Authors would like to thank the anonymous reviewers for their interesting questions and remarks and also for providing a bibliographical complement. Please find enclosed our responses.

Reviewer n°2

General comments

The following part was added: Several optimization approaches have been proposed in the literature since the early work of Bras and Rodríguez-Iturbe (1976) and Delhomme (1978) who proposed a methodology of network design based on the minimization of the mean areal kriging error variance. The adoption of geostatistical methods for rainfall network sizing and augmentation was also performed by Pardo-Igúzquiza (1998). In Delhomme (1978), the optimal location of rain gauges was identified using a technique called the fictitious point method while in Pardo-Igúzquiza (1998) an automatic optimization technique namely simulated annealing was adopted. Barca et al. (2008) provided a methodology for assessing the optimal location of new monitoring stations within an existing rain gauge monitoring network. The methodology used geostatistics and probabilistic techniques (simulated annealing) combined with GIS. A method composed of kriging and entropy that can determine the optimum number and spatial distribution of rain gauge stations in catchments was proposed in Chen et al. (2008). Chebbi et al. (2011) have considered mono objective criteria assuming 1 hour rainfall intensity interpolation and erosivity factor interpolation and using one single extreme rainfall event to conduct the analysis. Rainfall quantities retained in previous studies were mainly taken in a deterministic way. Effectively, a single rainfall pattern was selected for which the average kriging variance was minimized to achieve the best new raingage locations (Delhomme (1978), Pardo-Igúzquiza (1998), Chebbi et al. (2011)). In the present study, it is aimed to find out new observation locations using a collection of rainfall patterns or rainfall auxiliary variables each characterised by its probability of occurrence. Because robust optimization is an approach which can deal with the uncertainty in optimization problems by computing a solution that can cope with possible different scenarios (Mulvey et al., 1995, Bai et al., 1997, Beyer and Sendhoff, 2007), we claim that a robust network augmentation framework is proposed here.

Specific comments

1. Effectively, the reviewer is right. Thus, the following sentence was added: Based on rainfall intensity-duration-frequency curves (IDF), fitted in several locations of a given area, a robust optimisation approach is proposed…

2. Effectively, the text does not contain a clear definition of robust optimization. In a reference to Cunha and Sousa work (2010), it was said (p. 14207 line 20) that robust optimization aimed to face the uncertainty of the network working conditions. Also, the first sentence of the conclusion said: The robust optimization approaches are recommended in case where the variables of interest are uncertain. The hydrological risk is considered in the present study which aims to find out new observation locations for short duration rainfall raingages. So few sentences were introduced early in the introduction to overcome this lack of definition: In the present study, it is aimed to find out new observation locations using a collection of rainfall patterns or rainfall auxiliary variables each characterised by its probability of occurrence. Because robust optimization is an approach which can deal with the uncertainty in optimization problems by computing a solution that can cope with possible different scenarios (Mulvey et al., 1995, Bai et al., 1997, Beyer and Sendhoff, 2007), we claim that a robust network augmentation framework is proposed here.

3. Effectively, the text is not so clear. Please consider the following changes proposed to early paragraph 2.2 (p 14209 line 1): Since we are interested in short duration rainfall, the maximum rainfall intensity for specified durations is the variable to be studied in this paper. To deal with hydrological risk inherent to rainfall data, we would need data on the maximum rainfall intensities recorded for several events. However, the problem is that we do not have this type of information for the study area. Thus, the adjustment parameters of the intensity-duration-frequency (IDF) curves (Koutsoyiannis et al., 1998) are proposed as alternative or auxiliary variables (parameters a(T) and b(T) of Eq. 1).

   p14209 line 25 the following reference was added with respect to Montana model: (Burlando and Rosso, 1996)

4. Effectively, more precision is required to specify the level at which DGRE study was used. So, changes have been introduced by 1) adding the reference in "The following times of reference (5, 10, 15, 30, 45,…., 180 minutes) were considered in DGRE-ST2i (2007)." (line 11). 2) For stations having short observation periods (3 to 10 years) without gaps, DGRE-ST2i (2007) selected…3) The peak over threshold approach was adopted by DGRE-ST2i (2007) for the rain gauges ….4) For the rain gauges characterized by recordings without gaps and observed over long periods, DGRE-ST2i (2007) considered the *M* highest values…..5) the statistical study carried out by DGRE-ST2i (2007) with Hydraccess ….

   Authors acknowledge that they had access to all DGRE-ST2i (2007) results with required details. We also would like to underline that the methods adopted at DGRE-ST2i (2007) were fully adequate.

