DEFINITION AND IMPLEMENTATION OF INNOVATIVE COMPARISON TOOLS BETWEEN RADAR AND RAIN GAUGE RAINFALL MEASUREMENT

by

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ABSTRACT

Rain gauges and weather radars do not measure rainfall at the same scale; roughly 20 cm for the first and 1 km for the second. This significant scale gap in not taken into account by standard comparison tools (cumulative depth curves, normalized bias, RMSE, …) despite the fact that rainfall is recognized to exhibit extreme variability at all scales. In this paper we suggest to revisit the long lasting debate of the representativeness of point measurement by explicitly modelling small scale rainfall variability with the help of Universal Multifractals. First the downscaling process is validated with the help of 16 rain gauges located within a 1 km^2 area on the campus of Bradford University (United Kingdom). Second this downscaling process is used to evaluate the impact of small (i.e.: sub-radar pixel) rainfall variability on the standard indicators. This is done with rainfall data from the Seine-Saint-Denis county (France). Although not explaining all the observed differences, it appears that this impact is significant.

Keywords: radar - rain gauges comparison, Universal Multifractals, downscaling

1 INTRODUCTION

The two most commonly used rainfall measurement devices are tipping bucket rain gauge, and weather radar. A rain gauge typically collects rainfall at ground level over a circular area of diameter 20 cm whereas a radar scans the atmosphere over a volume whose projected area is roughly 1 km^2 (for standard C-band radar operated by most of the western Europe meteorological national services). Hence observation scales are in a ratio of more than 10^3 between the two devices. A basic consequence, (e.g. Wilson, 1979), is that direct comparison of the outputs of the two sensors is at least problematic. Methods have been developed to tackle this issue of the representativeness of point measurement (i.e. rain gauge) with regards to average measurements (i.e. radar) (Ciach et al., 1999), but they rely on assumptions which are not always valid (Ciach et al., 2003). Despite usually being mentioned this issue is actually not taken into account when standard comparison between rain gauge and radar rainfall measurements are carried out (Diss et al., 2009; Emmanuel et al., 2012; Figueras I Ventura et al., 2012; Krajewski et al., 2010; Moreau et al. 2009). These comparisons are based on scatter plots, cumulative rainfall depth curves, and the computation of various indicators such as normalized bias, correlation coefficient, root mean square errors, Nash-Sutcliffe coefficient… In this paper we suggest to revisit how the representativeness issue is taken into account in comparison tools between rain gauge and radar rainfall measurements by explicitly modelling the small scale rainfall variability with the help of Universal Multifractals (Schertzer and Lovejoy, 1987). They have been extensively used to analyse and simulate geophysical fields extremely variable over wide range of scales (see Schertzer and Lovejoy 2011 for a recent review). The issue of instrumental errors, although important, is not addressed in this paper.

2 RAINFALL DATA

2.1 Seine-Saint-Denis data set

The first data set used in this paper consists in the rainfall measured by 26 rain gauges distributed over the 236 km^2 Seine-Saint-Denis county (North-East of Paris). The rain gauges are operated by the Direction Eau et Assainissement (the local authority in charge of urban drainage). The temporal resolution is 5 minutes. For each rain gauge the data is compared with the corresponding radar pixel of the French radar mosaic of Météo-France whose resolution is 1 km in space and 5 min in time (see Tabary, 2007 for more details about the radar processing). Four rainfall events were analysed in this study (*Table I*).

Table I – General features of the studied rainfall events in Seine-Saint-Denis. For the cumulative depth the three figures corresponds to the average over the rain gauges or the corresponding radar pixels, the maximum and the minimum.

