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Creating Dynamic Maps of Noise Threat Using PL-Grid Infrastructure

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The paper presents functionality and operation results of a system for creating dynamic maps of acoustic noise employing the PL-Grid infrastructure extended with a distributed sensor network. The work presented provides a demonstration of the services being prepared within the PLGrid Plus project for measuring, modeling and rendering data related to noise level distribution in city agglomerations. Specific computational environments, the so-called domain grids, are developed in the mentioned project. For particular domain grids, specialized IT solutions are prepared, i.e. software implementation and hardware (infrastructure adaptation), dedicated for particular researcher groups demands, including acoustics (the domain grid "Acoustics"). The infrastructure and the software developed can be utilized mainly for research and education purposes, however it can also help in urban planning. The engineered software is intended for creating maps of noise threat for road, railways and industrial sources. Integration of the software services with the distributed sensor network enables automatic updating noise maps for a specific time period. The unique feature of the developed software is a possibility of evaluating auditory effects which are caused by the exposure to excessive noise. The estimation of auditory effects is based on calculated noise levels in a given exposure period. The outcomes of this research study are presented in a form of the cumulative noise dose and the characteristics of the temporary threshold shift.

Keywords: noise, dynamic noise map, reverse engineering, grid computing.

1. Introduction

Environmental noise that occurs in the urban areas is known to impose a threat to human health (Engel, 2004; Kompala, Lipowczan, 2007; Kucharski, 2007; Popescu, Moholea, 2010). The effects of this harmful factor can be observed in various aspects of human life. In 2002, in order to assess the noise pollution threat, the European Parliament along with the Council of the European Union issued the legal foundation for undertaking urban noise monitoring in all Member States, i.e. "*European Directive 2002/49/EC*" (2002) on assessment and management of environmental noise. The main aim of this Directive is to provide a common basis for assessing the noise problem across the EU. It commits the EC-member states to evaluate the noise impact for all agglomerations, for all major roads and major railways and for all major airports within their territories and to present in the form of strategic noise maps. Until 30 June 2007 noise maps had to be prepared for all cities, or more precise, for agglomerations with more than 250,000 inhabitants. Subsequently, noise maps of municipalities of over 100 000 inhabitants should have to be drawn up by 30 June 2012.

The release of the guidelines have raised numerous initiatives in order to asses an acoustic climate in European cities. Technical implementations are based on two main methods, namely noise measurements and noise pollution prediction. The first approach utilizes a grid of noise measuring devices which are registering sound pressure level values and associated data. Such systems have been deployed in several European cities, for example in Lille, France (Chopard *et al.*, 2007) where over 80 acoustic monitoring stations cover the urban area. In the second approach noise distribution is estimated based on noise source and propagation model. Systems based on this concept are implemented in most of large European cities. For instance the city of Gdansk, Poland developed strategic noise maps for road traffic, railway, tram and air traffic noise calculated according to the L_{DEN} and L_N noise indexes (2013). Developed acoustic disturbance maps are utilized to assess the threat citizens are exposed to, and introduce noise reduction strategies in critical locations of the urban area.

Computation of noise map for large city areas would result in high calculation time. To solve that problem the software for calculating road and railway noise on supercomputer platform was proposed and developed (Szczodrak, Czyzewski, 2009; Czyzewski *et al.*, 2011; 2012). The procedure of preparing the noise map requires knowledge of source data and propagation environment. Considering source models, we need to note that road and railway noise are the most frequent sources of disturbance that people are exposed to. The achievements of European Harmonoise and Imagine projects, providing a description of road and railway models (Jonasson, 2007; Salomons *et al.*, 2011), were utilized during the implementation of the software devoted to work on supercomputers (Szczodrak, Czyzewski, 2009; Czyzewski *et al.*, 2011; 2012; Kotus *et al.*, 2012). The Harmonoise model was intended to unify all the methods prepared and utilized by European Union state members.

In this paper we propose to combine the short-term noise measurement data together with model-based calculations in order to provide an accurate up to date noise map. Recently, an installation of acoustic sensors which measure noise level was conducted in Gdansk. These devices provide information that can be projected to the source model and update it by finding the inverse transform.

