<u>Response to the Short Comment SC4 #</u>

We thank our former colleague Dr. Sarvesh Singh in the LMEE Laboratory with whom we have also published many research papers as a coauthor, for his detailed reading of our paper. We are grateful to him, despite the fact he is perhaps a bit too personally involved, reading and commenting so abundantly our work, pointing out the weakness of some difficult explanations given too quickly. He has a good practice in inverse modeling for the air pollutant source reconstruction in flat and homogeneous terrains. However, we understand that this multidisciplinary study which requires wide knowledge, not only of the inverse problem, but also of the CFD modelling, optimization and experience in engineering, can lead to confusion and misunderstanding. Below we tried to answer (in italic form) to all of his comments (in red color), also many of his comments were repeated several times asking same question again and again.

Comment: The manuscript highlights an interesting and challenging problem related to the optimization of sensor networks in the context of a point source reconstruction. In general, the optimization of monitoring network consists of two important issues: (i) reducing the number of receptors and (ii) finding an optimal design of the arrangement of the monitoring network. Here, the study deals only with selecting a reduced set of number of receptors among an already established monitoring network, which is very limited form of a real problem.

Reply: *The optimization of monitoring network doesn't consist in general two important issues: reducing the number of receptors and finding an optimal design of the arrangement of the monitoring network, this affirmation is very simplistic. Fundamentally, the optimization of monitoring networks problems may concern:*

*<u>1. First deployment:</u> This case is the more complex and consists in defining different interesting areas (monitored area, vulnerable area, danger area, the potential locations, etc.) before optimizing the network. This problem cannot be dealt in general, because the studied zones change according to the situation (industrial zone, target of an aggression from the external, etc.). Once the search space is defined (i.e. the candidate locations for the sensors implantation), the problem can concern finding the best configuration of a minimal number of sensors (similar to problem 3 below) or the best spatial arrangement of a predetermined number of detectors (in some cases for example the protection against eventual terrorist attack, **a limited number of sensors is not important** and the security must be guaranteed by the maximum means).*

<u>2. Updating an existing network:</u> This problem consists in changing the sensors positions in the interesting area for the specific needs (such as an important variation of the meteorological situations after long time the network is designed) without changing the size of the networks (i.e. number of sensors).

<u>3. Reducing the size of an existing network:</u> The challenge here is to determine the optimal size of network and the best locations for the sensors implantation. Here the original network is considered as the search space.

<u>4. Increasing the size of an existing network:</u> This problem consists in determining the best positions to add to a set of sensors already placed on a site. The number of detectors to add can be prefixed or included in the optimization problem (i.e. must be determine).

The detailed problems are independent and each one of them have its own requirements.

It is also important to know that the optimization of sensors networks depend on the network type:

a. <u>Mobile network deployed only on emergency</u>: Here the detectors are rapidly deployed specifically for collecting the information (i.e. measurements) to be used for a specific need (neutralize the source, refurbishment an installations on industrial site, etc.). In this case, the meteorological conditions (as wind speed and direction, etc.) can be known in real time from the available observations or from numerical weather forecasting models and can be assumed as stationary. The optimization in this case can be performed in real time if the interesting area is not complex and the calculation can be conducted quickly in a very short time (using Gaussian model and an optimization algorithm for example). If the domain is complex (i.e. contains several obstacles), CFD model must be used to include the effect of the obstacles, the optimal locations to be instrumented by the sensors must be determined in upstream off-line.

b. <u>Permanent mobile network</u>: Here the vulnerable area is monitored permanently by detectors embarked in mobile systems (such as drones or robots). The optimization in this case consists in determining the best locations following the situation (meteorological conditions, presence of a danger, detection of an accident, etc.).

c. <u>Permanent static network</u>: Here the vulnerable area is monitored permanently by a fixed network that must be efficient regardless of the meteorological situations. The optimal design consists in finding the best arrangement of the detectors (the number can be minimal or prefixed).

As a conclusion, the optimization of monitoring network in an urban environment is a complex problem that must be deal with proper use of the inverse modeling, CFD modeling, and optimization techniques. The present study deals with the above cases (3) and (a). As also pointed out by Dr. Pudykiewicz, one of the reviewers of this paper and a distinguished scientist in this field, the subject of this study is challenging, very timely, and very difficult and there are very few papers addressing the problem in a comprehensive manner. In order to accomplish this task, we derived a method based on the combination of optimization techniques, inverse tracers transport modeling and Computational Fluid Dynamics. So the remark of Dr. Singh that the study is very limited form of a real problem is not true.

For more detail we have cited below some studies that can help to understand the challenges and the methods that can be used in the context of our work:

- *(Chen et al 2012): Optimization of water quality monitoring network in a large river <u>by combining measurements, a numerical model and matter-element analyses</u>.*
- *(Ainslie et al 2009): Application of an entropy-based Bayesian optimization technique to the <u>redesign of an existing monitoring network for single air pollutants</u>.*
- *(Mofarrah & Husain, 2010): A holistic approach for optimal design of air quality monitoring network <u>expansion in an urban area</u>.*
- *(Lepley et al 2011): <u>Dynamic sensor deployment</u> for the monitoring of chemical releases in urban environment.*

- *(Le et al, 2003): Designing networks for monitoring multivariate environmental fields using data with monotone pattern.*
- *(Jiang et al, 2007): Optimization of mobile radioactivity monitoring networks.*

Comment: The authors have already published the inversion methodology and simulated annealing algorithm (SA) with its application to wind tunnel experiment in Kuichi et al. (2016). The present study shows a similar application in an urban terrain field experiment by using a CFD model.

