Fractal analysis of space-time rainfall variability: limitations of rain gauge networks and applicability of dual-polarized weather radars

*IGOR PAZ[1,2], IOULIA TCHIGUIRINSKAIA[2], DANIEL SCHERTZER[2]

1. Instituto Militar de Engenharia, IME, Rio de Janeiro, Brazil, 2. HMCO, Ecole des Ponts ParisTech, University of Paris-Est, Champs-sur-Marne, France

Precipitation risk and water management is a key challenge for densely populated urban areas. Applications derived from high (time and space) resolution observation of precipitations are to make our cities more weather-ready. Finer resolution data available from dual polarized X-band radar measurements enhance engineering tools as used for urban planning policies as well as protection (mitigation/adaptation) strategies to tackle climate-change related weather events. For decades engineering tools have been developed to work conveniently either with very local rain gauge networks, or with mainly C-band weather radars that have gradually been set up for space-time remote sensing of precipitation. Most of the time, the C-band weather radars continue to be calibrated by the existing rain gauge networks. Inhomogeneous distributions of rain gauging networks lead to only a partial information on the rainfall fields. In fact, the statistics of measured rainfall is strongly biased by the fractality of the measuring networks. This fractality needs to be properly taken into account to retrieve the original properties of the rainfall fields, in spite of the radar data calibration. In this work, with the help of fractal analysis, we first demonstrate that the semi-distributed hydrological models statistically reduce the rainfall fields into rainfall measured by a much scarcer network of virtual rain gauges. For this purpose, we use rainfall data measured by the dual-polarimetric X-band radar operated at Ecole des Ponts with a resolution of 250 m in space and 3.41 min in time.

The increase in global urbanization and population density emphasizes the importance and the need to improve the adaptation of (unplanned) urban areas mainly to climate change. Managing extreme weather events, particularly intense precipitation ones and heat waves, in these areas is a major challenge for the future. The population's demand for a better quality of life motivates an improvement in the ability to measure, understand, model and predict hydrometeorological processes in urban environments, aiming at better flood control and associated risk management. Conventional local measurements in urban areas generally do not meet the World Meteorological Organization (WMO) criteria for the measurement of precipitation (WMO, 2014). Better spatio-temporal scales with accuracy and reliability are required. In this way, the use of ground-based remote sensing has been very important in elucidating complex urban environment structures, thus expanding hydrometeorological challenges. Weather radars provide high-resolution spatio-temporal measurements of rainfall fields. However, as they do not measure rainfall directly, radar-based rainfall estimates may have substantial uncertainties. To quantify the uncertainty on accumulated rainfall, comparison of different radar products or of ground measurements and precipitation estimates on radar pixels where rain gauges are located are usually performed. Polarimetric radars have opened a new perspective to improve estimates for stronger rainfall by using the specific differential phase (KDP) values to directly estimate the rainfall intensity. Coming together with rainfall data improvement, an efficient storm water management also deals with the accuracy and reliability of hydrological models, especially in urban areas where response times are shorter due to high levels of imperviousness and smaller catchments.

In this work, the pilot site of Bièvre catchment, which is a 110 km^2 semi-urbanized area in the southwest of Paris region, was selected as case study. The Bièvre catchment was modelled using InfoWorks CS

(Collection Systems), a widely used semi-distributed model (Soft, 2010), which was used to construct a network of virtual rain gauges located in the center of mass of each of its 27 sub-catchments. Then, an area of 8 km x 8 km was selected using the X-band radar grid (Figure). This choice corresponds to the most homogeneous distribution of virtual rain gauges over a square area of Bièvre catchment.

Hence, the fractal analysis of the virtual rain gauge pixels' distribution using the box-counting method (Lovejoy *et al.*, 2010) was performed. The obtained results suggest that the semi-distributed hydrological models statistically reduce the rainfall fields into rainfall measured by a much scarcer network of virtual rain gauges and that inhomogeneous distributions of rain gauging networks lead to only partial information on the rainfall fields. In fact, the statistics of measured rainfall is strongly biased by the fractality of the measuring networks. This fractality needs to be properly taken into account to retrieve the original properties of the rainfall fields, in spite of the radar data calibration. Additionally, a proper rainfall data re-normalization is needed when comparing gauged rainfall with the radar data, and consequently when quantifying the impacts of space-time variability within hydrological modelling.