The calculations were conducted on the supercomputer platform which is a part of the Polish Grid Infrastructure. The infrastructure was prepared within the PLGrid Plus project in which the most important task is to identify and establish specific computing environments, the so-called domain grids. This includes solutions, services and extended infrastructure (including software), tailored to the needs of various groups of scientists. The Polish Grid Infrastructure has been built to provide the Polish scientific community with an IT platform based on computer clusters, enabling research in various domains of e-Science. The infrastructure supports scientific investigations by integrating experimental data and results of advanced computer simulations carried out by geographically distributed research teams.

The work study presented in this paper was realized within the Acoustics domain grid. The aim of this domain grid is to provide efficient computational tools for the community of acousticians engaged in the noise threat reduction. Moreover, knowledge of noise and its influence on human health is popularized, since the outcome is presented in the form of noise map in the Internet accessible for wide spectrum of recipients.

2. Concept and Setup (location of sensors, map, measured quantities)

2.1. Location

For the experiments we have chosen an area where practically only road noise occurs as a source. Within the area of about 4 square kilometers, four sensors are deployed. Each sensor is continuously measuring sound

Fig. 1. Experiment localization, numbers denote measurement stations.

levels in the close vicinity of one road, which has the predominant influence on the obtained acoustic pressure values. There are three roads of a relatively high traffic flow (separate lane in each direction) and one road on which low traffic occurs. The map showing experimental setup is presented in Fig. 1. Roads encompassed by measurement stations are marked with colors.

2.2. Measurement system

The measurement data originates from the microphone setup built by Gdansk authorities. The network of acoustic pressure sensors have been deployed in the city area (Mioduszewski *et al.*, 2011). Sensors are installed on building facades. The measurement of the sound level is based on the "Backing Board" method developed by Fégeant (Fegeant, 1998). The principle of the method is to position a microphone flush to the totally reflecting surface. Such an approach allows for measuring sound pressure at any site with reflecting conditions similar to those produced by urban building facades. The measurement station is presented in Fig. 2.

Fig. 2. Measurement station.

For a source located on the same side of the microphone, Fégeant considered the total sound pressure level at the microphone as the sum of the incident, reflected and diffracted fields. On the hard surface, the incident and reflected fields can be considered as equal. In that case, the sound pressure level is doubled on the plate. This corresponds to the sound pressure increase of +6 dB (Berengier, 2012). Fégeant in his theoretical study determined a position of the microphone in the plate in such a way that the effect of diffraction can be minimized. The detailed discussion of results of measurements with this type of microphone including diffraction influence can be found in the literature (Memoli *et al.*, 2008). Due to fact that in our case the surface of the plate is much smaller than the surface of the façade we decided to neglect this effect.

Noise maps were calculated employing the supercomputer optimized software which uses Harmonoise source model and ray tracing method in propagation model (Szczodrak, Czyzewski, 2009; Czyzewski *et al.*, 2011; 2012). The process of creating dynamic noise map was performed in two stages. First, the propagation paths were obtained and attenuation on each propagation path was calculated. Assuming that geometry of the urban infrastructure does not change such attenuation data can be used for fast calculation of noise level in the designated city area. In the second step, the traffic data were united with the source model and total noise level in a grid of points was calculated based on previously obtained attenuation data. The traffic data were prepared for roads which have the main influence on the noise level measured by the monitoring stations.

Attenuations are calculated only once, but the second step can be repeated many times. The propagation model does not include a feature for calculating noise on building facades. The considered minimum distance to the building façade is 1 meter. The setup of the microphone is such that it measures sound level affected by the "façade" effect. Therefore, in order to maintain conformity with the model which calculates sound level in the free field, we obtain sound level according to Eq. (1) (Memoli *et al.*, 2008):

$$L_{\mathrm{free}} = L_{\mathrm{near}} - 3 = L_{\mathrm{facade}} - 6. \tag{1}$$

2.3. Measurements results

In the presented study the functionality of the dynamic noise mapping procedure was shown on the basis of one day measurement results (25.07.2011). The update time was set to one hour. For this purpose the A-weighted equivalent sound pressure levels calculated in one hour time periods were taking into consideration. The measurements results obtained in selected points are presented in Fig. 3.

