Quasi-continuous stochastic simulation framework for flood modelling

EGU General Assembly 2017, Vienna, Austria, 23-28 April 2017; Session HS7.5/NH1.8: Hydroclimatic extremes under change: advancing the science and implementation in hazard prevention and control

Yiannis Moustakis, Panagiotis Kossieris, Yiannis Tsoukalas, and Andreas Efstratiadis

Department of Water Resources & Environmental Engineering, National Technical University of Athens, Greece

This presentation participates in OSPP

Outstanding Student Poster & PICO Contest

Abstract

Typically, flood modelling in the context of everyday engineering practices is addressed through event-based **deterministic** tools, e.g., the well-known SCS-CN method. A major shortcoming of such approaches is the ignorance of uncertainty, which is associated with the variability of **soil moisture** conditions and the variability of rainfall during the storm event. In event-based modeling, the sole expression of **uncertainty** is the return period of the design storm, which is assumed to represent the acceptable risk of all output quantities (flood volume, peak discharge, etc.). On the other hand, the varying antecedent soil moisture conditions across the basin are represented by means of scenarios (e.g., the three AMC types by SCS), while the temporal distribution of rainfall is represented through standard deterministic patterns (e.g., the alternative blocks method).

In order to address these major inconsistencies, simultaneously preserving the **simplicity** and **parsimony** of the SCS-CN method, we have developed a **quasi-continuous** stochastic simulation approach, comprising the following steps:

(1) Generation of synthetic daily rainfall time series;

(2) Update of potential maximum soil moisture retention, on the basis of accumulated five-day rainfall;

(3) Estimation of daily runoff through the **SCS-CN** formula, using as inputs the daily rainfall and the updated value of soil moisture retention;

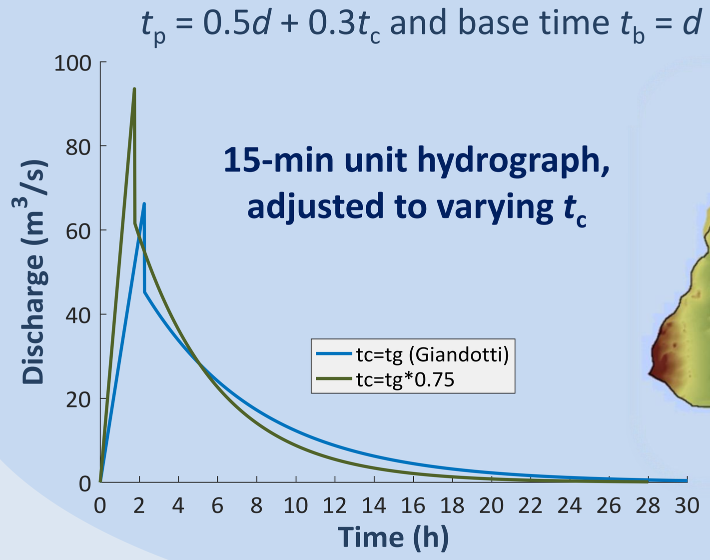
(4) Selection of extreme events and application of the standard SCS-CN procedure for each specific event, on the basis of synthetic rainfall.

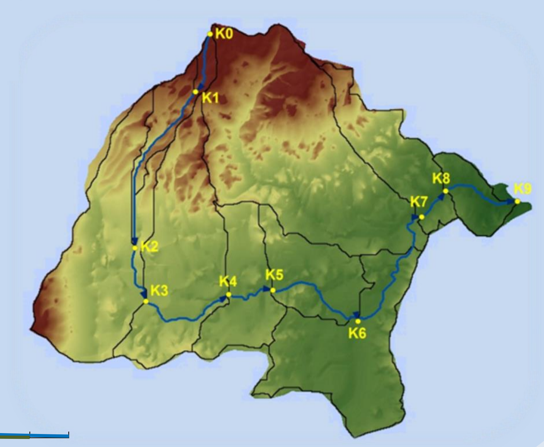
This scheme requires the use of two stochastic modelling components, namely the **CastaliaR** model, for the generation of synthetic daily data, and the **HyetosMinute** model, for the disaggregation of daily rainfall to finer temporal scales.

