

Participatory noise mapping

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Participatory sensing for sustainable urban living

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

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goals

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

- I. 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

Traffic, construction, crackers: Top noise polluters

Shibu Thomas / 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

Alok Jha
London, August 23

'Urban noise is killing thousands'

THOUSANDS OF people in Britain and around the world are dying prematurely from heart and other diseases caused by noise pollution, according to European health experts.

What you can do?

Buy a noise meter. These available for about Rs 2000 at various shops in Princess Street, Manesar Road, Khar, Dadar, etc. Start writing to your local police control room at 100 and 102. Ensure that you get a complaint number for the noise.

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'

Kavita Krishnan
kavita@india.org

CONGRESS president Sonia Gandhi's rally at Shiroji Park may have had a record turnout, but it also set a new high in noise pollution. Sonia Gandhi addressing a rally at Shiroji Park on December 17.

Citizens help police take motorists by their horns

DECIBEL LIMITS IN MUMBAI

RESIDENTIAL AREAS	55 dB
COMMERCIAL AREAS	65 dB
INDUSTRIAL AREAS	75 dB

Save Saket from the noise, say residents

Think you're going deaf?

the sunday interview / Sumaira Abdulali
Speak up against noise

NO HONKING TODAY

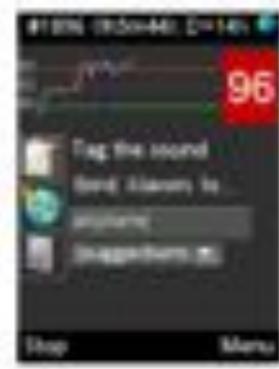
Mumbai, India

Mumbai, India

state of the art:



NoiseTube



NoiseTube
Mobile application



Web application / Community website



Hour noise exposure (0.0%)

62

Comment the sound
(e.g. bird, leaves)

traffic/construction
neighbours/office/pets
aircraft/industrial

Exit

Home

9



100

2 abc

der3

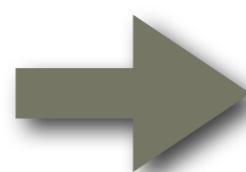
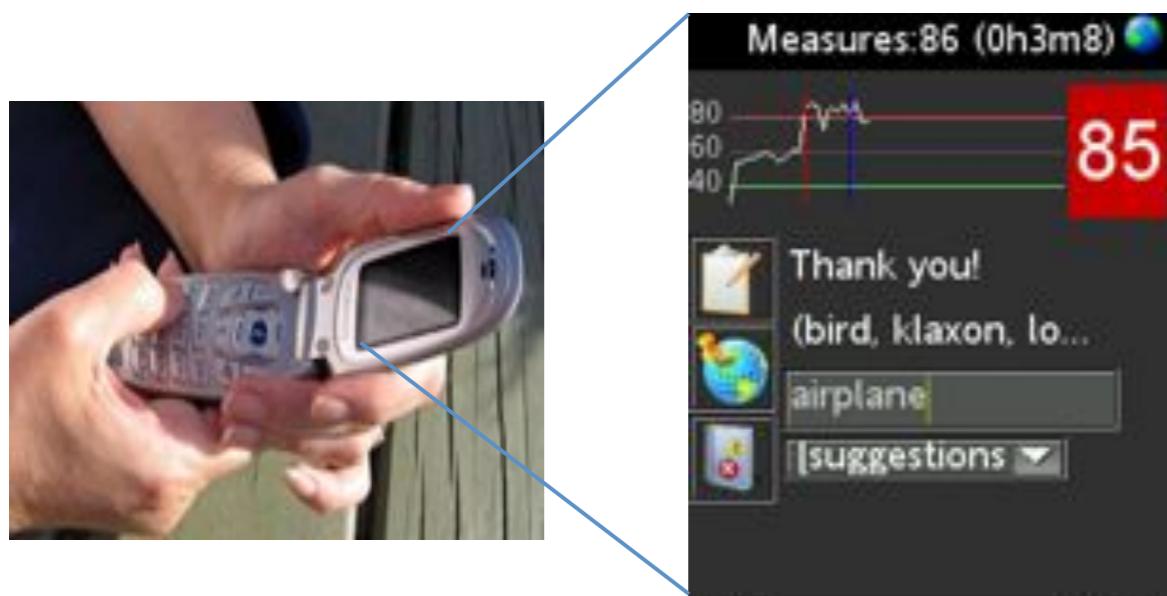
mn6





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

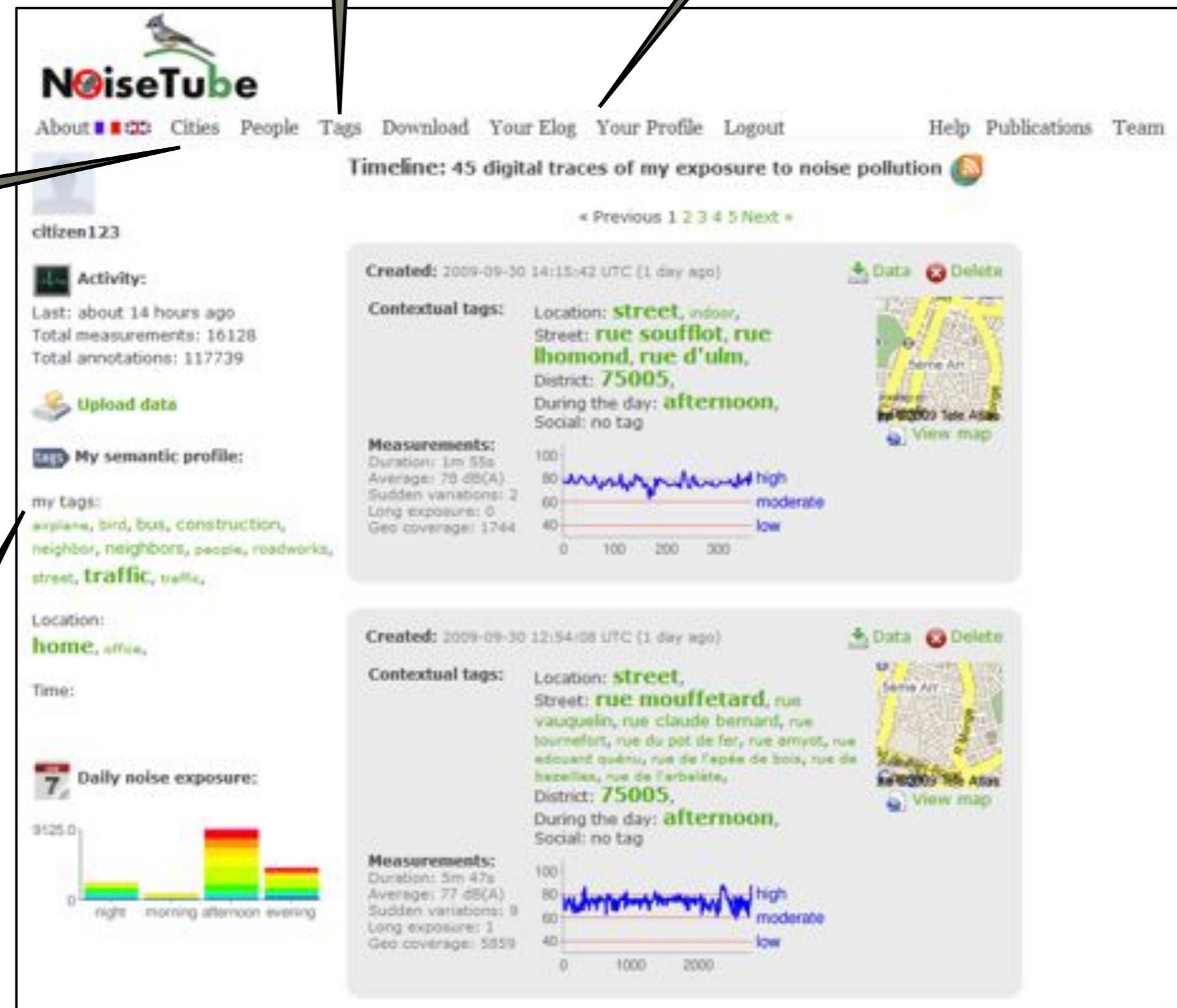
web-based community memory

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!

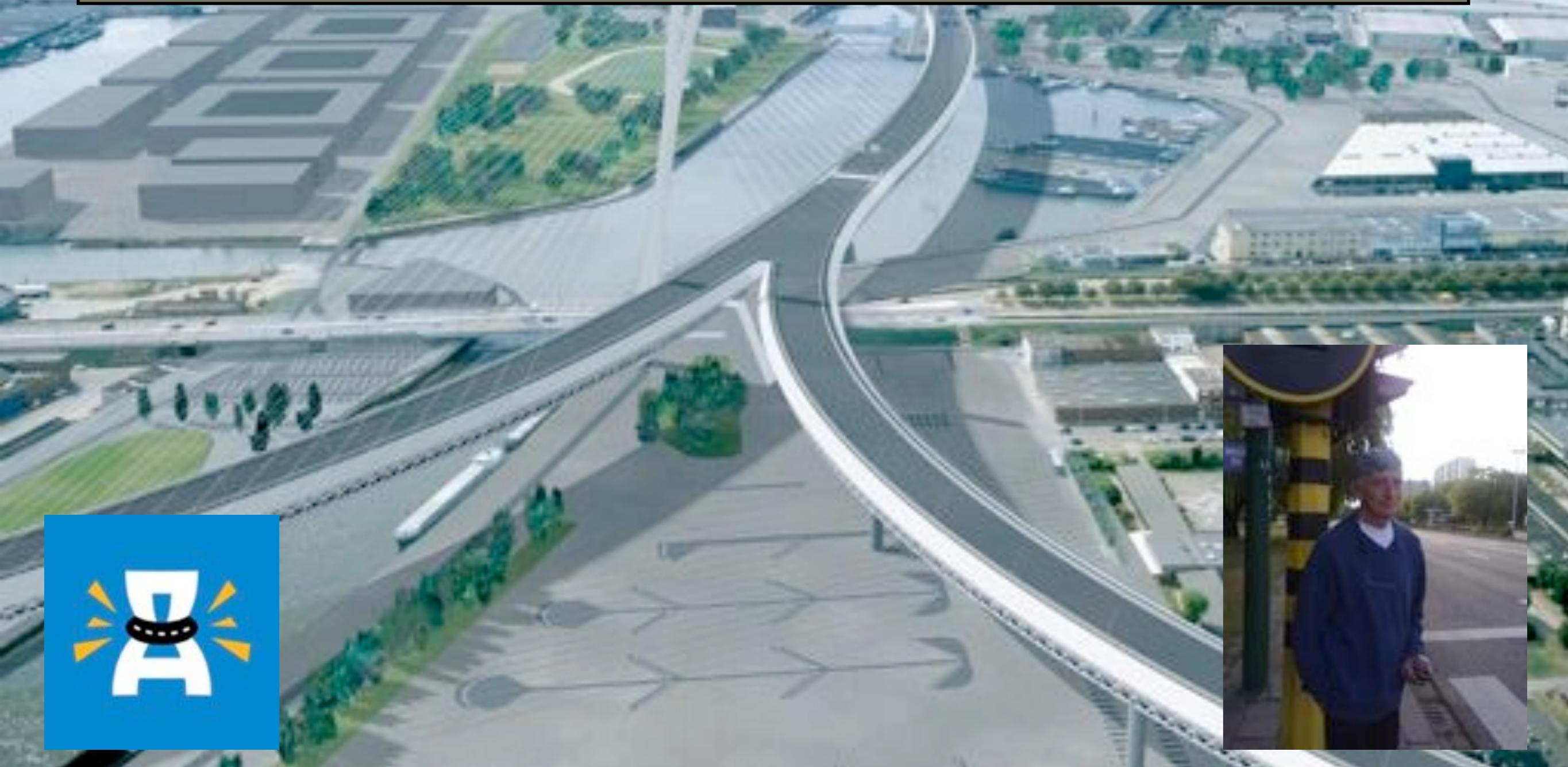
.. and also necessary from scientific point of view (validation)

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?

