Model radar rainfall uncertainty using ensembles

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Abstract

Weather radars are powerful instruments to estimate precipitation because they offer wide aerial coverage at high spatio-temporal resolution. Nonetheless, they are subject to different sources of error, hard to model through a complete physical description of the processes that cause the uncertainty. One of the most used approaches is instead to model the overall uncertainty in the data and to express it through an ensemble of equiprobable realization of the same rainfall field. This approach allows for an easy evaluation of uncertainty propagation in hydrologic, hydraulic and water quality models. It is possible to assess the propagation of uncertainty in models feeding them with all the ensemble members and observing the output spread. [1, 2] This work compares the most used approach presented by Germann et al. in 2009 (named REAL) [1] and a new approach developed by the authors. The idea is to sacrifice the directionality in the description of error spatial correlation, with the aim of improving flexibility and speed of the REAL method.

Motivation

This work is carried out as part of the Quantifying Uncertainty in Integrated Catchment Studies (QUICS) Programme. QUICS is an EU funded FP7 Marie Curie Initial Training Network (ITN). The objective is to develop the understanding of uncertainty causes in catchment studies, develop methods to quantify it, communicate the implications of uncertainty in hydrologic and water quality predictions for decision making and disseminate knowledge and best practices [6]. Precipitation estimates are the main input in many models and are one of the main sources of uncertainty. Modelling of hydrologic processes and water quality, especially at urban scale, requires a high temporal and spatial resolution, that weather radars can partially meet. Nonetheless, radar rainfall estimates carry an associated uncertainty that needs to be considered and quantified. The use of ensembles of radar rainfall estimates is one of the best methods to assess propagation of uncertainty in models. This works aims at comparing methods for ensemble generation and is developed in the QUICS Programme, Project 9.

Radar Errors

Radar estimates of precipitation are a useful instrument in hydrology, but are subject to a variety of error sources [3,4]. Some of the error sources are:

- Attenuation (a)
- Shielding (b)
- Partial beam blocking (c)
- Ground clutter (d)
- Beam overshooting (e)
- Bright band (f)
- Vertical reflectivity profiles
- Anomalous propagation (g)
- Types of precipitation (convective/stratiform)
- Drizzle/snow (h)
- Hail
- Evaporation (i)
- Orographic lifting (l)
- Conversion from backscattering to precipitation rates (Z/R)
- Sampling and averaging

The list is far from complete. Some of this errors can be adjusted, but a residual error remains, difficult to model source by source. The approach used to generate ensemble is to model the overall residual error.

