Participatory noise mapping

Dr. Ellie D'Hondt & Matthias Stevens

computer science ↔ sustainability

- environmental simulations
- distributed resource usage for hard computations
- improve the grain-size and quality of environmental measurement data
- increase awareness of citizens and thus provide support for political action

[Steels08] Luc Steels. Community Memories for Sustainable Societies. Special publication for the 20th Anniversary of Sony CSL, Tokyo spring 2008.

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goals

= collection of ICT tools to collectively manage common pool resources, e.g. our environment

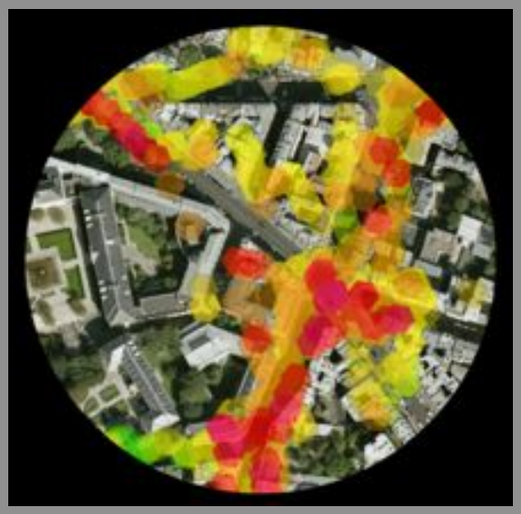
1. **To set up the technology for a *community memory* for urban environmental measurement surveys, in particular focusing on noise, microclimate and pollution;**
2. **to implement case studies in the Brussels Region & elsewhere.**




UbiComp + Citizen Science = Participatory Sensing

+

=






participatory/urban sensing

Heathrow, UK

Brussels, Belgium

noise is a real problem in cities all over the world


THE TIMES OF INDIA, MUMBAI **
MONDAY, MARCH 2, 2009

TIMES CITY

Traffic, construction, crackers: Top noise polluters

Shibu Thomas I TNN

Mumbai: Traffic, construction ac-

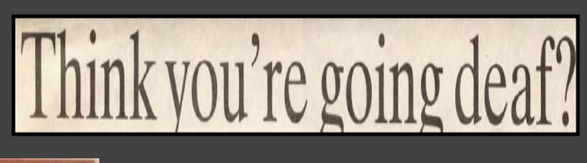
NGO Awaaz in a public interest litigation in the HC, "Noises created by drums and other instruments as

GREEN BRIGADE AGAINST ROOFTOP HELIPADS

sounds created on city roads.

"Readings in the Crawford Market area revealed that the back-

also rising, activists said. As no parameters are laid down while granting construction permissions, de-


Think you're going deaf?


PLEASE LET ME STUDY

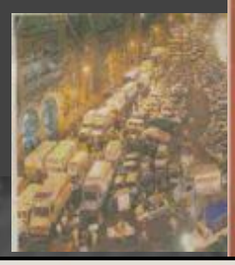

'Urban noise is killing thousands'

Alok Jha
London, August 23

KEEP IT DOWN

Health impact

WHO found that two per cent of Europeans suffer disturbed sleep because of noise pollution




DECIBEL LIMITS IN MUMBAI

RESIDENTIAL AREAS
55 dB

COMMERCIAL AREAS
65 dB

INDUSTRIAL AREAS
75 dB


the sunday interview / Sumaira Abdulali

Speak up against noise

NO HONKING TODAY


Times of India 7 October 2008

NGO tests firecrackers for noise pollution

TIMES NEWS NETWORK

Mumbai: Awaaz Foundation,


Sonia Gandhi's rally touches a new high

Noise level of 105 decibels flouts HC directive

Kavita Krishnan
kavita@mid-day.com

CONGRESS president Sonia Gandhi's rally at Shivaji Park may have had a record turnout for a non-Shiv Sena leader, but it also set a new high in noise pollution.

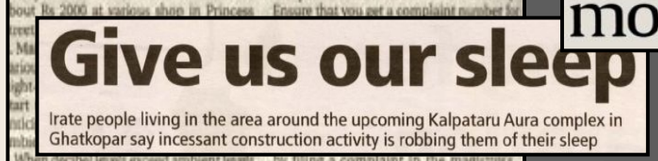
Sonia Gandhi addressing a rally at Shivaji Park on December 27


What you can do?

Buy a noise meter. These available for

the police control room at 100 and 102.

Ensure that you get a complaint number for


Give us our sleep

Irate people living in the area around the upcoming Kalpataru Aura complex in Ghatkopar say incessant construction activity is robbing them of their sleep


In Mumbai, today is 'No-honking day'

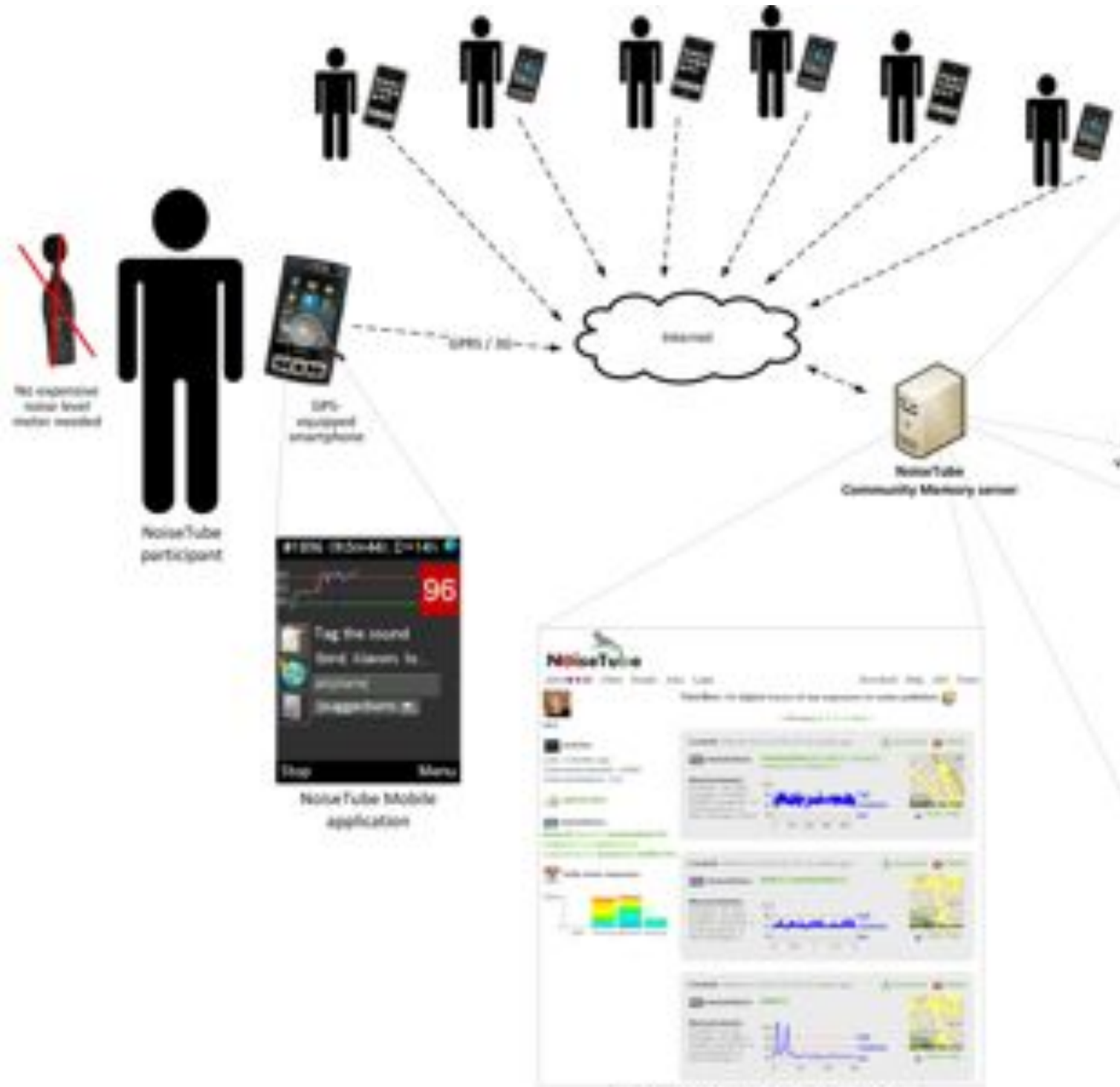

Citizens help police take motorists by their horns


Save Saket from the noise, say residents

Mumbai, India

state of the art:

NoiseTube

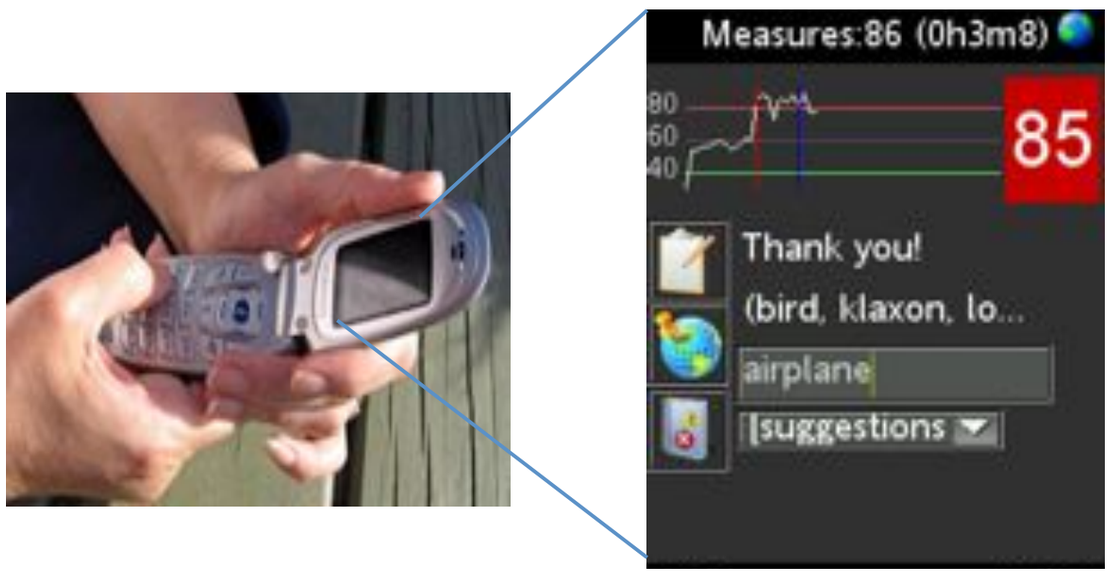



Your noise exposure (0.0s)
62
Comment the sound
(e.g. bird, klaxon)
traffic
construction
neighbors
office
pets
aircraft
industrial
Exit
Menu


423

environmental social tagging

= adding context to numeric pollution data to facilitate interpretation:



Users tag sources of noise, perceived annoyance, etc. Tags are sent and stored with measurement data

Tags are used to create rich, annotated noise exposure maps

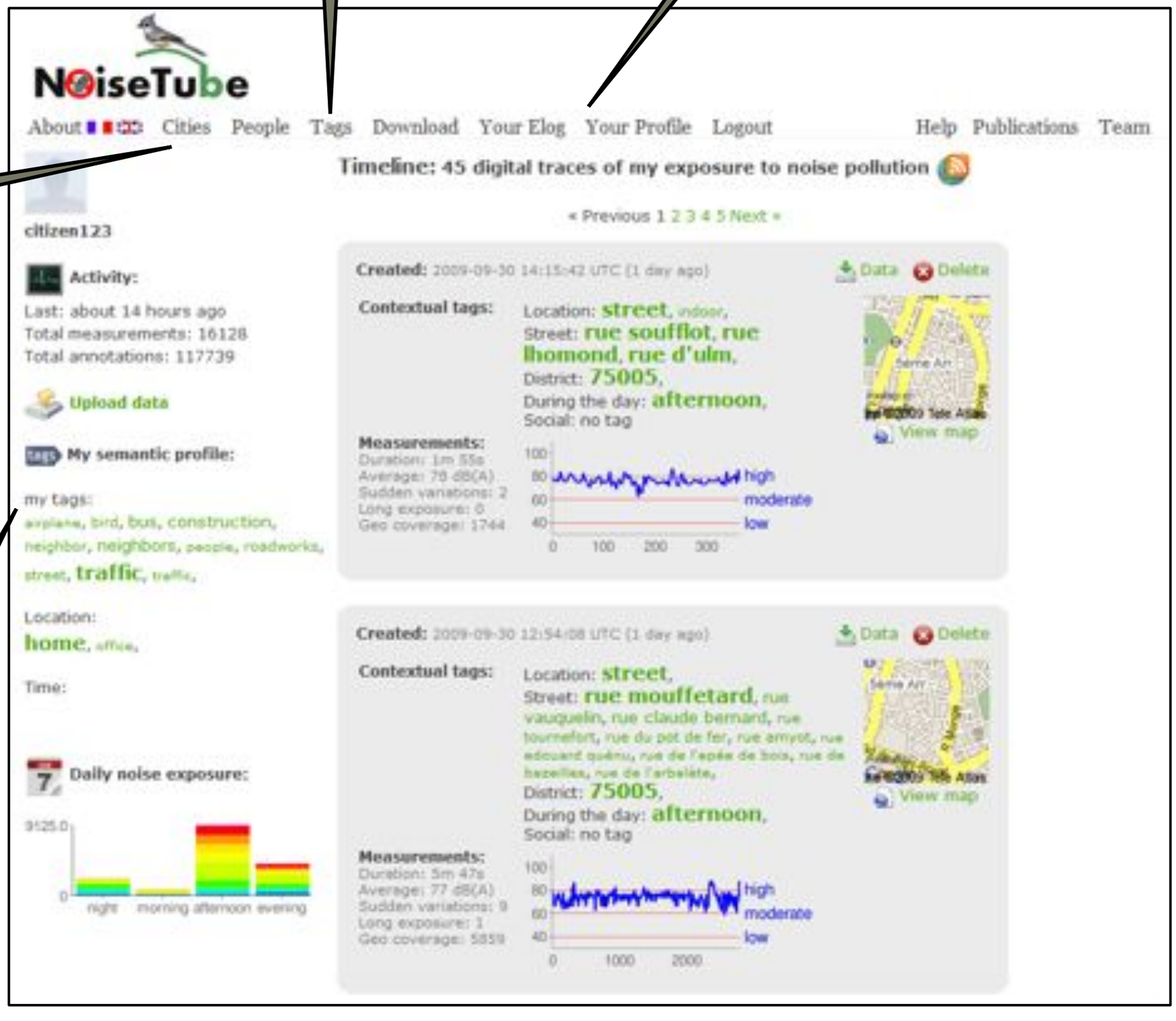
web-based community memory

tag-based search & exploration

user profiles

collective maps

social networking



individual tracks

collective maps

dynamic aggregated maps per city, combining all shared exposure data

finding & motivating users

- Individuals
  - personal awareness
  - worldwide & universal?
  - so far: limited/scattered results

- Coordination is needed!