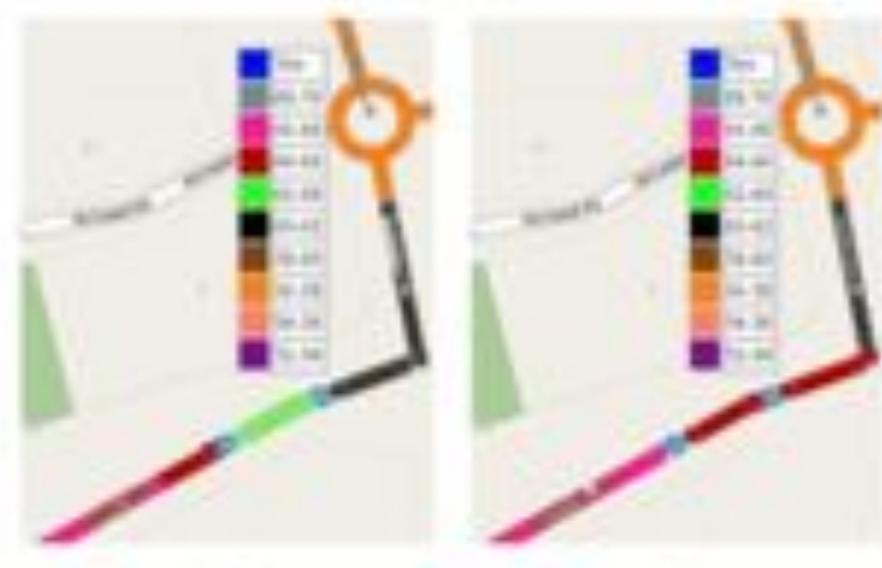
How do these maps compare to current environmental surveying methods, which are simulation-based (and rely only on a limited amount of measured data)?

rely only on a limited amount of measured data);

*analysis &
interpretation*

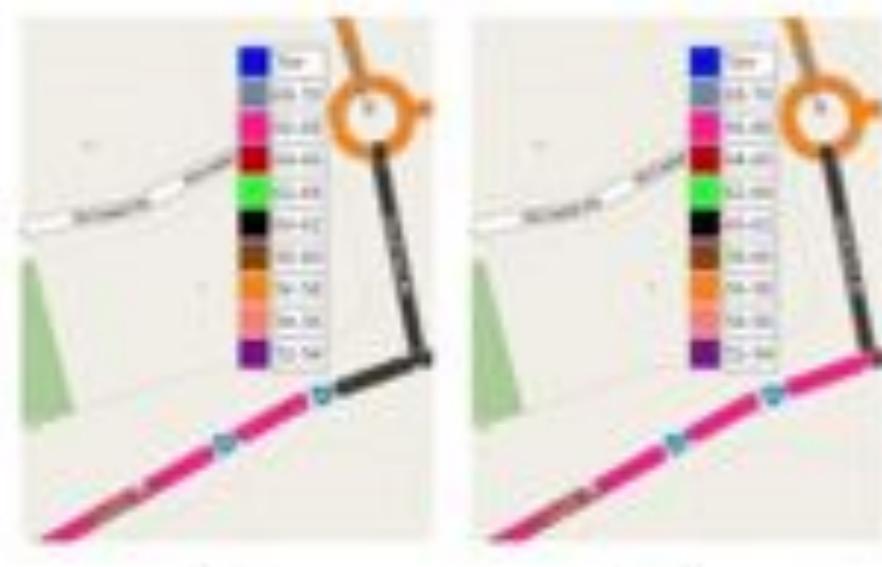
EU-norms

state of the art



(a)

(b)



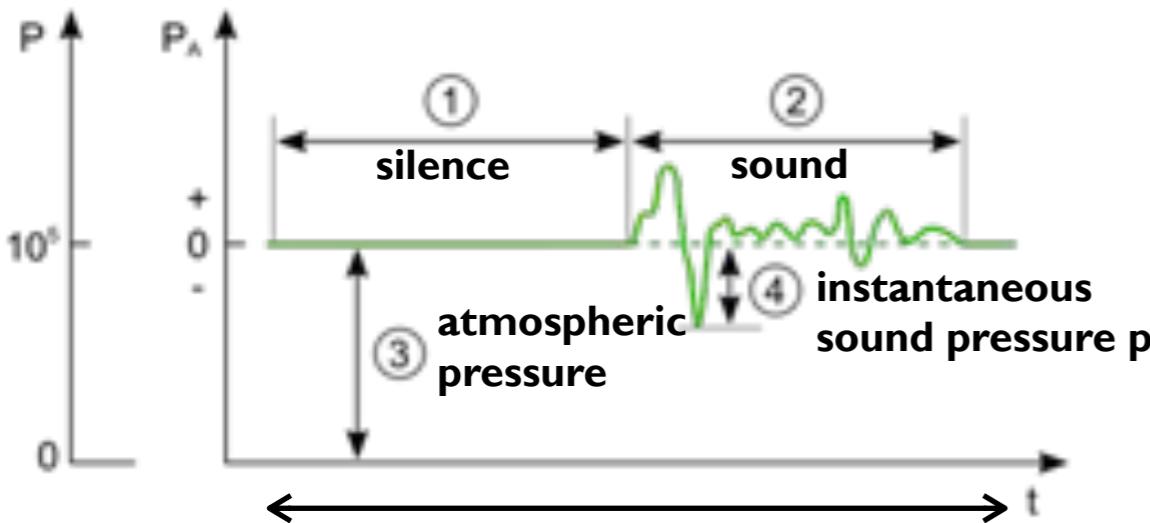
(c)

(d)

- 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)

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.

sound level measurement



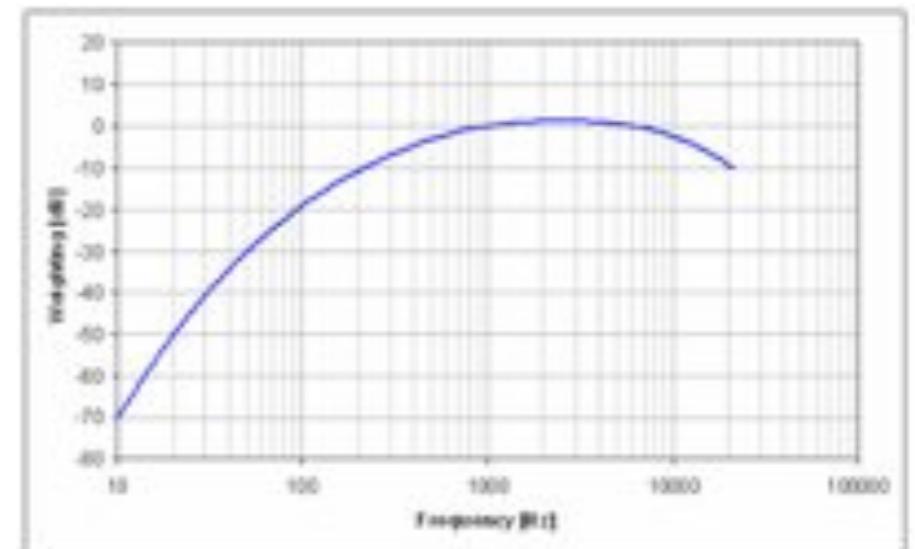
instantaneous sound level:

