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# Multifractal comparison of three optical disdrometers and a mini vertically pointing Doppler radar, and consequences on rainfall extreme quantification in urban environment.

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## Highlights

- Measurement and quantification of rainfall extremes are needed in urban areas.
- Four types of point rainfall measurement sensors are compared.
- Multifractal analysis is implemented to compare measurement across scales and not only at a single scale as commonly done.

## Introduction

Storm water management, for both preventing local flooding and optimizing water treatment, in urban areas remains a challenge, notably because of the intrinsic extreme variability across wide range of space-time scales of rainfall fields. In this context, proper assessment of rainfall and more specifically its extremes is much needed.

In this paper, a comparison of rainfall measurements carried out by 4 measurement devices - 3 optical disdrometers from three different manufacturers and a mini vertically pointing Doppler radar - in an urban area is presented. The comparison is carried out across scales, and not at a unique resolution as commonly done, to obtain more robust results, valid across scales. The framework of Universal Multifractals is used (Schertzer and Lovejoy, 1987). It is presented in the upcoming section before introducing the studied data and preliminary results.

## Methodology

Rainfall measurements are usually compared using various scores at a given resolution, often the maximum one. Given the extreme variability across space-time scales of rainfall fields, this approach does not enable to fully compare the measured intermittency and variability. Hence, a methodology focusing on the variability across scales is required to handle these features. A widely used candidate is multifractals (see Schertzer and Tchiguirinskaia 2020 for a recent review). In this physically based and mathematically robust framework, the statistical moments of arbitrary  $q^{\text{th}}$  power of a conservative field  $\epsilon_\lambda$  at the resolution  $\lambda$  ( $= L/l$ , the ratio between the outer scale of the phenomenon and the observation scale) exhibits a scaling behaviour:

$$\langle \epsilon_\lambda \rangle \approx \lambda^{K(q)} \quad (1)$$

where  $\langle . \rangle$  denotes ensemble average and  $K(q)$  is the scaling moment function which fully quantifies the variability across scales of the studied field.

In the specific framework of Universal Multifractals (Schertzer and Lovejoy, 1987), conservative fields are fully characterised with the help of only two parameters which have physical interpretation:

- $C_1$ , the mean intermittency co-dimension, which measures the average sparseness of the field. A homogeneous field fills the embedding space and has  $C_1 = 0$ ;

-  $\alpha$  ( $\in [0, 2]$ ), the multifractality index, which measures the variability of the intermittency, i.e. its dependence with respect to the considered level of activity.  $\alpha = 0$  corresponds to a case for which there is no such a dependency, i.e. all activity levels have the same intermittency and the field is monofractal.

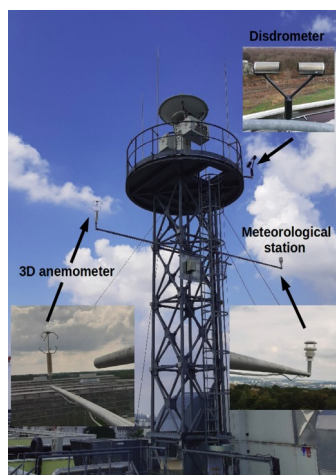
Non conservative fields have an additional parameter  $H$ , called the degree of non conservation which measures the scale dependency of the average field ( $H = 0$  for a conservative field).

A convenient notion to quantify the extremes that one can observe in a given sample is the “maximum observable singularity”, denoted by  $\gamma_s$ . It has meaning across scales and not only at a single resolution and can be computed from UM parameters  $\alpha$  and  $C_1$ . Examples of use can be found in Douglas and Barros 2003 or Royer et al. 2008.