Outcomes of this approach are a large number of synthetic flood events, allowing for expressing the design variables in statistical terms and thus properly evaluating the **flood risk**.

Study basin

- Rafina stream basin, 123.3 km², Eastern Attica, Greece
- Intensity-duration-frequency expression
  $i = 207\,(T^{0.15} - 0.61) / (1 + d/0.17)^{0.77}$
- CNII = 60, initial abstraction ratio λ = 5% (SCS parameters)
- Time of concentration, t_c = 7,4 h (Giandotti formula)
- Synthetic unit hydrograph parameterized vs. t_c, with time to peak $t_p = 0.5d + 0.3t_c$ and base time $t_b = d + 5t_c$ (d: unit rainfall duration)





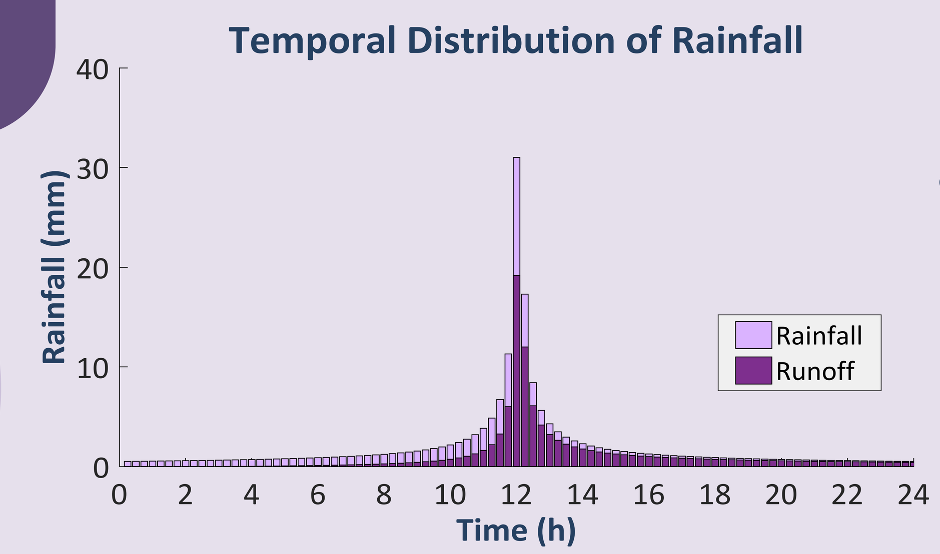
Acknowledgements

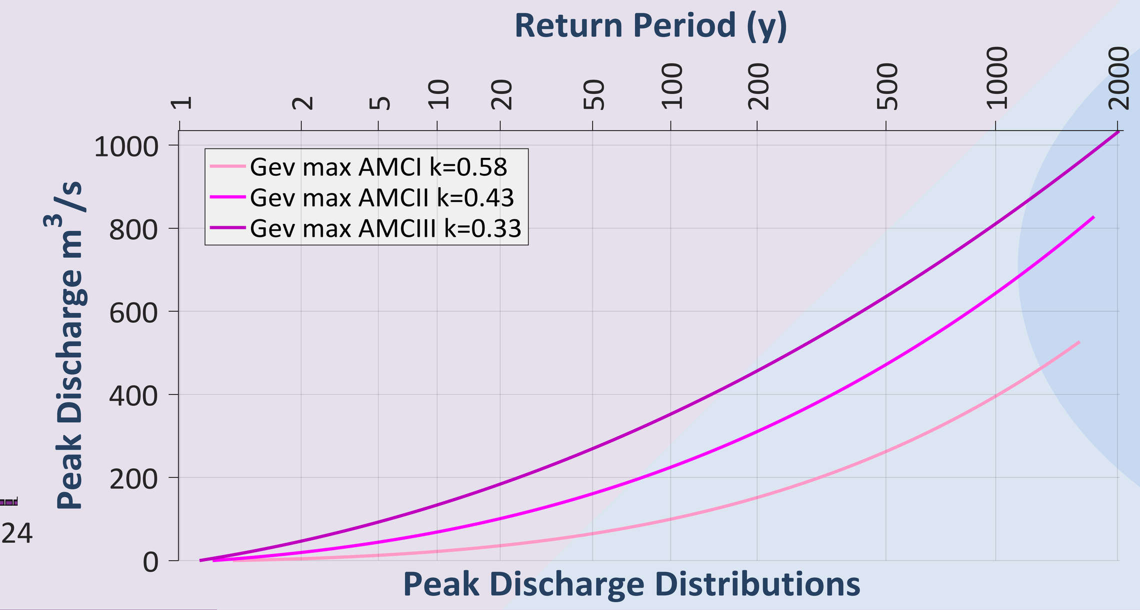
This work is conducted within the frame of Y. Moustakis's diploma thesis, to be submitted in June 2017. The current presentation, demonstrating some preliminary results, is available at http://www.itia.ntua.gr/1680. The School of Civil Engineering of NTUA provided moral support for the participation of the student in the Assembly.

