Participatory noise mapping

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Abstract. Participatory sensing allows for a person-centric approach to gathering environmental measurement data with, in principle, high granularity in space and time. Here we report on a citizen science experiment for noise mapping a 1 km^2 area in the city of Antwerp using NoiseTube, a participatory sensing framework for monitoring ambient noise. At the technical side, we set up measuring equipment in accordance with official norms insofar as they apply, also carrying out extensive calibration experiments. At the citizen side, we collaborated with up to 10 volunteers from a citizen-led Antwerp-based action group. From the data gathered we construct purely measurement-based noise maps of the targeted area with error margins of about 5dB, comparable to those of official simulation-based noise maps.

Keywords: Environmental policy — pollution measurement — participatory sensing — citizen science — mobile phones — Web 2.0.

1 Motivation & background

As urbanisation is increasing, so is urban noise pollution. As a result official bodies, such as the EU, are imposing norms for establishing urban noise maps, limits on ambient sound levels, as well as measures for achieving them. Due to scalability issues noise maps are currently generated through simulation models, where only limited actual noise measurements are involved. Crowd-sourcing through participatory sensing techniques can alleviate these issues and instead allow for a person-centric approach to gathering measured data on a much larger scale. The NoiseTube project [4] establishes all required tools and techniques for constructing participatory noise maps. NoiseTube enables citizens to measure their personal exposure to noise by using GPS-equipped mobile phones as noise sensors. The system allows participants to share and visualise data through a website (http://www.noisetube.net).

While NoiseTube has been used extensively for individual measuring tracks, it was, until recently, not yet deployed for coordinated measurement campaigns. In this article we report on a citizen science experiment for noise mapping a 1km^2 area in Antwerp using NoiseTube. Our main objective is to investigate

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what the quality of the obtained maps is. Indeed, since participatory sensing has not yet reached enough users to overcome the so-called *cold-start problem*, it is very difficult to estimate what quality one can expect from participatory pollution maps. While some such maps have been produced [3, 5], they are either very limited in size or not concerned with the quality of data.

2 Results & future work

The goal of our experiment was to create a participatory noise map of a $1km^2$ area in the Linkeroever area in the city of Antwerp. We chose this area because our volunteers lived in the neighbourhood but also because it has a varied topology, consisting of busy roads, residential areas and even walking paths. We were fortunate in that we could collaborate with one of the best-known citizen-led action groups in Belgium, *Ademloos*. This non-profit association has been labouring for the past ten years for a more sustainable solution to the city's congestion problems. In a first phase, carried out early July 2010, four volunteers followed a pre-defined measurement trajectory for a week during a peak-hour (7:30–8:30 AM), and for another week during an off-peak hour (21:00–22:00 PM). In a second phase in November 2010 ten volunteers were asked to measure for at least one hour every day in the chosen area but without pre-described time slots. While the first phase guarantees enough data per space-time coordinate for statistical averaging to make sense, in the second phase it is more difficult to produce a complete noise map for the area as the combined data has more "gaps" in time as well as in space. The results we report upon here deal with the first phase of the experiment; results on the second phase are forthcoming.

In order to be able to focus the quality of the produced data we eliminated as many free parameters as possible, by using identical Nokia 5230 phones and pre-defined walking trajectories, and by giving users clear guidelines on how to carry out measurements. Also, to facilitate data comparison with existing methods we adapted our methods to European norms insofar as possible. These norms prescribe, amongst others, that devices should be calibrated and calculate A-weighted equivalent sound levels over arbitrary periods of time [2]. We have put much effort in calibration experiments, calibrating each phone independently in an anechoic chamber (see Fig. 1). Further experiments were carried out in the field to gauge outdoor phone performance as a sound level meter and as a localisation device.