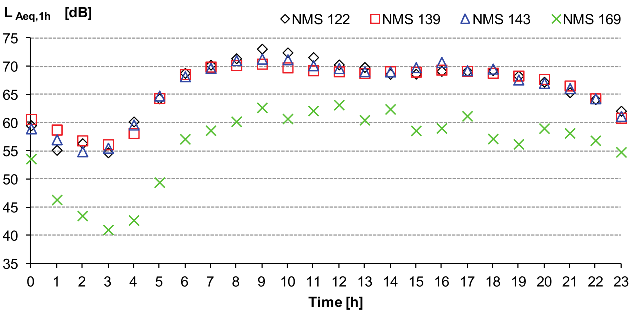

Fig. 3. Selected noise measurement results obtained by noise monitoring stations.

Noise levels in points 122, 139 and 143 were congruous. The essential differences were noticed for hours between 0–3 and 9–11 AM. Noise levels indicated by NMS 169 were relatively lower because the traffic flow on the nearest road was also relatively low. The presented real measurement data were used in the calculation of the reverse function. This procedure was described in detail in the next section.

3. Algorithm description

Typically, if we want to calculate the noise map for a given area, we need the input data for the noise source model. In the considered case, only road noise sources were taken into account. In consequence, we need information about: the number of vehicles per hour, type of road surface, type of vehicle, vehicle speed.

The employed noise monitoring stations did not deliver data about the road noise parameters. The missing data are calculated on the basis of the measured noise level. The reverse engineering technique is applied for this purpose. We assume that monitoring stations measure noise the main source which derives from the nearest road. To get the input data for the noise source model we need to calculate the number of vehicles on the basis of the measured noise level. Other factors of road noise source remain constant. The block diagram of the proposed methodology of the dynamic noise map calculation is presented in Fig. 4.

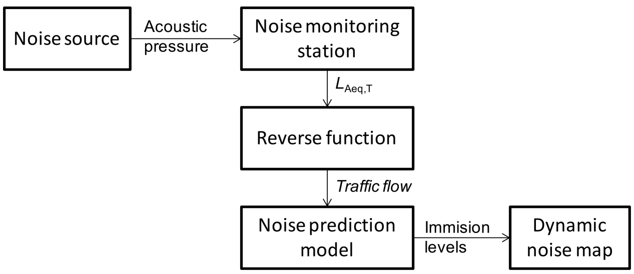

Fig. 4. Block diagram and data flow of the proposed methodology of the dynamic noise map calculation.

First, noise levels as a function of the number of vehicle per hour were calculated independently for all measurements points. Next, on the basis of these results the reverse function (RF) which can be used to determine the number of vehicles for a given noise level was calculated. The initial traffic volume on each road was adopted from the data obtained from the preexisting noise map of the city of Gdansk representing long-term averaged values. For monitoring stations impacted by noise originating from more than one road (or carriageway), the following methodology of evaluation of RF (reverse function) parameters was applied. A division of the traffic flow between each road was calculated. An assumption was made, that this division is generally stable. The noise level was calculated in the point where the monitoring station was located for diverse values of the traffic flow, taking into account the above given assumption. Consequently, the noise level measured by the monitoring station can be expressed as a sum of noise levels generated by each road. Based on obtained data, parameters of reverse functions were calculated. The traffic volume value varied maintaining the proportion of its intensity on each road. For example, according to the values shown in Table 1, row 5, the ratio of the traffic flow between roads 186 and 189 is 1.12.

It is important to emphasize that the noise level calculated in the first step include all propagation factors between the noise source and the measurement point, such as: distance, ground reflections, other buildings, sound attenuation in the atmosphere, type of the ground. It means that the reverse function also includes such factors during the computation of number of vehicles (traffic flow – TF) derived from the noise level. The model of the reverse function is given by Eq. (2):

$$TF = a \cdot (L_{Aeq,1\,\mathrm{h}} - K_{\mathrm{facade}})^b, \tag{2}$$

where a and b – constants depending on the type of road and position of the measuring microphone, $L_{Aeq,1\,\mathrm{h}}$ – A-weighted sound equivalent level for one hour time period, K_{facade} – correction of pressure doubling conditions, in considered cases the measuring microphones were mounted directly on the facade surface (equal to 6 dB).

