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Convection permitting climate models and Urban Drainage systems: Analysis and recommendations

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Abstract

Recently, outputs from convection permitting climate models started to be available for some regions. Unlike traditional climate models, they solve deep convection which make them relevant to provide the high spatial and temporal resolutions needed in urban hydrology. In this study, we compare the ability of such models to replicate hourly rainfall patterns for a few European locations with diverse climates, and we compare future rainfall produced by these models to outputs from a statistical downscaling model to quantify their added value for urban drainage studies.

Highlights

- Convection permitting models and statistical downscaling gives similar time-series.
- Convection permitting generates more temporally consistent outputs than statistical downscaling.
- While both solutions can be combined for optimal use in UD, we recommend using ensemble informed strategies.

Introduction

Outputs from climate models are being increasingly used by urban drainage scientists to study the evolution for urban drainage systems in a context of climate change. However, as climate science move forward and open dataset policy is becoming a norm, new datasets are being released. Up to recently, urban drainage scientist could only access daily resolution datasets at coarse spatial resolution which were insufficient for modelling urban catchment where local precipitation at a sub-hourly scale is often required. To overcome those barriers, downscaling methods have emerged to bridge the gap between physically-based climate models and local observations. Lastly, the recent advances in climate science allowed for the emergence of convection-permitting regional climate models (CP-RCM), a physical-downscaling method, with promising use in urban hydrology.

In this study we investigate the added value of convection-permitting models as inputs for drainage models. For that purpose, we compare the information added between daily and hourly resolution for both CP-RCM and statistical downscaling method and evaluate CP-RCM against local observations, for a range of locations with a range of climate particularities.

Methodology

Data and locations

The locations for the investigation are based on the availability of climate data (precipitation at sub-hourly resolution for approx. 20 years as well as temperatures) for the observed period and the availability of outputs of convection permitting (CP) models (Table 1). They cover a large range of European climates (subarctic, humid continental, mediterranean, oceanic, etc.). The CP outputs comes from the NORCP project (Lind et al., 2023) for the Fenno-Scandinavian domain, the ALP3 project (Caillaud et al., 2021) for the pan alpine domain (as well as the Northwest European domain NWE3), and the VHR-PRO_It (Raffa et al., 2023) for the Italian domain.

Table 1: Setup of the different **c**onvection permitting outputs including the initial global climate model considered as well as the intermediate RCM and the CP-RCM. The cities are extracted because observed timeseries of precipitation with sub-hourly resolution of approx. 20 years were available.

GCM	Intermediate RCM	CP-RCM	Domain	Cities
CNRM-CM5	CNRM-ALADIN	CNRM-AROME	ALP3	Lyon and Paris (France), Bologna and Genoa (Italy), Innsbruck (Austria)
CNRM-CM5	CNRM-ALADIN	CNRM-AROME	NWE3	Lyon and Paris (France)
EC-EARTH	-	HARMONIE-AROME	HCLIM3	Trondheim (Norway), Föllinge (Sweden)
GFDL-CM3	-	HARMONIE-AROME		
CMCC-CM	COSMO-CLM	COSMO-CLM	VHR-PRO_IT	Bologna and Genoa (Italy)

Workflow and experiments

Each location will be analysed with the following procedure. Only the results and discussions for Bologna are presented here. The statistical downscaling (SD) method/model mentioned below and used in this analysis is the one developed in Pons et al. (2022).

Hourly rainfall timeseries analysis

Four timeseries were compared at hourly resolution: i) the observed timeseries aggregated at hourly resolution (reference), ii) the CP timeseries, iii) SD timeseries generated from observed timeseries aggregated at daily resolution, iv) SD timeseries generated from CP timeseries aggregated at daily resolution. They were compared for different seasons and different classes of temperatures. We assessed the ability of CP-RCM and SD models to reproduce local precipitation patterns through a comparison of hourly rainfall distributions and through frequency analysis (intensity-frequency-duration analysis for return periods of 1, 5, 10, 20 year).
Similar analysis was conducted for future CP-RCM outputs (2081-2100 hourly future rainfall) and SD models in order to quantify the potential gain using hourly data from convection permitting data in the future.

Sub-hourly rainfall timeseries and temperature precipitation analysis

In order to work with sub-hourly data needed for urban hydrology studies, statistical downscaling models were calibrated with both observed data (rainfall and temperature) and CP data (rainfall and temperature), to gain knowledge on the precipitation temperature relationship of CP models by comparing the resulting SC models. SD models were used to generate 15-minute resolution timeseries, from observed timeseries and CP timeseries.

Timeseries suitability for urban drainage modelling

Following the last step, timeseries at 15-minute resolution were used as inputs for two green roofs models (*see* Pons et al., 2022). The E-green roof is a typical extensive green roof model reacting to short rainfall events and with low storage capacity. The D-green roof is a detention optimized roof with hight storage capacity and higher inertia in hydrological behaviour. It is more sensitive to medium duration events and initial water content. Those two green roofs models help assessing if the timeseries generated are suitable for urban drainage use. Depending on the final use of the time-series, the choice of models for analysing the time-series as well as the performance indicator considered should be adjusted. In the current study, survival distributions of discharge are considered as it shows a large variety of performance of green infrastructures ranging from mild to major events. Extreme events will be later considered and require a separate analysis.