Participatory noise maps for phase one of the Ademloos experiment are shown in Fig. 2. An interactive version of these and other maps can be found online (http://soft.vub.ac.be/ mstevens/gis/linkeroever.php). The map on the left shows the peak hour and is based on 30977 measurements, while that on the right shows the off-peak hour and is based on 36394 measurements. While these measurements were made during different days of the week, they are accumulated here to obtain averages for the chosen hours. In order to produce noise maps for a collection of measurement tracks we need to introduce a statistical component in our software. Indeed, we cannot just present 20 tracks –

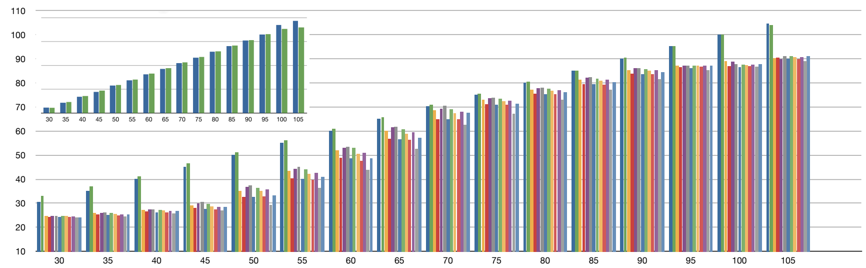

Fig. 1. White noise calibration results. The main graph shows measured sound levels at 5dB intervals by, from left to right, the reference microphone, a sound level meter, and ten Nokia 5230 phones; the inset shows measured sound levels after calibration.

contributed by our volunteers for each week – jointly on a map. Instead, we distribute measurements over a grid covering the total area, mapping colour-coded statistical averages on each grid element. The grid size is 40mx40m, as per the average GPS error we determined for the target area. To ensure statistical credibility, only grid elements with more than 100 measurements were retained. The chosen trajectory is clearly recognisable in each map. The peak-hour map contains 68 grid elements, has an average of 434 measurements per grid element, average sound level of 63,5 dB over all grid elements, and an average standard deviation of 4,2 dB over all grid elements. The off-peak-hour map contains 76 grid elements, has an average of 452 measurements per grid element, average sound level of 60,6 dB over all grid elements, and an average standard deviation of 4,1 dB over all grid elements. The spread of average sound level per grid for both maps is between 55dB and 70 dB, with a clear difference between the off-peak map (containing lighter colours) and the peak map. The main busy road, horizontally traversing the middle of the area, is clearly recognisable in each map. We note that simulated noise maps typically have standard deviations of ±5dB [1].

In this first validation experiment we have succeeded in constructing purely measurement-based, participatory, statistically credible noise maps of the targeted area with error margins of about 5 dB, comparable to those of official noise maps. In contrast with the latter, our maps allow arbitrary choice of areas and time slots. So far the statistical component for creating collective noise maps is decoupled from the NoiseTube website; instead we produced groups of users, measurement strategies, and maps offline. We plan to integrate this statistical component into our server software, adding further functionalities such that arbitrary communities – geographical (neighbourhood concerns), through common interests (how do peak hours in different cities compare?) or task-oriented (city hall wants to evaluate how the annual town fair affects noise in their commune) – can set up a campaign on the NoiseTube website, tweaking parameters such as grid size, area and time of measurement, and quality of the data. As our

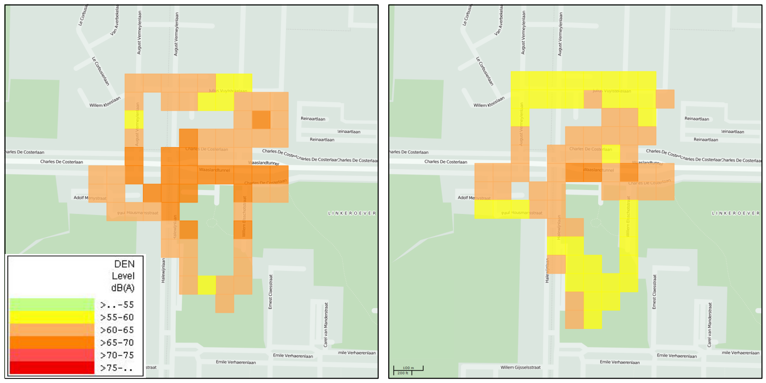

Fig. 2. Participatory noise maps: peak hour on the left, off-peak hour on the right.

website is already capable of dealing with real-time data, these campaigns could run indefinitely, gathering data along the way. Essentially the same approach as exposed here can be used to set up arbitrary measurement campaigns, with only two constraints: first, that there is a limit to the quality of the data, depending on the amount of data gathered, and second, that map granularity is limited by the typical GPS-error of mobile phones (note that we have reached this limit in our experiment). In this context it is important to complement obtained sound levels with a quality indicator, which depends on aspects such as statistical spread and amount of data involved in the pertaining sound level estimate. Further work is also needed to introduce smarter street-based visualisations and to compare our maps with official noise maps of the area.