Reply: *'' Kuichi et al. (2016)'', do you mean Kouichi et al. (2016)?*

This comment of Dr. Singh is not completely true and also misleading as in the study of Kouichi et al. (2016), which is in fact a conference paper, the dispersion experiment of the gas and the modeling study were performed in very idealized conditions in a wind tunnel (standard deviation adjusted specifically for the wind tunnel, wind speed fixed according to the best results, measurements far from the boundary layer, dispersion in a homogeneous space without obstacles, etc.). All these aspects simplify the complexity of the optimal design problem and don't lead to fine analysis of the locations importance on the reconstruction of the source parameters. The current study of the networks optimization in view of the source reconstruction in urban domain is a very complex and challenging problem and the renormalization inversion method has never been the subject of this study, this clearly justifies the originality of this work. With proper citations of our earlier works, in this study, we never claimed to present the inversion methodology. In fact, the earlier source reconstruction results were presented for comparison purposes only with proper citation of that work. In this study, we derived a methodology for designing the optimal monitoring networks ***in an urban like environment*** *based on the combination of optimization techniques, inverse tracers transport modeling and Computational Fluid Dynamics. Dr. Singh comment that this is just an application in an urban terrain field experiment by using a CFD model, cannot be justified as Dr. Pudykiewicz also pointed out that this study is challenging and very difficult and there are very few papers addressing the problem in a comprehensive manner. In fact, the complexity of the problem increases manifold for urban environments where simple analytical or Gaussian models have limitations and cannot be apply for such complex environments. This study presents a method for designing the optimal monitoring networks in an urban like environment.*

Comment: It does not involve any new development in the model or inversion / optimization algorithm.

Reply: *Fundamentally an optimization study does not require development in the used methods or algorithms but it is ensured by three essential phases:*

1. Choice of an objective functions: (also known as cost functions), in our case this function is the optimality criterion which describes the quality of a network and which is in agreement with the defined problem (mobile or static network, for reconstruction of a source or for other need, etc.).

2. The problem statement: this consists in defining how the optimization problem is approached (i.e. discrete or continuous search areas, definitions of spatial zones, etc.).

3. The choice of the optimization algorithm: which is generally in coherence with the phase 2 (Determinist optimization, Hard optimization, etc.)

The complexity of the optimization problems is in the well definition of these three phases specially the choice of the optimality criterion and also in the implementation and the exploitation of the retained techniques. In this study, we never claimed any development in the inversion or optimizations algorithms as these techniques were already available in the literature. We derived a methodology for designing the optimal monitoring networks in an urban like environment which is based on the combination of optimization techniques, inverse tracers transport modeling and Computational Fluid Dynamics. Which attests to a new development for optimally designing the sensors monitoring network in an urban like environment.

Comment: The presentation of the results is classically similar to a point source reconstruction study which do not highlight any significant contribution related to optimal networking.

Reply: *In the present study, the obtained optimal networks were analyzed qualitatively and quantitatively for all the trials of MUST field experiment. The dispersion of the sensors in the urban like environment was critically analyzed according to the source position and the meteorological situation. A fine analysis is performed to highlight the common structures (Skeleton) in the optimal networks. Also, a posteriori study is realized in order to evaluate the performance of the optimal networks. For this the errors in source parameters estimation are compared with the errors obtained from the original network which leads to the important conclusions in networks size reduction in the framework of source reconstruction in an urban environment. As the applicability of the obtained monitoring networks is validated and analyzed by estimating the source parameters from the concentration measurements from the optimal networks, it is obvious to present and analyzed the source reconstruction results and compare these with from previous study. We do not agree with Dr. Singh's point that this study does not highlight any significant contribution related to optimal networking. In fact, using the proposed methodology, we were accurately able to estimate the source parameters using the measurements only from 1/4th and 1/3rd sensors with approximately similar accuracy compare to the network of original number of sensors. This is significant contribution that reduces the number of sensors in an urban like environment and without compromising the ability of the network with minimal number of sensors to estimate the source.*

Comment: The application of renormalized inversion and SA methodology in optimizing receptors are associated with several issues which are not clarified in the text.

Reply: *As mentioned in the abstract and in the text the renormalized inversion method, the SA and the CFD model were coupled to obtain the optimized network of the receptors and the related issues were partially presented when the methodology of the networks optimization was presented for an urban like environment. We have more clarified these issues in the updated version of the manuscript.*

Comment: Besides, there are several examples of uncleared and overstated sentences, misinterpretation of mathematics, poor description of results and methodology.

Reply: *Unfortunately we cannot answer to a not given examples. Can you please indicate the ''uncleared and overstated sentences'' and the ''misinterpretation of mathematics''? However, we will carefully read again and correct the text in updated manuscript for such examples (if any).*

Comment: Overall, it needs to be justified that what is the significant outcome of this study and how their approach of determining optimal network, which is biased towards measurements, is justified in a general framework?.

Reply: *As clarified before (see the first reply) this study is carried out in the framework of the cases (3) and (a). We do not study all the envisaged cases. It is clear that the problem of sensors network optimization is not trivial and need to be solved according to a given configuration. We remind that in this study we provide answer to the specific operational need for witch it is necessary to deploy sensors in emergency situations where the meteorological conditions are known in real time and some information about the measurements are available. We explain more: for example, in an industrial site the area where an eventual source can be located is known. Consequently, the source is roughly localized and the optimized network is deployed to refine the estimation of the source position which helps to repair the installation. A second concrete case concerns the estimation of the intensity of hazardous accidental release. This data (i.e. intensity of the source) is primordial for following and/or for predicting the evolution of the accidental plume. In such specific case, it is judicious to be based on the scenarios which justify the use of concentrations in optimal design. For more clarification we cite some example of works based on scenarios (i.e. a priori informations are available) where the measurements were used in the optimal design of the monitoring networks:*