Constants a and b are obtained for all measurement points. The constants values were determined using the method of least squares. Figures 5 and 6 present the process of selection of the RF parameters for a chosen road. The left charts in Figs. 5 and 6 show the results of calculation of the noise level in the localization of the measurement microphone. This result is obtained by the road noise source model integrated with the propagation model. A typical relation of the noise level change as function of the road traffic flow was obtained, this way. All other parameters of the source model have the following default values: speed 70 km/h (50 km/h

Table 1. Constants values of the reverse function for traffic flow calculation computed for all roads. The number of NMS and the average traffic flow were also presented.

NMS No.	122		139		143		169
Road No.	186	189	676	675	68	73	422
a	9.30E-23	8.25E-23	2.15E-23	2.30E-23	2.73E-24	2.73E-24	4.98E-18
b	1.37E+01	1.37E+01	1.41E+01	1.41E+01	1.45E+01	1.45E+01	1.12E+01
Avg. TF	398	353	731	784	780	780	85

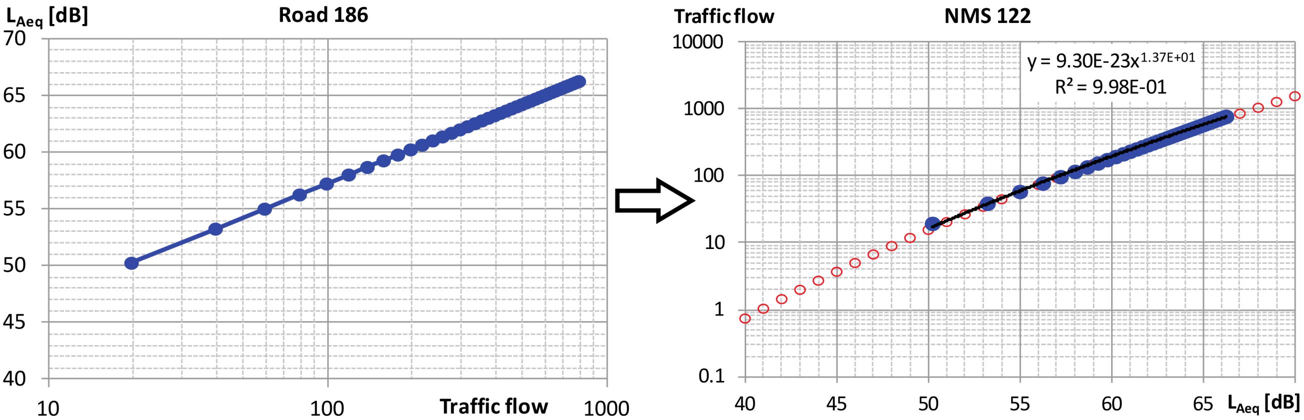

Fig. 5. Reverse function calculation for road no. 186 (Noise Monitoring Station no. 122).

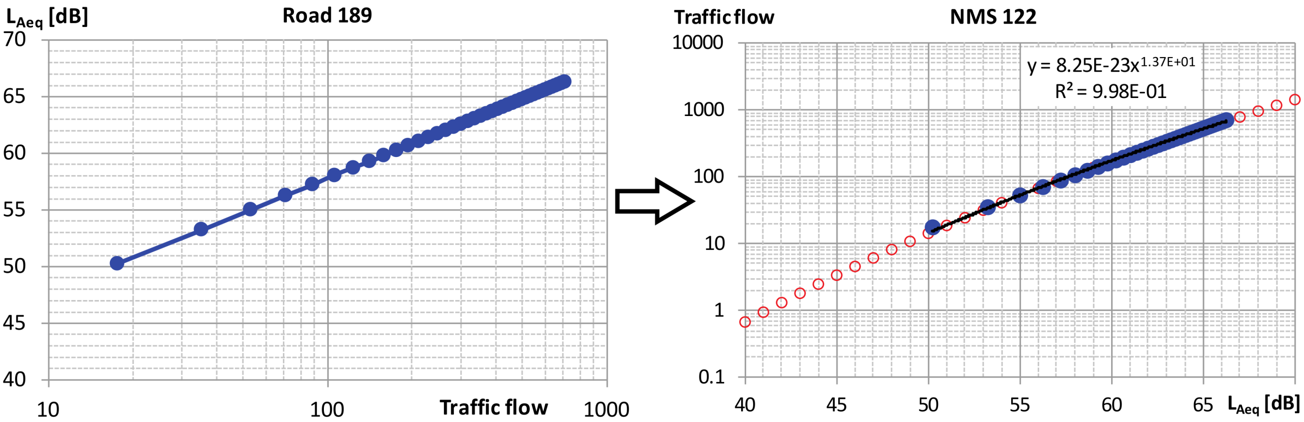

Fig. 6. Reverse function calculation for road no. 189 (Noise Monitoring Station no. 122).