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References

1. Brussels Instituut voor Milieubeheer: Bruit des transports - Cartographie stratégique en Région de Bruxelles-Capitale. Technical report (2010).
2. European Commission: Commission Recommendation on the Revised Computation Methods for Noise. Annex II of Directive 2002/49/EC. Official Journal of the European Union, L 212 (46)(22.8.2003):49–64 (2003).
3. Kanjo, E.: NoiseSPY: A Real-Time Mobile Phone Platform for Urban Noise Monitoring and Mapping. Mobile Networks and Applications, 15(4):562–574 (2010).
4. Maisonneuve, N., Stevens, M. and Ochab, B.: Participatory noise pollution monitoring using mobile phones. Information Polity, 15(1-2):51–71 (2010).
5. Rana, R. K., Chou, C. T, Kanhere, S. S., Bulusu, N. and Hu, W.: Ear-Phone: An End-to-End Participatory Urban Noise Mapping System. In: 9th ACM/IEEE International Conference on Information Processing in Sensor Networks, pp. 105–116. ACM, New York (2010).

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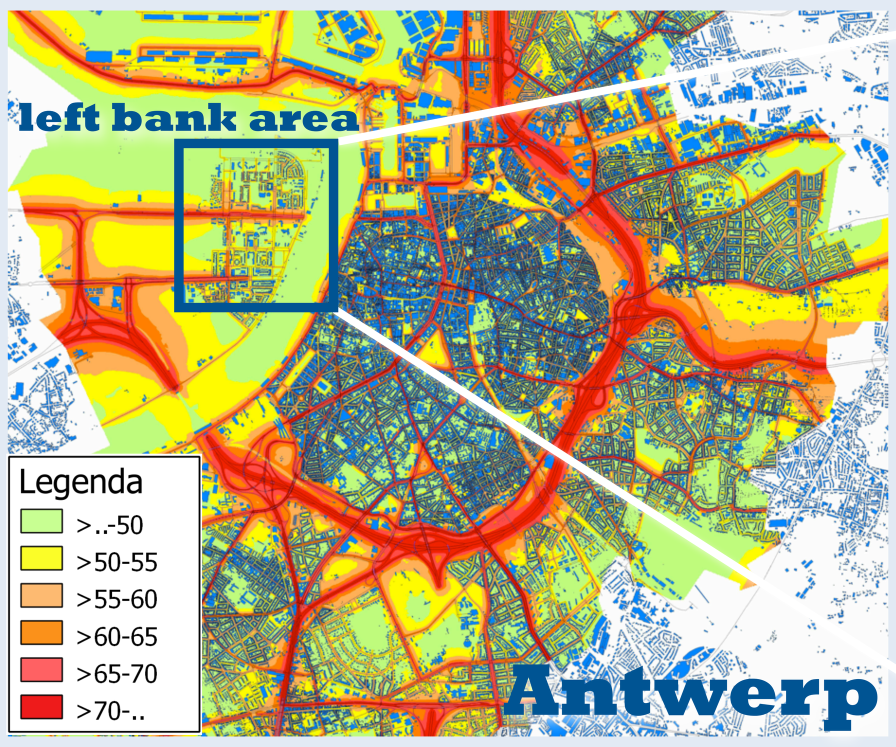
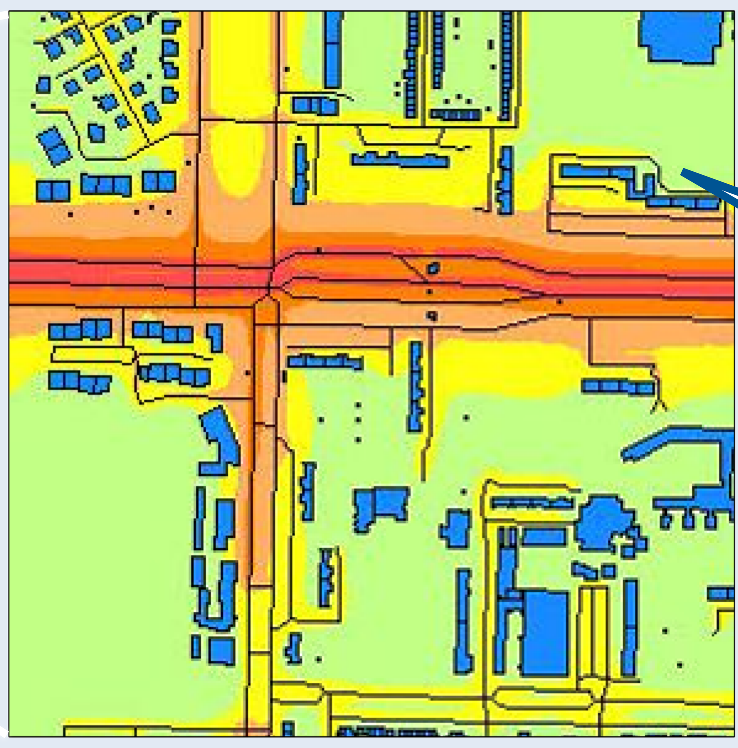
1 Simulated noise maps