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

**average over time T =
equivalent continuous
sound level:**

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

A-weighting



$$L_{Aeq} \text{ (dB(A))}$$

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

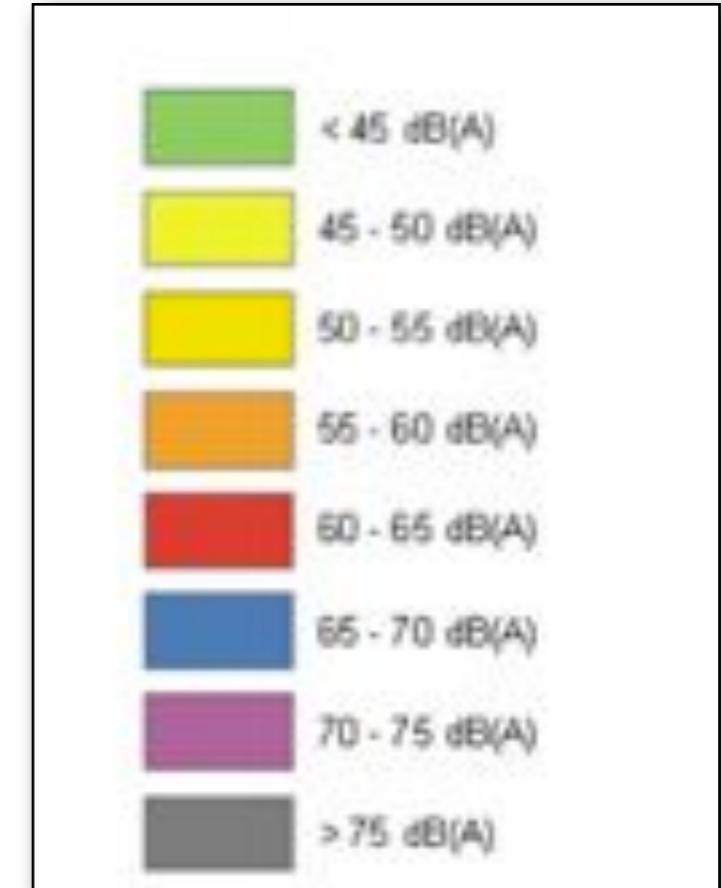
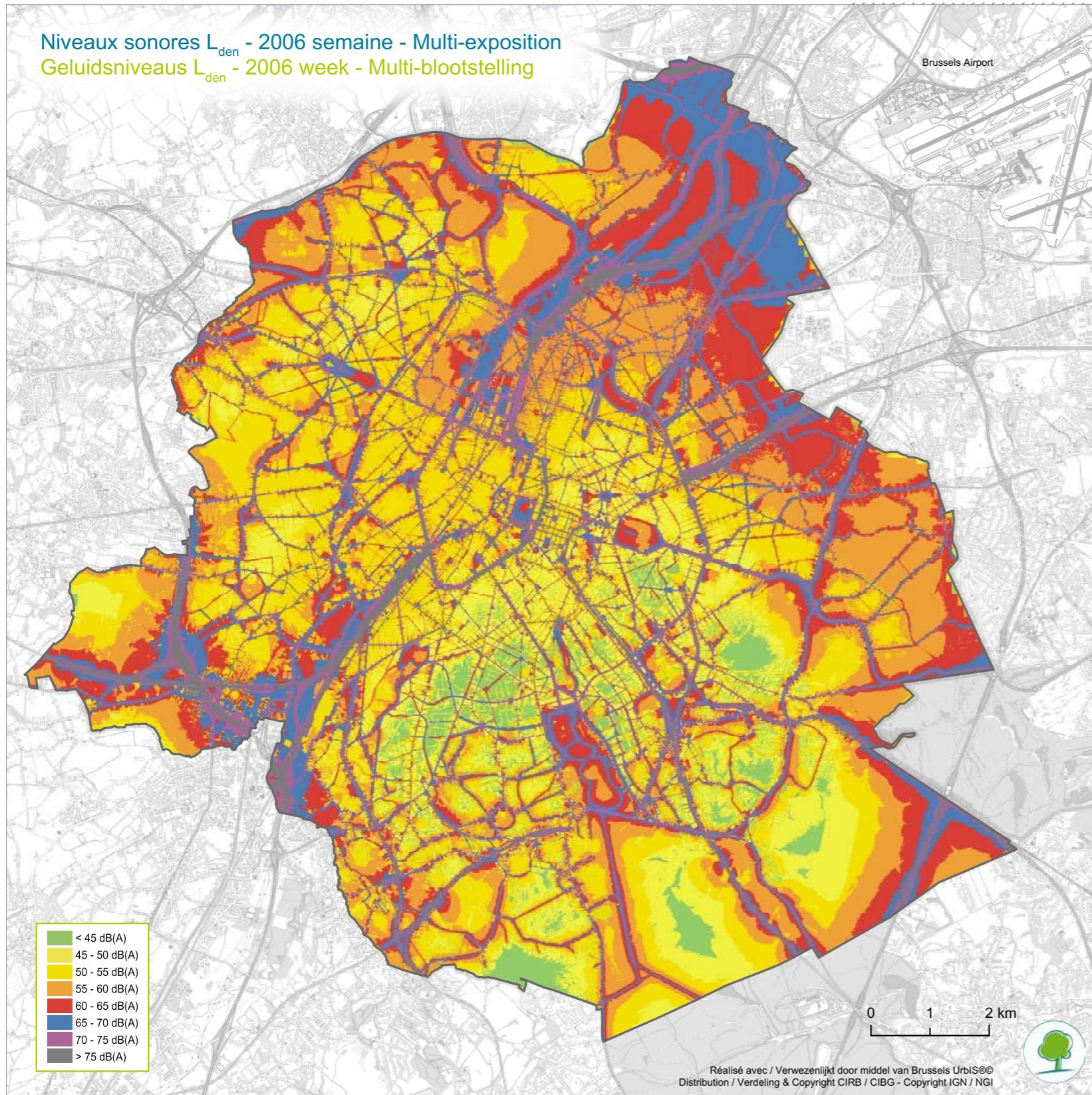


EU norms

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

- 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

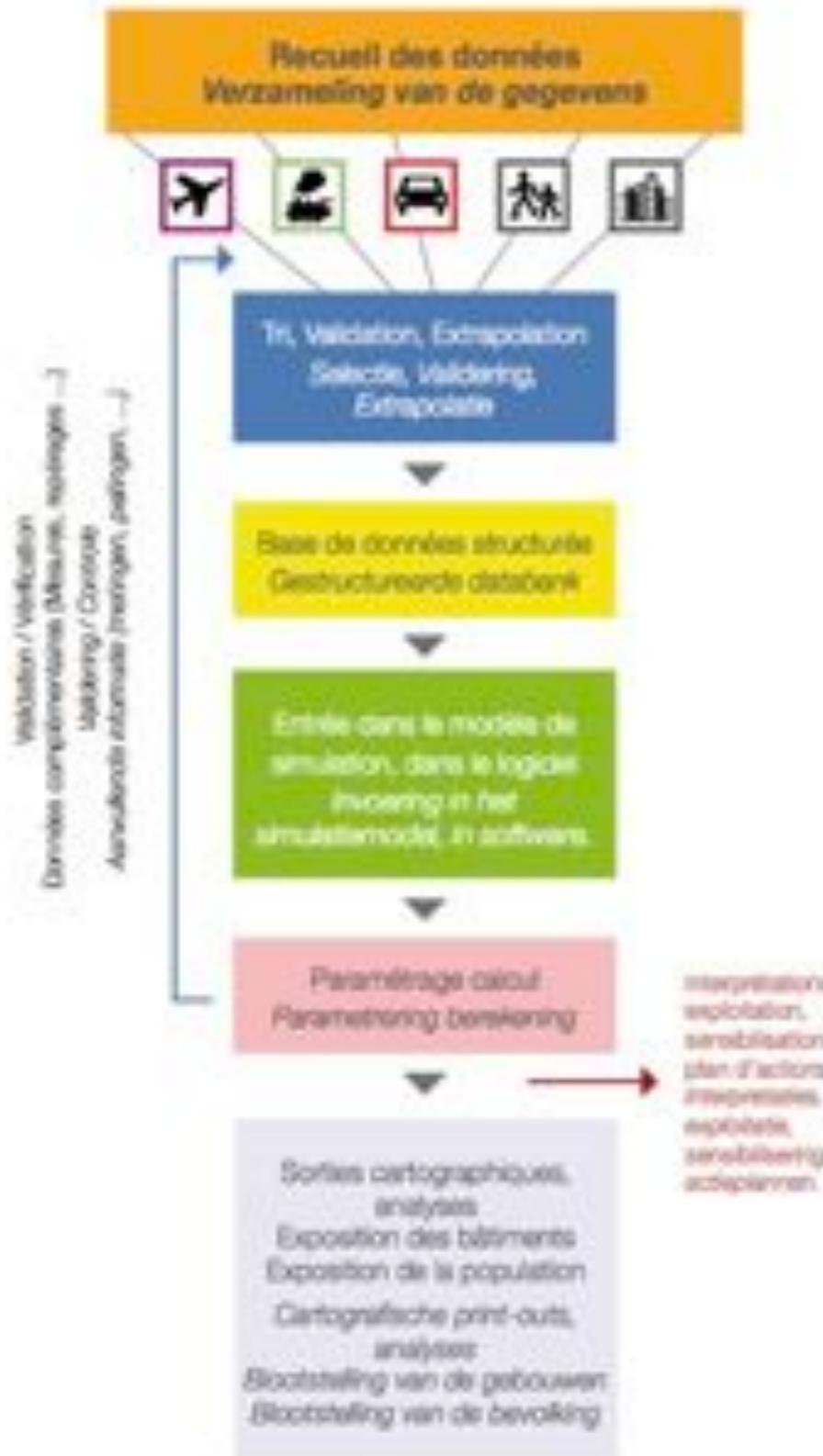
L _{den}				
Niveaux sonores Geluidsniveaus	Nombre d'habitations Aantal woningen	% des habitations % van het totaal aantal woningen	Habitations avec façade calme Aantal woningen met een rustige gevel	% des habitations soumises aux niveaux sonores précisés et bénéficiant d'une façade calme % van het aantal 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...	
Bruyant Luid	70 dB(A)	Rue animée, grand boulevard, ... Weg met druk verkeer, grote laan ...	Difficile Moeilijk
	65 dB(A)		
Bruit urbain modéré Matig stadsbewoeling	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...	
	45 dB(A)		
Bruit de fond calme Rustig achtergrondgeluid	40 dB(A)	Intérieur cour, campagne, ... Binnenplaats, platteland...	A voix normale Praten met normale stem
Très calme Zeer rustig	30 dB(A)	Ambiance nocturne en milieu rural Nachtgeluid in een landelijke omgeving	
Silence Stilte	20 dB(A)	Désert Woestijn	A voix basse Fluisteren

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

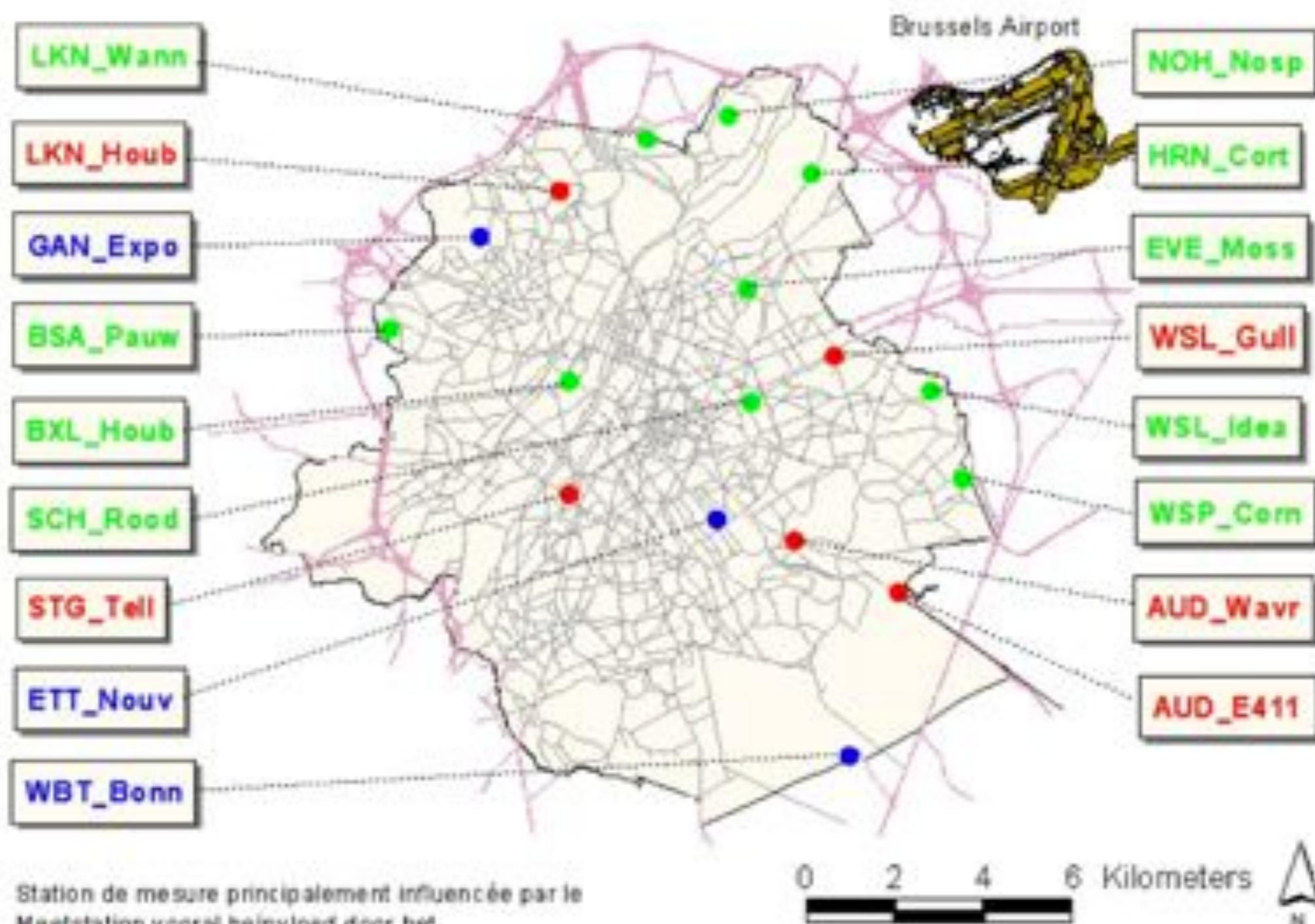
noise maps through simulation



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



noise maps through simulation



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Distributie: C.I.B.O. 20 Kunstlaan, 1000 Brussel