- *(Ma et al 2013): Comparison and improvements of optimization methods for gas emission source identification.*
- *(Mason et Bohlin, 1995): Network optimization of a radionuclide monitoring system for the comprehensive nuclear test ban treaty.*
- *(Berry et al, 2006-a): A facility location approach to sensor placement optimization.*
- *(Watson J-P et al, 2004): A multiple-objective analysis of sensor placement optimization in water networks.*
- *(Krause et al, 2008) Efficient Sensor Placement Optimization for Securing Large Water Distribution Networks.*
- *(Hamel et al, 2010): Sensor Placement for Urban Homeland Security Applications.*
- *(Abida et Bocquet, 2009): Targeting of observations for accidental atmospheric release monitoring.*

Also we can find in the literature some works of sensors networks optimization based on <u>error cost function (error objective function) similar to the optimality criterion that we proposed in our study:</u>

- *(Abida et al, 2008): Design of a network over France in case of a radiological accidental release.*
- *(Saunier et al, 2009): Model reduction via principal component truncation for the optimal design of atmospheric monitoring networks.*
- *(Jiang et al, 2007): Optimization of mobile radioactivity monitoring networks.*

This study shows that it is possible to reconstruct a source of atmospheric emissions with a limited number of concentration measurements and presents a methodology for selecting the 'best' sensors positions basing on an optimality criterion and by coupling an optimization algorithm an inversion method and a CFD model that include the complexity of an urban domain. This study presents a practical method for managing realistic situations. In an area of interest it is not possible to place the sensors anywhere. This study present an investigation on the measurements vector used in the inverse problems.

<u>General Comments:</u>

Comment 1. In network optimization problem, finding an optimal rearrangement of a set of receptors and then, their evaluation for source estimation are two independent set of problems. The determination of optimal rearrangement should be performed independent of knowledge of measurements and it must contain available maximum information in the domain regarding observability of emissions. The second problem regarding evaluation of source retrieval should be carried out as a next step to validate the efficiency of such networks in the presence of random model-measurement errors. In this study, the two set of problems are mixed and arrangement of network is determined given the knowledge of measurements which is a biased choice of receptors. In addition, the study does not discuss any criterion which could quantify the information in a particular design or impact of model-measurement errors on the chosen network.

Reply: *We agree with Dr. Singh's remarks that in a network optimization problem, finding an optimal rearrangement of a set of receptors and then, their evaluation for source estimation are two independent set of problems. In fact, we also followed the same procedure. The network optimization problem was independently presented and performed before any evaluation by estimating the source parameters using the measurements from the sensors from the obtained optimal network. However, since the optimization methodology utilizes some concepts (not the source estimation part) from the renormalization inversion methodology, we presented it after the source estimation methodology. As also explained in the manuscript and more clearly in the updated version, the network optimization problem is completely independent from the source estimation evaluation. It is very clearly explained in the flow diagram in Figure 2 and shows that source was estimated only when we obtained the optimal monitoring network. In this work, the first step consist to find the best configuration of a limited set of sensors using the meteorological data, the sensors positions on the instrumented area, a CFD technique and the concentration observations. The second step consists to evaluate a posteriori the performance of the optimal networks in comparison with the original network used in MUST field experiment.*

The problem of optimal design of sensors networks for source reconstruction can be performed (i) without a priori information or (ii) with a priori information of the source (such us its position, intensity, etc.) and the observations (i.e. pollutant concentrations) can be used in the optimization process see as examples (Ma et al, 2014).

In a case when the source is considered completely unknown (as example in terrorist attack) the challenge is to design a network able to reconstruct an eventual source regardless of its position and intensity. Thus a specific cost function could be defined in order to assure the optimal design and the concept of information can be used. The PhD thesis of Kouichi (2017) and Kouichi et al. (2016) was inspired by this concept for defining the entropic criterion based on the renormalization method in order to estimate the best arrangement of the sensors for source characterization regardless its intensity and position. This work is already a subject of a publication that we realized.

In a case when some knowledge about the source are available we remind as example on industrial sites the 'danger zone' were the source can be located is completely known (storage tank of hazardous products, network of pipelines, etc.) for this reason works of optimization can be conducted based on scenarios for witch a priori information on the source was utilized (other example in specific situation of accidental release the position of the source is known (observed in the site) and the need is to estimate its intensity in order to estimate the dispersed quantities of a hazardous agent this can help to predict the evolution *of the accidental plume or to determine the contaminated area or to estimate the quantities inhaled by the personals exposed on site, etc.*

Concentrations measurements can routinely be available from an already existing large monitoring network. In this study we utilized these concentration measurements to reduce the size of a large network. The updated version of the manuscript also discusses a posteriori error analysis of the source reconstruction based on the random measurements errors from an obtained monitoring network.

Comment 2. Throughout the text, authors have mentioned the keyword "optimal network". A big question here, is how to prove that a particular design is optimal?. This requires rather mathematical or statistical arguments / proofs to support the fact that a design is optimal. This can not be shown by showing source retrieval which is nothing but just the estimation of 3 parameters (location, (x, y) and strength q).

Reply: *Throughout the text we mentioned that there is no guarantee in the convergence of the SA and we confirmed (based on the adequate bibliographical references) that the obtained network can be the optimal or the near optimal one. This complex combinatorial optimization approach retained a big attention in the literature and the SA is selected following the recommendations from more than one works of networks optimization in the framework of the atmospheric dispersion context (Abida et al, 2008; Abida et Bocquet, 2009; Jiang et al, 2007; etc.). Nevertheless before utilizing the probabilistic algorithm SA, we tested its performance in comparison with the Genetic Algorithm GA of evolutionary research technic (Kouichi, 2017). Concerning the statistical study after the achievement of the optimization we plan to perform this investigation as continuity of this first study.*

Comment 3. A big limitation of this approach is the subjectivity and biasness in the methodology and their dependence on the measurements. The optimality of the reduced set of receptors is shown based on the accuracy of the point source retrieval which is not relevant. The good retrieval results with presumed lesser number of receptors are not surprising since their chosen cost function depends on the measurement's values which always force the SA algorithm to choose the receptor locations with good model measurement accuracy. They completely ignored the fact that their network design criterion should be independent and prior to the knowledge of measurements, which is one of the big limitations. To be precise, the optimization methodology utilizes the same cost function for both the tasks: (i) Identifying a reduced set of receptors and (ii) retrieving the point source parameters. The cost function utilizes the actual measurements and measures the deviations between measured and predicted concentrations at the chosen set of receptors. The iterative SA algorithm tries to minimize this cost function, which means it selects the receptors with good model-measurement accuracy, i.e. which are closer to the measurements. This will eventually results in good retrieval depending on the model error. This clarifies the fact that the choice of receptors is always subjective to the model-measurement accuracy and will vary in case of perturbation in the model measurement variables. Thus, this is a poor approach and always biased towards model-measurement accuracy which do not signify the objective of optimization of receptors. The optimization of receptors should have performed independent and prior to the knowledge of measurements, which is not done here.