.. and also necessary from scientific point of view (validation)

authority-led initiatives

citizen-led initiatives

Typical participative scenario: mapping noise pollution in a given area by a limited group of (untrained) citizens: Ademloos

research question

implementation

data aggregation

How do we make participatory noise maps and what is the quality one can expect to achieve?

How do these maps compare to current environmental surveying methods, which are simulation-based (and rely only on a limited amount of measured data)?

analysis & interpretation

EU-norms

state of the art

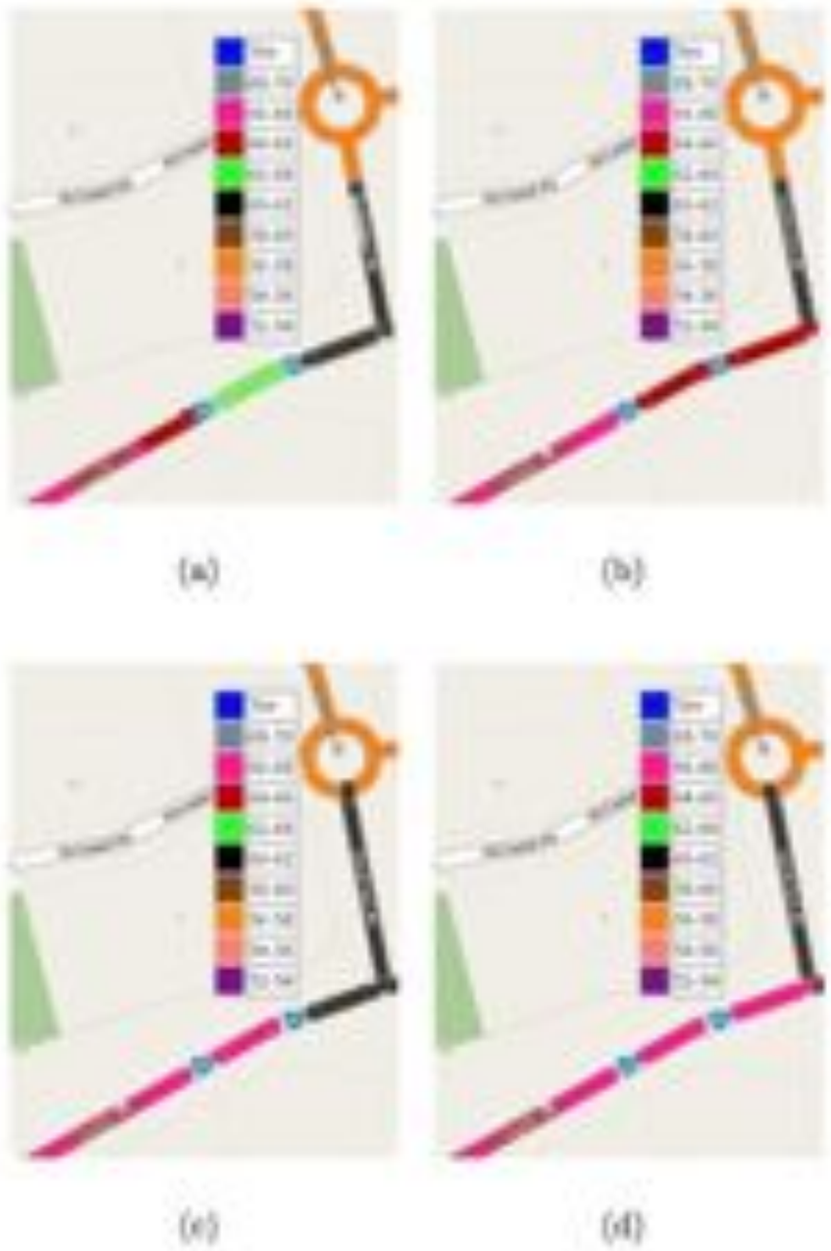
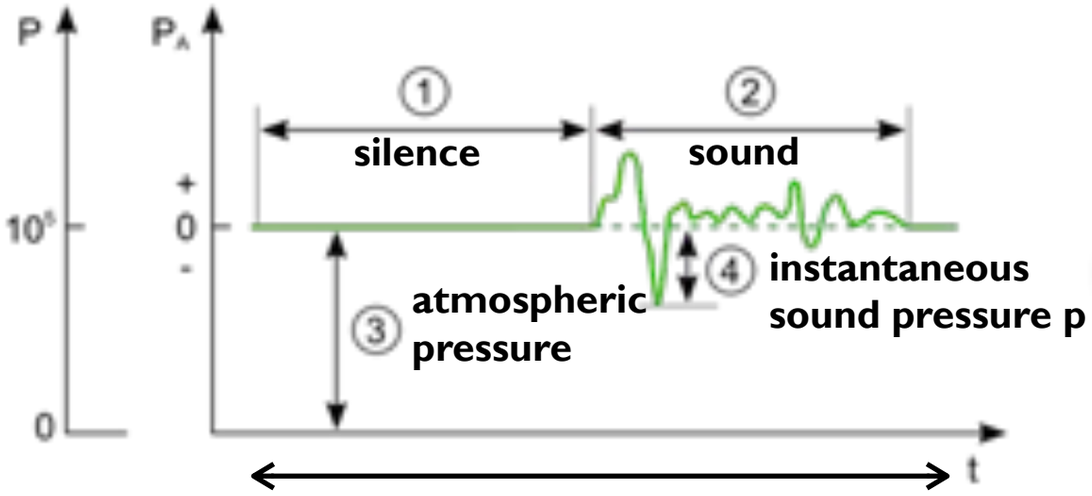


Figure 9: Noise map reconstruction during a peak hour (8:00am-9:00am) using data from (a) 1 person, (b) 3 persons, (c) 5 persons and (d) 7 persons.

- Rana &al, Ear-Phone: An End-to-End Participatory Urban Noise Mapping, Proc. 9th Int. Conf. on Information Processing in Sensor Networks
- Focus on technique for making up for missing data ("compressive sensing")
- No real maps ever made (to our knowledge)

sound level measurement



instantaneous sound level:

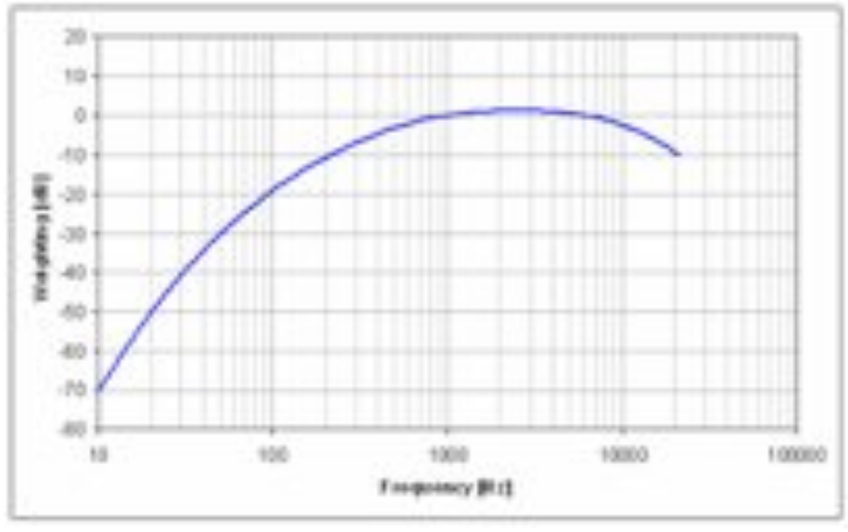
$$L_p = 10\log_{10}\left(\frac{p^2}{p_{ref}^2}\right)\mathrm{dB}$$

average over time T = equivalent continuous sound level:

$$L_{eq} = 10\log_{10}\frac{1}{T}\int_0^T\left(\frac{p^2}{p_{ref}^2}\right)dt \quad (\mathrm{dB})$$

+

A-weighting



$$L_{Aeq} \quad (\mathrm{dB(A)})$$

EU norms

- Noise maps obligatory for
  - cities > 250 000 inhabitants
  - roads > 6 million vehicles per year
  - railways > 60 000 passages per year
  - and this every 5 years from 2012 onwards

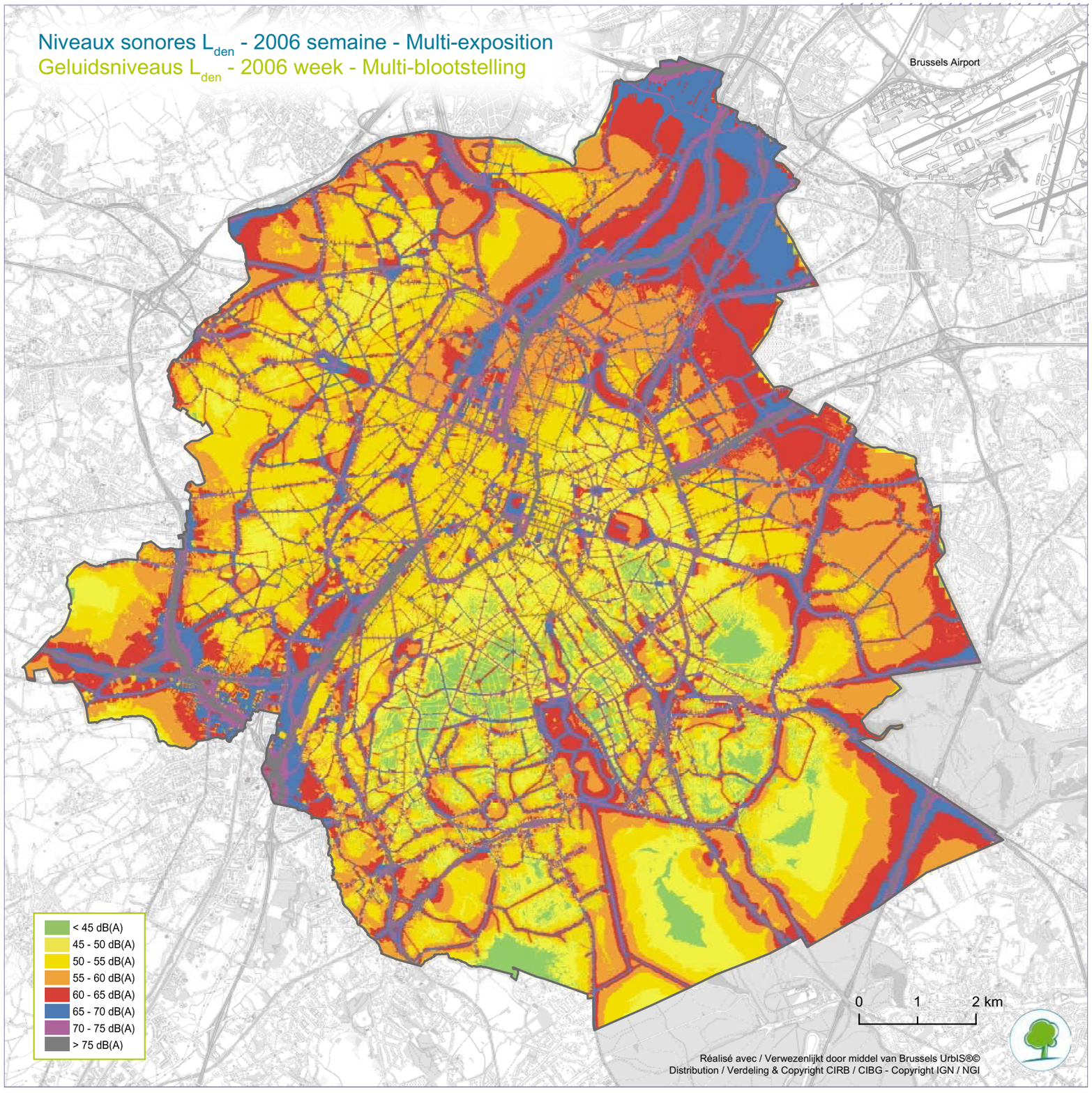
- by simulation and/or measurement

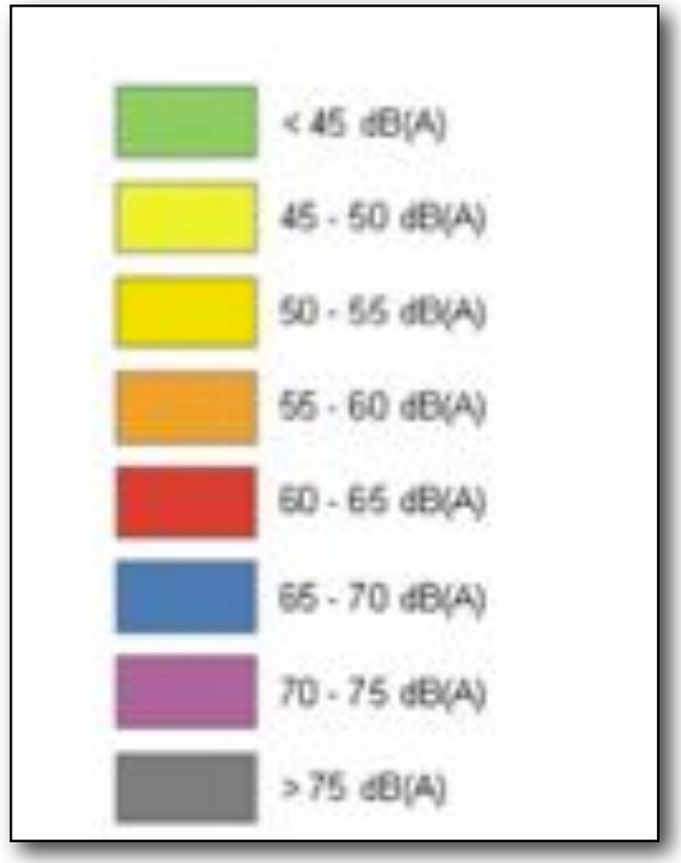
EU norms

$$L_{den} = 10\log_{10}\frac{1}{24}\left(12.10^{\frac{L_{day}}{10}} + 4.10^{\frac{L_{evening}+5}{10}} + 8.10^{\frac{L_{night}+10}{10}}\right) \text{ (dB)}$$