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



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



guidelines for measurements

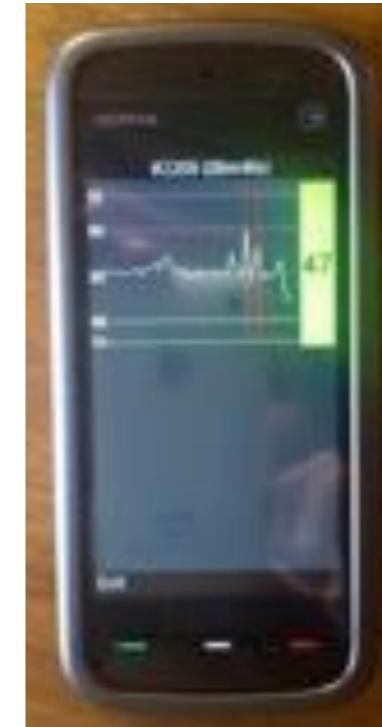
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measurement equipment

10x



+



EU-norms:

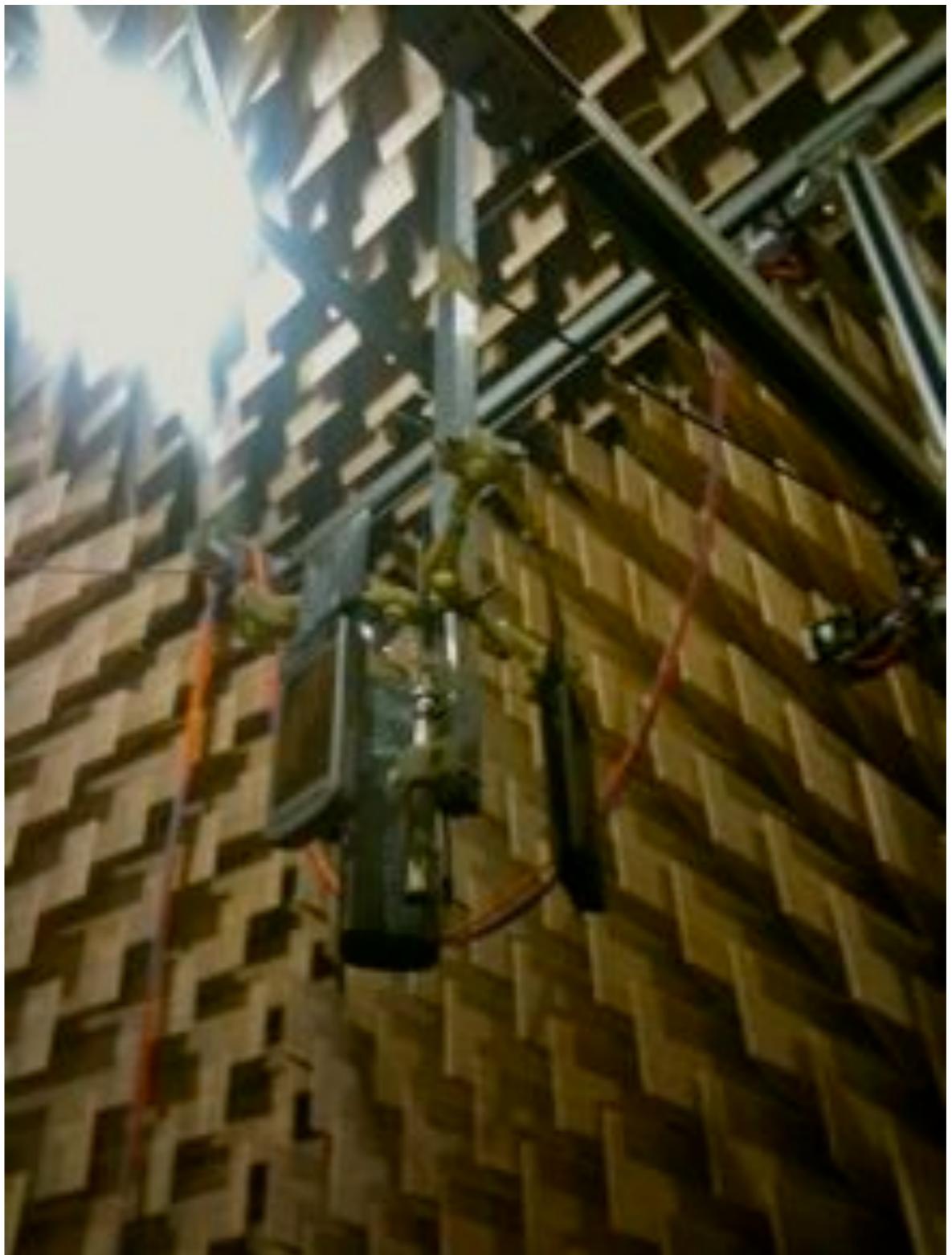
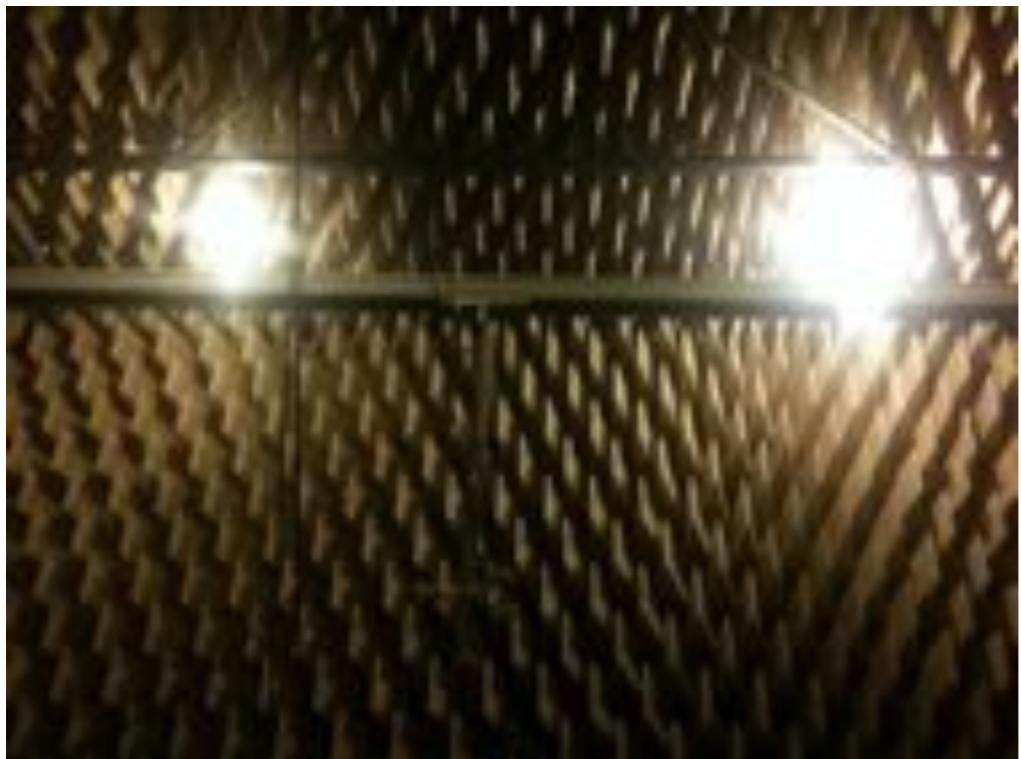
- A-filtering
- direct read-out of dB(A)
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- calibration
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*realistic set of
phones (from
eBay)*