Deterministic approach

Key assumptions

- Three typical **Antecedent Moisture Conditions**, resulting to three CN values (CNI = 39, CNII = 60, CNIII = 79)
- Design hyetograph, considering 24 h rainfall disaggregated through the **alternative blocks method**
- Constant time of concentration through the **Giandotti** formula, resulting to constant unit hydrograph





Preliminary Results

- Peak discharge strongly depends on AMC.
- The variability of peak discharge against AMC increases as the return period increases.
- As the soil becomes more wet, the scale parameter k of the GEV-max distribution, fitted to estimated peak flows, approaches the scale parameter of daily rainfall maxima, which is embedded in the idf function.

Highlighting inconsistencies

- Considering only three AMC values is **severely unrealistic**, since it disregards the wide range of potential soil moisture conditions across time (Efstratiadis *et al.*, 2014b).
- Arbitrary selection among the three conditions does not take into consideration the tendency of rainfall occurring in clusters of wet days, thus **ignoring the rainfall regime** in the study area.
- The alternative block method assumes that the cumulative rainfall depth corresponds to the same return period for every time interval, thus resulting to **highly unlikely** storm patterns.
- The time of concentration is treated as a constant, i.e. independent of the flow dynamics; in fact, t_c exhibits **significant variability** across flood events, as well as during each event (Michaelidi *et al.*, 2017; **poster HS2.1.1, A96**).
- Due to all above inconsistencies, it becomes clear that only a **stochastic approach** can remedy the fundamental shortcoming of the deterministic approach that a rainfall of a given return period will generate a flood of the same return period.

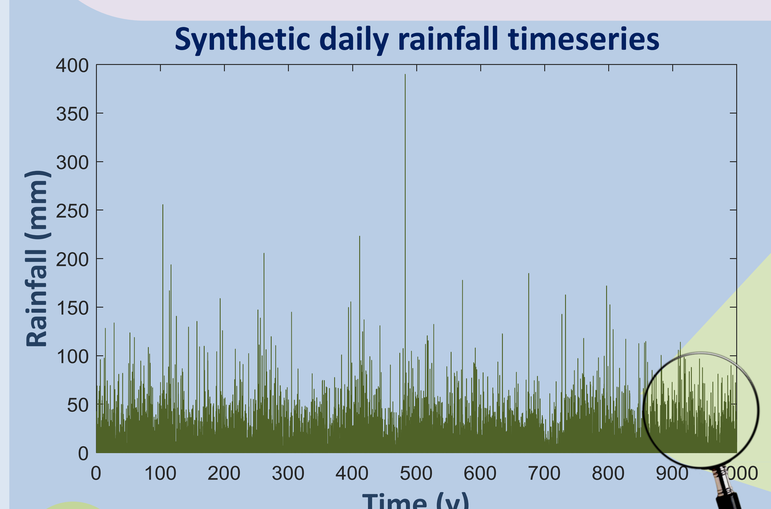
Addressing the emerging issues: Stochastic Approach