- where day: 7-19, evening: 19-23, night: 23-7
- each L is a time average over these periods
- needed: # people exposed to L_{den} and L_{night} values
  - within 5dB bands between 55 and 75 dB and > 75dB
  - at 4 m above the ground on the most exposed façade
- separate value for road, rail, air traffic & industrial sources
- through measurements or simulation

official noise maps





WHO norms:
day <55 dB(A)
night: < 40 dB(A).

official noise maps

official noise data

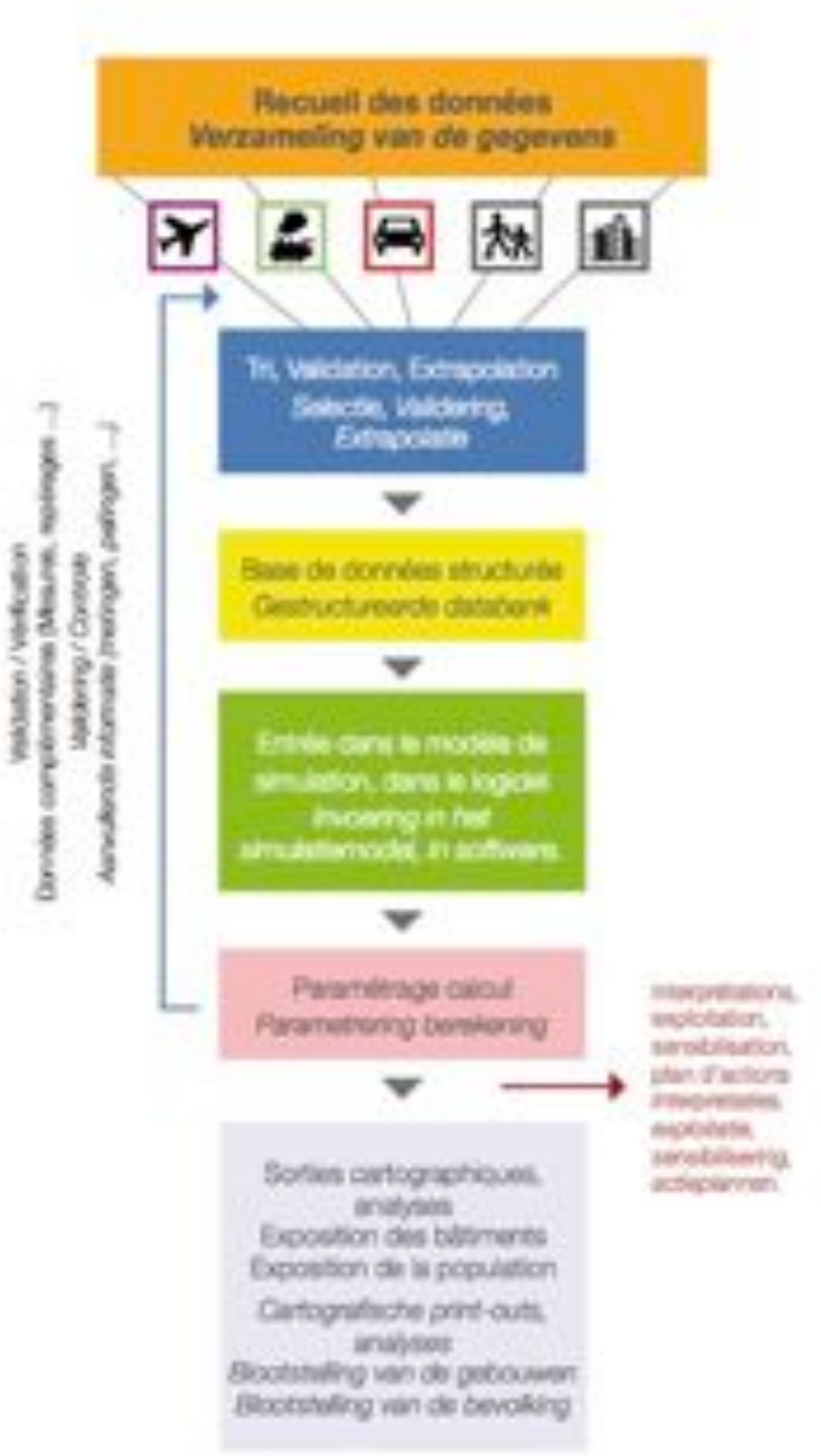
L_{den}				
Niveaux sonores Geluidsniveaus	Nombre d'habitations Aantal woningen	% des habitations % van het totaal aantal woningen	Habitations avec façade calme Aantal woningen met een rustige gevel	% des habitations soumises aux niveaux sonores précisés et bénéficiant d'une façade calme % van het aantal woningen blootgesteld aan precieze geluidsniveaus en met een rustige gevel
< 45 dB(A)	5223	3%	0	0%
45 - 50 dB(A)	23429	13%	0	0%
50 - 55 dB(A)	56351	30%	1	0%
55 - 60 dB(A)	49766	27%	1	0%
60 - 65 dB(A)	31083	17%	28	0%
65 - 70 dB(A)	15904	9%	444	3%
70 - 75 dB(A)	3891	2%	557	14%
> 75 dB(A)	561	0%	134	24%

interpretation

Sensation moyenne Gemiddelde geluidservaring	Niveau sonore Geluidsniveau	Type d'ambiance extérieure Geluidsomgeving	Conversation Gesprek
Très bruyant Zeer luid	80 dB(A)	Autoroute, chantier, ... Autoweg, bouwwerf…	Difficile Moeilijk
Bruyant Luid	70 dB(A)	Rue animée, grand boulevard, ... Weg met druk verkeer, grote laan …	
	65 dB(A)		
Bruit urbain modéré Matig stadslawaai	60 dB(A)	Centre-ville, rue de distribution, ... Stadscentrum, winkelstraat…	En parlant fort Luid praten
	55 dB(A)		
Relativement calme Relatief rustig	50 dB(A)	Secteur résidentiel, rue de desserte, ... Residentiële wijk, verbindingsweg…	A voix normale Praten met normale stem
	45 dB(A)		
Bruit de fond calme Rustig achtergrondgeluid	40 dB(A)	Intérieur cour, campagne, ... Binnenplaats, platteland…	
Très calme Zeer rustig	30 dB(A)	Ambiance nocturne en milieu rural Nachtgeluid in een landelijke omgeving	A voix basse Fluisteren
Silence Stilte	20 dB(A)	Désert Woestijn	

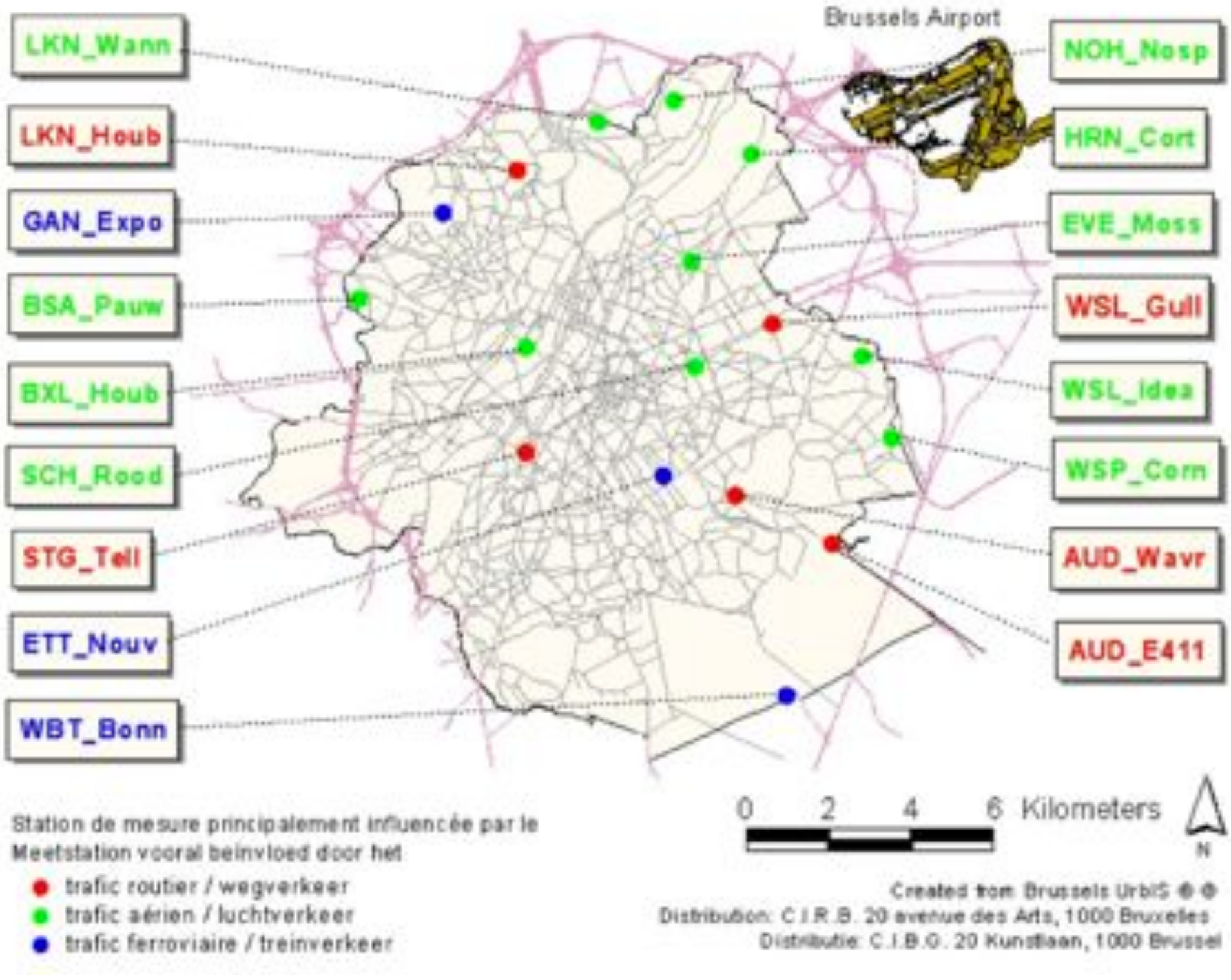
note: 3dB≠ is barely audible (mosquito at 3m distance)

noise maps through simulation



- sources covered:
  - traffic, train, industry, airports
- limited measurement
- data + propagation model
  →noise map

noise maps through simulation



EU norms

- The measuring apparatus has to incorporate:
  - ☑ A-filtering
  - ☑ direct read-out of dB(A)
  - ☑ $L_{A,eq}$ over arbitrary Δt
  - ☑ calibration
  - ☑ spherical wind shielding
  - ☑ read-out of wind speed & direction
  - ☑ speed registration of passing vehicles

from: Reken- en Meetvoorschrift geluidhinder 2006, Bijlage IV, versie aug. 2009

noise maps through measurements

- crowd-sourcing → massive amounts of data
- geotemporal tagging for data organisation
- professional calibration
  - in controlled environment (anechoic chamber)
  - in the field
- user-friendliness is an issue

NoiseTube

guidelines for measurements

- The measuring apparatus has to incorporate:
  - ☑ A-filtering
  - ☑ direct read-out of dB(A)
  - ☑ $L_{A,eq}$ over arbitrary Δt
  - ☑ calibration
  - ☐ spherical wind shielding
  - ☐ read-out of wind speed & direction
  - ☐ speed registration of passing vehicles

from: Reken- en Meetvoorschrift geluidhinder 2006, Bijlage IV, versie aug. 2009

measurement equipment

10x

+

EU-norms:

- [x] A-filtering
- [x] direct read-out of dB(A)
- [x] $L_{A,eq}$ over arbitrary Δt
- [x] calibration
- [ ] spherical wind shielding
- [ ] read-out of wind speed & direction
- [ ] speed registration of passing vehicles

realistic set of phones (from eBay)

comparison

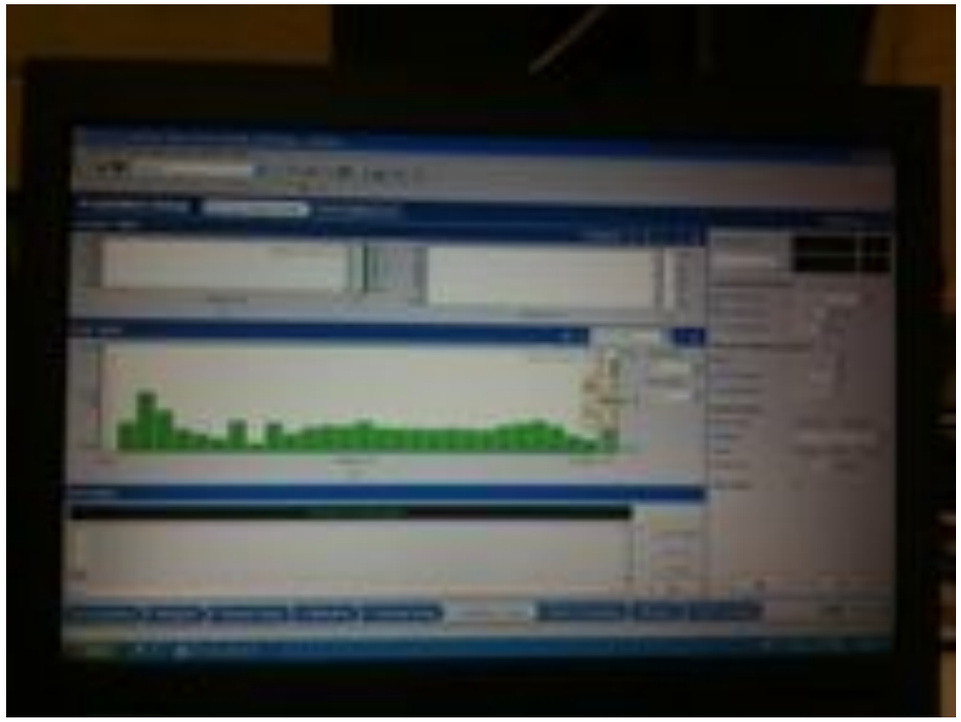
simulated	participatory
only 4 sources of sound	all sounds
accurate but few measurements	less accurate but many measurements
not scalable	scalable
authorities only	all citizens
large cities & roads	all areas
pre-defined time averages	arbitrary time durations
some data inaccessible	all data in hands of citizens
little contextual information	context through tags

calibration

Calibration work carried out in collaboration with Prof. Guillaume, Acoustics & Vibration Group, Applied Sciences, VUB.