## Case study

As briefly introduced, rainfall data collected by three types of disdrometers and a mini vertically pointing Doppler radar are used in this study. The devices are OTT Parsivels<sup>2</sup>, Campbell Scientific PWS100, ThiesClima 3D-Stereo and a mini vertically pointing Doppler radar manufactured by ThiesClima. Precise functioning of the devices along with appropriate references can be found in Gires et al. (2018, 2022) except for the 3D-Stereo\* which was acquired and installed recently. The devices are part of the TARANIS observatory (exTreme and multi-scAle RAiNdrop parIS observatory) of the Fresnel Platform of École des Ponts ParisTech (<https://hmco.enpc.fr/Page/Fresnel-Platform/en>); and are operated by Hydrology Meteorology and Complexity laboratory of École des Ponts ParisTech (HM&Co-ENPC) on its campus roughly 20 km West of Paris. Fig. 1 shows pictures of the devices' locations.

The Parsivel<sup>2</sup> and PWS100 have a recording time step of 30 s and are operated since 2016. The mini vertically pointing Doppler radar has a recording time step of 1 s and is operated since 2021. The 3D-Stereo provides precise time (ms) of each drop passing through its sampling area and is operated since 07/2023.

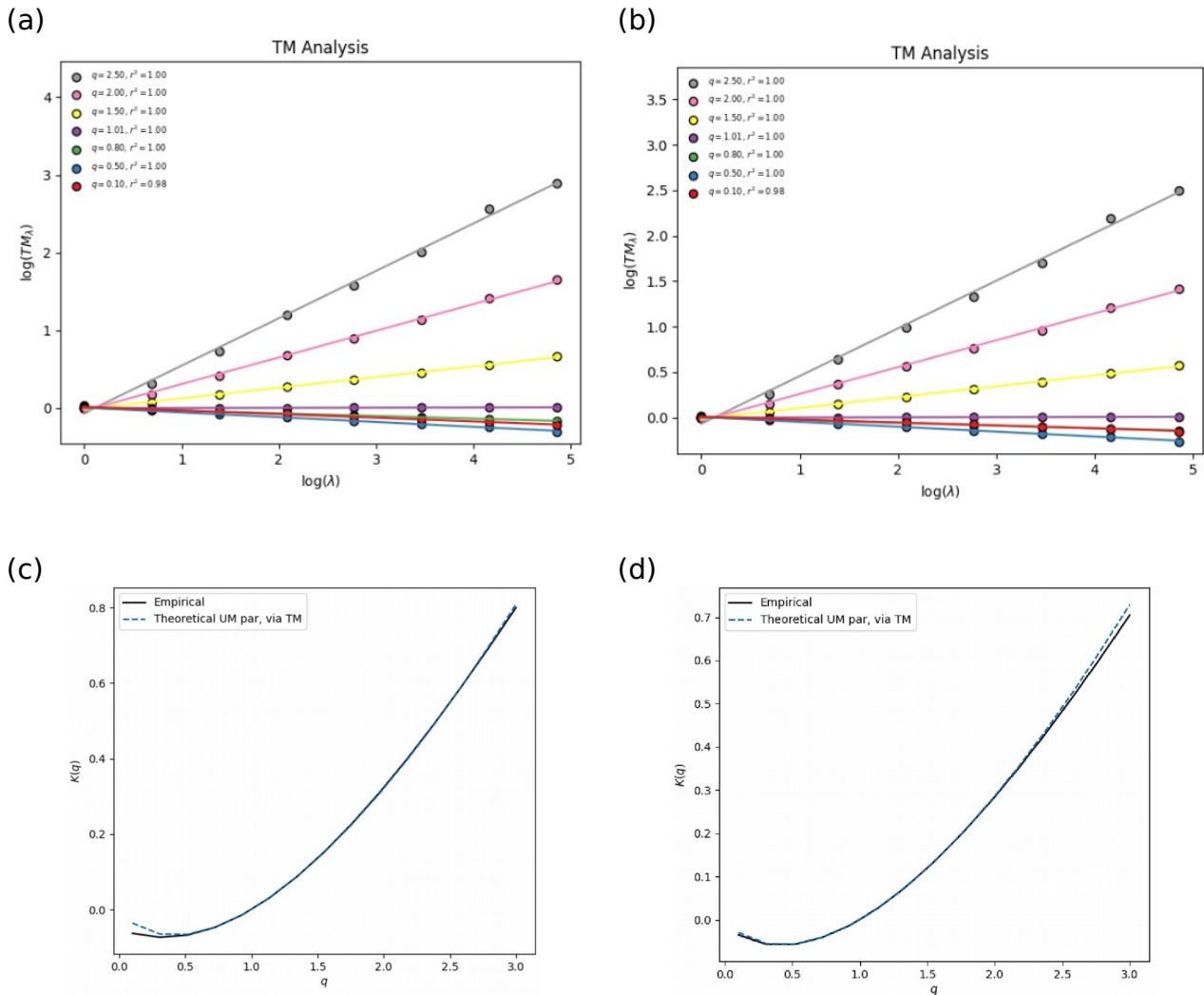


**Figure 1.** (left) Radar tower from which a dual polarization X-band radar, a Parsivel, a meteorological station (including the mini vertically pointing Doppler radar) and a 3D sonic anemometer are operated. (right) Picture of roof of the building from where (from left to right) 3D-Stereo, PWS100 and two Parsivel2 are operated.

\* <https://www.thiesclima.com/en/Products/Precipitation-measuring-technology-Electrical-devices/?art=1339>

## Results and discussion

In a first step, the scaling behaviour of collected rainfall data is assessed on scales ranging from  $\sim 1\text{h}$  to  $30\text{ s}$  (i.e. with series of size 128 time steps of  $30\text{ s}$  which corresponds to the finest recording time step of the coarser device). In order to achieve this, an ensemble analysis covering all the recorded events is carried out. It is illustrated in Fig. 2 for two devices and a series of recorded rain events between 07/2023 and 10/2023. More precisely, Eq. 1 plotted in log-log (top row) shows a unique scaling regime with excellent