Reply: *This comment is similar to the comment n°1 and some evoked points in the introduction so we conserve the same responses. We hope that the clarification that we presented before help for best understanding the aim and the approach of this study.*

Comment 4. The study do not provide any insights / discussion on systems observability while remaining ill-posed, quantification of information gain or loss during optimization of the network, statistical or mathematical criterion leading to network optimization and sensitivity of the network design with respect to the perturbation in the model-measurement variables. Also, the study do not mention any optimality criterion, design of experiment or information theory criterion.

Reply: *The sensitivity of the network design with respect to the perturbation in the model-measurement variables is studied a posteriori and discussed in the revised version according to the recommendation of the Referee#2. Concerning the optimality criterion and the information theory we remind as we mentioned before (reply for comment 1) that the entropic criterion is defined by Kouichi (2017) and is the subject of another publication. We hope that the clarification that we presented before, specially the framework and the challenge of this study is now clear (mobile networks, with a priori information, etc.)*

Comment 5. Another issue with the methodology is that the SA algorithm may not converge always to the same set of reduced receptors. More often, there is high probability that the reduced set will change in every repeated simulation since the number of possible combinations are really high. In this case, how do you guarantee the optimality of design?. Also, the authors never compared between various such different sets corresponding to same trials as how they are varying or what are the differentiation between them. It seems that the authors just choose the arrangement with least reconstruction error which is not logical.

Reply: *This comment is similar to the comment n°2 and some evoked points in the introduction so we conserve the same responses that we clarified before.*

Comment 6. If the objective was simply to have a reduced set of network where model measurement errors are minimum (which is done here), why authors just did not select those locations where model predictions are matching with measurements?. This could be done simply by comparing model predictions and measurements instead of a massive SA computation. Based on the proposed approach, this can not be called an optimization of the monitoring network.

Reply: *Selecting the locations where model predictions are matching with measurements doesn't guarantee a 'best' estimation of the source parameters (inverse problem and direct problem are completely different). Effectively, this is one among the important results of this study. As we used a data assimilation approach, the best network is obtained for the best reproduction of the observations (i.e. correspond to minimal quadratic distance between the modeled and the measured concentrations). Also, as stated by Dr. Singh about the network based on the matching of direct model prediction with measurements, the direct model also required the knowledge of the exact source parameters and this information may not be available in general. However, in this study, we utilized only the concentration measurements and not the source parameters to obtain the monitoring networks.*

Comment 7. The proposed approach also raises questions regarding the efficiency of the network in case of perturbed model-measurement fields/variables. Also, the retrieved parameters are highly sensitive toward the design of their network which raise further questions regarding the efficiency of the chosen network. The optimized choice of network will always be subjective with respect to the wind variability, model, model errors and measurements. In trials, where model does not perform well, the error will always be high, for example see in trials 2. This will raise the issue of failure of their monitoring networks in identifying correctly the emissions in case of large model errors. This is why the arrangement of the receptors vary in all the trials, even when in some trials, the wind conditions are approximately similar.

Reply: *This study presents our first attempt of sensors networks optimization for the reconstruction of releases source in urban domains. The door still open for continuity in order to integrate the effect of meteorological conditions variability or to integrate the influence of the models errors. Nevertheless, following the recommendation of the Referee#2, the effect of random measurement errors is now integrated into the analyses of the optimal networks performance. Some limitations of this work are also included in the updated version of the manuscript. It is not always true as Dr. Singh commented that in trials, where model does not perform well, the error will always be high, for example see in trials 2. In trial 2, the predicted concentrations from direct model were in good agreement with the observations (NMSE = 0.17, Correlation coefficient = 0.95, Index of Agreement = 0.97) (Kumar et al., 2015a). Even by utilizing the concentration measurements from all 40 sensors in source estimation, the retrieval error was large in this trial 2 (Kumar et al., 2015b). Also, all problems of the optimizing the network, e.g., networks without using concentration measurements, one single network for all meteorological conditions, etc cannot be deal in a single study. The optimal networks dealing with some of these problems were partially presented in the PhD thesis of Kouichi (2017) and will be presented in separate publications.*

Comment 8. The study also discusses about weights which they, later, referred as visibility functions highlighting prior informations regarding emissions. However, authors never mention "why they could not determine a criterion based on just visibility weight functions"? Which could be far relevant and independent to the measurements.

Reply: *The method that we described to assure the optimization is not unique, it is possible to use the visibility as optimality criterion and it is a different approach. In any case, we mentioned that the renormalized errors criterion is the unique cost function that can be used to assure the design in such problem configuration. The optimization approach only based on the visibility weight function was also performed as another research problem in the PhD thesis of Kouichi (2017). Dr. Singh is well aware of this study and corresponding partial results as he was also present in the final PhD viva presentation of Hamza Kouichi.*

Comment 9. It is not clear why they could not find a common optimal network which could work in all the trials for point source retrieval?. The original network of 40 receptors was already working in all the trials irrespective of model errors and varying meteorological conditions. It is useless to propose different configurations based on different meteorological conditions since meteorology can never be constant in a real scenario. The different configurations for different trials again highlight subjectivity of their approach. Thus, the study do not bring any significant outcome regarding the optimization of receptors.