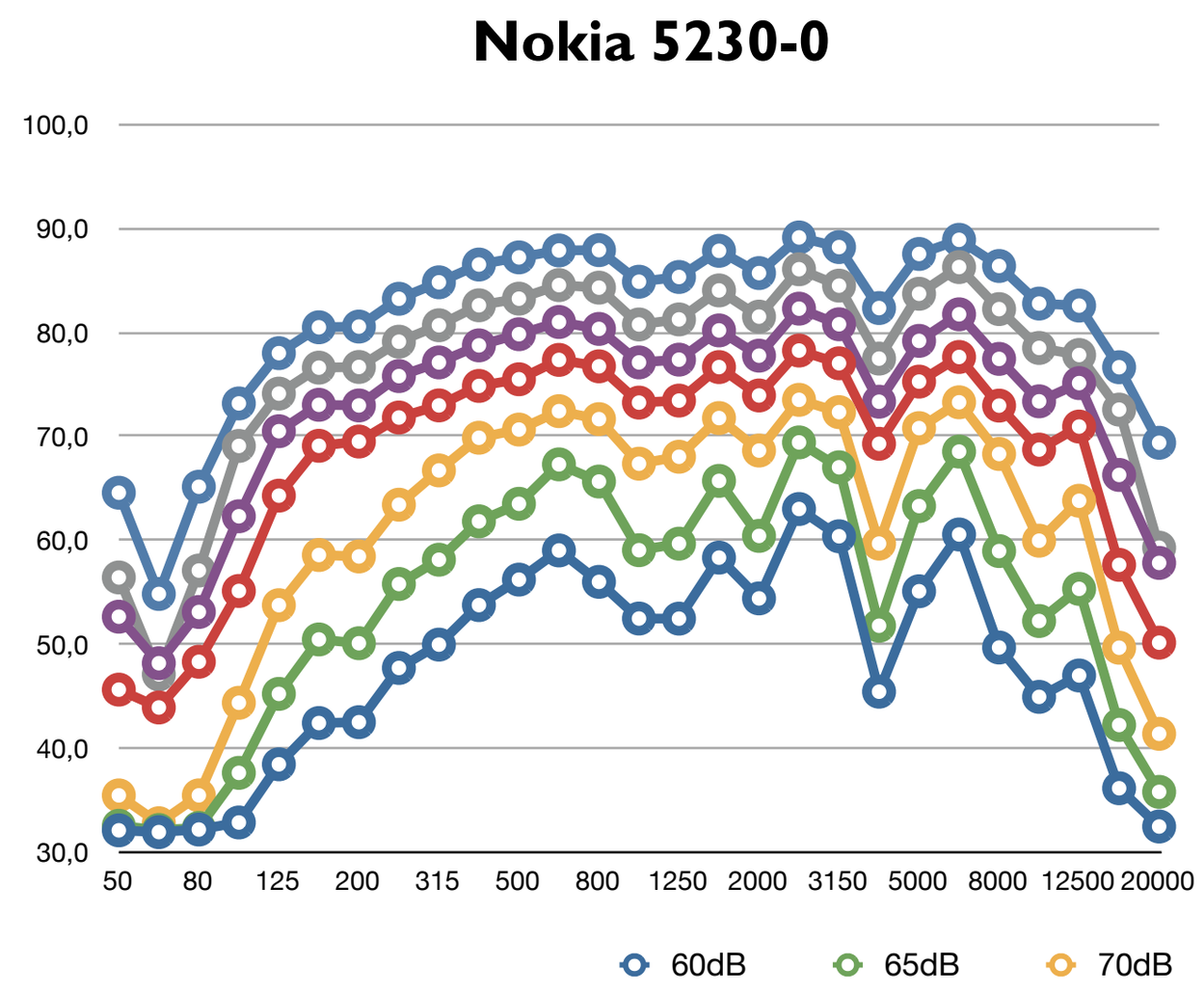
calibration: frequency

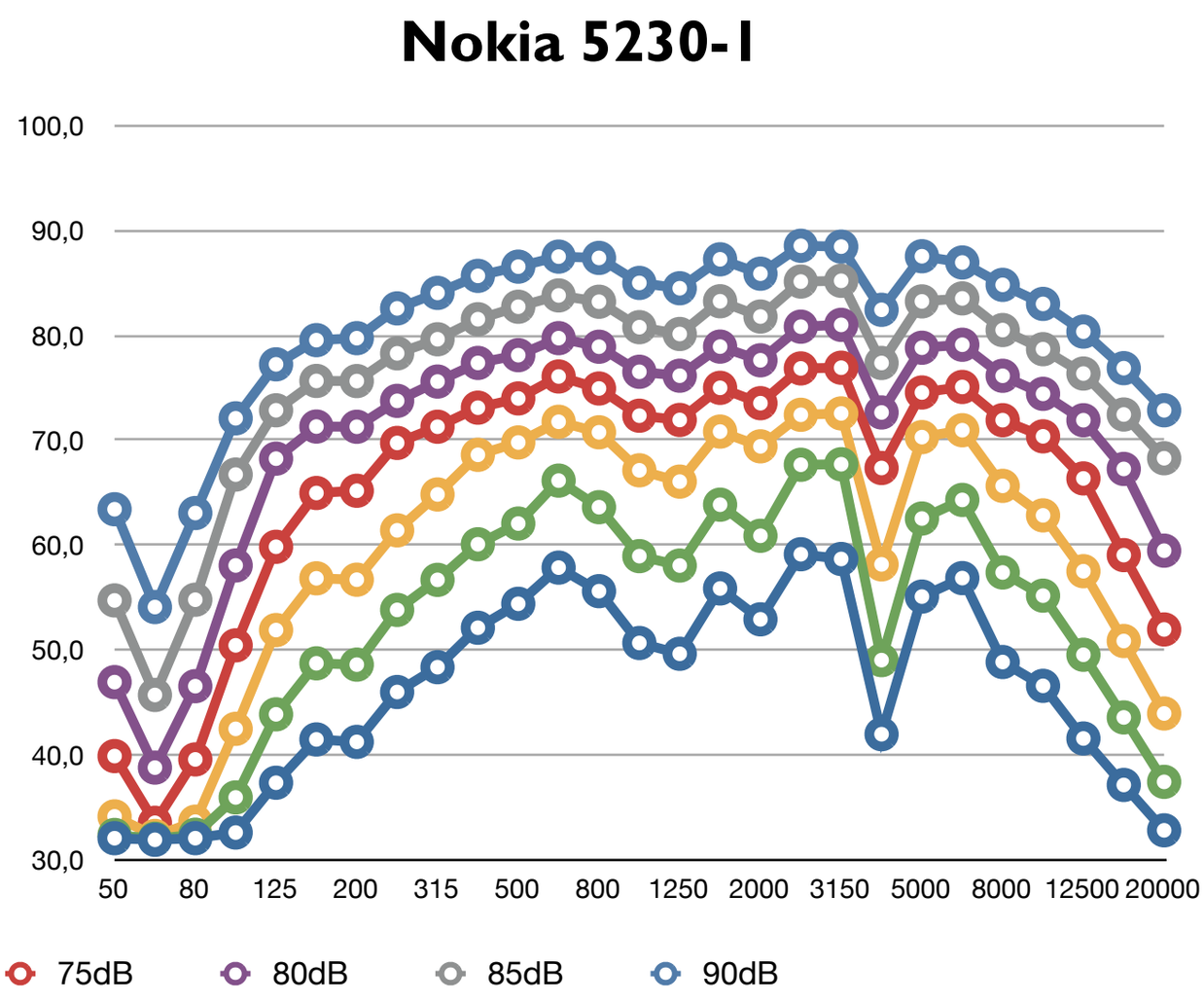
2 phones tested



calibration

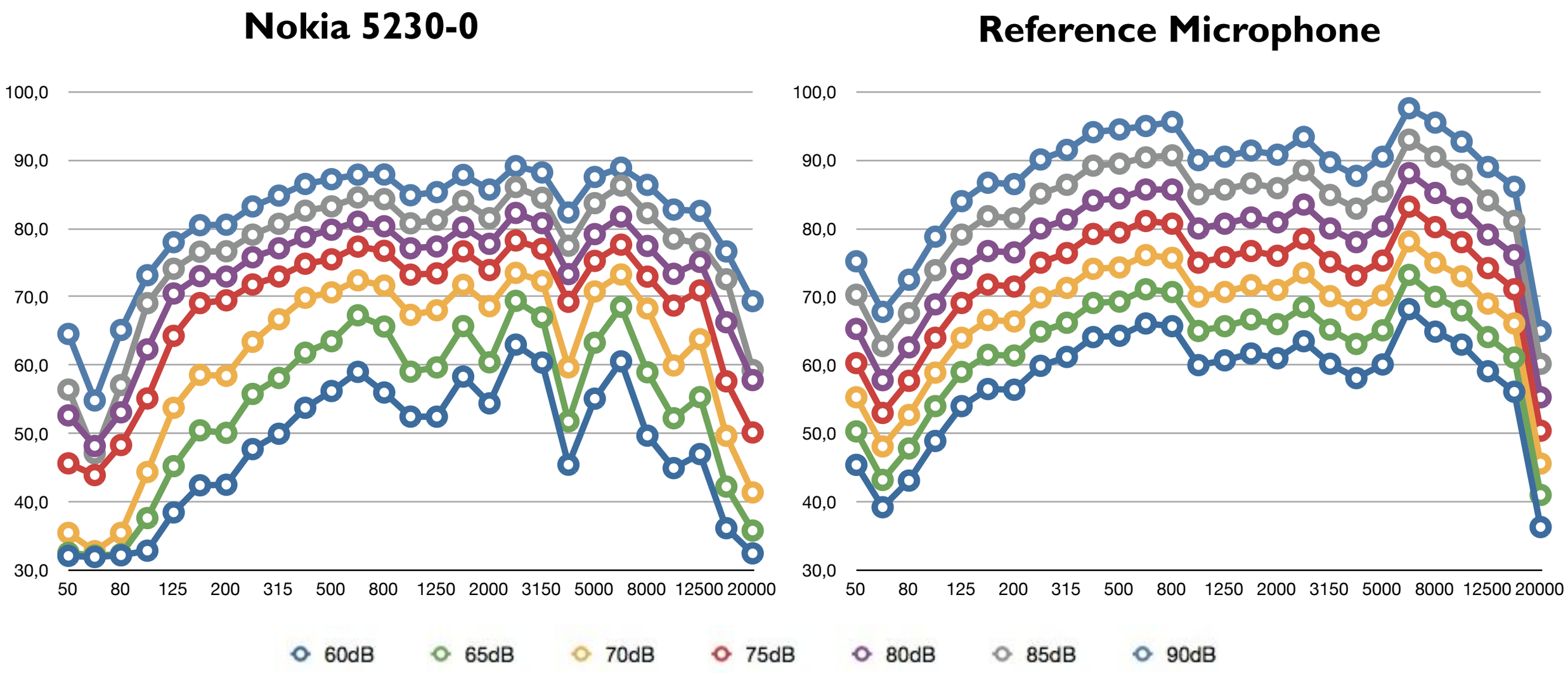
calibration: frequency





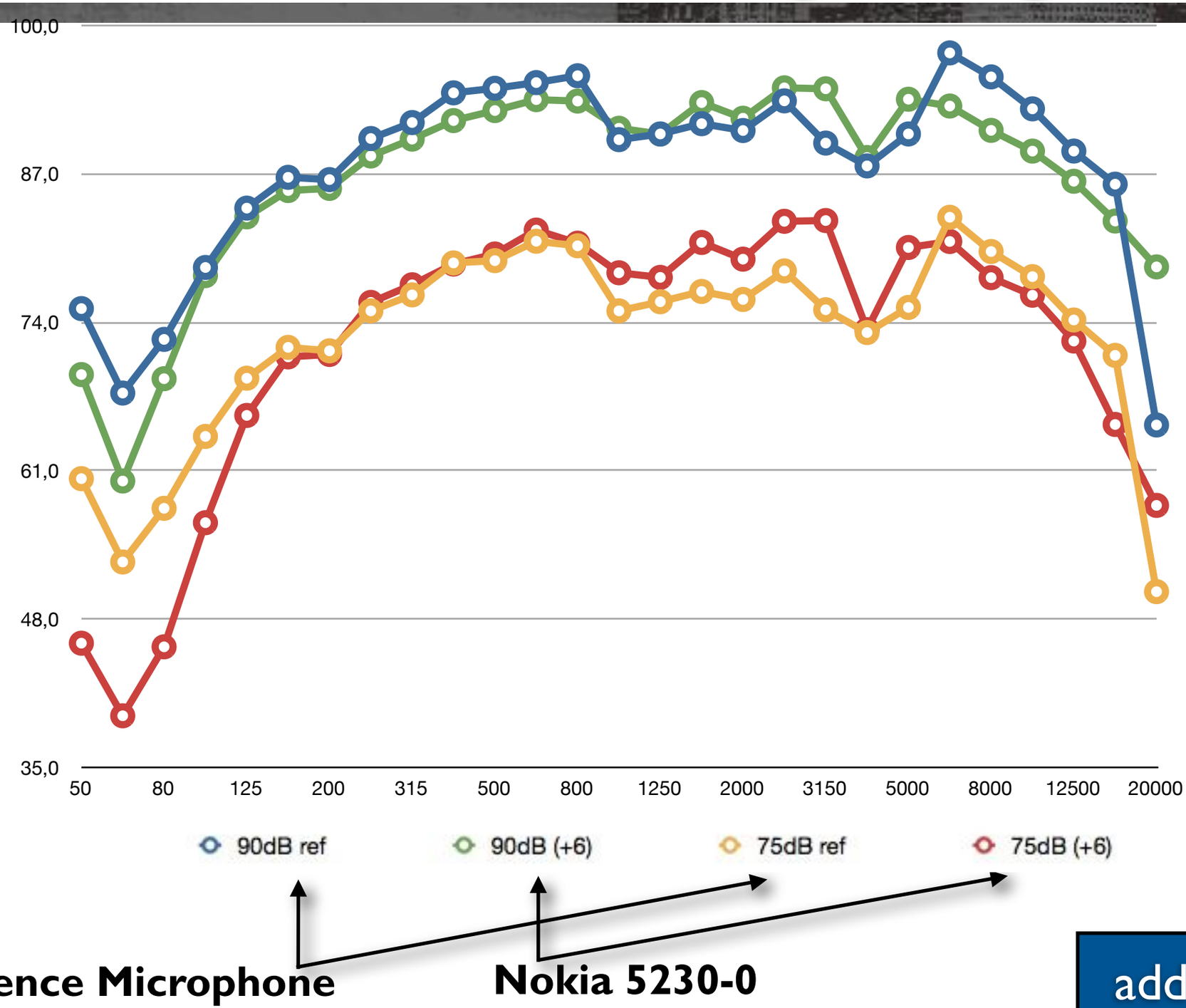
no significant differences → focus on 1 phone

calibration: frequency



there is a dependency on sound level
(more ≠between levels at higher dB)

calibration: frequency



Reference Microphone

Nokia 5230-0

add 6dB globally

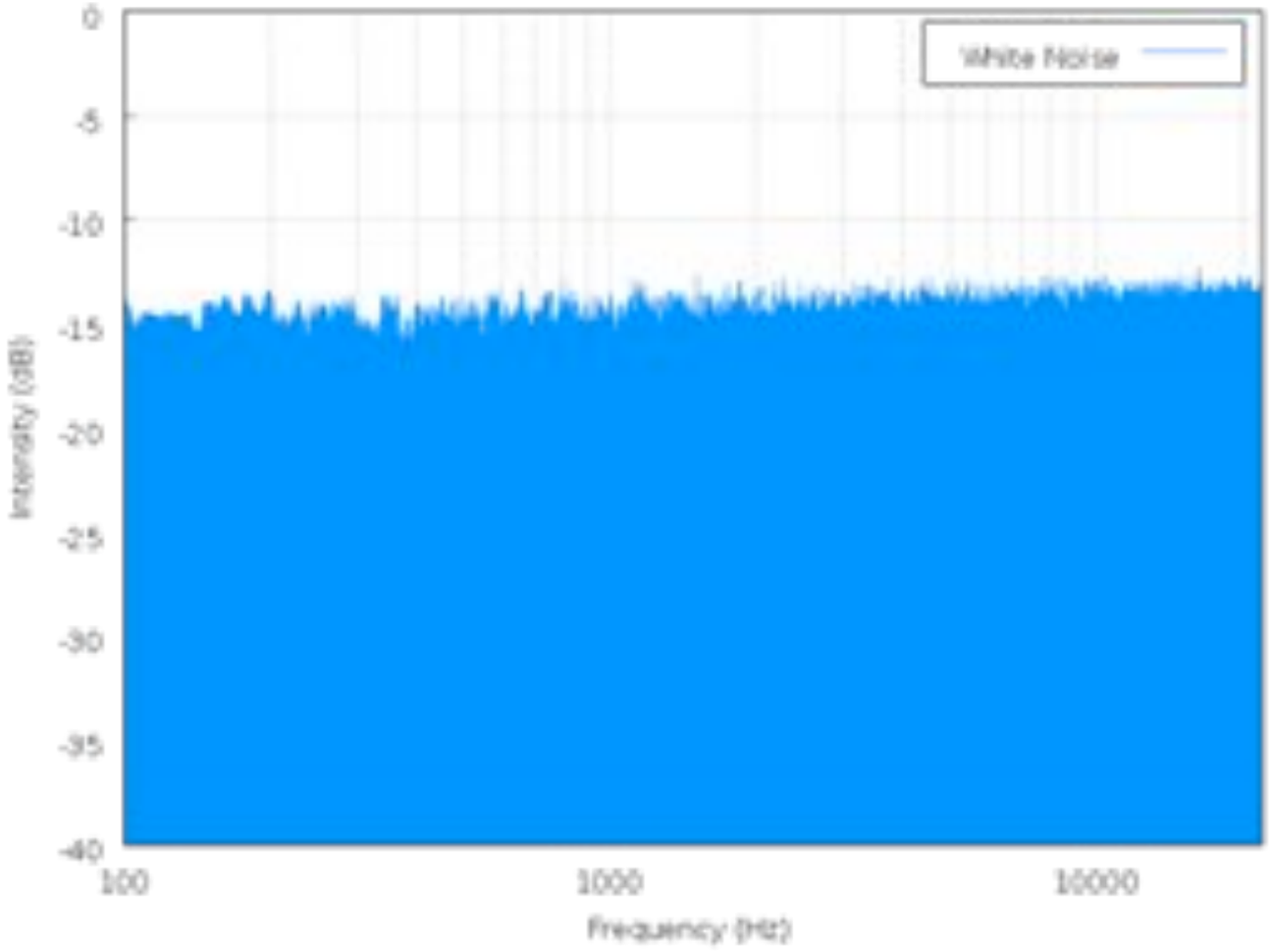
phone follows mike quite well, except for low dB/frequency

calibration: frequency

- for frequency-dependent calibration one needs to develop a digital filter, which is hard!
- sound level dependency points to frequency-independent technique
- correspondence between phone & reference is good in the domains that matter

conclusion: digital filter is overkill, use frequency-independent calibration technique instead (using white noise)