	9 Feb. 2009	14 Jul. 2010	15 Aug. 2010	15 Dec. 2011
Approx. Event duration (h)	9	6	30	30
Available gauges	24	24	24	26
Rain gauge cumul. Depth (mm)	11.4 (10 - 12.8)	37.9 (47.8 – 23.4)	50.1 (62.8 – 27.4)	22.4 (28.2 – 18.2)
Radar cumul. Depth (mm)	8.5 (9.3 – 7.5)	28.7 (35.8 – 21.2)	50.6 (59.2 – 36.0)	22.4 (28.2 – 19.8)

2.2 Bradford University campus data set

The second data set used in this paper consists in the rainfall measured by 16 rain gauges installed over the campus of Bradford University (United-Kingdom). Eight measuring locations with 2 co-located rain gauges are installed on the roofs of the campus, this has been done to help find random rain gauge errors, as described in Ciach and Krajewski (2006). The maximum distance between two rain gauges is 404 m and the time resolution 1 min. The measured rainfall rate is averaged over 5 minutes so that the two data sets have the same resolution. Three rainfall events were analysed (*Table II*).

Table II – As in *Table I* for the studied rainfall events in Bradford.

	22 June 2012	6 July 2012	15 August 2012
Approx. Event duration (h)	24	10	3
Available gauges	16	16	16
Rain gauge cumul. Depth (mm)	42.5 (49.4 – 36.5)	36.2 (38.0 – 32.3)	16.8 (17.6 – 15.2)

3 STANDARD COMPARISON BETWEEN RADAR AND RAIN GAUGES

The radar and rain gauge data of Seine-Saint-Denis are compared with the help of indicators commonly used for such tasks (Diss et al., 2009; Emmanuel et al., 2012; Figueras I Ventura et al., 2012; Krajewski et al., 2010; Moreau et al. 2009):

- Normalized Bias (*NB*): $NB = \frac{\langle R \rangle}{\langle G \rangle} - 1$
- Correlation (*corr*): $corr = \frac{\sum_{\forall i} (G_i - \langle G \rangle)(R_i - \langle R \rangle)}{\sqrt{\sum_{\forall i} (G_i - \langle G \rangle)^2} \sqrt{\sum_{\forall i} (R_i - \langle R \rangle)^2}}$

- Root mean square error (*RMS*E): $RMSE = \sqrt{\frac{\sum_{\forall i}(R_i - G_i)^2}{N}}$
- Percentage ($\%_{1.5}$) of radar time steps (R_i) contained in the interval $[1.5G_i ; G_i / 1.5]$

Where *R* and *G* correspond respectively to radar and rain gauge data. The time steps of either a single event or all of them are used in the sum for each indicator. For this short paper time steps of 15 minutes with average rain rate greater than 1mm/h (either by radar or rain gauge) are considered (the full paper will contain the results for time steps of 5 min which are needed for some applications in urban hydrology and 1 h which are commonly used by meteorologists). *Table III* displays the computed values which exhibit rather significant variations from one event to the other.

Table III – Standard radar - rain gauge comparison indicators computed for the Seine-Saint-Denis data set

	9 Feb. 2009	14 Jul. 2010	15 Aug. 2010	15 Dec. 2011	All
Nb. of time steps	395	353	2108	933	3789
NB	-0.31	-0.25	-0.027	-0.043	-0.12
Corr	0.56	0.74	0.75	0.76	0.78
RMSE	1.17	11.6	0.97	1.47	3.71
$\%_{1.5}$	45	33.1	60	60	56

4 BRIDGING THE SCALE GAP TROUGH DOWNSCALING

4.1 Methodology

In this paper we suggest to the use the framework of Universal Multifractals (UM) to downscale the radar data and bridge the scale gap. This framework is rather convenient to achieve this, because its basic assumption is that rainfall is generated through a space-time cascade process meaning that downscaling simply consists in stochastically continuing the underlying cascade process. The latter is characterized with the help of only two parameters; C_1 the mean intermittency (which measures the average sparseness of the field) and α the multifractality index (which measures the variability of the intermittency, i.e. its dependence with respect to the considered level of activity). The UM parameters used here are α=1.8 and C_1=0.1 which corresponds to the ones usually found focusing the analysis on the rainy portion of the rainfall field (de Montera et al, 2009; Mandapaka et al., 2009; Verrier et al., 2010, Gires et al., 2012). In this paper discrete cascades are implemented, meaning that the rainfall over a large scale structure is distributed in space and time step by step. At each step the “parent structure” is divided into several “child structures”. To be consistent with the scaling of life-time vs. the structure size in the framework of the Kolomogorov picture of turbulence (Kolmogorov, 1962) the scale of the structure is divided by 3 in space and 2 in time at each step of the cascade process (Marsan et al., 1996; Biaou et al., 2005; Gires et al., 2011), which leads to 18 child structures. Seven steps are implemented on the initial radar data whose observation scale is 1 km in space and 5 min in time, leading to a final resolution of 46 cm in space and 2.3 s in time. After the field is averaged in time over 5 minutes to exhibit the same temporal resolution as the rain gauge data.