Results and discussion

Figure 1 shows survival distributions of precipitation in Bologna at hourly resolution for low and high ranges of temperatures. For the low range of temperature, there is an agreement between the observed timeseries, the CP timeseries, and the SD timeseries of less than one order of magnitude for frequencies higher than 10^{-3}. Extreme values, tend to be overestimated by SD timeseries. For the high class of temperature, the upper bound of SD timeseries provides results similar to historical data. It means that observations, physically-based model, and statistical model are in agreement. It further means that statistical downscaling models, when trained with sufficient amount of observed data, can give similar results to convection permitting models which may be needed while only a few runs are available. The SD timeseries seems to smoothen out temperature precipitation dependency: overestimation of low precipitation regime in cold temperature and underestimation of high precipitation regime in warm temperature. Such a bias in SD model could be fixed by improving the training procedure and using higher resolution precipitation data.

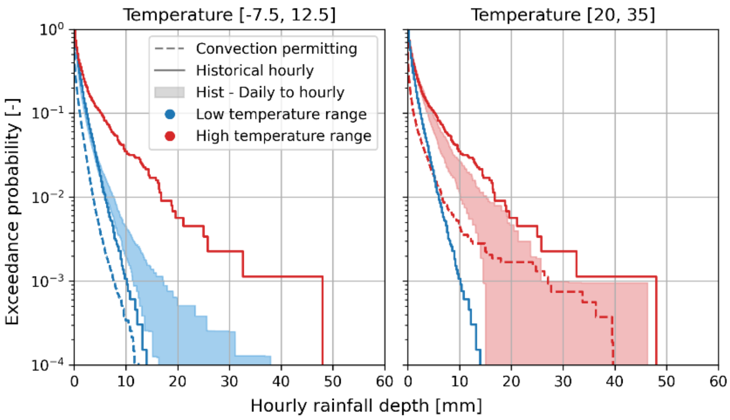

Figure 1: Distribution of hourly rainfall depth for the reference/evaluation period (2004-2023) in two different temperature class based on the Bologna dataset.

On Figure 2, the impact of different time-series inputs on the performance of the E and D green roofs is investigated. The grey shaded area shows results with “uninformed” time-series. The timeseries were not generated with a SD model, but by evenly distributing precipitation or without distributing precipitation. This simplified procedure was applied to both daily and hourly inputs. It shows that daily resolution information is insufficient for each roof and temperature classes as the range may be too large to draw a reliable performance estimate. The hourly range on the opposite provide a narrower range of 1 order of magnitude wide. It suggests that hourly climate data may be sufficient for day-to-day moderate rains. However, when a better estimate is required, downscaling methods should be considered. On the E-green roof, limited difference between the different time-series can be observed. It could mean that the statistical downscaling method captures sufficient information to jump from daily to 15 minutes resolution. For the D-green roof on the opposite (Figure 2 centre), both time-series generated from daily inputs lead to overestimation of discharges. It suggests that the statistical downscaling is not able to accurately capture the temporal structure of rainfall events. It also shows that results based on convection permitting outputs have an added value for systems with longer inertia.

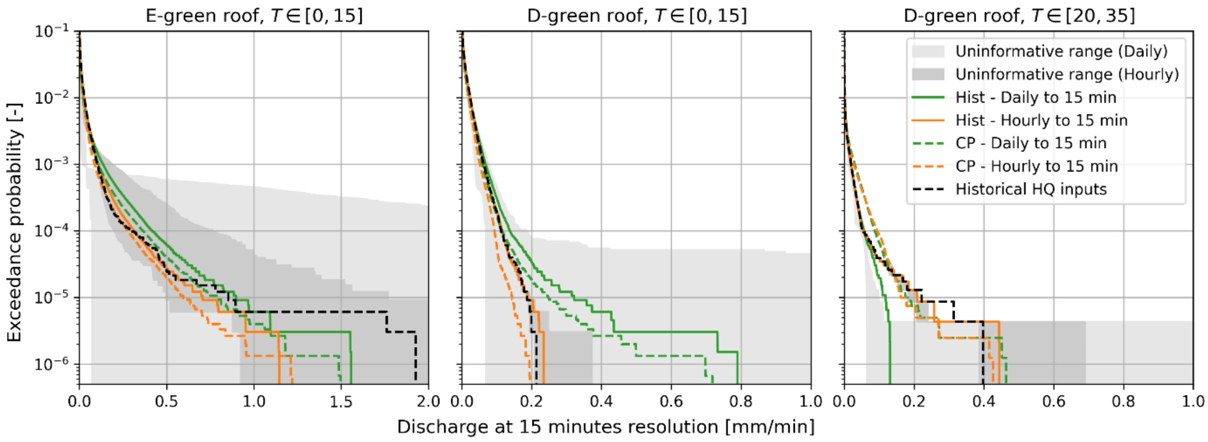

Figure 2: Survival distribution of discharge for the E-green roof in a class of low temperature (left) and the D-green roof in both low (center) and high class of temperatures (right). Different precipitation time-series are considered as inputs

Conclusions and future work

Preliminary results presented in this abstract suggest outputs from climate-convection permitting could have a potential to provide additional information used by statistical downscaling to produce more realistic sub-hourly rainfall timeseries. Thus, it could increase our trust in future sub-hourly timeseries taking into account climate change. It should be however noted that discrepancies in the temporal structure of rainfall events remains. CP models allow for generating more temporally consistent rainfall events.

Next steps consist in expending this initial work with the Bologna dataset to the other locations for which CP and SD models are available.

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