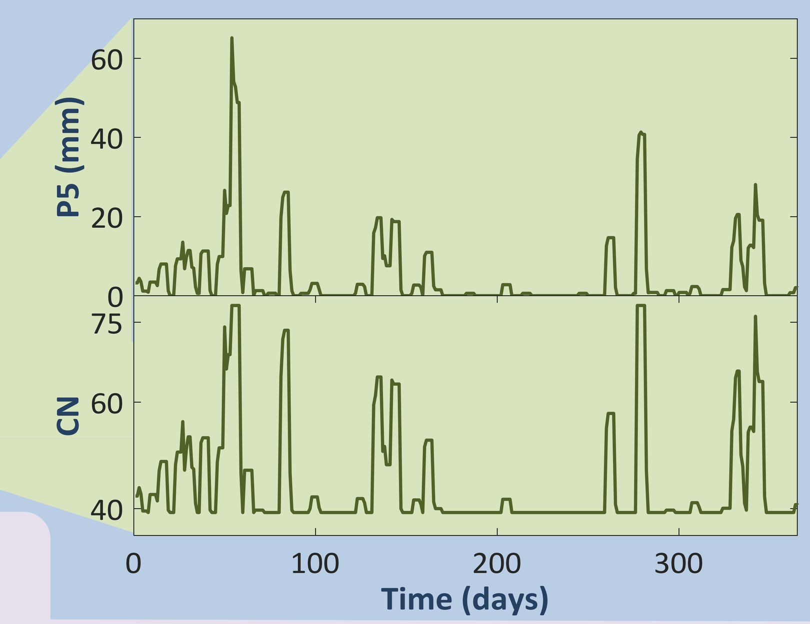
1 Generation of **synthetic daily** rainfall timeseries using the **CastaliaR** stochastic model. The model preserves the statistical characteristics of the historical data, as well as the underlying Hurst-Kolmogorov dynamics, thus faithfully representing the rainfall regime (Efstratiadis *et al.*, 2014a).

2 Daily updating of the value of maximum potential soil moisture retention S, which is function of CN.

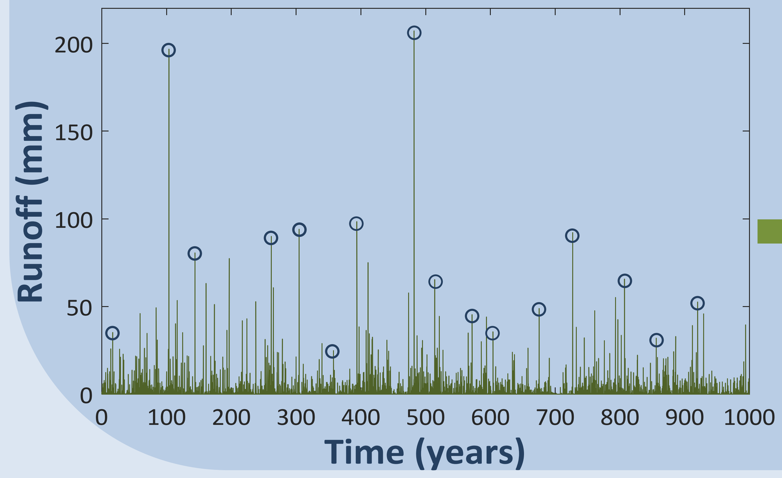
CN is no longer treated as a discrete variable, but rather as a **continuous** one, which is daily updated on the basis of **accumulated five-day rainfall** (P_5), by employing a simple **linear interpolation** between the typical dry and wet Antecedent Moisture Conditions, corresponding to lower and higher 10% of non-zero P_5, respectively.