Furthermore, since the Bièvre catchment was calibrated to C-band radar data, in case of the number and distribution of the virtual rain gauges would be reliable in comparison to the C-band radar resolution (1 km^2) –actually the catchment area has only 6 rain gauges –, the number of rain gauges to perform the calibration of better-resolution radar data (e.g. non polarimetric X-band radar) should be big enough to respect the same fractality of the big scales. This also means that the size of the sub-catchments should be comparable to the resolution of the rainfall data used, which would drastically increase the number of sub-catchments and become unmanageable.

Figure Caption: Virtual rain gauges' distribution over the 27 sub-catchments and ENPC X-band radar grid and the selected area of 8 km x 8 km.

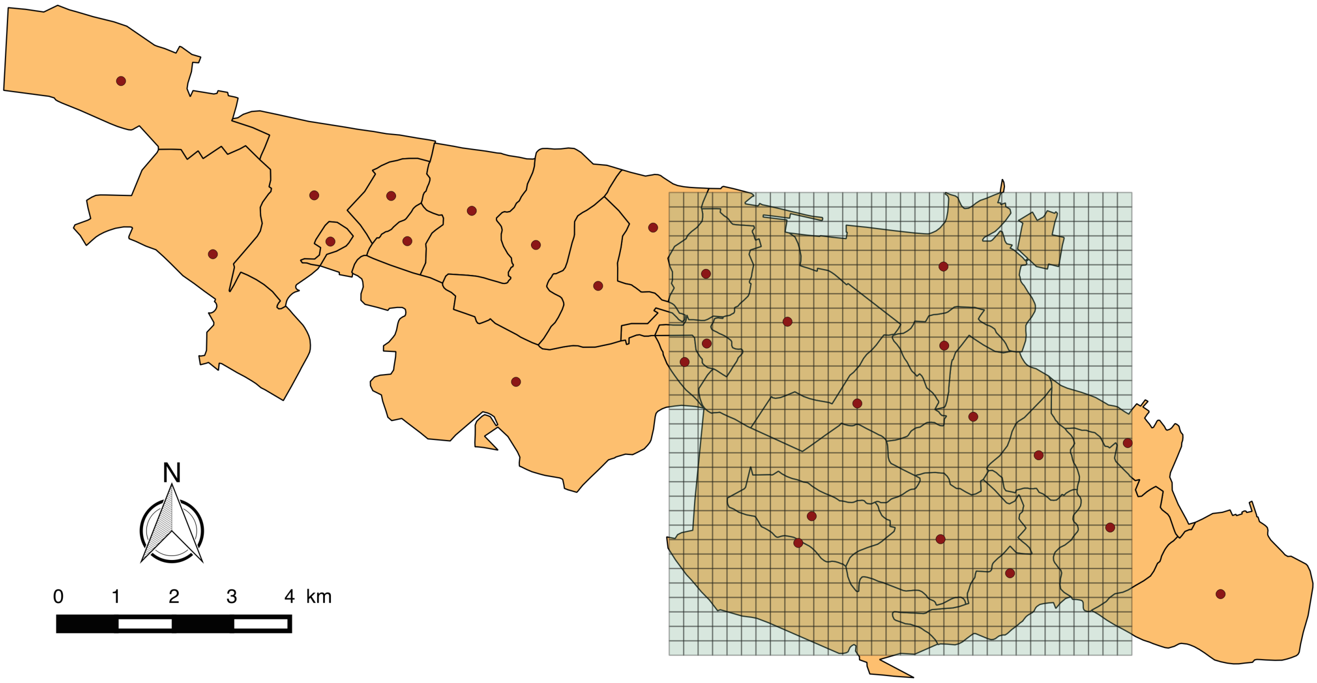
REFERENCES:

Lovejoy, S., Schertzer, D. & Tsonis, A. 1987. Functional box-counting and multiple elliptical dimensions in rain. Science, 235(4792):1036–1038.

Soft, M. 2010. Infoworks CS 11.0 help file. Wallingford, UK.

WMO, 2014. Guide to meteorological instruments and methods of observation. WMO-No. 8, http://www.wmo.int/pages/prog/www/IMOP/CIMO-Guide.html, last access 14 July 2018.

Keywords: polarimetric X-band radar, space-time rainfall variability, fractals, hydrological modelling


N
0 1 2 3 4 km