5. p 14210. Effectively the return period supplies the probability. We propose to add the sentence: Here, we adopt the hydrological risk definition where the risk is p=1/T (Bobée and Ashkar, 1993) so that we may consider that *T* reflects the hydrological risk, t is rainfall duration in minutes, *a(T)* and *b(T)* are Montana IDF model parameters.

6. It is proposed to rename section 2.2 as: **2.2 The IDF data base** and to create a new section **2.3 Geostatistical framework for IDF parameters** before the paragraph "In this study *a(T)* and *b(T)* are taken as geostatistical variables (Matheron, 1965)…

7. As it was stressed before in question 5, the return period T is adopted as surrogate for risk assessment. When one maps parameters *a(T)* or *b(T)* over the study area, it contributes to rainfall risk assessment since using interpolated values of *a(T)* and *b(T)* results in a map of *I(t, T)* which helps quantifying the rainfall risk. However, to ovoid further complications, the term "risk assessment" was suppressed.

8. The paragraph (line 11 p 14212) has been changed by including some sentences explaining which method was used and giving the appropriate references: The decision model presented here is built within the framework of robust optimization and is inspired by the case studies reported in Mulvey et al., 1995. The objective function is written using the concept of regret by considering a quadratic term expressing the difference, for each scenario, between the values of the standardized mean spatial kriging variance achieved by the solution to be implemented and by the optimal solution for the scenario. This means that the optimal solution for the model

proposed will be solution robust (Laguna 1998). As such, the optimal solution obtained will be “close” to the optimum for any of the realised scenarios ensuring the optimality robustness.

9. In Eq. 7 and further the weight *Prob* was replaced by the symbol ω.

$$\omega(T) = u(T) \Big/ \sum_{i=1}^{i=NT} u(T_i)$$

Where NT is the number of return periods considered in the study, this means the number of scenarios considered in the study.

10. about the use of the term OF (P14212 and 14213). These equations have been replaced by:

To evaluate the mean spatial kriging error variance over the study domain, a grid mesh with a resolution of 4 km was used. The optimization problem consists of minimizing the objective function expressed by:

$$\text{Min} \quad \sum_{i=1}^{NT} \omega(T=T_i) * \left(S(T=T_i) - S_{ref}(T=T_i)\right)^2 \qquad (8)$$

$\sum_{i=1}^{NT} \omega(T=T_i) = 1$; $\omega(T=T_i)$ as indicated in (Eq.7) and S_{ref} $(T=T_i)$ being the value of the standardized mean spatial kriging variance obtained for every return period T_i independently of the other return periods. It is taken as reference.

In addition, standardization of the mean spatial kriging variance is obtained by using the interquartile range of *a(T)* kriging error variance map:

$$S(T=T_i) = \left(\sum_{i=1}^{n} \left(\sigma_{i(a(T=T_i)))}\right)^2 / n \right) \Big/ F(T=T_i)$$

(9)

Where $(\sigma_{i(a(T=T_i)))})^2$ is the variance of kriging errors of $a(T=T_i)$ at the computing node i depending on locations of stations and n is the number of grid nodes.

$$F(T=T_i) = \left(\sigma^2_{75\%(a(T=Ti))} - \sigma^2_{25\%(a(T=Ti))}\right) \qquad (10)$$

$\sigma^2_{75\%(a(T=T_i))}$ is the 75% percentile of the pattern of the variance of kriging errors of $a(T=T_i)$

$\sigma^2_{25\%(a(T=T_i))}$ is the 25% percentile of the pattern of the variance of kriging errors of $a(T=T_i)$

This objective function is subjected to domain constraints expressed by the set of possible locations for the stations (as such the solution space is defined).

11. p14215 line 7: In a previous paper (Chebbi et al., 2011), mono objective criteria have been considered assuming 1 hour rainfall intensity interpolation and erosivity factor

> interpolation and using one single extreme rainfall event to conduct the analysis. The comparison of previous results with the present study highlights that the mean spatial kriging variance in the case of the mono objective criterion is lower or equal to that obtained in the case of the robust optimisation. Nevertheless, the essential advantage of the robust optimization lies in the fact that it allows to overcome the problem of using one single rainfall event and yields networks which work ‘adequately’, when considering various extreme events with different return periods.

Technical corrections

P 14206 line 20 and line 24: 14 is the number of rain gauges for which Data inputs of IDF curves are available (DGRE-ST2i, 2007) while 13 is number of rain gauges of the initial network functioning in March 1973.
P 14207: line 8: this reference has been suppressed
P14208 line 20: It seems that a point “.” is missing in the editorial document.
P14209 Montana has been deleted in the new title. Thank you.
P14210 line 9: Yes; thank you
P 14210 line 19 Yes; thank you
P 14226 Fig. 1 ; it has been corrected