for point 169), percentage of heavy vehicles – 2, 3, 4, 5 respectively for points 169, 122, 139, 143. During the experiments these values remained constant. Calculation of the reverse function requires exchange of function argument and value. The right side of Figs. 5 and 6 shows the resultant reverse function representing traffic flow dependency of the noise level. The use of the function type given by Eq. (2) and the least squares method allow for deriving constants a and b. In the considered case the values are respectively: $9.3 \cdot 10^{-23}$ and 13.7. Blue points in charts presented at the right side of Figs. 5 and 6 were calculated based on the measured noise level. Points marked with red circles denote values extrapolated with the obtained RF. The continuous line represents the graphical form of the function RF. Determination of model parameters was done for each monitoring station and all roads that affect measured noise level. In case of streets that consist of separated carriageways, the model parameters were determined for both carriageways, as both have influence on the noise measurement result. A series of simulations was done in order to calculate the noise level in the location of each monitoring station. Initial value of traffic flow was modified according to the scale factor α, which varied between 0 and 2. Table 1 presents calculated constants a and b for particular roads and carriageways and corresponding monitoring stations. Traffic flow data for roads not encompassed by noise monitoring stations were calculated separately for every time period. The calculation method relied on scaling the long-term averaged value of traffic flow for each road by global scale factor. This factor was obtained by computing proportions of traffic flow obtained by the reverse function to the long-term averaged traffic flow, for each road encompassed by the monitoring station, and then taking the mean value.

4. Experiments and results

The proposed methodology and the developed algorithm were used to prepare noise maps for the considered area in one hour time intervals. Maps for the area of 1650×1610 meters were calculated. The noise level was calculated in a grid of points spaced equally by 10×10 meters, what resulted in 26982 points. The following main parameters of the propagation model were set as follows: reflections of the 1st order, search ray 2 000 meters, reflected ray 100 m, the distance between following rays 2 degrees, and the building sound reflection coefficient 0.8. The ground type for the whole area was set to 10 000 kNsm^{-4} (representing hard ground) (Taraldsen, Jonasson, 2011). In the first stage (see Sec. 2.2), calculation was performed on 432 cores and took 2847 seconds. On the basis of the proposed reverse function and measured noise levels the workday traffic flow profile can be calculated. Several characteristics of the traffic flow for selected roads are presented in Fig. 7.

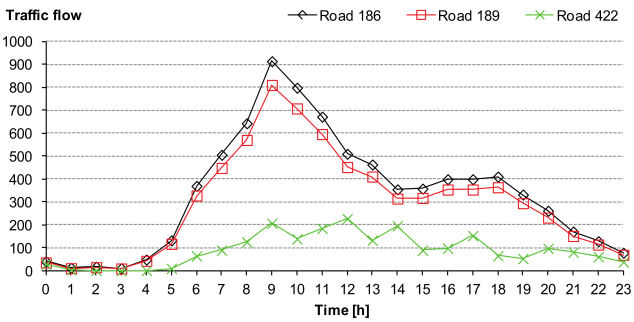

Fig. 7. Traffic flow calculated for selected roads.

As shown in Fig. 7, the traffic flow is relatively high on roads no. 186 and 189 (based on noise levels obtained by NMS 122). The road no. 422 has lower throughput because it has one lane in each direction (based on noise levels obtained by NMS 169). This is the reason of large difference in the traffic flow volume. The traffic flow data calculated for all considered roads were used to compute dynamic noise maps. The update time was one hour. The noise maps calculation can be time-synchronized with real noise measurement results. The final maps obtained for a various hours are presented in Figs. 8, 9 and 10. The range of noise pollution impact can be observed in detail.