Reply: *As we clarified before (see first reply in page 2 / case of permanent static network), finding a common optimal network which could work in all the trials is a different optimization problem, also an adequate optimality criterion (entropic criterion extended for several meteorological situations) is defined by Kouichi (2017). Dr. Singh is well aware of this study progress and corresponding partial results as he was also present in the final PhD viva presentation of Dr. Hamza Kouichi. We remind, this study is specific to emergency situations where the meteorological conditions can be known in real time and don't varying* *significantly (it is assumed as stationary because the problem of optimization in urban environment is very complex and this is our first tentative in this framework).*

Comment 10. How do you describe physical features and efficiency or quality of the reduced configuration?. This is never mentioned in the results and discussion. The discussion mainly involves only source retrieval.

Reply: *We analyzed qualitatively (structures of the optimal networks in the instrumented area) and quantitatively (errors in source reconstruction) and the results showed that no trend is obvious thus proves that the problem of sensors networks optimization in urban environment is not trivial also the reduction of an original network achieved successfully and the performance for source reconstruction is maintained.*

Comment 11. Why their optimization always results in finding most of the sensors (5-6 detectors in the reduced configuration) close to the source location? It was never explained in the text. Does your optimized choice of receptors depends significantly on the receptors closer to the source location?. If yes, then what is use of optimizing since you will never know the source in accidental scenarios?

Reply: *Most of the sensors are selected by the SA close to the source location and this tendency is logical because these sensors make the area around the real source well visible from the network, nevertheless this doesn't guarantee a correct reconstruction of the source. As examined by Kouichi (2017), in some cases a limited number of sensors close to the source are not enough also adding sensors to a 'key configuration' don't improve the precision in source parameters estimation thus prove that the reduction of the number of sensors is justified. We remind that this study is for a specific need where a priori information (i.e. the measurements) is available and the network are optimized to be deployed in emergency situations.*

Comment 12. Why signal to noise ratio is not shown for all the reduced configurations? and it should be compared with the original network?

Reply: *Can you please clarify what do you mean by 'signal to noise ratio' in this context?*

Comment 13. The authors have simply described the errors in retrieving the location and intensity of the source. The responsible reasons behind it were never explained?. This shows that authors are just interpreting the retrieval rather than really analyzing the results.

Reply: *This comment is similar to the comment n°10 so we conserve the same responses.*

Comment 14. What is the role of weight function in your reduced configuration?. Does it have any effect on the systems observability and how it do affect your retrieval?

Reply: *Fundamentally, the role of the weight function in the renormalized data assimilation is minimizing the over interpretation of the observation, concerning the optimal networks no evident trend is relieved this confirm the complexity of such problem.*

Comment 15. Why did you describe vectors on the figures of the source retrieval?. While it seems that you are retrieving source parameters in a weighted least-squares framework?. It was never explained in the results that what is the impact of reducing the receptors on the retrieved general source vector?.

Reply: *The source vector* ***s*** *is not described separately but analyzed with the visibility field obtained by the optimal networks and for each trial of the MUST experiment. The goal is to assure a qualitative examination and to validate the fact that the optimal network covers correctly the source position. Also to confirm that in the monitored area only one punctual source is detected, in the figures by analyzing the level in the source vector we confirm that the maximum is unique so the estimated source after the reduction of the original network size is physically coherent.*

Comment 16. A general choice of using a weight matrix in a least-squares methodology is measurement error covariance matrix. Authors did not justify how could they utilize matrix Hw as an alternative to measurement covariance matrix?. In addition, the Hw matrix is not a diagonal matrix which means that using Hw as a weight matrix will induce unphysical correlations among receptors which could be false as well. Did you analyze their impact on source retrieval?, If not, then why and how could you use them directly? Perhaps, you could assume an unity matrix. If not, why?

Reply: *As explained by Issartel et al. (2012), classically, the least squares are weighted using the covariance matrix (Hw) of the measurement errors. However, in practice, this matrix cannot be determined for the prevailing part of these errors arising from the limited representativity of the dispersion model. Issartel et al. (2012) proposed an alternative weighting based on a matrix Hw introduced by Issartel et al. (2007), that is related to a unified approach of the parametric and assimilative inverse problems corresponding, respectively, to identification of the point of emission or estimation of the distributed emissions. The weighting was shown to optimize the resolution and numerical stability of the inversion (Issartel et al., 2012). The importance of the most common monitoring networks, with point detectors at various locations, is stressed as a misleading singular case. As discussed by Issartel et al. (2012), it is possible to understand a drawback of two classical choices of Hw as the identity matrix, associated with the ordinary norm, or as the diagonal covariance matrix of noise supposed to be uncorrelated in the various measurements. The justification to utilize the matrix Hw is proposed and given in Issartel et al. (2012). A brief discussion about the justification is presented in the revised version.*

Comment 17. Another issue is with the presentation of the methodology. The study begins by posing an under-determined inverse problem of estimating state of emissions while their objective was to optimize a reduced set configuration for point source retrieval which is an overdetermined inverse problem. Why authors did not begin by directly posing the over-determined problem of point source retrieval?. Why they have presented unnecessary details regarding more general inverse problem of estimation emission state if it was not their objective?. The presented details were already published by several researchers in the literature. Further, authors again formulate the point source retrieval problem in a weighted least-squares sense. Why?. Why two different methods were presented for the same problem?.