- large cities (> 250 000)
- model roads (> 6m vehicles/year), railways (> 60 000 trains/year), airports & industry
- shows dB(A) values
- accuracy ±5dB



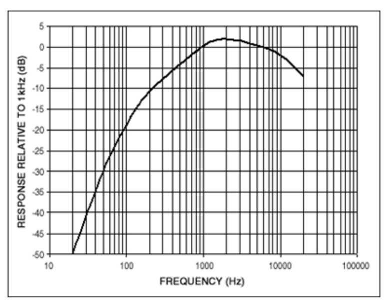


- 1 average day, night or evening/year
- updated every 5 years

2 Equipment

& with

NoiseTube

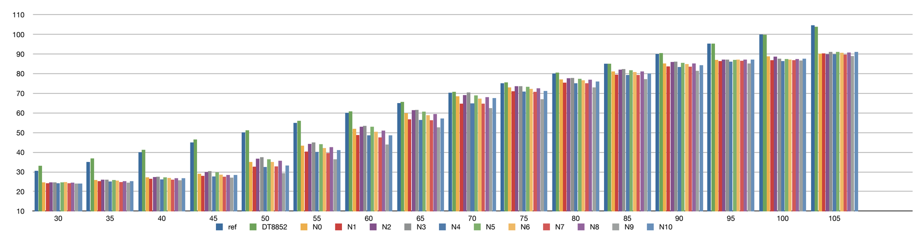


A-weighting filter

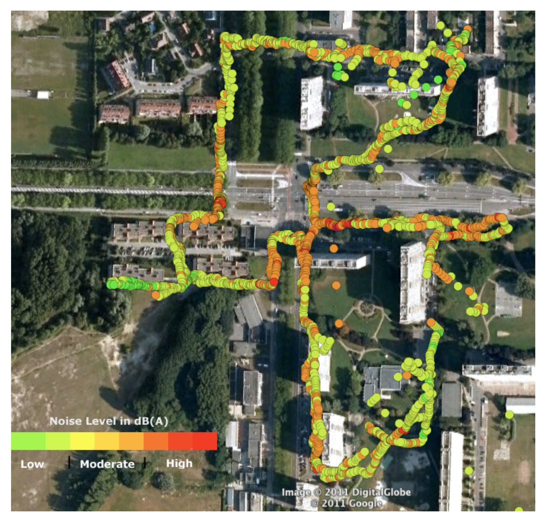
+ $L_{eq} = 10 \log \frac{1}{T} \int_0^T \frac{p^2}{{p_0}^2} dt$

Computation of equivalent continuous sound level (in dB(A))