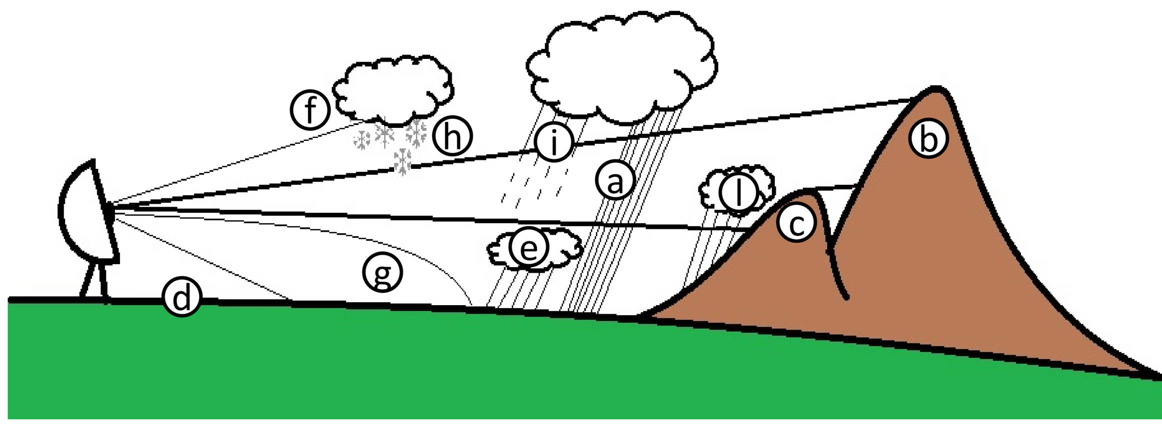


Figure 1: schematic representation of some error source processes

REAL method: model radar rainfall errors through their covariance

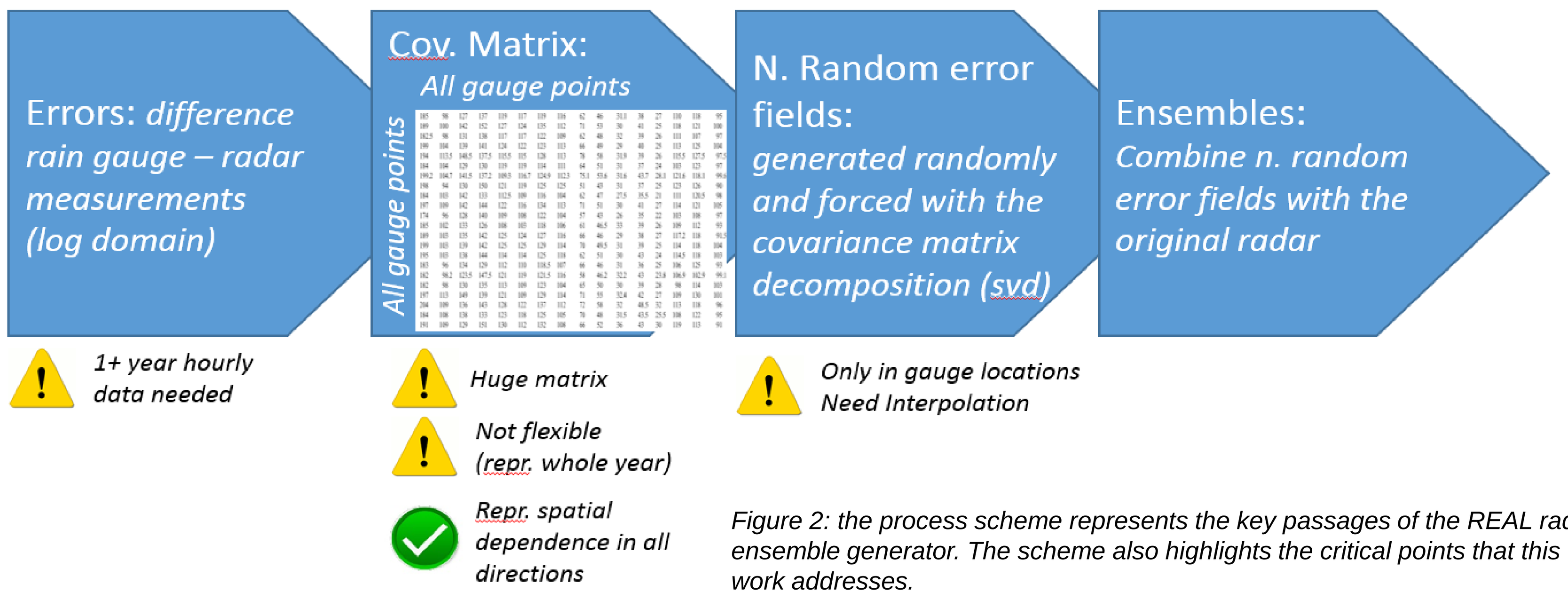


Figure 2: the process scheme represents the key passages of the REAL radar ensemble generator. The scheme also highlights the critical points that this work addresses.