Reply: *Before presenting the optimization methodology a brief mathematical formulation of the renormalisation technique is presented for the simple reason that we cannot define the optimality criterion without presenting its origin and its physical signification. If we present directly the adequate cost function (i.e. normalized errors) this cannot be appropriate for readers that don't have any information about the renormalisation method. Concerning the* *'detail' of point source estimation simply because for the quantitative analyses (i.e. performance in source parameters estimation) we use this method so it is logic to present this 'detail'. However, as suggested, this part is reduced subsequently in the updated manuscript.*

Comment 18. Why do you need to compute a general vector s of state of emissions?. The objective was just to estimate point source parameters which could be estimated with the weighted / non-weighted least-squares method?. Please clarify?.

Reply: *This comment is similar to the comment n°15 so we conserve the same responses.*

Comment 19. Again, in the results, figures highlights distribution of weights and vector s which was never related to their monitoring network optimization. Their presentation confuses the overall objective of the study. Do you propose an optimal design for point source retrieval or a general source retrieval?. The figures related to weights are never explained as why they were needed? or what information do they provide related to the monitoring arrangement?. The given explanation is just copy-paste from previous papers of the authors.

Reply: *This comment is similar to the comment n°15 & n°18 so we conserve the same responses. However, the figures related to the visibility function are discussed with respect to the corresponding monitoring networks in the updated version of the manuscript.*

Comment 20. Why authors did not compare the weights in comparison to their weights corresponding to the original receptors?.

Reply: *We compared the performance of the optimal networks in comparison to the original network this implicitly and indirectly inadequate the role of the weights for each network.*

Comment 21. Another issue is also related to the common base network among the 10 and 13 sensors network. Why their strong base network involves only 7 receptors? In general, the 10 sensors networks should be a subset of the 13 sensor network, if not then why?. Please clarify?. It is also surprising that in some trials the common base network involves only 3 sensors. This is unusual having so much variation in having common base sensors among 10 and 13 sensor network in trials. The authors should provide the reasoning behind?, not just mentioning the results.

Reply: *The analyses of the common structures (Skeleton) in the optimal networks confirm that the solution is not unique so more than one network can lead to a good estimation of the source parameters. This result is very important and is in coherence with the works of Kovalets et al. (2011) and Efthimiou et al. (2017) that confirmed for the same experimental data the best source reconstruction using 10 sensors is possible for 5 or 10% among a significative set of randomly networks.*

<u>Specific comments:</u>

1. Abstract, Page 1, line 7. The sentence "The optimal networks in the MUST urban regions enabled ...". Rephrase the sentence. How could an optimal network enable a reduction?. I would like to mention again that the reduced set of receptors were never proved optimal.

Reply: *The sentence is rephrased for more clarity in the updated version. However, other part of this comment is similar to the general comments n°2 & 5 and some evoked points in the introduction so we conserve the same responses that we clarified before.*

2. Abstract, Page 1, line 11. The sentence “This study presents first application of the renormalization data assimilation approach for the optimal network design : : :..” is overstated and wrong. I could not find where and how did you apply renormalize data assimilation for optimal network design. Renormalize assimilation is only for retrieving the source parameters. I do not see in the text, how it could retrieve the reduced set of receptors. Also, you have interpreted a least-squares framework without justifying their inherent equivalence and choice of parameters with respect to the renormalization. Why?.

Reply: *We modified this sentence in updated version, however, the late part of this comment is similar to more than one comments and some evoked points in the introduction so we conserve the same responses. We hope that after the clarification, the aim and the presented methodology are now clear. A brief discussion about the justification of the weighted least-squares with respect to the renormalization framework is presented in the revised version.*

3. Page 1, line 18, the sentence “However, pre-deployment of these limited number of sensors : : :..”. Please clarify, how could a pre-deployment of sensors helps to achieve maximum information from set of noisy concentration measurements. The objective of pre-deployment of sensors is to have maximum a priori information regarding state of emission and to correctly capture the data while extracting and utilizing information from the data is the final task of data fusion techniques.

Reply: *This comment is similar to more than one comment and some evoked points in the introduction so we conserve the same responses.*

4. Page 2, line 2. The sentence “detection of an unknown continuous point source’s parameters ...” is wrong. How could you detect point source parameters? They are rather retrieved or estimated.

Reply: *We agree with this comment and accordingly the sentence is modified.*

5. Page 2, line 12. See the sentence “The establishment of an optimal network requires...”. Why do you think that for an optimal network it requires availability of concentration measurements?. Please justify? Measurements may be required for the evaluation or validation but for establishment a network can be made with the meteorology and dispersion model.

Reply: *This comment is similar to more than one comment and some evoked points in the introduction so we conserve the same responses. This point was explained earlier in detail.*

6. Page 2, line 20, See the sentence “This approach includes the geometric and flow complexity inherent : : :..”. I do not think if there is any inverse approach which includes such things for optimization process. The flow variables are accounted through the model, perhaps in the inverse approach in the form of sensitivities which is also derived from adjoint model. All the STE approach can include such information from model.

Reply: *The approach term written here doesn’t mean to refer the inversion or STE approach only. It refers to the whole methodological approach to optimize the network by coupling the optimization techniques, inverse tracers transport modeling and Computational Fluid Dynamics. It is modified to avoid the confusion.*

7. Page 2, line 26. What is “regularized norm square”. I do not think Sharan et al., 2012 have included such terms.

Reply: *The sentence is modified.*

8. Page 3, lines 3-5. Issartel, 2005, Sharan et al., 2009, 2012 and Kumar et al., 2015b, do not discuss any iterative algorithm to minimize the difference between observed and modeled concentration.

Reply: *The sentence is modified.*

9. Page 3, line 8, “does not required”. Please correct the sentence.

Reply: *Corrected.*

10. Page 3, lines 16-17, Kumar et al. (2015b, 2016) do not provide any extension to renormalized inversion. It was just an application with CFD model.

Reply: *Modified.*

11. Page 3, lines 22-29. The authors defined the objective to determine optimal network but never achieved. In line 23, “A methodology was proposed : : :: : :.”. If the objective was to better characterize the source, why one need to reduce the number of receptors. The reduction of receptors simply refers to the reduction of information regarding the observability of state of emissions. In line 26, “For this purpose : : :., but with comparable information”. Where do you show in the manuscript that the reduced information is comparable to the original network. In line 27, “This work explores with two requirements : : :...”, What does it mean, there is no movement of sensors. You have performed only selection of sensors.