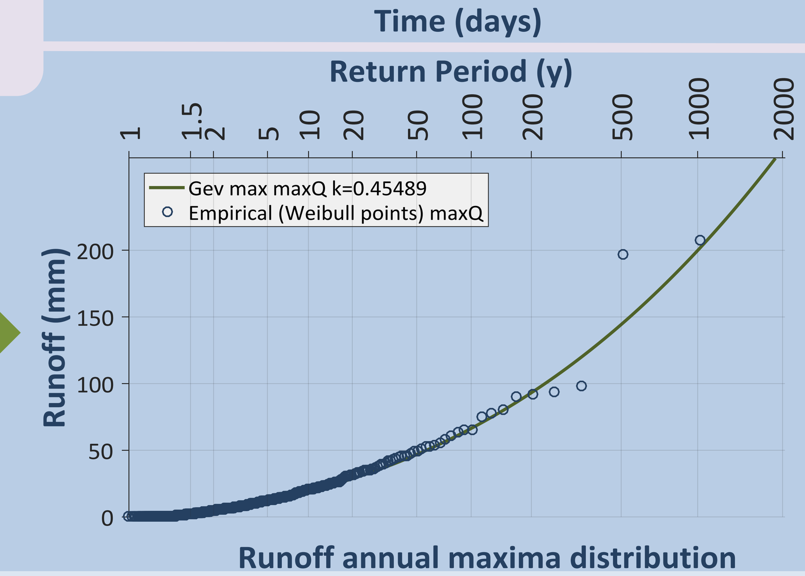
Alternatively, a daily hydrological model can be applied, that comprises a Soil Moisture Accounting procedure. However, conceptual models need calibration, thus being not appropriate for ungauged basins.



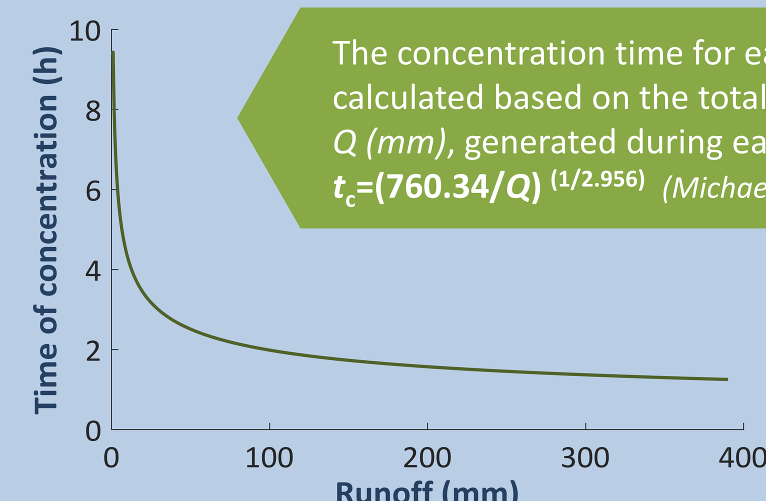


3 Estimation of **daily runoff** through the **SCS-CN** formula, using as inputs the daily rainfall and the updated value of soil moisture retention S.



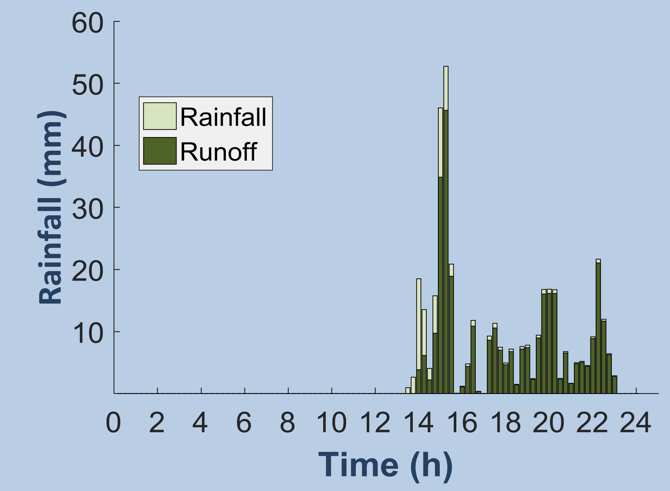


4 Our extreme analysis is based on the annual maxima rather than the peak over threshold approach, in order to avoid considering correlated flood events as independent ones.
The variability of CN across days dictates that the annual maximum flood events do not necessarily coincide with the annual maximum rainfall depths, so the event analysis is based on the extraction of **annual maxima of daily runoff**, rather than runoff generated by annual maxima of daily rainfall.
The selected events are, then, disaggregated, the time of concentration is updated according to the total amount of runoff, thus, updating the unit hydrograph, enabling us to finally calculate the Peak Discharge of each event.