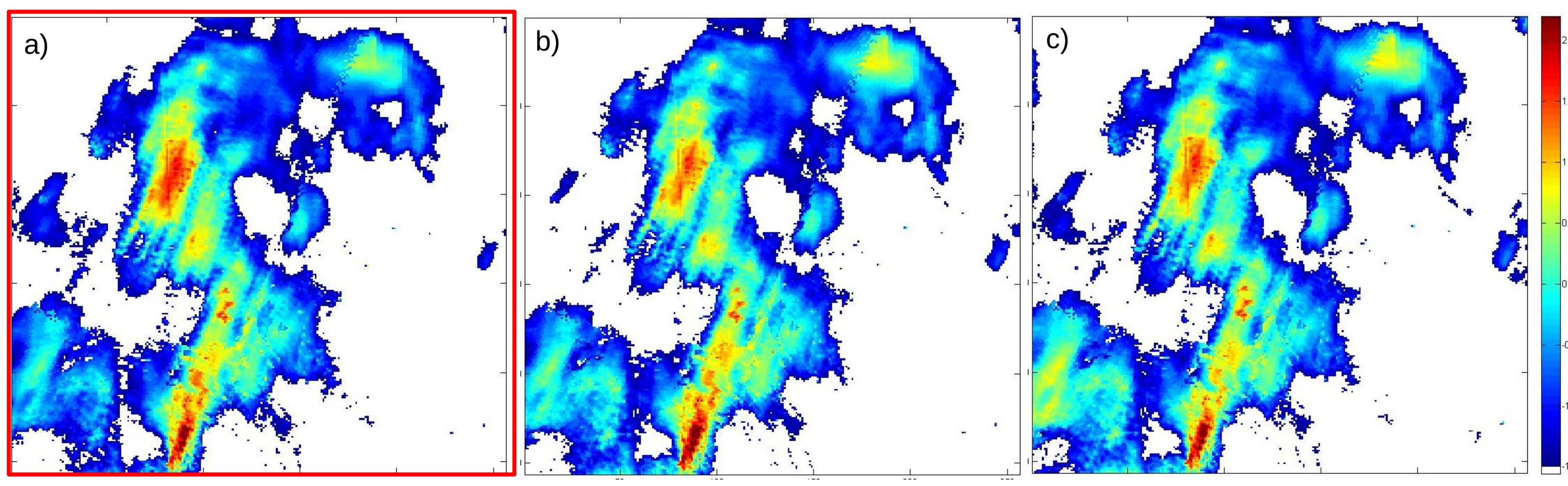


Figure 3: the illustration shows an original radar acquisition (a) on a 256km x 256km area over England on 04/05/2008, 11:00, and two corresponding ensemble members (out of the 100 generated), obtained with the REAL approach (b,c).

The objective of this work is to find the best method to model the radar rainfall errors and to generate ensembles for different model applications. Most of the existing methods in literature are based on the REAL ensemble generation method proposed by Germann et al. in 2009. The REAL method estimates the radar error using quality checked rain gauge data as an approximation of true rainfall. The error are modelled as the difference between a rain gauge and the radar, in logarithmic domain. The error characteristics are descripted through the covariance matrix of the errors. The ensemble error component are then generated combining the decomposition of the covariance matrix, obtained by LU or SVD, and a random normal generated error. This approach forces the ensemble members to maintain the covariance structure of the measured errors. The REAL approach works well with a medium number of point measurements, but is not very robust nor efficient when the number of rain gauges is large. The critical passages are the calculation of the covariance matrix, which is computationally demanding because it needs to be calculated on at least one year of hourly data for each gauge location in order to be representative; and the covariance matrix decomposition, which requires the covariance matrix to be positive definite.