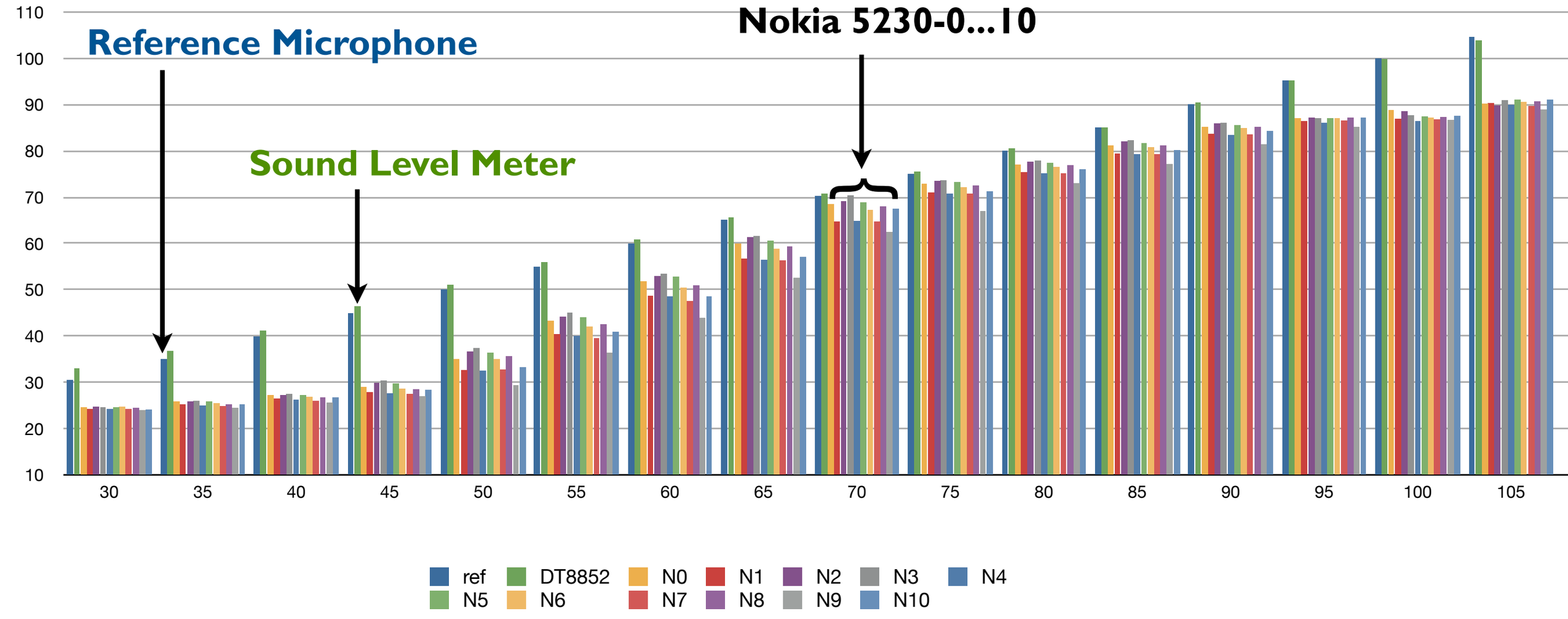
calibration: white noise



white noise = all frequencies equally present

calibration: white noise

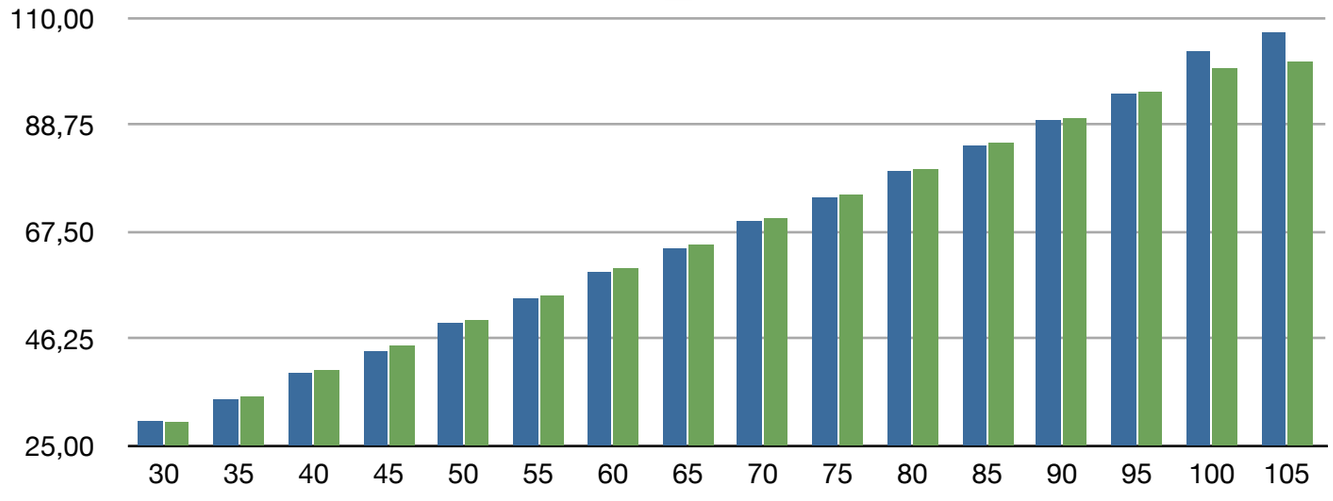
10 phones tested



calibration: white noise

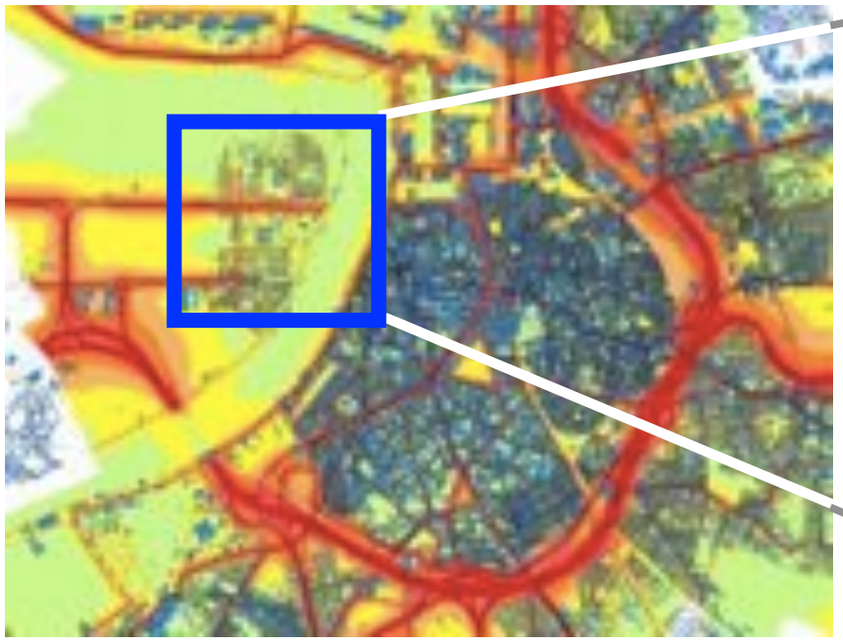
NoiseTube +

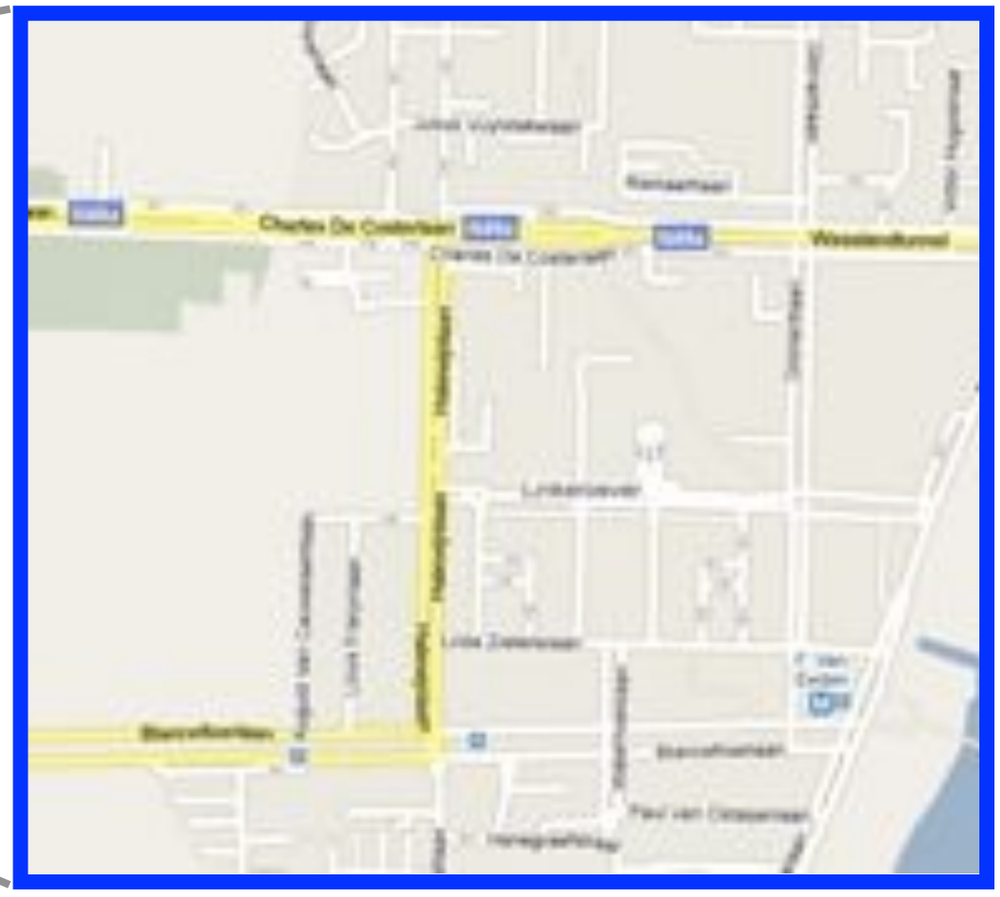
```
private static final doub       NOKIA_5230_0 = {{24.64, 30.00}, {25.83, 35.00}, {27.24, 40.10}, {29.05, 44.90}, {35.00, 50.10}, {43.34,
55.00}, {51.84, 60.05}, {59.95, 65.05}, {68.51, 70.05}, {72.92, 75.10}, {77.02, 79.95},{81.20, 84.95},{85.18, 89.95}, {87.25, 95.00},
{88.84, 100.00}, {90.18, 103.8}};

private static final double[][] NOKIA_5230_1 = {{24.22,30.00},{25.21,34.90},{26.49,39.90},{27.92,45.05},{32.62,50.00},{40.37,55.00},
{48.71,60.10},{56.77,65.00},{64.77,69.90},{71.06,75.10},{75.38,80.00},{79.43,85.00},{83.67,89.90},{86.46,94.60},{86.90,100.00},
{90.30,104.80}};

private static final double[][] NOKIA_5230_2 = {{24.70, 30.10}, {25.93, 35.25}, {27.31, 40.00}, {29.90, 45.25},{36.71, 49.95}, {44.18,
54.80}, {52.94, 59.90}, {61.41, 65.10}, {69.16, 69.80}, {73.53, 75.10}, {77.62, 80.05},{82.02, 85.05},{86.00, 90.25}, {87.14, 94.90},
{88.64, 100.00}, {89.81, 104.00}};

private static final double[][] NOKIA_5230_3 = {{24.59,30.00},{26.04,35.00},{27.46,40.20},{30.41,45.20},{37.37,50.05},{45.01,55.10},
     {53.43,60.00},{61.61,65.10},{70.45,71.10},{73.68,75.00},{77.89,80.10},{82.28,85.20},{86.03,90.10},{87.12,95.90},{87.64,100.20},
{91.01,104.40}};

.....
```



Nokia 5230-0 dBA dBAref **Reference Microphone**

coordinated mapping for citizens





We want to map noise participatively in this area.
How do we define such a measuring campaign?

coordinated mapping for researchers

We want to control as many parameters as possible, to evaluate the participatory technique (new research!).

- identical phones
- simplified NoiseTube
- identical tracks
- measurement technique
- ensure quantity of measurements
  - pre-define time & area for measuring
  - fixed # people

protocol: track choice

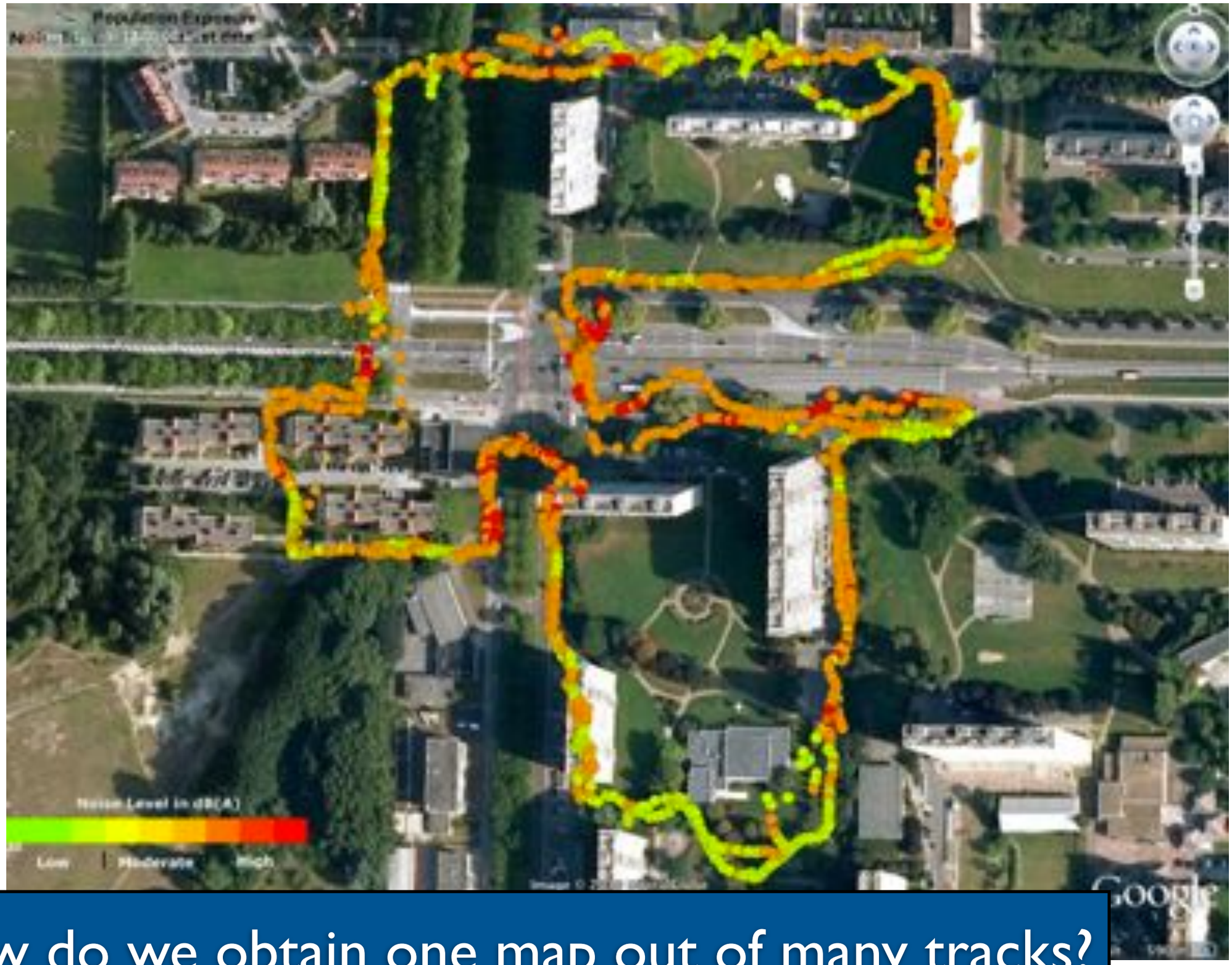
protocol

We want to measure at peak and off-peak hours.
How do we divide the work?

- choose time:
  - week 1: peak hour (7:30 - 8:30)
  - week 2: off-peak hour (21:00 - 22:00)
- 4 volunteers →

- how much data/effort?
  - 5 days x 2 tracks per day x 4 people = 40 tracks
  - 5 days x 1 hour per day x 4 people = 20 hours of field work
  - ± 1800 measurements per track (1 per 2 sec)

one map out of one track



how do we obtain one map out of many tracks?

analysis: tools

40 tracks in xml → Scheme vector with clean data

```
(define make-list-from-track
  sxml:document)

(define remove-tags
  (sxml:modify '("NoiseTube-Mobile-Session/measurement/@tags" delete)))

(define remove-measurements-without-location
  (lambda (track)
    ((sxpath "NoiseTube-Mobile-Session/measurement[ @location]")
     track)))
...

(define extract-tuples
  (lambda (track)
    (map (lambda (measurement) (append (time measurement)
                                       (list (loudness measurement)
                                             (latitude (location measurement))
                                             (longitude (location measurement)))))
         (map (lambda (pair) (cdr (cadr pair))) track))))

(define clean-up-track
  (lambda (track)
    (extract-tuples
     (remove-measurements-without-location
      (remove-tags
       (make-list-from-track track))))))
```

analysis: tools

40 tracks in xml → Scheme vector with clean data

```
(5 21 4 1 66 51.2292898506540O6 4.380786121046)
```

• • •

analysis: grid

Choose a grid and divide up measurements accordingly.

