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DATA ASSIMILATION FOR URBAN NOISE MAPS GENERATED BY A META-MODEL

Antoine Lesieur¹

Vivien Mallet¹

Pierre Aumond²

Arnaud Can²

¹ INRIA, LJLL, Sorbonne Université, F-75012 Paris, France

² UMRAE, Univ Gustave Eiffel, IFSTTAR, CEREMA, F-44344 Bouguenais, France

antoine.lesieur@inria.fr, vivien.mallet@inria.fr,

pierre.aumond@ifsttar.fr, arnaud.can@ifsttar.fr

1. INTRODUCTION

A regulatory noise map is a 2D representation of the equivalent average noise level field over an urban area. In methods such as CNOSSOS-EU, the emission algorithm is based on a discretization method, each road section is described by a set of ponctual sources whose intensity depends on the road, traffic (density and speed) and weather data, and the propagation algorithm computes the transmission path between the sources and the receivers. When the propagation phase is applied at a city level, the high number of sources and receivers makes this method computationally expensive. It is not suitable for the generation of hourly or even daily noise maps, the computation time would be too energetically intensive. In addition, The accuracy of the noisemap computation is limited by the quality of its input data. Traffic data, is only measured on a restricted area and some roads are assigned with a rough approximation for their traffic data. Keeping track of the noise level helps to better evaluate sleep disturbance and noise annoyance.

The use of a network of microphones spread across a study area has shown some results to infer a noisemap from ponctual noise data. However, There were few attempts to merge the sensors with the simulated map conducted to compute a spatial interpolation in order to estimate the noise level in area with no noise sensor [1].

As part of the CENSE project, the objective of this work is to develop a strategy to display accurate hourly noisemaps, starting with:

- An open source noise map simulator,
- Annually averaged input data for the simulation,
- Hourly traffic and weather data from local sensors,
- A network of microphones spread across the study area.

The approach presented here uses both model and observation data and then allows a much more dynamic approach where 1 h noise level can be evaluated. This work proposes a two steps approach:

- Meta-modeling: quickly approximates the noisemap output of the model with a meta-model. A meta-model is a way to estimate how a noisemap behaves

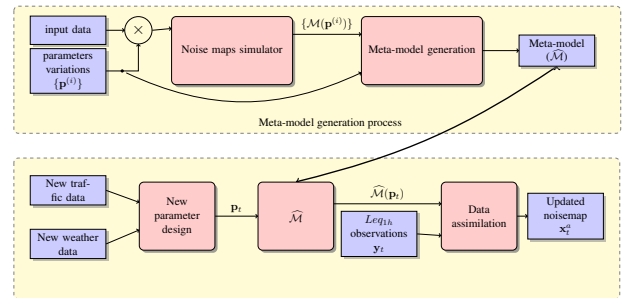


Figure 1. functional diagram of the data assimilation process, each significant block is described in the indicated paragraph

regarding some small variations of its parameters. Meta-models for noisemaps have been studied in a previous work [2]

- Data assimilation: Provides an analysis map which combines both the data from the simulation and the data from the observation.

A validation phase will be executed with a leave-one-out cross validation method.

2. DATA ASSIMILATION

The solution which will be used in this work is called BLUE, for Best Linear Unbiased Estimator. Starting with the output of the meta-model, a correction layer is superposed, which depends on \mathbf{B} , the covariance matrix of the error between the simulation at the observation points and the observed values, \mathbf{R} , the covariance matrix of the observation error and the real time estimation error.

At each timestep, a so-called background map $\mathbf{x}^b = \widehat{\mathcal{M}}(\mathbf{p}) \in \mathbb{R}^n$ is computed as shown in the functional diagram in figure 1, it is an estimation of the real state noise level distribution field \mathbf{x}^t . It is impossible to know the exact value \mathbf{x}^t whether from the simulator or from the sensors. In addition a set of observations $\mathbf{y} \in \mathbb{R}^p$ is given. Let:

- $\mathbf{H} \in \mathbb{R}^{p \times n}$ be the observation matrix which maps \mathbf{x}^t to the observed values \mathbf{y} , so that \mathbf{y} is the observation of the state $\mathbf{H}\mathbf{x}^t$.

- e^b be the simulation error, e^o be the observation error and \mathbf{B} and \mathbf{R} their respective covariance matrices.