Reply: *This comment is similar to more than one comment and some evoked points in the introduction so we conserve the same responses.*

12. Page 4, line 2, please correct “concentrations measurements”.

Reply: *Corrected.*

13. Page 4, line 4, please correct “an horizontal plane”.

Reply: *Corrected.*

14. Page 4, lines 8-10, The sentence “This study deals with linear relationship, as except from the nonlinear chemical reactions : : :..” is wrong. Most of these process are nonlinear in your case due to complex flow structures.

Reply: *This statement was based on the cited reference and we will verify it again and remove/correct it accordingly.*

15. Page 4, line 26, citing Kumar et al., 2016 is not appropriate. Please cite appropriate reference.

Reply: *We will check and correct the appropriate reference if needed.*

16. Page 4, lines 28-30, I understand that the inverse solution from Eq. (2) will lead to peaks at the grid cells coinciding with the measurement cells. This is obvious since the sensitivity matrix has peaks at the measurement cells which are reflected in the inverse solution. However, the difficult part to understand is "why do you call these large values of sensitivities at measurement cells an artificial information? Or a virtual/unphysical reality?". The peak at measurement cells is obvious since the concentration is always maximum at source location and in adjoint computations, you have replaced your measurement cells as source. Please clarify.

Reply: *These points were already clarified in many papers of Dr. J.-P. Issartel (main developer of the Renormalization inversion theory) and also in some other papers of his coauthors including Dr. Singh. In fact, this was one of the main force to the development of the renormalization inversion technique for source estimations which Dr. Singh has also used a lot in his papers.*

17. Page 5, line 5, Why do you think that normalizing peaks in the sensitivity matrix with weights will cure the peak problem. I mean, even if you normalize peaks (infinitely large value) by some nonzero weight values, it will not change anything.

Reply: *We don't understand this comment can you please more clarify?*

18. Page 5, line 9, citing Kumar et al., 2016 is not appropriate. Please cite appropriate reference.

Reply: *We will check and correct the appropriate reference if needed*

19. Page 6, line 3, "but with comparable information". It is never done in the study.

Reply: *What do you mean by" It is never done in this study"? In evaluation of the optimized networks, we have compared the source estimation performances of the obtained optimal networks of reduced number of sensors with the original network of 40 sensors. The obtained optimal networks provided comparable estimates of the source parameters with the estimates obtained from the original network of 40 sensors.*

20. Page 6, line 4, "delivers maximum of the information". It is never shown in the study.

Reply: *It is statement that refers to define one of the objective of an optimized monitoring network to deliver maximum of the information in respect to the source estimation from reduced number of sensors in an optimized network. We do not think any wrong in this sentence.*

21. Page 6, line 11, why cost function is defined according to Hw norm. Please clarify?.

Reply: *Because our approach is based on the renormalized data assimilation method as an inverse technique. It was explained in several studies, originally discussed in a study by Issartel et al. (2012). It is more clarified in the updated version of the manuscript.*

22. Page 6, line 12. Check sentence "As the cost function is convex, its minimum value must correspond to the maximum intensity of the source". WHY?. Please clarify?. The intensity of source here is q. Check your mathematical expressions. You will obtain an estimate of q for each location vector x. In such case, the maximum value of q in the domain may go to infinity

in case where weights w are very small or zero. It is not necessary that the maximum value of q will occur at the minimum of the cost function or at the source location.

Reply: *We agree with Dr. Singh's remark about the cost function which was mistakenly stated that way. This sentence is removed/modified from/in the updated version of the manuscript as it doesn't affect the subsequent part of the methodology.*

23. Page 6, line 15. This is not clear how you can utilize matrix H_w in place of measurement error covariance matrix in Eq. (9). This is not obvious. Justify?.

Reply: *As it was explained in several studies, originally discussed in a study by Issartel et al. (2012), it is more clarified in the updated version of the manuscript.*

24. Page 6, line 16, why two notations q and q0 (section 2.4) are utilized for the same representation?

Reply: *Thank you for pointed it out. We have corrected it to the same symbol throughout the manuscript.*

25. Page 6, line 19, "conditions of maximum intensity: : :.". It seems that authors have difficulties in understanding mathematics. Why equating first order derivative to zero will give maximum intensity?

Reply: *The sentence is corrected. It is just a simple derivative test of a function to find its critical points that determines whether each point is a local maximum, a local minimum, or a saddle point. Here, equating the first order derivative to zero leads to an estimate of the source intensity.*

26. Page 6, line 25, The expression for equation (13) is wrong. Please correct it.

Reply: *Corrected.*

27. Page 6, line 26. The mathematical expression is wrong.

Reply: *It seems to be correct; however, we will verify it again and modify if needed.*

28. Page 6, line 27. How do you guarantee the global minimum in SA algorithm?.

Reply: *This comment is repeated again and similar to more than one comments and some evoked points in the introduction so we conserve the same responses.*

29. Page 7, line 16, "average of the difference of the cost functions calculated for a large number of cases". How did you compute it?

Reply: *This is for estimating the starting 'temperature', the procedure consists in generating a set of randomly networks of same size then in evaluating the quality of each network using the renormalization algorithm.*

30. Page 7, line 19, "An equilibrium is reached : : :..". This means that the SA algorithm stops when cost function becomes constant. Then how do you prove global minimum?

Reply: *This comment is similar to more than one comments and some evoked points in the introduction so we conserve the same responses.*

31. In combinatorial optimization problem, it is not necessary that SA will provide the same solution or same set of receptors as the converged solution. In this case, how did you choose the solution?.