- currently: ± 35m x 35m matrix grid
- GPS errors are of this size

analysis: grid

Choose a grid and divide up measurements accordingly.

```
(define (gridpredicate i j)
  (let* ((l (limits i j))
         (latlimit (car l))
         (longlimit (cadr l)))
    (lambda (meas)
      (let ((lat (latitude meas))
            (long (longitude meas)))
        (and (>= lat latlimit) (< lat (+ latlimit latitude-spacing))
             (>= long longlimit) (< long (+ longlimit longitude-spacing))))))))

...

(define (distribute-over-grid-and-strip tracks)
  (define (distribute-over-grid-iter i j result)
    (if (= i 20)
        result
        (if (= j 20)
            (distribute-over-grid-iter (+ i 1) 0 result)
            (let ((next-element (gridfilter i j tracks)))
              (if (< (length next-element) 10) ; only keep grid elements with more than 10 measurements
                  (distribute-over-grid-iter i (+ j 1) result)
                        (distribute-over-grid-iter i (+ j 1) (cons (list i j next-element) result)))))))
  (distribute-over-grid-iter 0 0 '()))
```

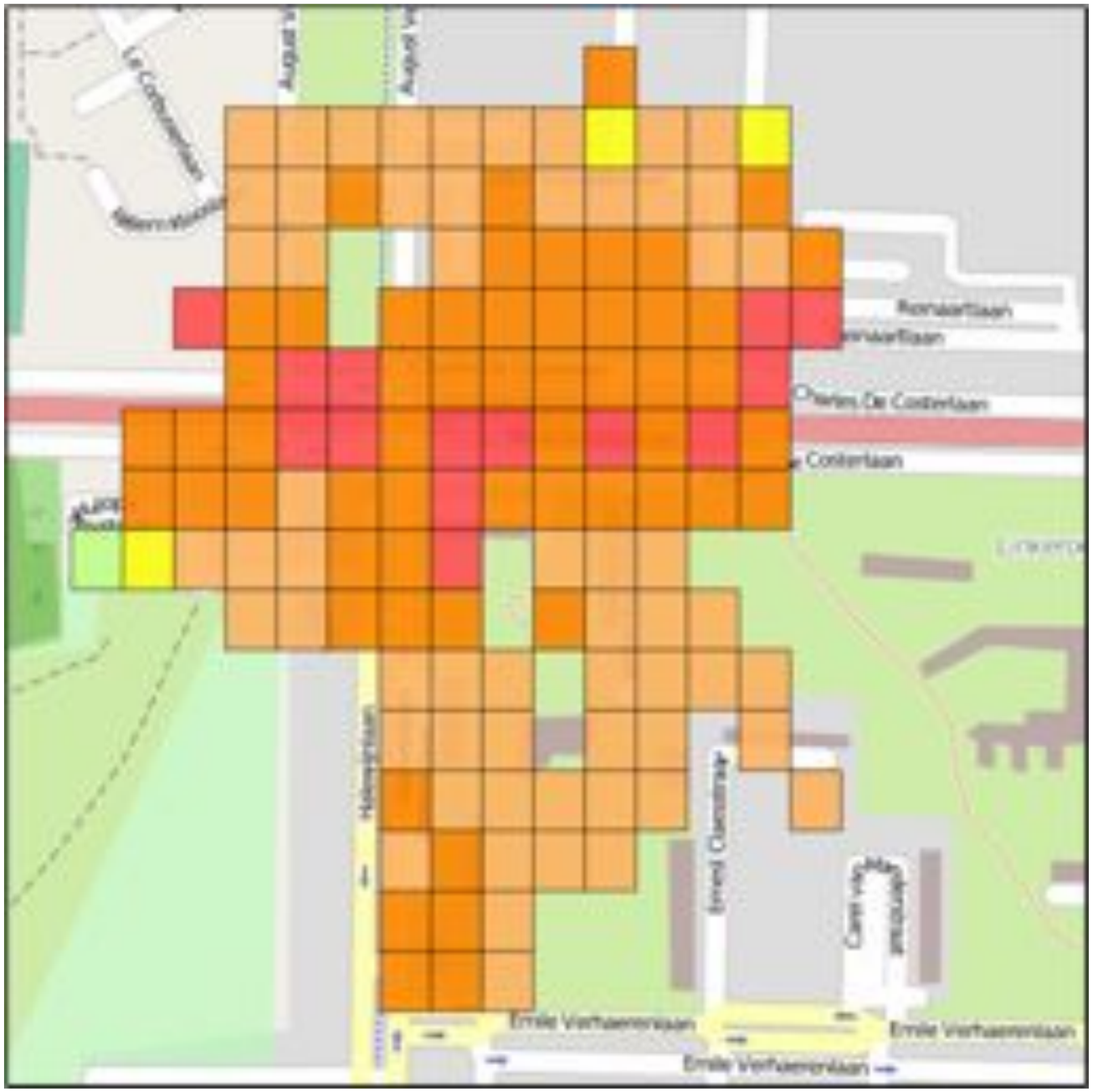
analysis: statistics

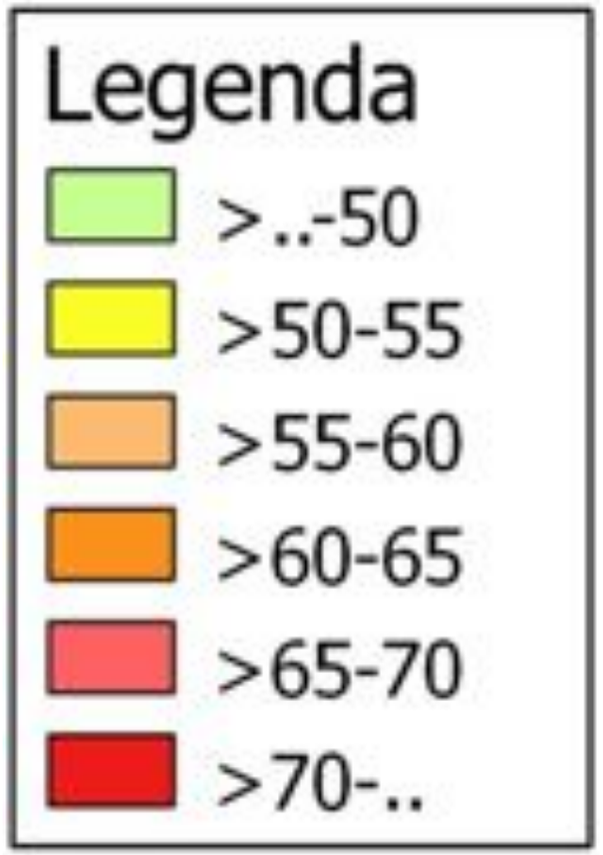
Compute average + standard deviation per grid element & make ready for map representation

```
(define (statistics measurements)
  (let* ((dBvals (map loudness measurements))
         (l (length dBvals))
         (average (/ (apply + dBvals) l))
         (square (lambda (number) (* number number)))
         (deviation (sqrt (/ (apply + (map (lambda (value) (square (- value average))) dBvals)) l)))
         (mindB (apply min dBvals))
         (maxdB (apply max dBvals)))
    (list (inexact average) (inexact deviation) mindB maxdB l)))

(define (noise-map data)
  (let* ((latitude-index car)
         (longitude-index cadr)
         (measurements caddr )
         (process (lambda (grid-element)
                    (append (find-grid-corners (latitude-index grid-element)
                                               (longitude-index grid-element))
                            (statistics (measurements grid-element)))))))
    (map process data)))
```

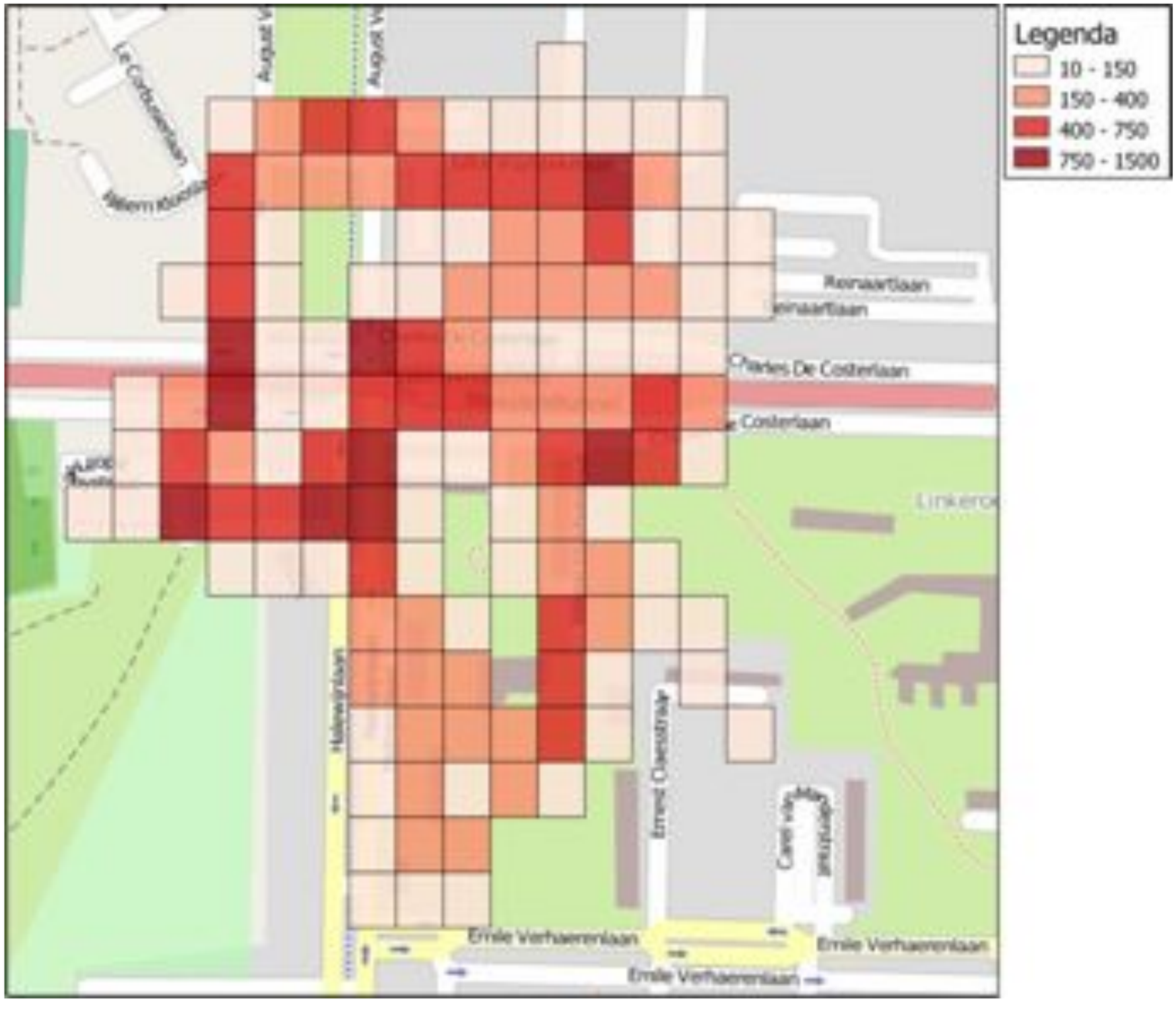
results: noise map

Import in GIS software to obtain noise maps (preliminary).