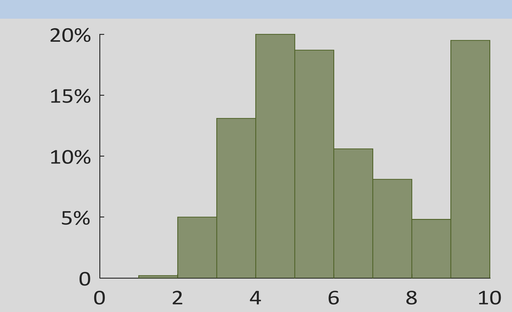
The concentration time for each event is calculated based on the total amount of runoff, *Q (mm)*, generated during each event t_c**=(760.34/Q)** $^{(1/2.956)}$ *(Michaelidi et al, 2017)*

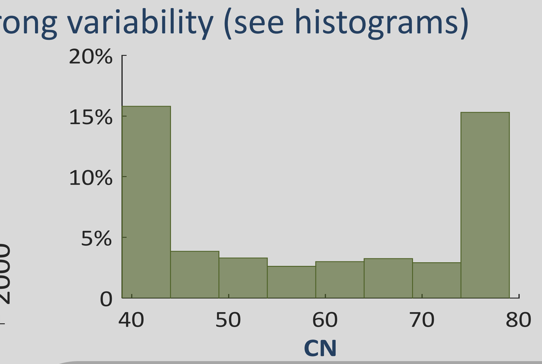
Disaggregation of daily rainfall to finer temporal scales (**15 min**) using the **HyetosMinute** stochastic model, which is based on the **Rectangular Pulse Bartlett-Lewis** model *(Kossieris et al,2016)*.