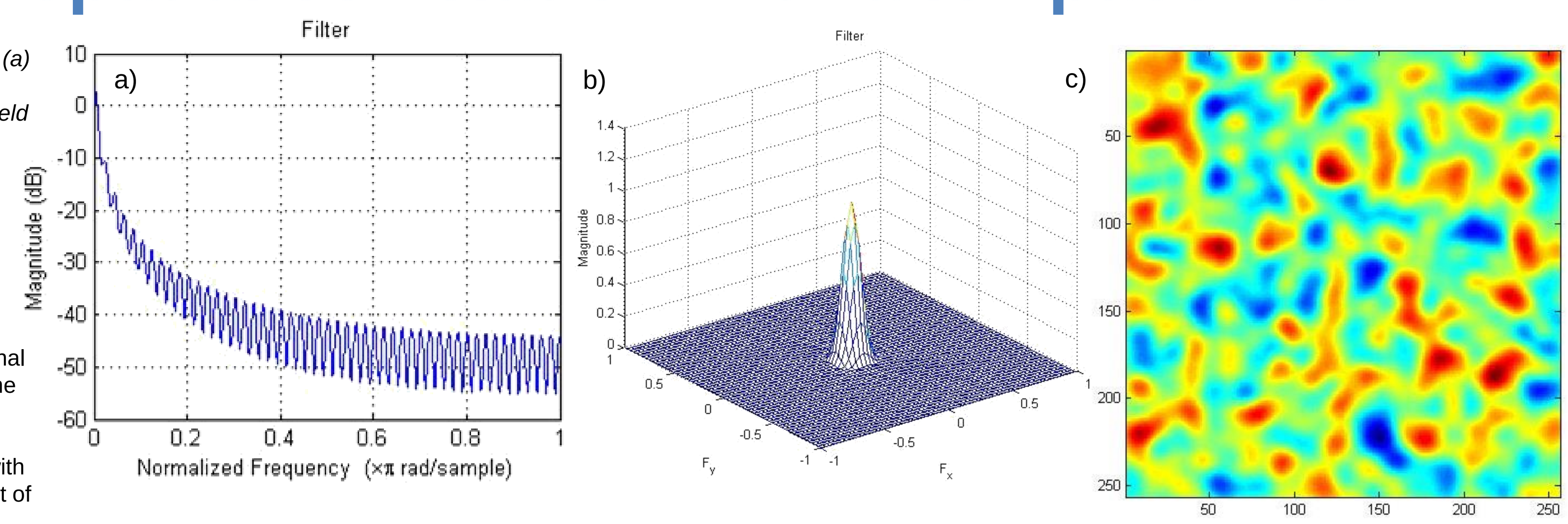
New method: model radar rainfall error spatial correlation with a lowpass filter

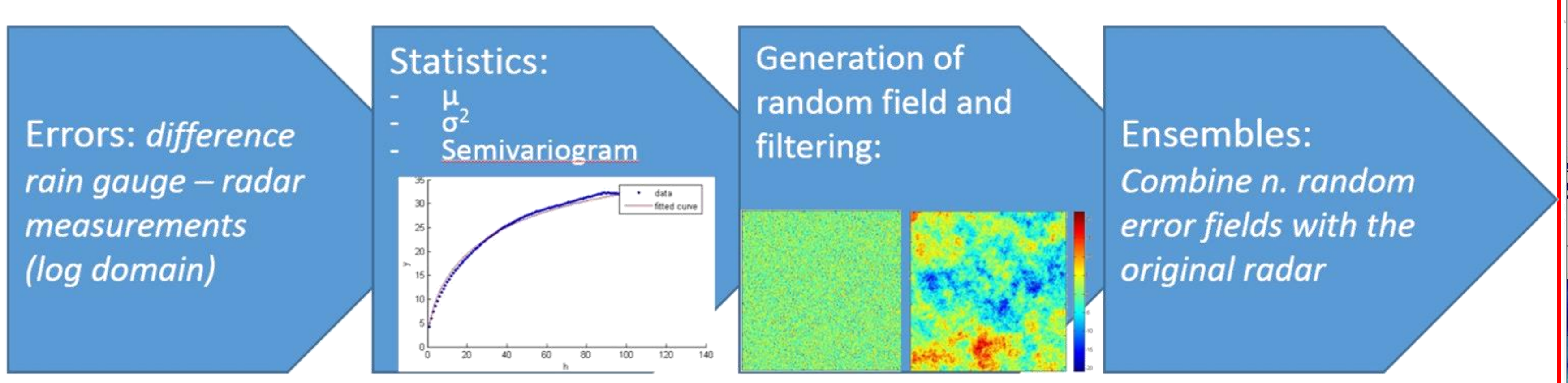
To deal with some of the problems reported in Figure 2, the authors are developing an alternative approach to generate radar ensembles. The main difference is that, instead of describing the error covariances between each gauge point, the spatial correlation characteristics are described through one semivariogram, with an assumption of isotropy. The error components of the ensembles are generated filtering random gaussian fields with a lowpass filter, designed to obtain a field with the same semivariogram. The error components are then scaled to get the target variance and combined with the original radar acquisitions to obtain the ensemble members, like in the REAL method. This approach sacrifices directionality of spatial correlation description to improve speed, efficiency and flexibility of the algorithm.