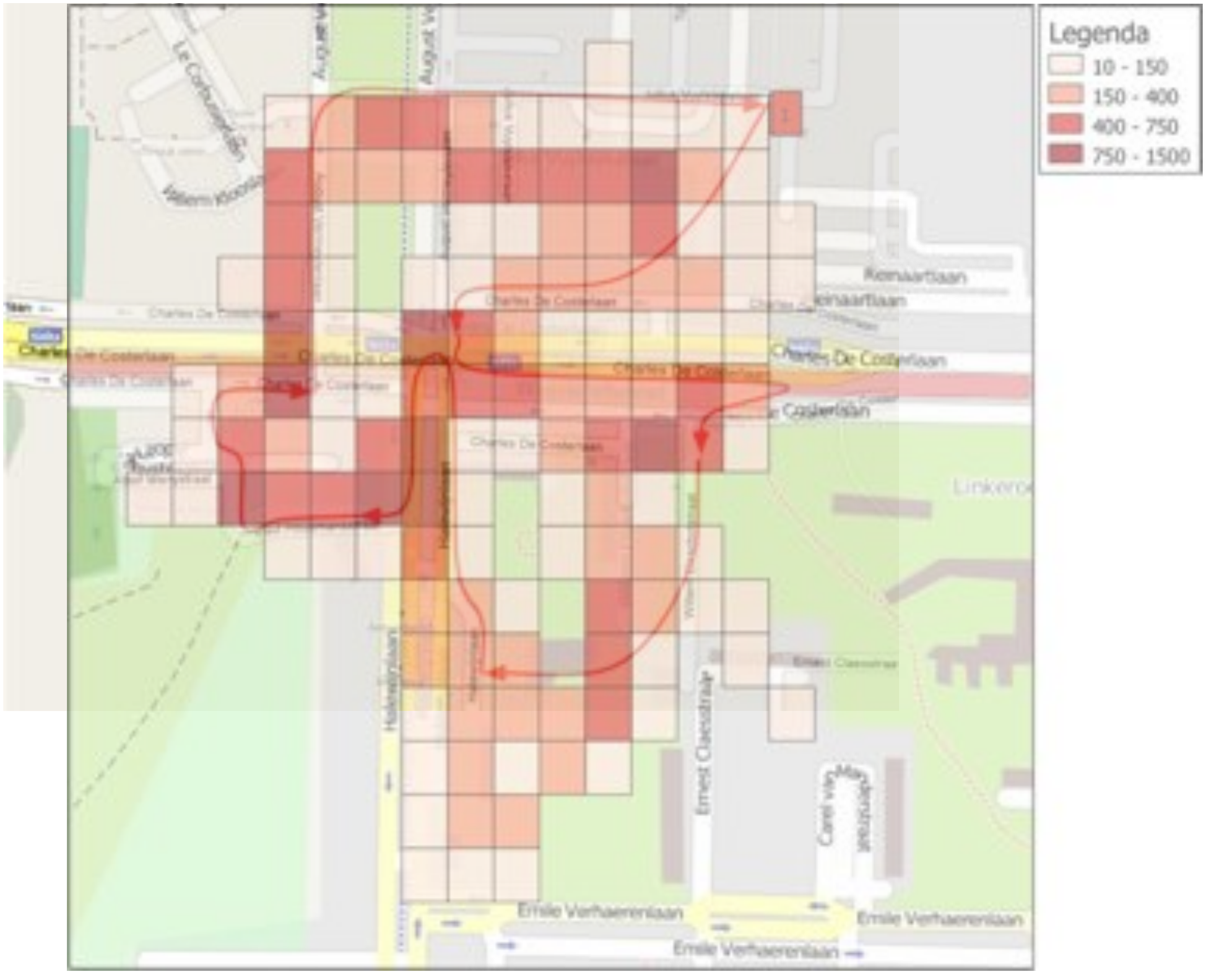




results: # measurements



results: # measurements



results: comparison

statistical analysis

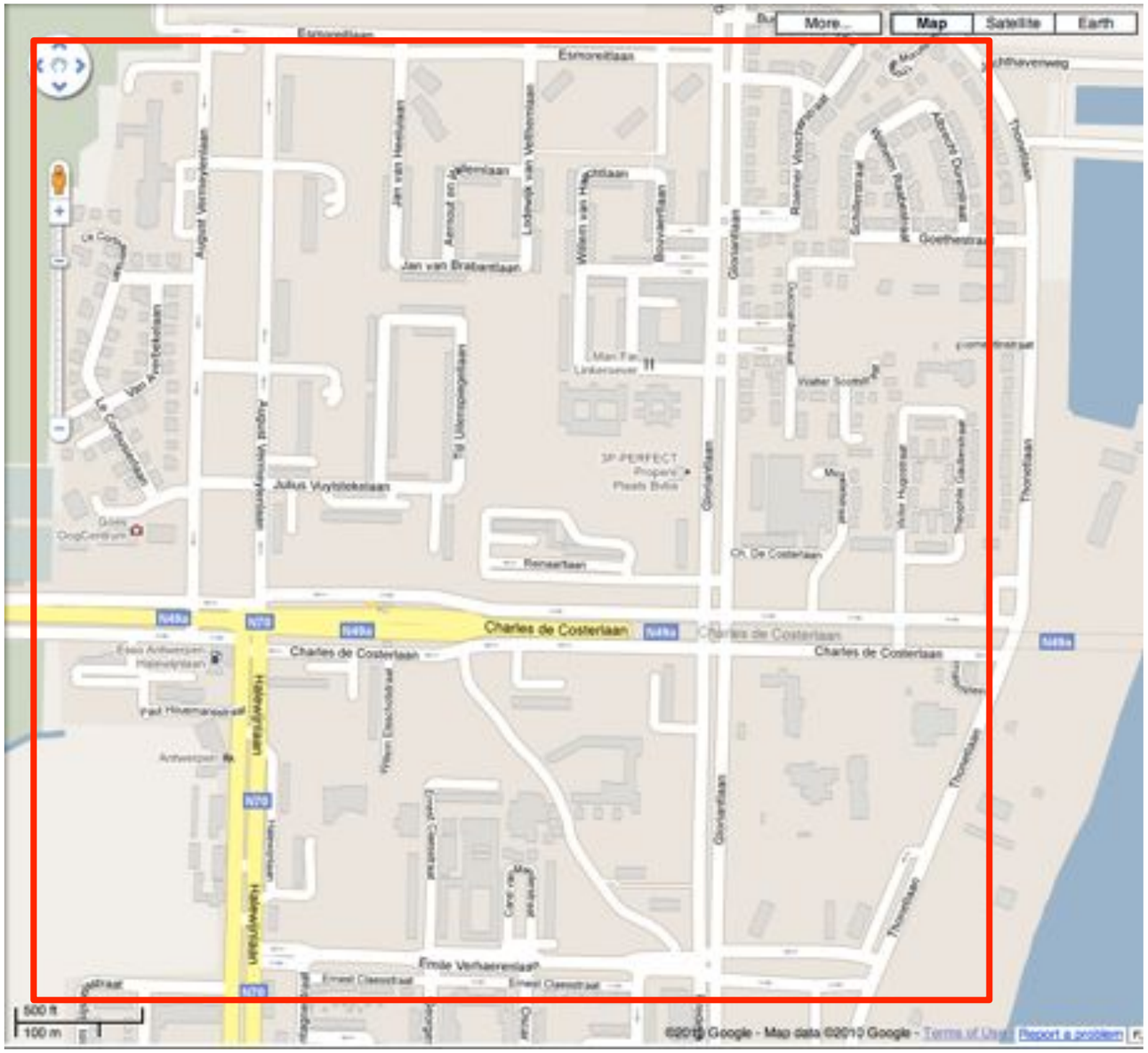
GIS development

comparison

wild mapping

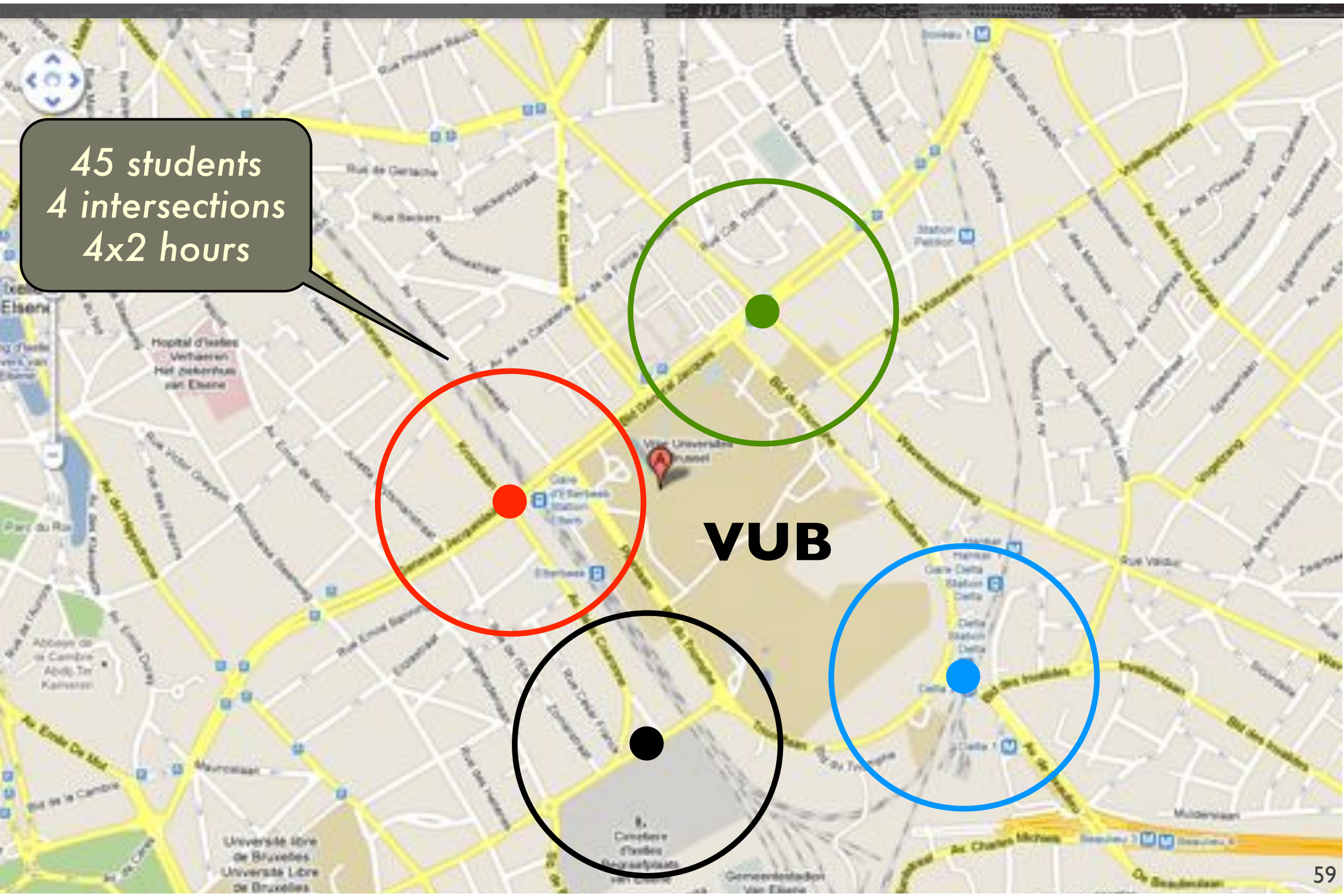
What quality can we achieve with global participation, i.e. without coordination?

- any time of day
- 10 volunteers
- > 1 hour per day
- within fixed area of 1km^2



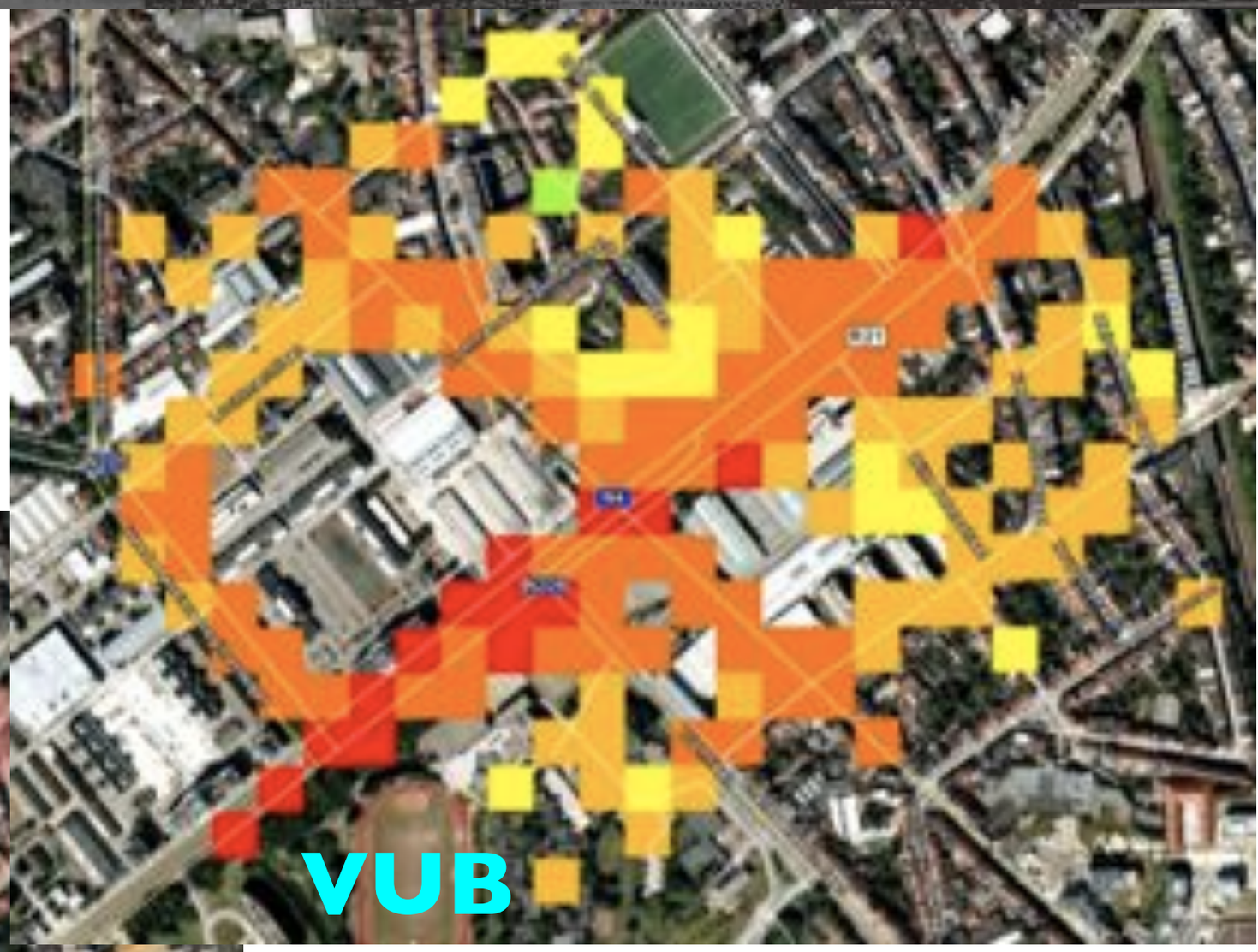
one track

confirmation



confirmation

Mon. 13 Dec
13-15h



0-50
50-55
55-60
60-65
65-70
70-80
80-90

confirmation

extensions

version 2.0

calibration

NoiseTube

Development work carried out in the context of supervised Bachelor (2), Master (1) and Ph.D. projects.

environmental participatory sensing

Surround NoiseTube

Development work carried out in the context of supervised Bachelor project (1).

context-aware participatory sensing

Development work carried out in the context of supervised Master Thesis (1).

dissemination

... to the public at large, the scientific and engineering community, as well as governmental policy makers.

European Science Foundation — **Exploratory Workshop:** ***IoT for a Sustainable Future***

La Semaine du Son Bruxelles

crosstalks

MICT Universiteit Gent

CIRB CIBG

Leefmilieu Brussel — Bruxelles Environnement

MRTE Mobilités, réseaux, territoires et environnement

Stadspiratie Congres Stedelijk Netwerken

IDEA Intelligent Distributed Environmental Assessment

vito vision on technology

CeBIT

Scholengroep Brussel onderwijs van de Vlaamse Gemeenschap

TEDx Brussels

UBICOMP2010

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2. M. Stevens and E. D'Hondt, 2010, NoiseTube & BrusSense: Participatory sensing for sustainable urban life. In *We can change the weather: 100 cases of changeability*, Eds. M. Wynants and S. Engelen, pages 92–93, Crosstalks, ASP-VUBPress.

3. M. Stevens and E. D'Hondt, Crowdsourcing of Pollution Data using Smartphones. In *Proc. of the Workshop on Ubiquitous Crowdsourcing*, UbiComp2010, Copenhagen, Denmark, Sep 26- 29, 2010, Sept. 2010.

4. E. D'Hondt and M. Stevens, 2010, Community memories for sustainable urban living, In I*NNOV 2010 – Proc. of the 1st Int. Multi-Conference on Innovative Developments in ICT*, Athens, Greece, July 29-31, 2010, pages 77–80.

5. J. Vallejos, M. Stevens, E. D'Hondt, N. Maisonneuve, W. De Meuter, T. D'Hondt, and L. Steels, Context-aware Resource Sharing for People-centric Sensing. In *First Int. Workshop on Software Research and Climate Change* (WSRCC-1), Ed. S. Easterbrook, part of Onward! 2009 (co-located with OOPSLA 2009) in Orlando, FL, USA, October 26, 2009.