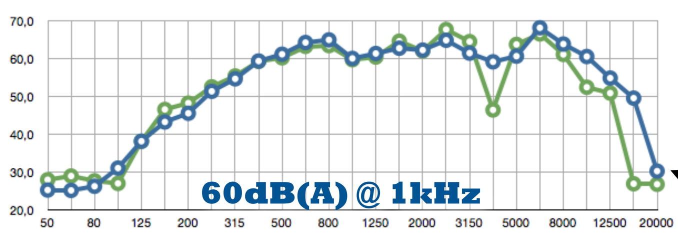
+



Phone-specific correction function (reference & sonometer & 10 Nokia 5230s shown)



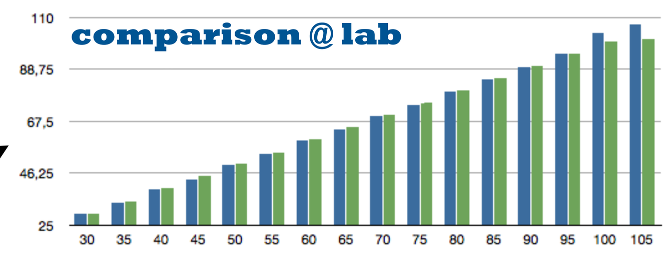
Calibration experiments to evaluate & improve accuracy:

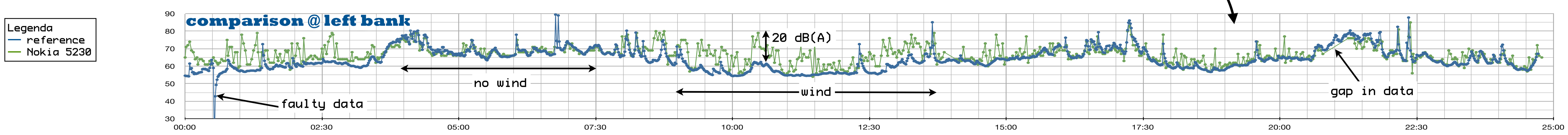


calibration experiments

Evaluation per phone, frequency, intensity and for white noise

after calibration

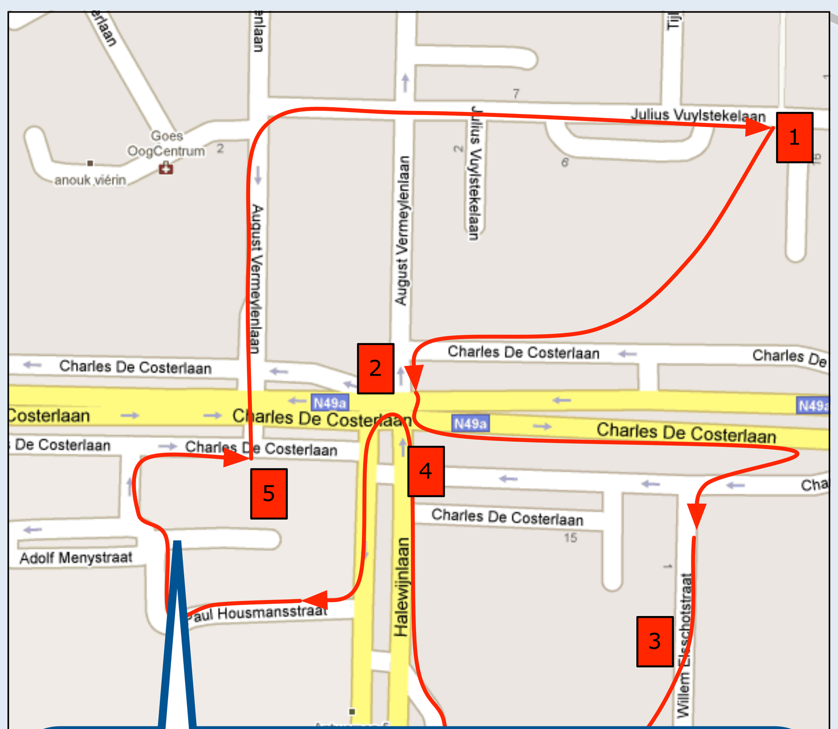




3 Measurement campaign.

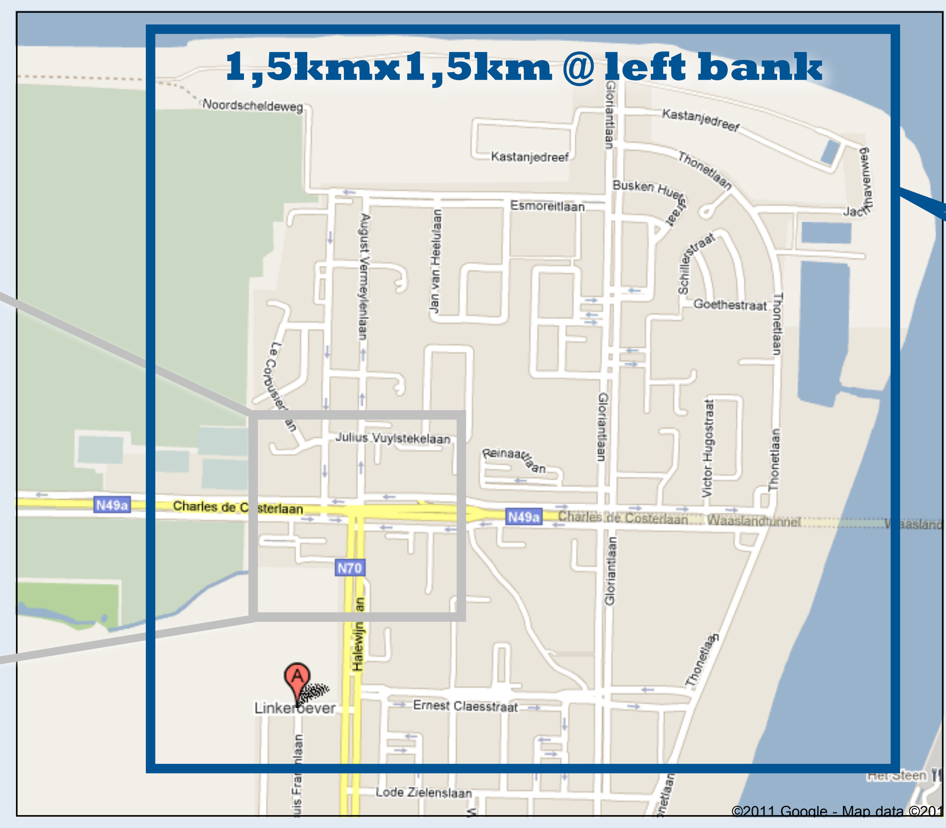
Does it work? Imagine a typical scenario: mapping noise pollution in a given area by a limited group of (untrained) citizens: volunteers from **Ademloos**, an Antwerp-based action group.

3.1 Coordinated mapping



8 people • 2 weeks • 4 people/week • 1 peak hour • 1 off-peak hour

3.2 Wild mapping



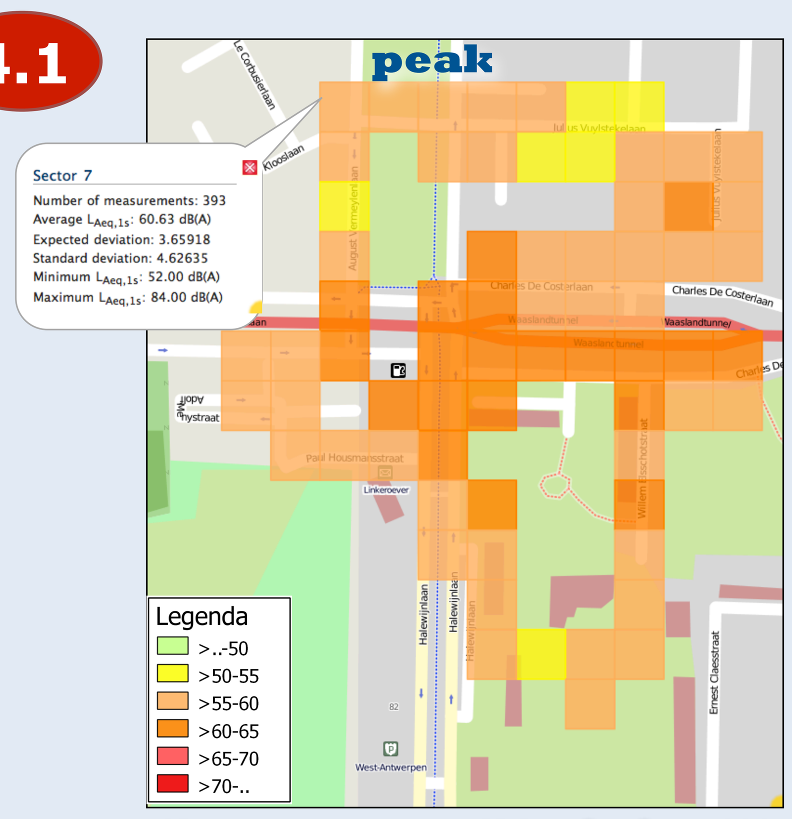
- 10 people • 1 week
- any time of day
- at least 1h per day