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

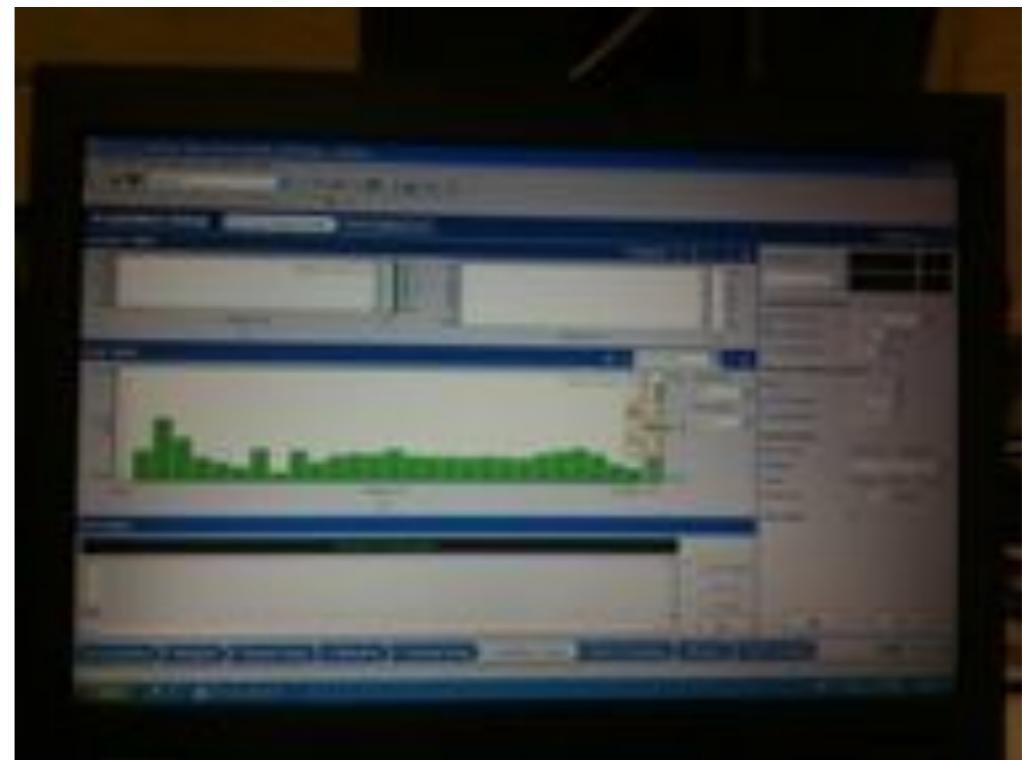
calibration



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

calibration: frequency

2 phones tested

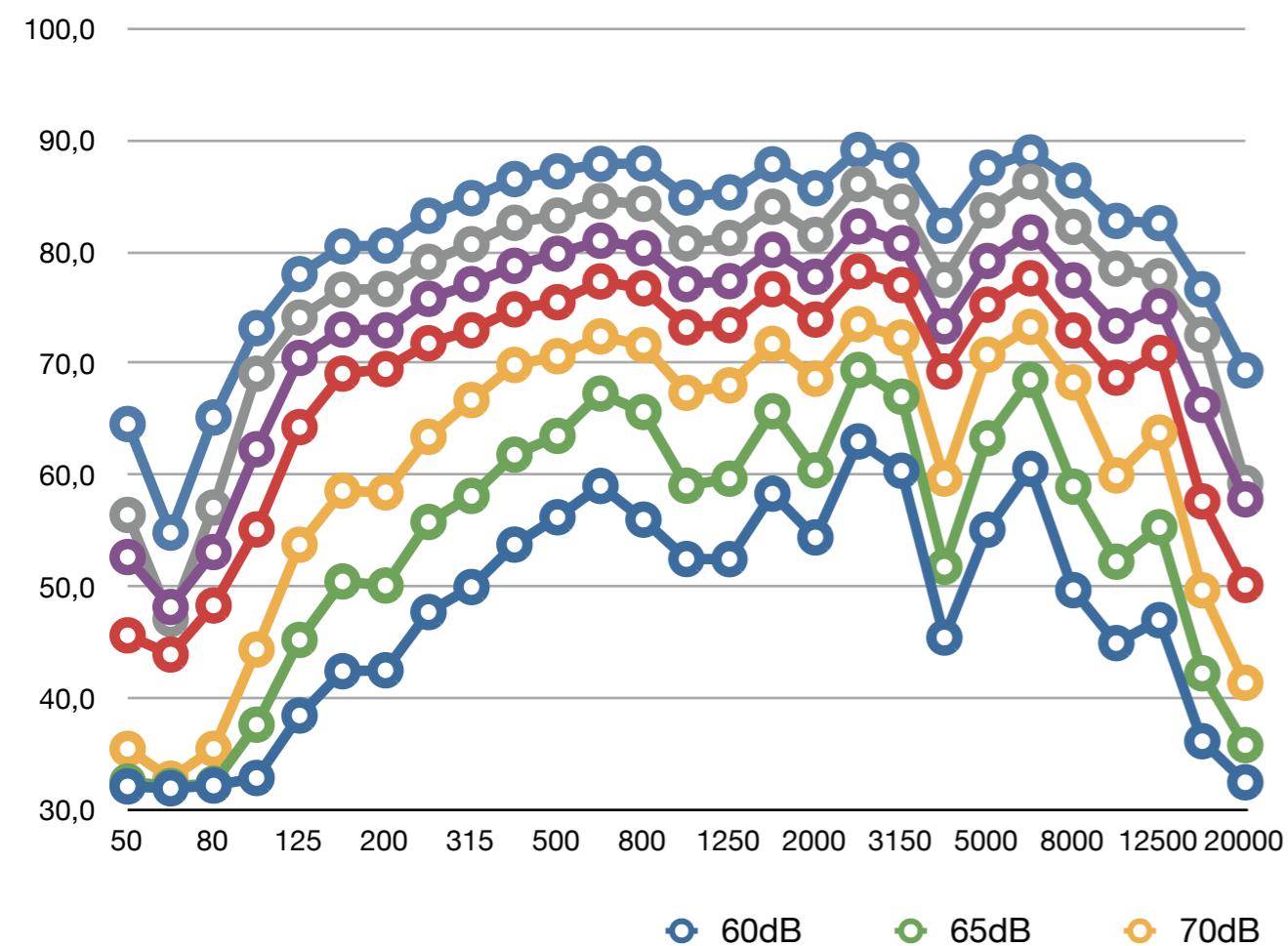


calibration

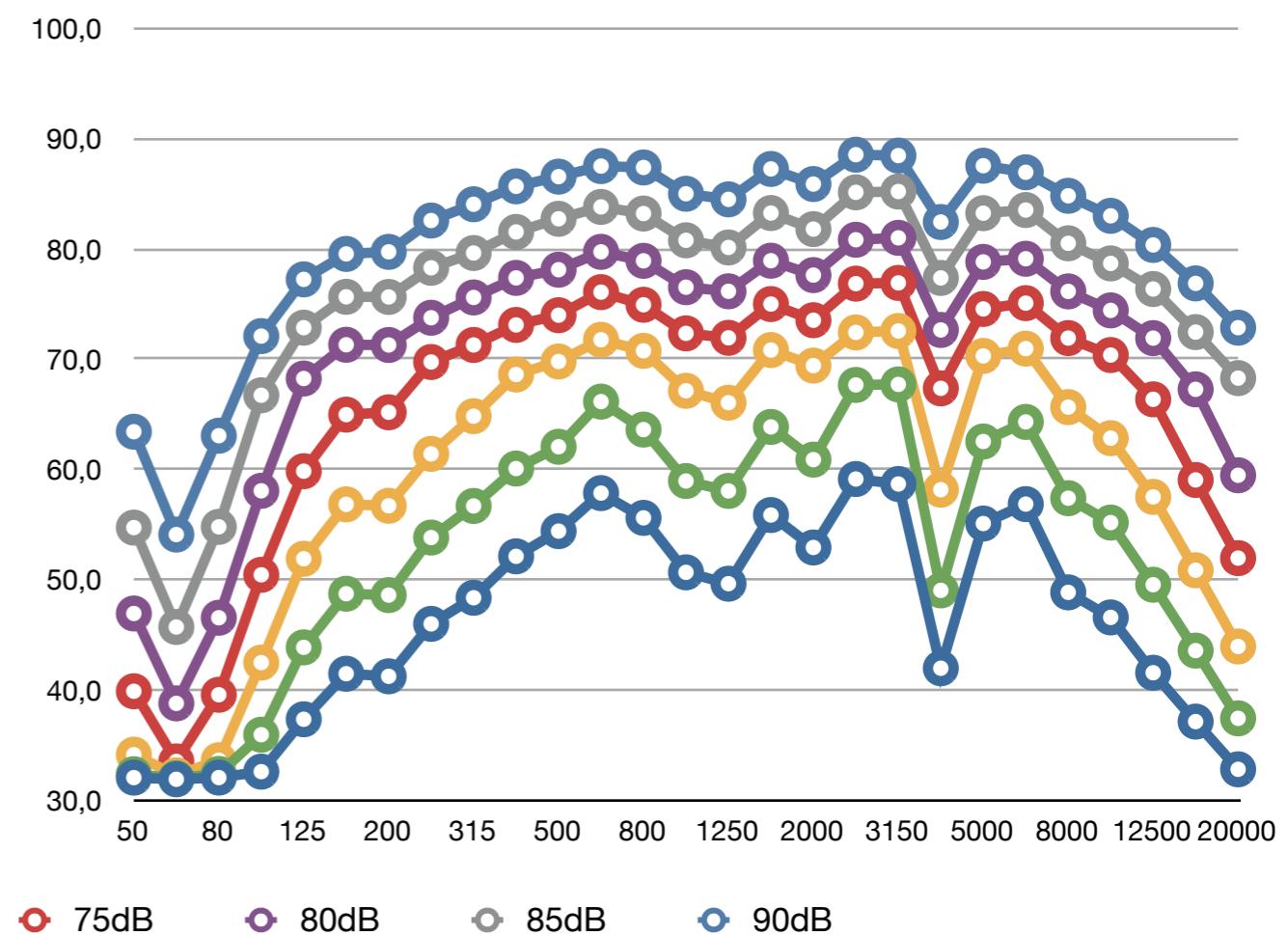


calibration: frequency

Nokia 5230-0



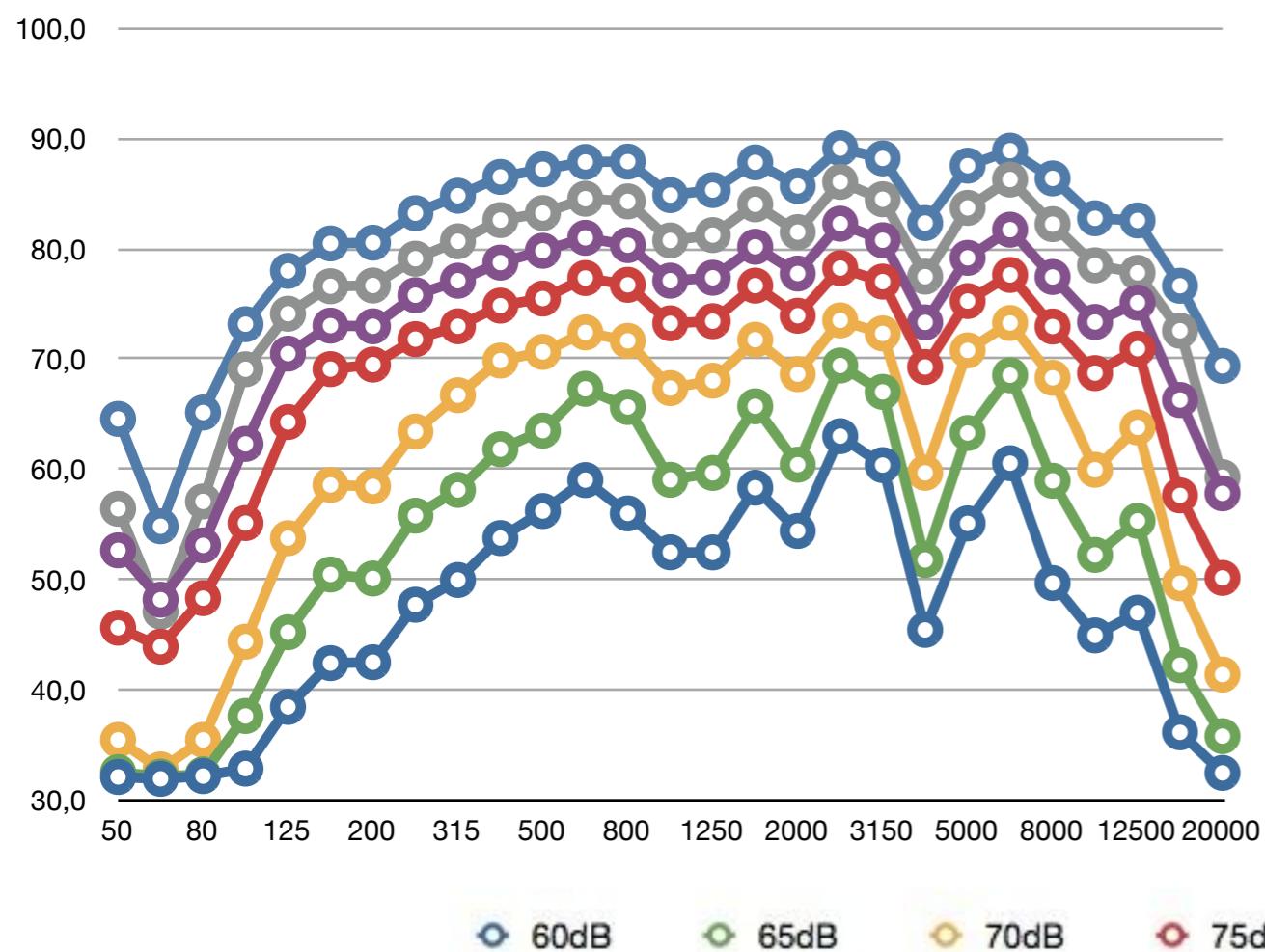
Nokia 5230-I



