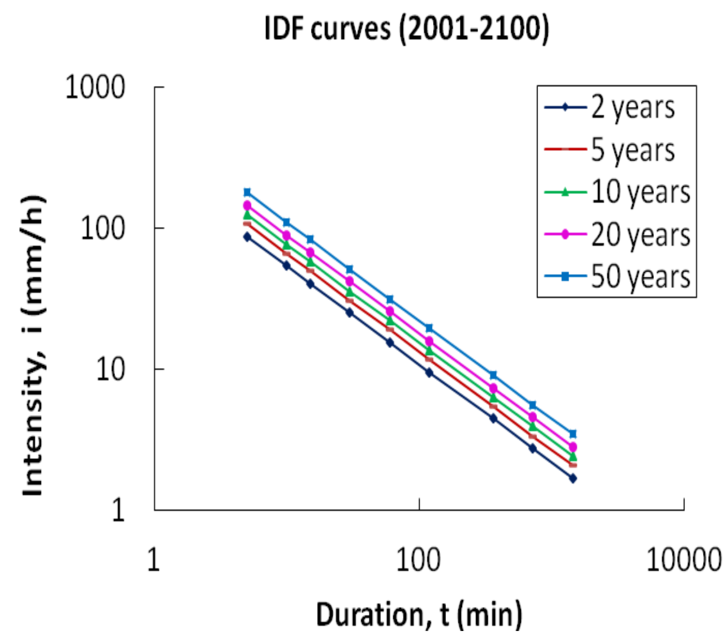
IDF curves derived from the downscaled daily rainfall series provided by KNMI-RACMO2 for current (1950-2000) and future climate (2001-2100)

Increase on future rainfall intensities is up to 35% for 5 min rainfall duration and 50 years return period for Thessaloniki.

Return Period, T	2	5	10	20	50
Increase Percentage	5.8 %	13 %	19 %	26 %	35 %





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Rainfall intensities for current (1950-2000) and future (2001-2100) climate

T \ t	**0.083333**	**0.16666**	**0.25**	**0.5**	1	2	6	12	24
2	6.8931	8.5084	9.6236	11.8789	14.66259	18.09867	25.26791	31.18929	38.49829
5	7.8812	9.7280	11.0032	13.5817	16.76445	20.6931	28.89004	35.66024	44.01699
10	8.7218	10.7655	12.1767	15.0302	18.5524	22.90003	31.97119	39.46343	48.71143
20	9.6520	11.9137	13.4753	16.6332	20.53102	25.34234	35.38094	43.67224	53.90654
50	11.0356	13.6215	15.4070	19.0175	23.47413	28.97514	40.45276	49.93261	61.63399
100	12.2125	15.0743	17.0501	21.0457	25.97766	32.06536	44.76708	55.25796	68.20731
200	13.5150	16.6819	18.8685	23.2903	28.7482	35.48515	49.54153	61.15126	75.48167
500	15.4523	19.0733	21.5733	26.6289	32.86922	40.57191	56.64325	69.91724	86.30189
1000	17.1003	21.1075	23.8741	29.4689	36.37475	44.89894	62.6843	77.37396	95.50605

T \ t	**0.083333**	**0.16666**	**0.25**	**0.5**	1	2	6	12	24
2	7.2942	9.0026	10.1822	12.5672	15.51091	19.14414	26.72388	32.98361	40.70961
5	8.9290	11.0203	12.4642	15.3838	18.98727	23.4348	32.71334	40.37603	49.83361
10	10.4049	12.8420	14.5245	17.9267	22.12585	27.30855	38.12082	47.05014	58.07105
20	12.1248	14.9648	16.9254	20.8900	25.78322	31.82262	44.42214	54.82748	67.67012
50	14.8423	18.3187	20.7188	25.5720	31.56186	38.95483	54.37821	67.11562	82.83661
100	17.2957	21.3468	24.1436	29.7990	36.779	45.39402	63.36686	78.20976	96.52941
200	20.1547	24.8754	28.1345	34.7247	42.85853	52.8976	73.84133	91.13774	112.4856
500	24.6718	30.4505	34.4402	42.5073	52.46414	64.75321	90.39094	111.5639	137.6963
1000	28.7500	35.4840	40.1331	49.5337	61.13641	75.45685	105.3325	130.0053	160.4574

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IDF curves derived from the downscaled daily rainfall series provided by KNMI-RACMO2 for current (1950-2000) IDF relations for the 1963-1987 period for Macedonia Airport station