4.2 Validation

The validation of this downscaling process is done through the analysis of the variability among the rain gauges installed on the Bradford campus which are located in an area smaller than 1 km^2. For each time step of 5 minutes, the averaged value of the 16 rain gauges is considered as the rainfall rate over the surrounding 1 km^2 area. This data is then downscaled as explained in the previous sub-section, leading to 2187 x 2187 (2187=3^7, where 7 this the number of cascade steps implemented) virtual – rain gauges. Finally the temporal evolution of the cumulative rainfall depth is computed for all the virtual rain gauges and the 5, 25, 75 and 95 % quantiles are evaluated for each time step. The corresponding curves (C_5(t), C_{25}(t), C_{75}(t), C_{95}(t)) along with the temporal evolution of the cumulative rainfall depth of all the 16 actual rain gauges are displayed

Fig. 1. For the June event the simulated variability does not seem great enough to fully grasp the disparities among the rain gauges, although the lowest rain gauge cumulative is likely to be an underestimate. It appears this rain gauge has suffered a small temporary blockage or other random error, as it is significantly lower compared with the other rain gauge in this pair. There is also a relatively large disparity between the pair of rain gauges displaying the highest cumulative rainfall, although both are still higher then $C_{95}(t)$. The rain gauge related error will be subject of further study. For the July event the downscaling process is validated. Concerning the August event it seems that the simulated variability is greater than the observed one. Despite few limitations it appears that the downscaling methodology suggested in this paper can roughly be validated (a more extensive validation will be carried out for the full paper version) and used to revisit the issue of repetitiveness in the radar rain-gauge comparisons.

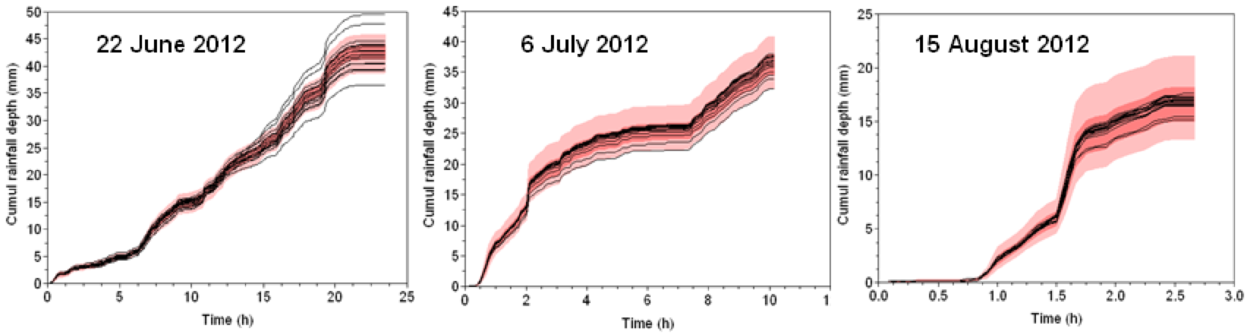

Figure 1 – Temporal evolution of the cumulative rainfall depth for the 16 gauges of the Bradford campus. $C_5(t)$, $C_{25}(t)$, $C_{75}(t)$, $C_{95}(t)$ are also plotted ($C_{25}(t)$ - $C_{75}(t)$ and $C_5(t)$ - $C_{95}(t)$ are the limit of resp. the dark and the light area

5 IMPACT OF SMALL SCALE RAINFALL VARIABILITY ON THE STANDARD INDICATORS

In order to analyse the impact of small scale rainfall variability on the indicators commonly used to compare radar and rain gauge data, the following methodology is implemented on the Seine-Saint-Denis data set: (i) for each rain gauge, the rainfall data from the corresponding radar pixel is downscaled to a resolution of 46 cm (as explained in the section 4.1) (ii) 625 virtual rain gauges are considered within each downscaled radar pixel (iii) Standard indicators are computed with each of the virtual gauge. The output of this process is a set of 625 values for each indicators. The disparities among these indicators reflects only the influence of small scale rainfall variability.