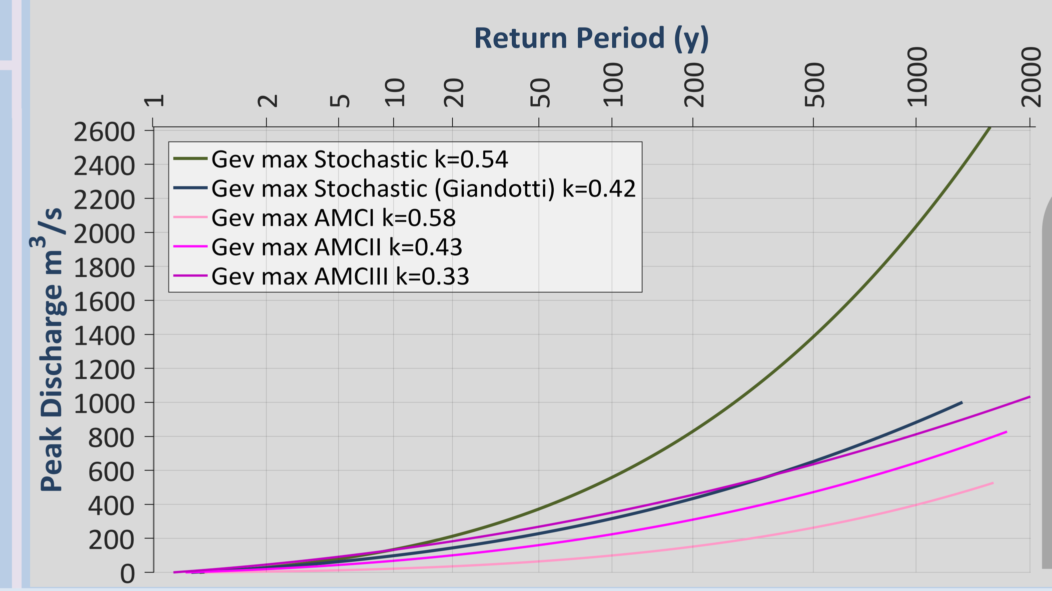
Results

- The stochastic approach produces **significantly more severe floods** than the deterministic one.
- In order to determine what is the driving force that generates the highest floods, our analysis was conducted by also treating t_c as constant (calculated via the Giandotti formula). The results indicate that the variability of t_c is crucial factor, as expected.
- The differences between the two approaches increase as the return period increases.





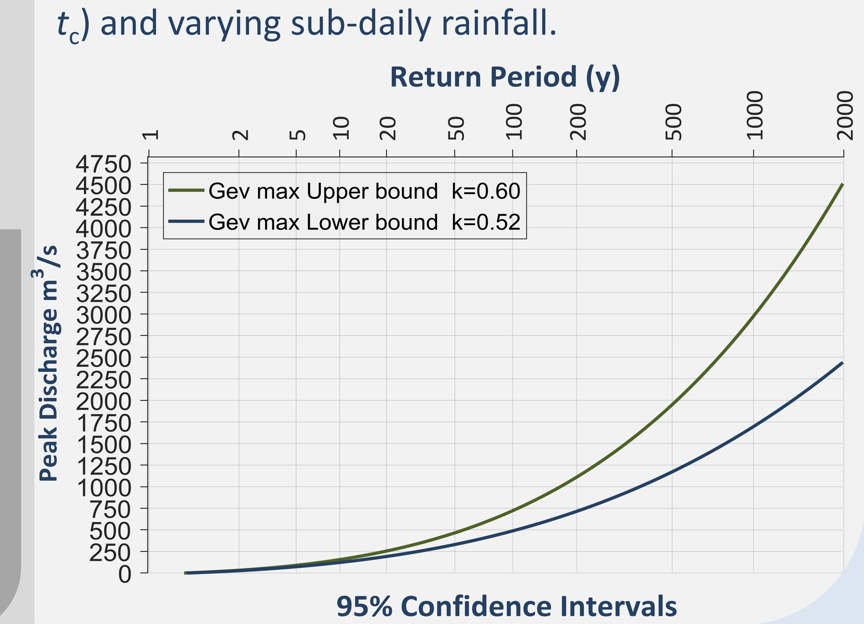
- CN values and t_c that govern floods and are usually treated as constants, have a strong variability (see histograms)



Since the extreme rainfall may occur for any AMC and may have any temporal distribution, the stochastic approach, accounting for the **statistical regime of rainfall across all temporal scales**, is the sole consistent option in flood modelling.

Combined Monte Carlo Simulation

In order to account not only for the variability of AMC across days, but also the stochasticity of sub-daily rainfall, we also conduct a combined Monte Carlo scheme, by running each daily event with multiple sub-daily rainfall patterns. This allows for estimating the **joint uncertainty** of varying daily rainfall (thus varying AMC, CN and t_c) and varying sub-daily rainfall.



References

- Efstratiadis, A., *et al.*, A multivariate stochastic model for the generation of synthetic time series at multiple time scales reproducing long-term persistence, *Environ. Model. Soft.*, 62, 139–152, 2014a.
- Efstratiadis, A., *et al.*, Flood design recipes vs. reality: can predictions for ungauged basins be trusted?, *Nat. Haz. Earth Syst. Sci.*, 14, 1417–1428, 2014b.
- Michaelidi, E., *et al.*, Adaptation of the concept of varying time of concentration within flood modelling: Theoretical and empirical investigations across the Mediterranean, *EGU General Assembly 2017*, EGU2017-10663-1, 2017.
- Kossieris, P., *et al.*, A rainfall disaggregation scheme for sub-hourly time scales: Coupling a Bartlett-Lewis based model with adjusting procedures, *J. Hydrol.*, 2016 (in press).