4 Results.

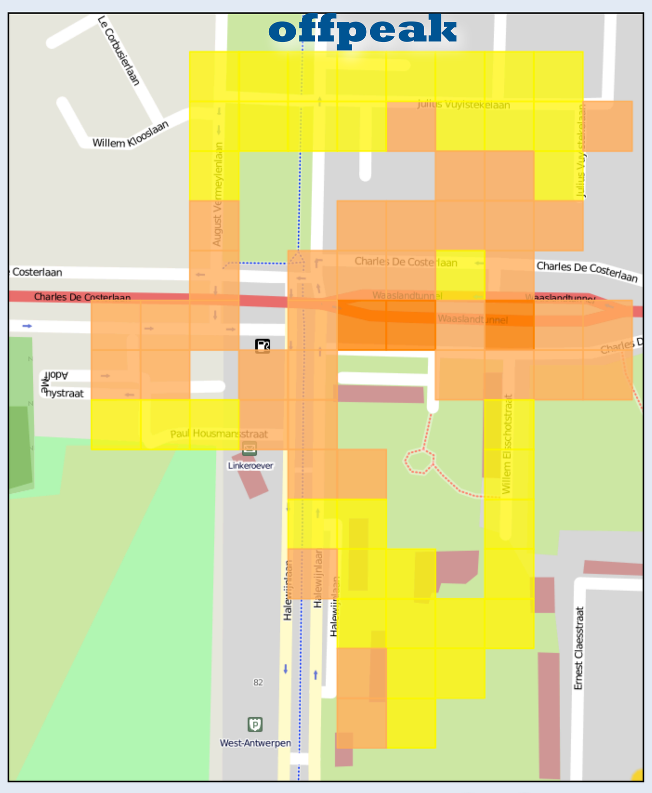
Divide the area into 40mx40 squares & compute averages

(note: GPS errors on max 8,25m for latitude, 11,41 for longitude as measured at 7 positions in the area)