Figure 2 displays histograms of these values along with the values computed with the actual rain gauges. The size of these histograms is not negligible indicating that the representativeness issue should be addressed when comparisons are carried our. The observed *RMSE* (except for the July event) are consistent with what could naturally be expected because of small scale rainfall variability (*Fig. 2.c*). This is also true for the *NB* of the August and December events. On the other hand, it appears that the observed values of *corr* and $\%_{1.5}$ are not explained by small scale rainfall variability, meaning they are associated with instrumental errors.

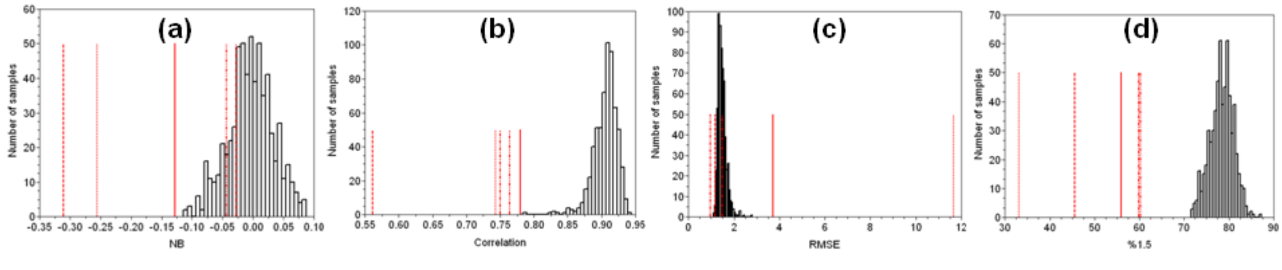

Figure 2 – Histograms of computed *NB* (a), *Corr*. (b), *RMSE* (c) and $\%_{1.5}$ (d) for the 625 samples of different virtual rain gauge position within the radar pixels. The values of the indicators for all the event (solid) and the event of 9 Feb. 2009 (dash), 14 Jul. 2010 (dash dot), 15 Aug. 2010 (long dash dot) and 15 Dec. 2011 (dash bi-dot) are also displayed in red.

6 CONCLUSIONS

In this paper the issue of representativeness of point measurement with regards to average one is revisited in the context of comparison between rain gauge and radar rainfall measurement. This is done by explicitly modelling the small scale rainfall variability not grasped by C-band radars (i.e. occurring below 1 km in space and 5 min in time) with the help of Universal Multifractals. It appears that small scale rainfall variability has a significant impact on the standard comparison tools that are usually implemented to compare rain gauge and radar measurements. However this issue does not fully explain the observed value of the indicators meaning that a methodology to properly distinguish the instrumental error from the representativeness issue should be developed within that framework of multifractal modelling of rainfall. This is also a first step in improving existing merging techniques between the two rainfall measurement devices which can help in providing the accurate fine scale rainfall needed for urban hydrology applications.

7 ACKNOWLEDGEMENTS

The authors acknowledge Météo-France and especially Pierre Tabary and Valérie Vogt, and “Direction Eau et Assainissement” of Seine-Saint-Denis and especially Natalija Stancic and François Chaumeau, for providing respectively the radar rainfall estimates and the rain gauges data in an easily exploitable format. The authors greatly acknowledge partial financial support form the Chair “Hydrology for Resilient Cities” (sponsored by Veolia) of Ecole des Ponts ParisTech, and EU INTERREG RainGain Project. The purchase of the Bradford rain gauges was made possible through a research grant (RG110026) from The Royal Society.

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