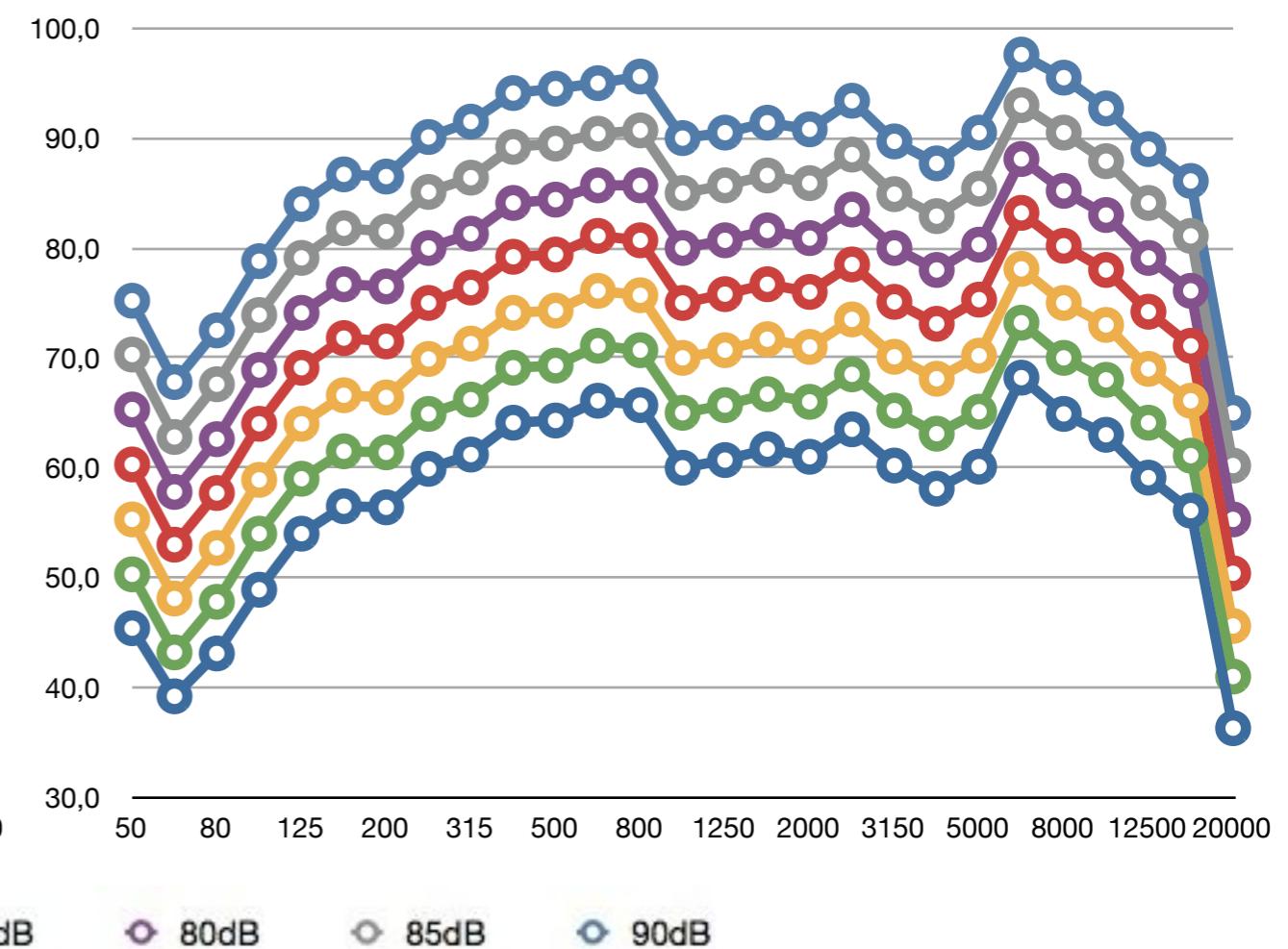
no significant differences → focus on I phone

calibration: frequency

Nokia 5230-0

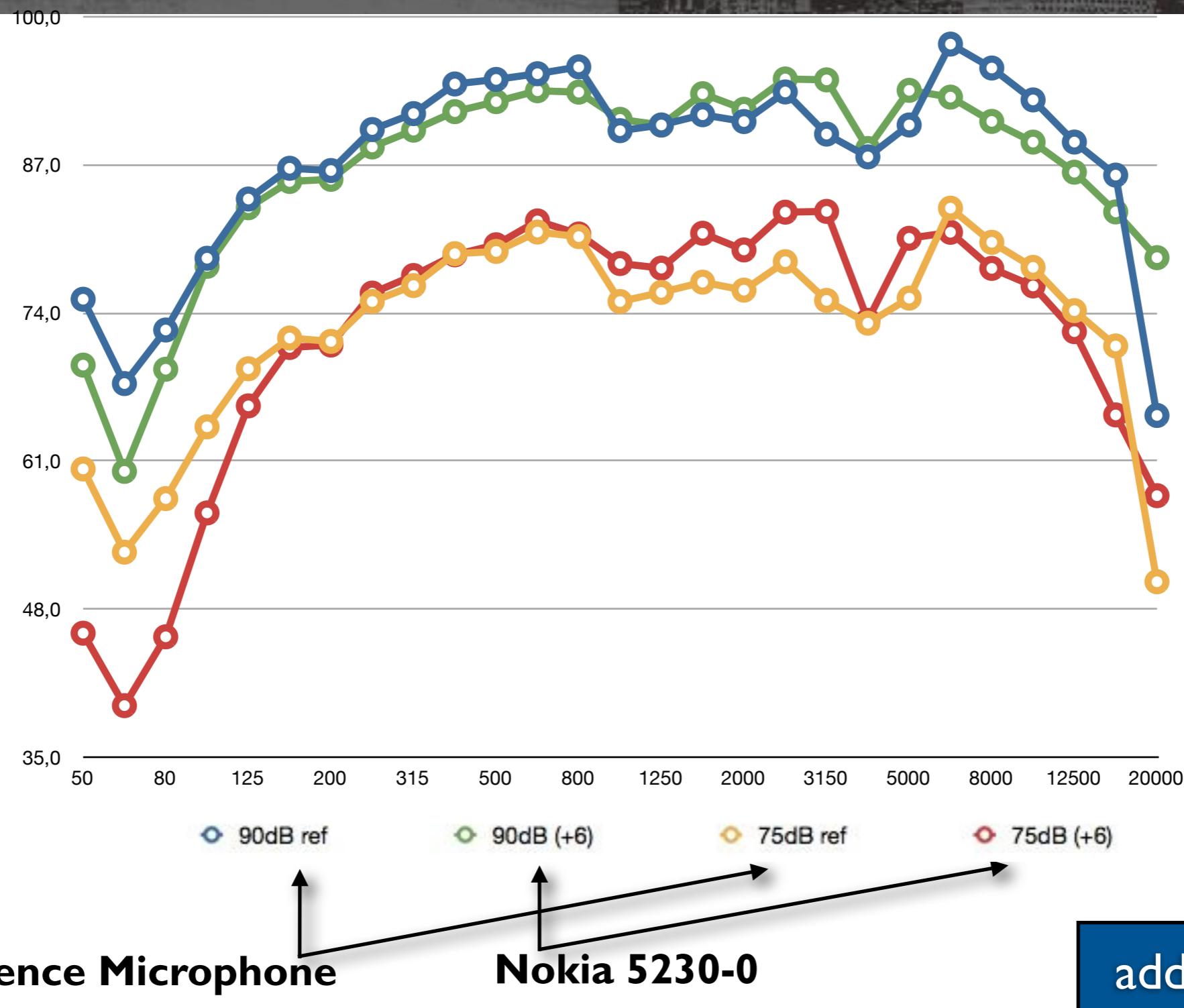


Reference Microphone



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

calibration: frequency



Reference Microphone

Nokia 5230-0

add 6dB globally

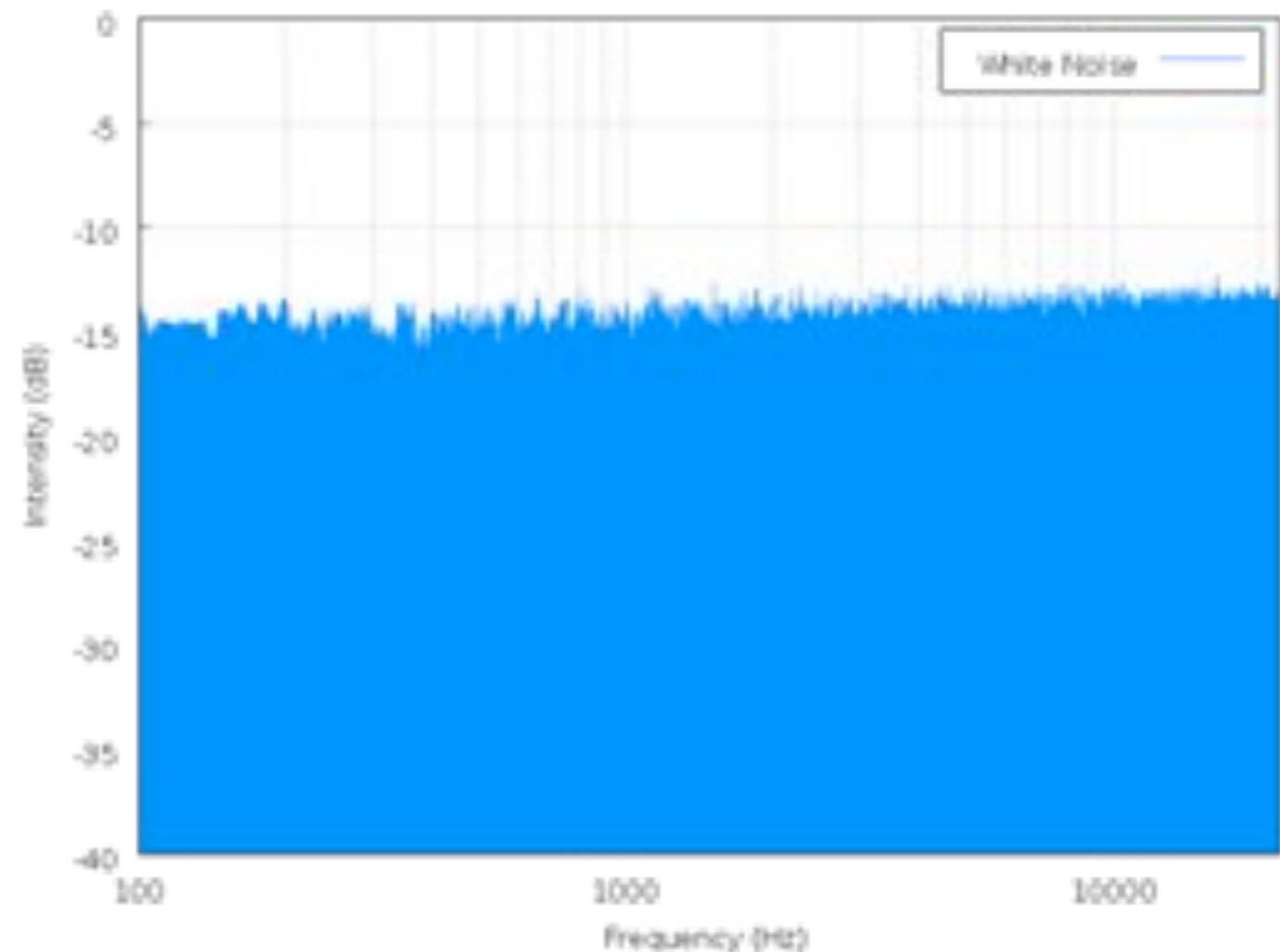
phone follows mike quite well, except for low dB/frequency