scaling, and the slopes of the straight lines give  $K(q)$ . The corresponding scaling moment function are shown in bottom row along with the theoretical ones plotted using the assessed UM parameters ( $\alpha_{Pars} = 1.28$ ,  $C_{1,Pars} = 0.21$  and  $\alpha_{3D-Stereo} = 1.35$ ,  $C_{1,3D-Stereo} = 0.18$ ). Similar results on scaling behaviour are retrieved for rainfall data collected with PWS and mini-Doppler.



**Figure 2.** (a) Trace moment analysis of the underlying conservative field of an ensemble of rainfall data collected with Parsivel between 07/2023 and 10/2023. (b) Empirical and theoretical  $K(q)$  for the same data as in (a). (c) and (d) panels are the same plots for the same series of events but with 3D stereo data.

Differences between UM parameters can be interpreted in light of precise functioning of the devices. For the ensemble of rainfall events and devices whose multifractal plots are displayed in Fig. 2, we find  $\gamma_s$  equal to 0.78 and 0.74 for the Parsivel and 3D-Stereo data respectively. This suggests that stronger extremes are measured with the help of the Parsivel.

In a second step the multifractal behaviour at smaller scales, i.e. starting with series with 1 s time steps for the mini vertically pointing Doppler radar and 0.1 s with the 3D-Stereo are analysed. In general scaling behaviour is also observed but it hints to a transition towards a different regime.

## Conclusions and future work

In this paper, we compared the rainfall measurements across scales of three rainfall measurement devices, namely three disdrometers and a vertically pointing mini doppler radar, installed in a urban environment and explored the consequences on the estimation of rainfall extremes. All the devices exhibited very good scaling behaviour on scales ranging from few hours to 30s. Differences between assessed UM parameters are limited and interpreted relying on the devices' functioning and meteorological conditions. In a second step, the scaling behaviour at higher resolution (down to 1s for the mini radar, and 0.1s for the 3D stereo disdrometer) is explored. Some differences are observed and this enable to explore the transition between individual drops behaviour and the emerging collective behaviour that is rainfall.

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