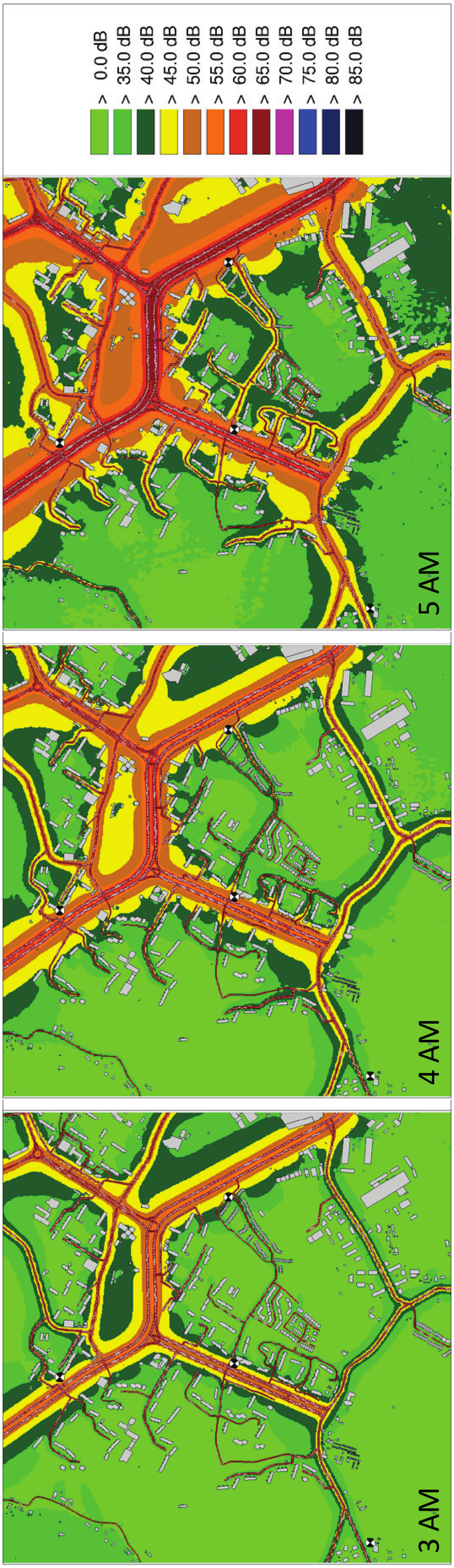

Fig. 8. Noise maps for 2011.07.25 (Monday), hours: 3 AM, 4 AM, 5 AM (from left).

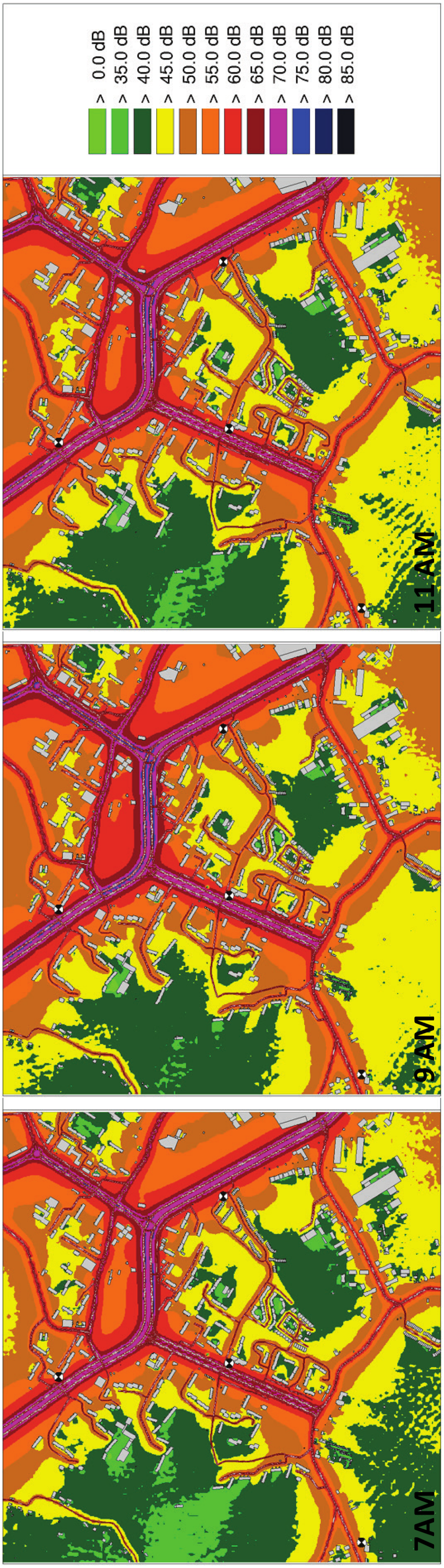

Fig. 9. Noise maps for 2011.07.25 (Monday), hours: 7 AM, 9 AM, 11 AM (from left).