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)

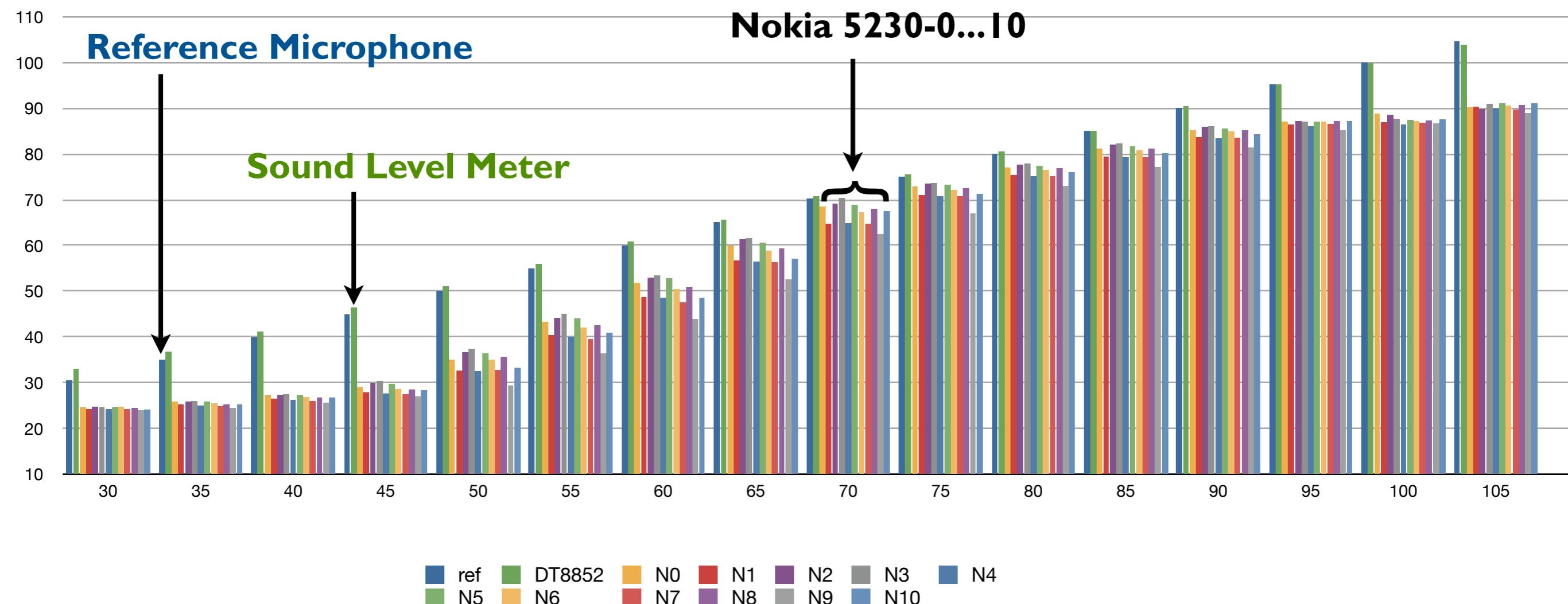
calibration: white noise



white noise = all frequencies equally present

calibration: white noise

10 phones tested



calibration: white noise



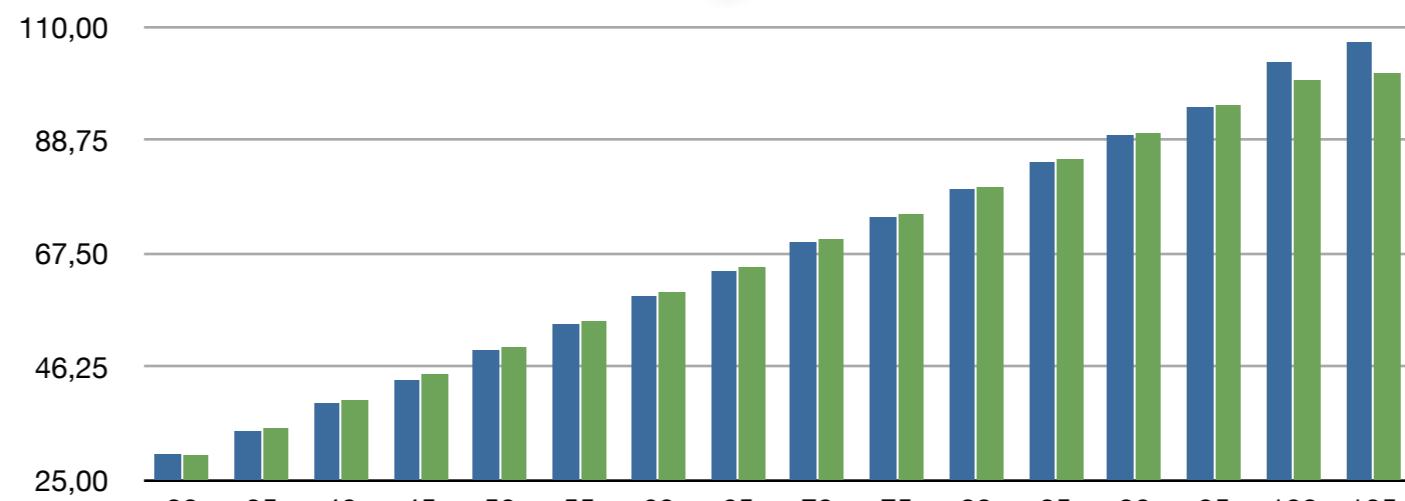
```
private static final double NOKIA_5230_0 = {{24.64, 30.00}, {25.83, 35.00}, {27.24, 40.10}, {29.05, 44.90}, {35.00, 50.10}, {43.34, 55.00}, {51.84, 60.05}, {59.95, 65.05}, {68.51, 70.05}, {72.92, 75.10}, {77.02, 79.95}, {81.20, 84.95}, {85.18, 89.95}, {87.25, 95.00}, {88.84, 100.00}, {90.18, 103.8}};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