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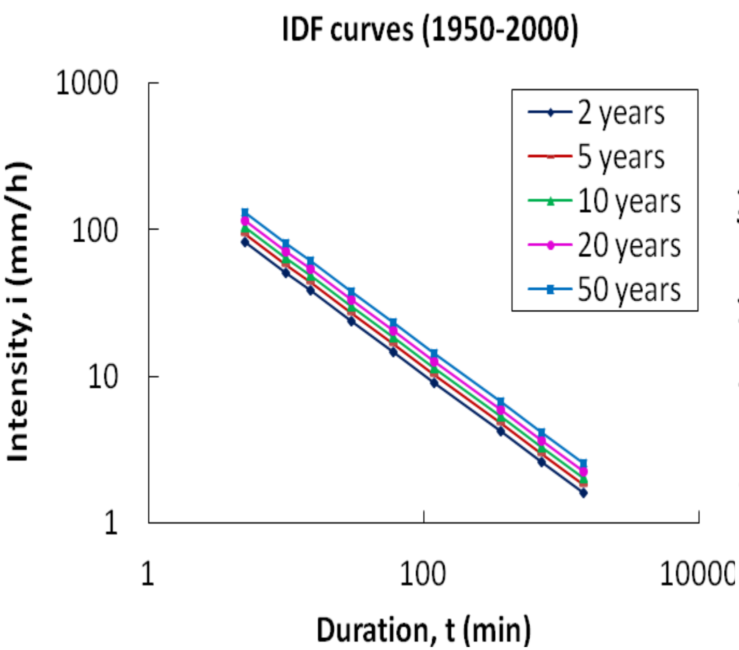
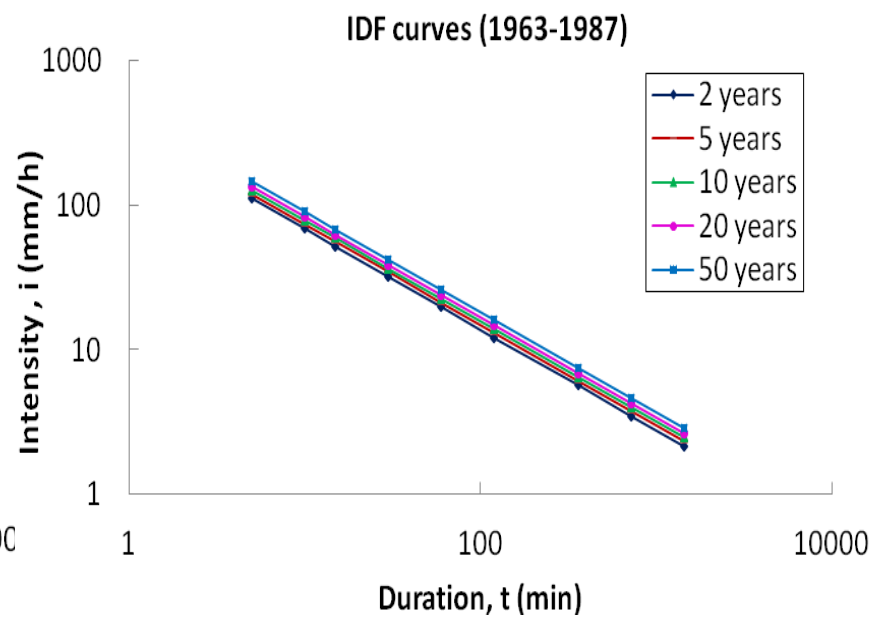
The KNMI model appears to have a tendency to underestimate daily and sub-daily precipitation and more pronounced for the small return periods.





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IDF and DDF relationships indicate a clear increasing trend on rainfall intensities and rainfall depths for Thessaloniki.

✓**Increase on rainfall intensities and depths is up to 35% for 5 minute rainfall duration and 50 years return period!**

Challenge

Improving the accuracy of rainfall input data hydrological models' **uncertainty is reduced** and more efficient and **sustainable drainage systems** can be designed!

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Although RCMs simulations provide finer spatial resolutions in comparison with GCMs, the direct comparison of IDF curves based on observed data with those based on RCM simulations for current climate (1963-1987) is not appropriate since the RCM data represent average values over an area of 25x25 km while the observations are local (at-site) measurements.

Future study

Mismatch of spatial scale reduction!

A spatial downscaling method should be applied in order to link better climate variables provided by the RCM data with the local station data in Thessaloniki.

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Thank you for your attention!

Discussion

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