Reply: *This comment is similar to more than one comments and some evoked points in the introduction so we conserve the same responses. All the details about the SA and haw it is employed in this context are available in Kouichi (2017).*

32. Page 8, step 2 and step 3 show that the choice of receptors depends on the measurements. Thus, there is no optimality in network. The authors have simply chosen the reduced set of receptors based on good retrieval results which is biased.

Reply: *The question is repeated again and the answers to these points are already given to his previous comments.*

33. Page 9, lines 8-11. These are not clear. What do you mean by near-optimal network?. What are the conditions for "near overall optimum condition".

Reply: *As explained before, all this details are available in the cited references in the literature.*

34. Page 11, line 11, "The network optimization process : : :..". This shows that the choice of receptors are biased towards the model-measurement accuracy.

Reply: *Again the same question is repeated and so we conserve the same responses as given earlier.*

35. Why the configuration of networks should vary based on meteorological stability conditions.

Reply: *This is evident because the arrangement of the sensors in the monitored area should be according to the wind direction for example. It is clear that we cannot place sensors in regions were no measurements will be collected. We remind that the objective of this study is not to optimize a permanent static network.*

36. Page 12, lines 8-9. "These results exhibit that the SA : : :..". How it prove optimality of monitoring network?

Reply: *The answer is already given to this question as this comment is similar to more than one comment and some points in the introduction.*

37. Page 12, line 19. "were observed independently of the number of sensors". Why?. Please clarify?.

Reply: *This is showed in Table 2. However, the sentence is modified to avoid any confusion.*

38. Page 12, line 20, "larger location errors do not : : :.". Why?. Please clarify?

Reply: *This is noted in the results.*

39. Page 12, line 23, "a large number of sensors are close to the source positions ..". Why so?. Please justify?.

Reply: *This is noted in the qualitative analyses. This point is already clarified in response to a similar earlier comment.*

40. Page 12, line 29, "visibility functions have significant levels : : :..". What does this mean?.

Reply: *This is noted in the qualitative analyses please see figures 4 & S2.*

41. Page 13, line 6, "increase in the number of sensors in a network has little influence on the accuracy: : :." Why? Please clarify?

Reply: *This is clear in the text because by adding sensors in a performance network can more add measurements and model errors in the methodology which may affect the estimation of the parameters of the source.*

42. Page 13, lines 8-10, "In some trials, it was also noted : : :..not necessary benefial." How could you justify this?. In fact, how did you evaluate if information added by a sensor is fruitful or not? If just based on accuracy of source retrieval, then it is illogical? If an information added by a new sensor is not beneficial then why it should increase the location error?. Also, how location error may decrease with decreasing the number of sensors? You can say this just because you are looking at source retrieval estimates. However, reducing the receptors will make the source retrieval unstable and more sensitive to the noise.

Reply: *We tried to explain these points in this section of the manuscript as it was observed in some trials. The distance of an estimated source to real source was observed to decreases with an increase in sensors number and also with the decrease number of sensors in some other cases. At this moment, we do not have a theoretical explanation for this behavior. However, it is also logical that increasing the number of the sensors after a number may not always provide the best estimation because with addition of the more no. of sensors, we also add more model and measurements errors in the estimation process. These errors may affect the source estimation results in some trials. As pointed out by Dr. Singh, reducing the receptors will make the source retrieval unstable and more sensitive to the noise, this problem may also required a theoretical justification of the minimum number of sensors needed for source estimation. And it is beyond the scope of this study. However, these limitations are now explained in the updated manuscript.*

43. Page 13, line 17, What do you mean by ": : : diversity of structures independently of the number of sensors." You computation is based on fixed number of sensors and there is no discussion of diversity. However, in the following explanation, this is not understandable that why you have different number of common networks in different trials?. It seems that optimized choice of receptors is not really optimized. Otherwise, why in some trials (1, 11), only 3 sensors are found as a common base?. Also, even having 7 receptors as common in 10 and 13 sensor arrangement can not be called a strong common base. There is no explanation why all the 10 sensors are not subset of 13 sensor network. If, it was really optimized that it must have been. If not so, then please explain why?

Reply: *This comment is similar to the major comments n°21 so we reserve the same responses that we clarified before.*

44. Page 13, line 22, "The performances do not systematically converge independently to the size of the networks". What does it mean and why it does not converge?. Further, it is

mentioned that in trial 1, 13 sensor network leads better performance than a 10 sensors network and algorithm leading to near global optimum is contained in the 13 sensor network. This really proves that fact that you choice of receptors is biased by your source retrieval which is not the objective of an optimal network.

Reply: *This comment is similar to more than one comment and some evoked points in the introduction so we conserve the same responses. However, we wish to point out again that the choice of the receptors were not determined based on the source estimation. These optimal sensor locations were independently estimated based on the measurements, adjoint functions, and SA algorithm. The source estimation is performed only to validate the performance of obtained optimal networks.*

45. Page 13, line 27. Why there is no common trend in skeleton network observed in several trials?. There must be at least with similar flow conditions. If not, justify?

Reply: *This comment is similar to more than one comment so we conserve the same responses.*

46. Page 13, line 29, "optimal networks can satisfy conditions of a near overall optimum (to be minimized)". What are the near overall optimum conditions?. If you are referring "minimization of cost function". This is a wrong approach.

Reply: This comment is similar to more than one comment. *Throughout the text we mentioned that there is no guarantee in the convergence of the SA and we confirmed (based on the adequate bibliographical references) that the obtained network can be the optimal or the near optimal one. This complex combinatorial optimization approach retained a big attention in the literature and the SA is selected following the recommendations from more than one works of networks optimization in the framework of the atmospheric dispersion context (Abida et al, 2008; Abida et Bocquet, 2009; Jiang et al, 2007; etc.). Nevertheless before utilizing the probabilistic algorithm SA, we tested its performance in comparison with the Genetic Algorithm GA of evolutionary research technic (Kouichi, 2017).*

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