Based on \mathbf{x}^b , \mathbf{B} , \mathbf{y} , \mathbf{R} and \mathbf{H} , an analysis state vector \mathbf{x}^a is computed as the so-called “Best Linear Unbiased Estimator” which is linearly dependant on \mathbf{x}^b and \mathbf{y} , has unbiased error $e^a = \mathbf{x}^a - \mathbf{x}^t$, and has a variance with minimum trace. This estimator is uniquely defined as

$$\mathbf{x}^a = \mathbf{x}^b + \mathbf{K}(\mathbf{y} - \mathbf{H}\mathbf{x}^b) \quad (1)$$

where

$$\mathbf{K} = \mathbf{B}\mathbf{H}^T(\mathbf{H}\mathbf{B}\mathbf{H}^T + \mathbf{R})^{-1} \quad (2)$$

3. RESULTS: CROSS VALIDATION

An experiment has been conducted in an area of Paris, France of 3 km² with a grid of 8456 receivers and a network of 16 observation points on a time period of 9 months in 2015.

The leave-one-out cross-validation consists in removing the observations of a given microphone from the data assimilation process. Only the observations from the other microphones are used to correct the noise level distribution. This procedure is carried out for all microphones, one by one, only one microphone is removed at a time. At the removed station, the meta-model performance is compared to the performance after assimilation of the observations of the other microphones. This enables to check whether the assimilation properly distributes in space the corrections that originate from the observed locations. The cross-validation evaluates the effects of the data assimilation method at locations without any observations.

Figure 2 shows how the correction due to the observations propagates across the study area. It follows the intuition that the more an observation point is overestimated (resp. underestimated) the more its neighborhood will have a negative correction (resp. positive).

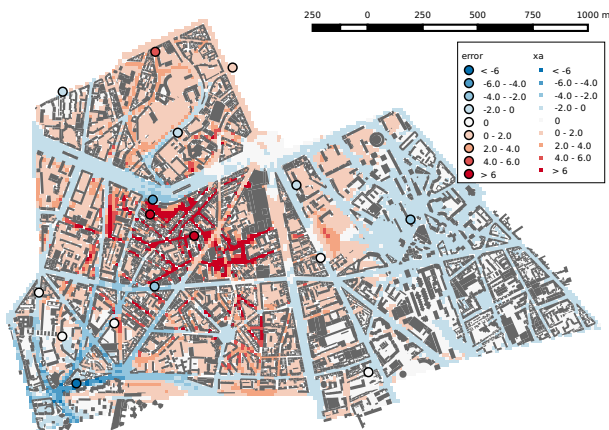


Figure 2. This map displays an example of the correction given by the observations at a given time.

This reduction of the variance is noticeable in figure 3 where the root mean squared error is displayed at each

month for each step of the data assimilation process. At each step the RMSE is reduced and goes from an average of 3.6 dB(A) with the annual simulation only (up to 4.2 dB(A) during the month of August) down to an average of 2.9 dB(A) at the final stage.

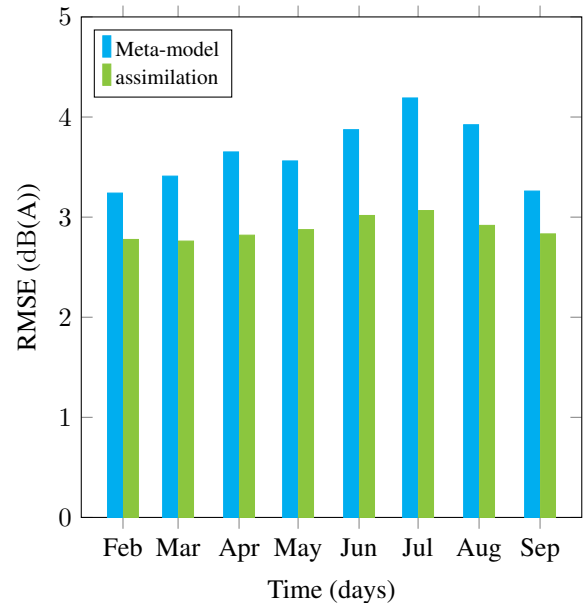


Figure 3. RMSE in dB(A) of the error between the observation and the background (blue) or the analysis in leave-one-out cross-validation (green)

4. CONCLUSION

The data assimilation applied to noisemaps generated through a meta-model favorably improves the performance of the generated noisemap (from an average RMSE of 3.85 dB(A) to 2.78 dB(A)) and allows to grasp the hour to hour evolution of the noise level distribution across the study area.

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