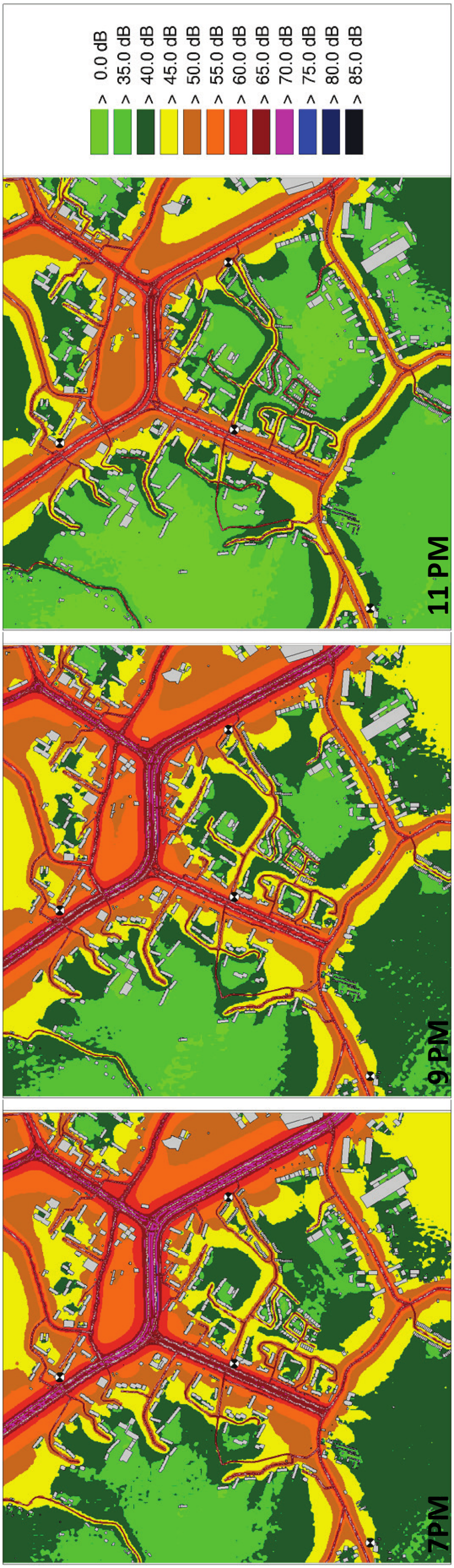

Fig. 10. Noise maps for 2011.07.25 (Monday), hours: 7 PM, 9 PM, 11 PM (from left).

5. Conclusions

As a result of the described work, the system for dynamic noise maps calculation employing supercomputing grid and sensor network was practically implemented, and tested. Implementation of the software for the traffic flow determination on the basis of acoustic climate measurements was performed. The calculated traffic flow data were used to automatically update noise source model. It was optimized towards working on the computer cluster, and thus accelerating noise maps generation process. Through a unique approach to the map generation process, dynamic noise maps may be presented to the public in a convenient and attractive manner.

The utilization of measured data allows for achieving unprecedented accuracy of short-term and long-term sound level distribution visualization. The achievement of the proper results of the model is conditioned by providing exact data of the traffic parameters, even though it cannot be guaranteed that computed levels are always reflect the real ones. Local sound events may have an influence on the total instantaneous noise level. The verification of sound levels based on a series of real measurements increases credibility of the simulation results. Employing the supercomputer allows for creating such maps in a reasonable time.

Future work could be aimed at applying sound recognition algorithms in order to identify sound events not related to the traffic noise. Moreover, the use of hardware devices for traffic flow measurements, which are currently being installed in the city, would help to achieve precise source model parameters.

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