4.1

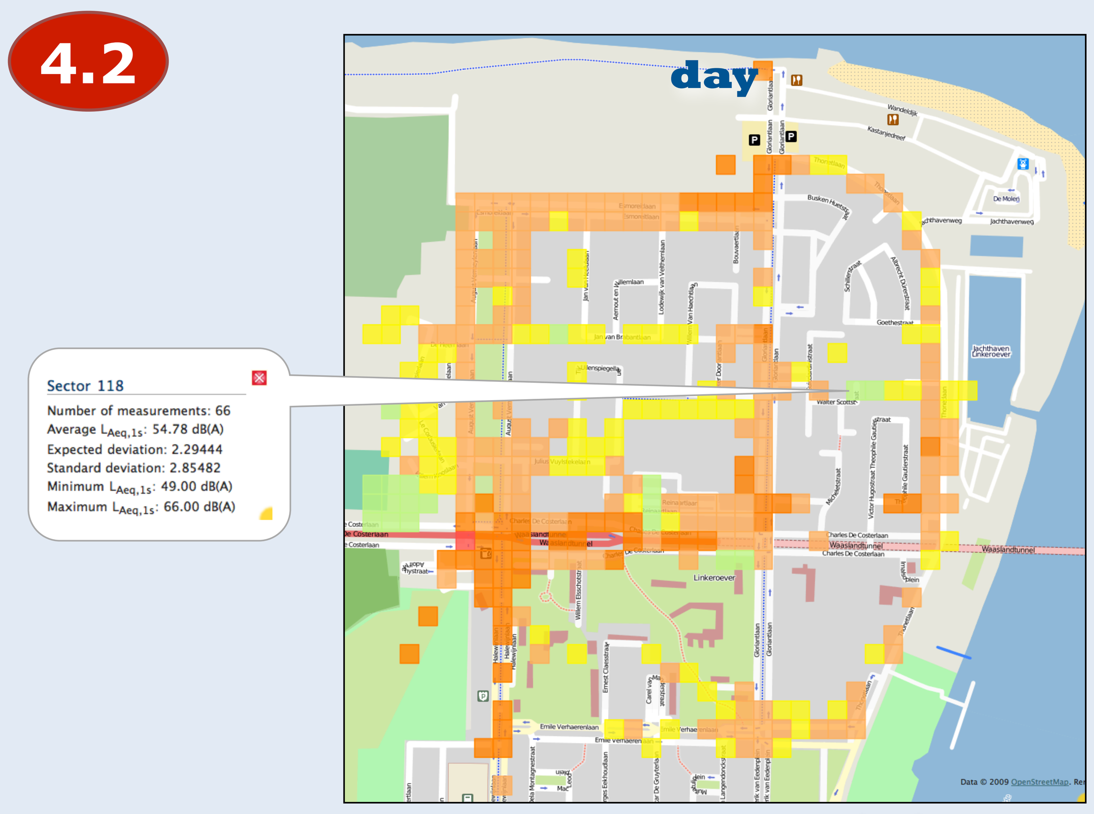


68 squares • average 434 and at least 100 measurements per square • average sound level 63,5 ± 4,2 dB(A)

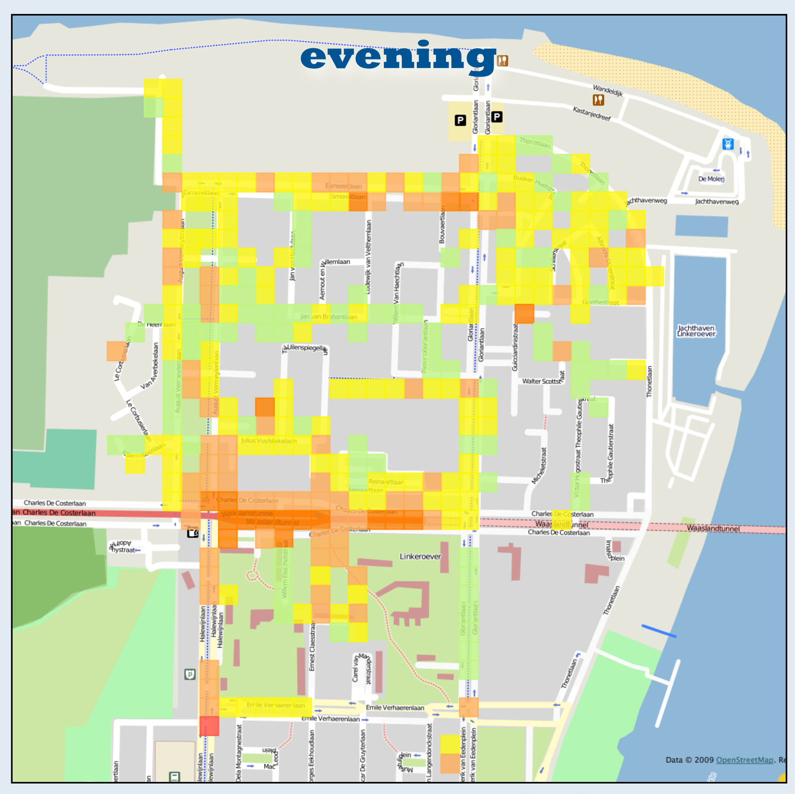


76 squares • average 452 and at least 100 measurements per square • average sound level 60,6 ± 4,1 dB(A)

4.2



329 squares • average 150 and at least 100 measurements per square • average sound level 61,1 ± 4,5 dB(A)



90 squares • average 90 and at least 10 measurements per square • average sound level 58,0 ± 4,4 dB(A)