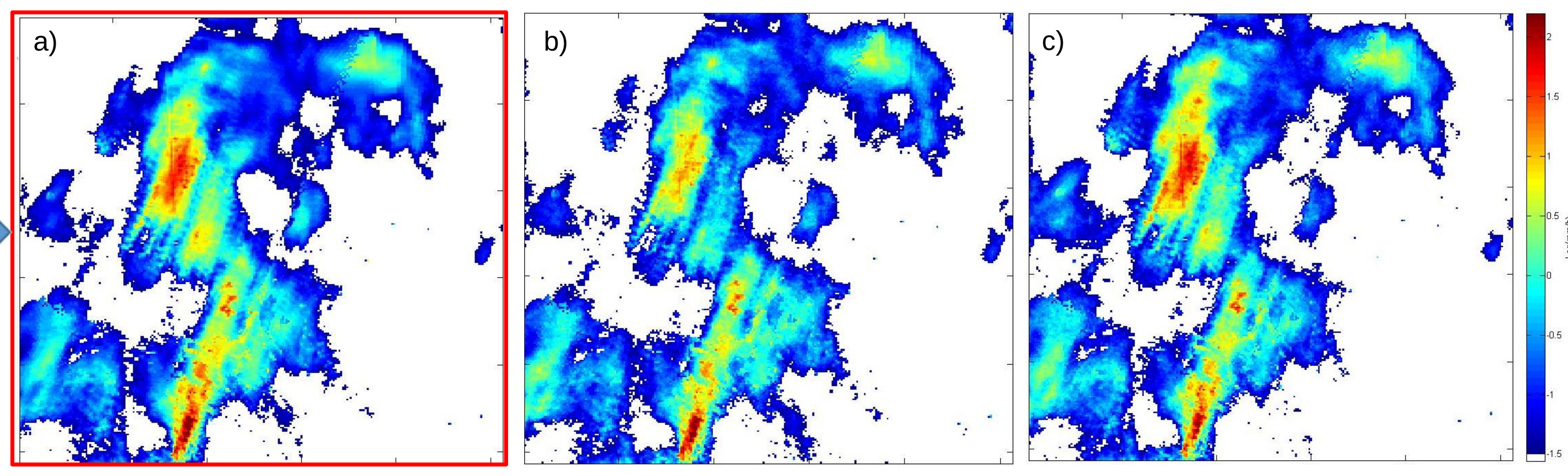
Figure 4 (right): Example of 1D (a) and 2D (b) lowpass filter magnitude and the correlated field obtained applying the filter to a random Gaussian field (c).

Figure 5 (below): the process scheme represents the key passages of the new radar ensemble generator.

Figure 6 (right-below): the original radar acquisition (a), in the same area and at the same time of Figure 3 is compared with two ensemble members obtained with the developed method (b, c) out of the 100 generated.







Discussion and future work

The REAL method is one of the best and most used ensemble generators in literature. The purpose of this work is not to question the validity of the approach, but to propose a different method for a part of the ensemble generation algorithm. Although still under development, this new approach seems promising for its speed and flexibility. If the REAL method needs to process at least one year of data in order to assess the covariance, the new method can be applied acquisition by acquisition, once the characteristics of the errors are known. This opens the possibility to calculate mean, variance and semivariogram of the errors routinely, in order to update them for different seasons, different types of precipitation, or in case the radar hardware or the raw data processing algorithms are updated. Furthermore, the method is more robust to errors in the rain gauges, because they are averaged out in the statistics calculations. Instead, they can represent a problem in the covariance matrix positive definitiveness for the REAL method. Finally, the errors are directly generated on the radar grid, with no need of interpolation.
The method is almost complete, but refinements need to be applied to the variance calculation passage, in order to account for the errors arising from the comparison of punctual and aerial measurements [5]. Once the method is ready, a test will be done to assess the performance in hydrologic model applications and to compare it with the REAL method performance.

Acknowledgements and references

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