```
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}};
```

....



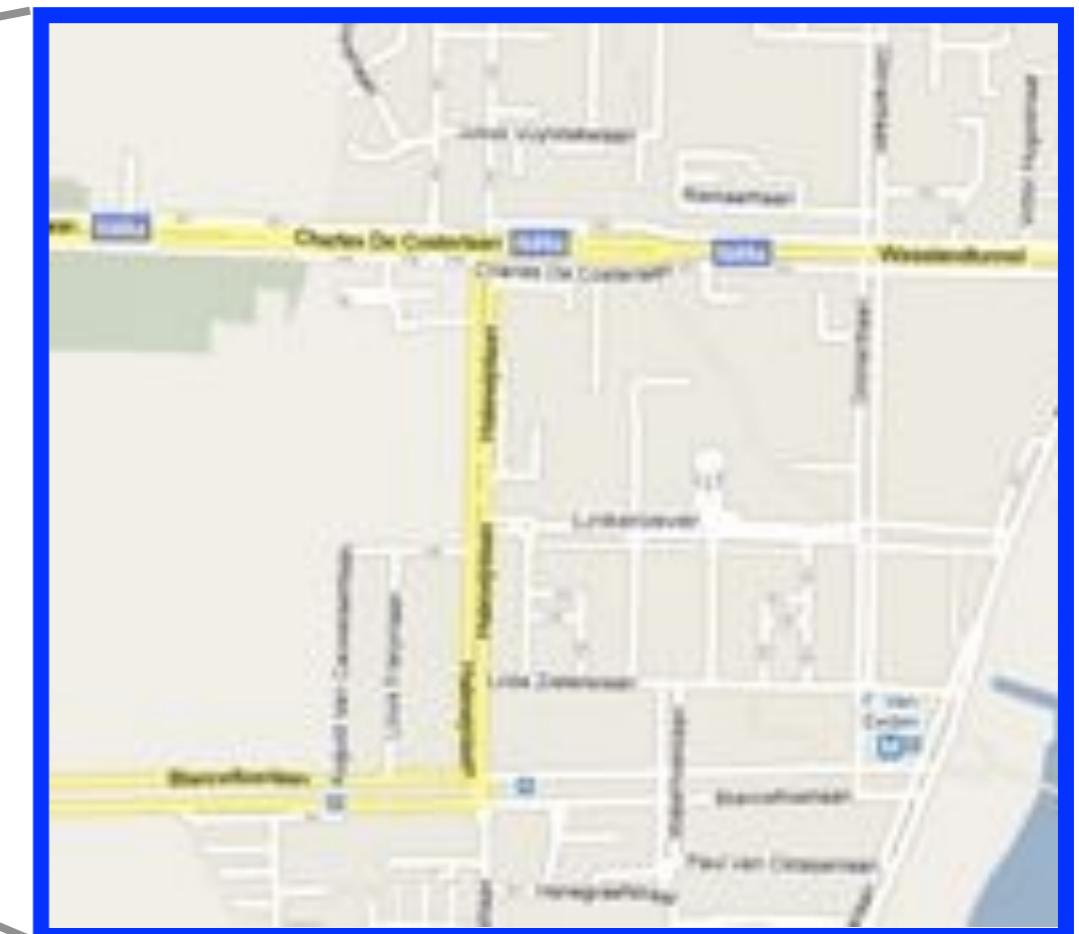
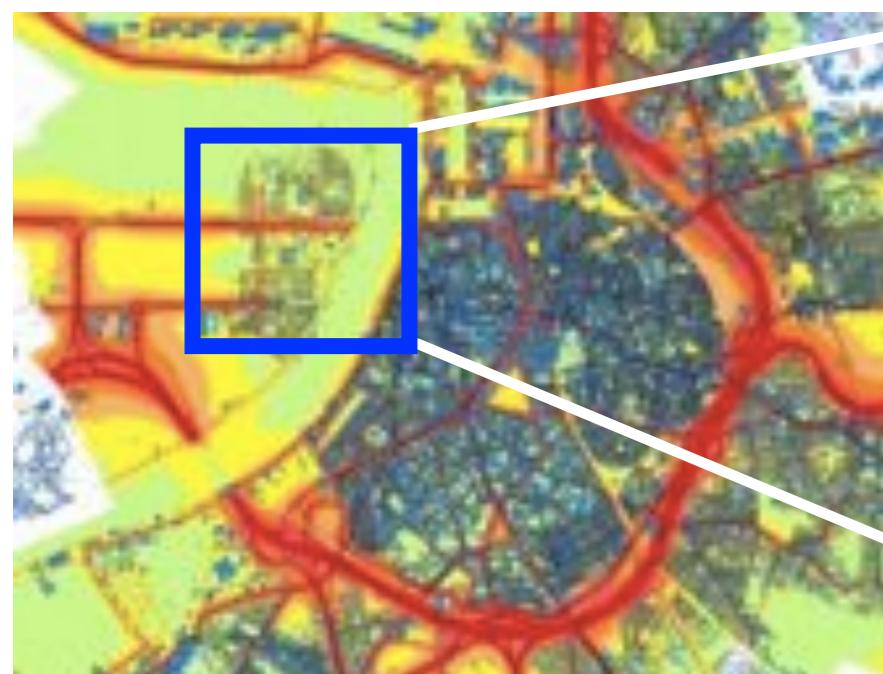
Nokia 5230-0

■ dBA

■ dBRef

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?
 - $5 \text{ days} \times 2 \text{ tracks per day} \times 4 \text{ people} = 40 \text{ tracks}$
 - $5 \text{ days} \times 1 \text{ hour per day} \times 4 \text{ people} = 20 \text{ hours of field work}$
 - $\pm 1800 \text{ measurements per track (1 per 2 sec)}$

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
  (lambda (xml:document)
    ...))

(define remove-tags
  (lambda (xml)
    (xml:modify '("NoiseCube-Mobile-Session/measurement/@tags" delete) )))

(define remove-measurements-without-location
  (lambda (track)
    (let ((xpath "NoiseCube-Mobile-Session/measurement[ @location ]"))
      (xpath:remove track xpath)))))

(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 51.229289850654006 4.380786121046) (5 21 4 2 66 51.229289876471213 4.3807502260441025) (5 21 4 4 62
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analysis: grid

Choose a grid and divide up measurements accordingly.



- currently: $\pm 35m \times 35m$ 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

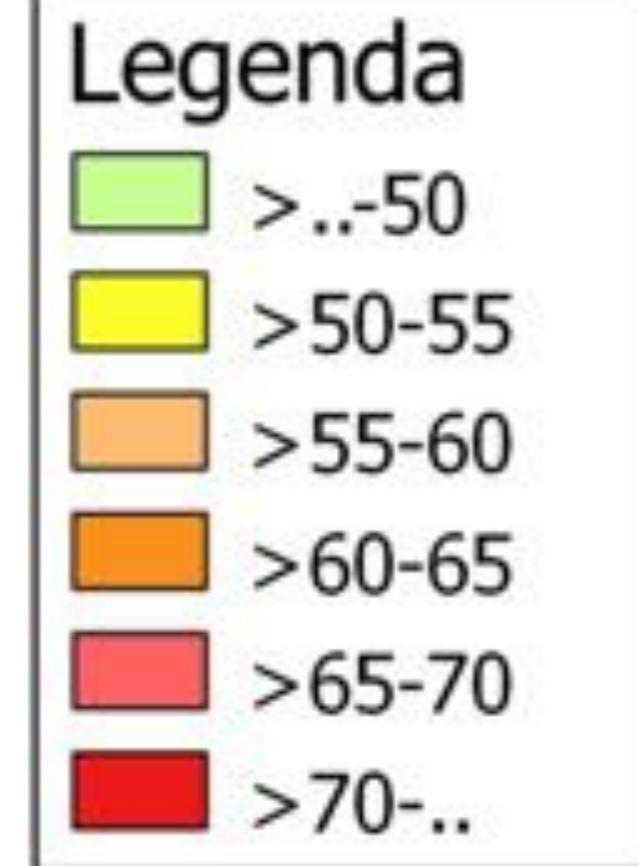
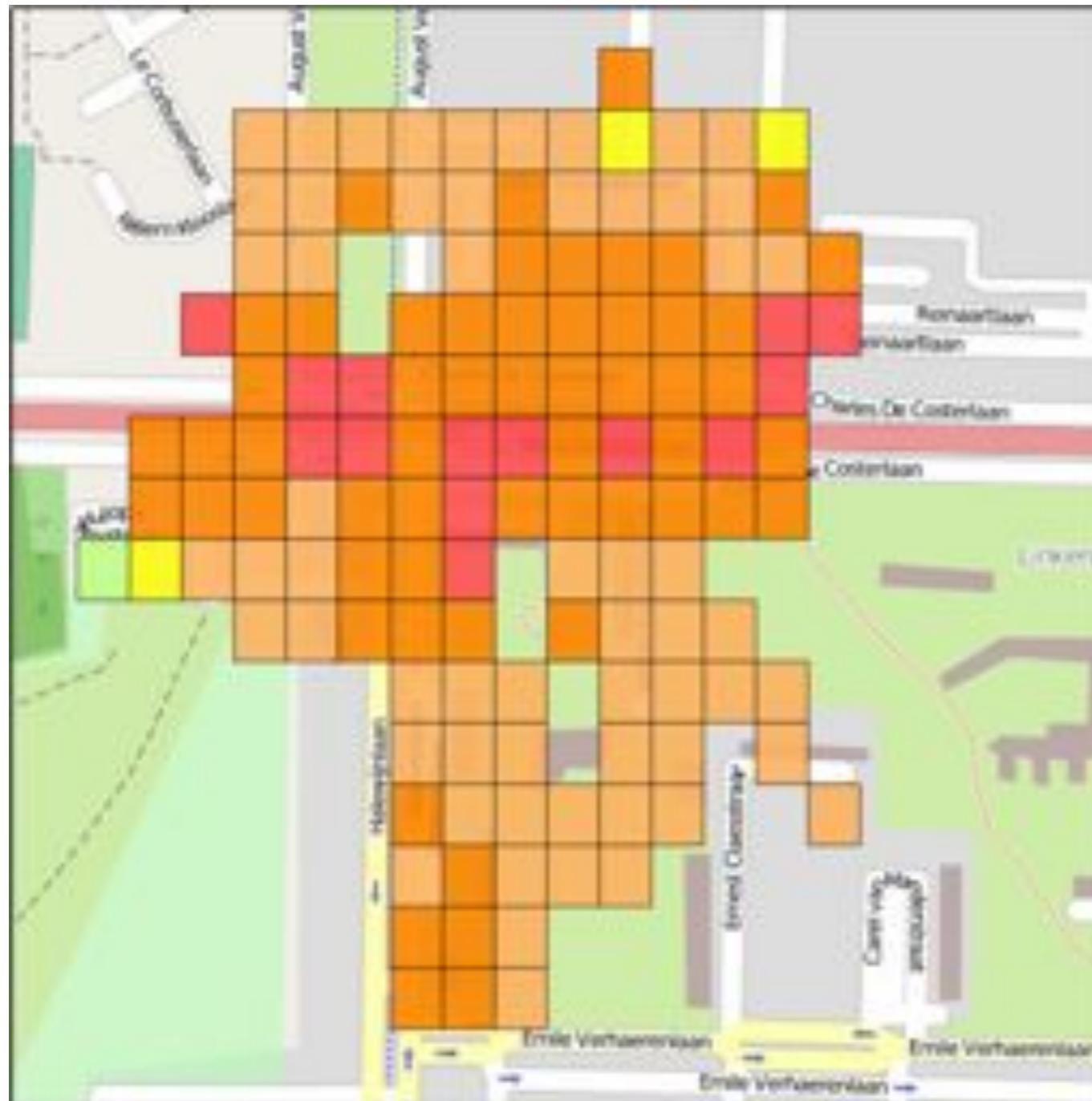
Compute average + standard deviation per grid element
& make ready for map representation

```
(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

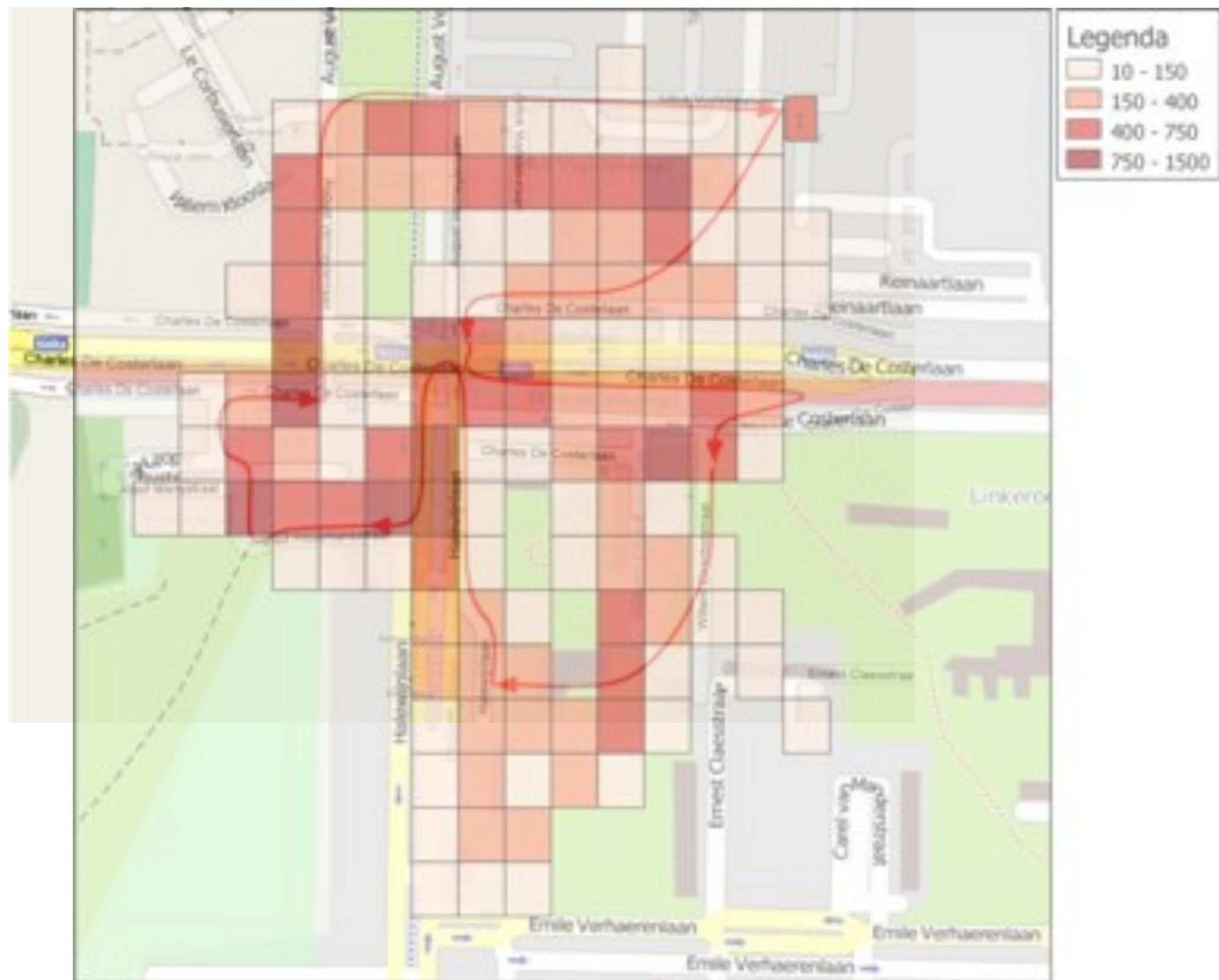
Import in GIS software to obtain noise maps (preliminary).



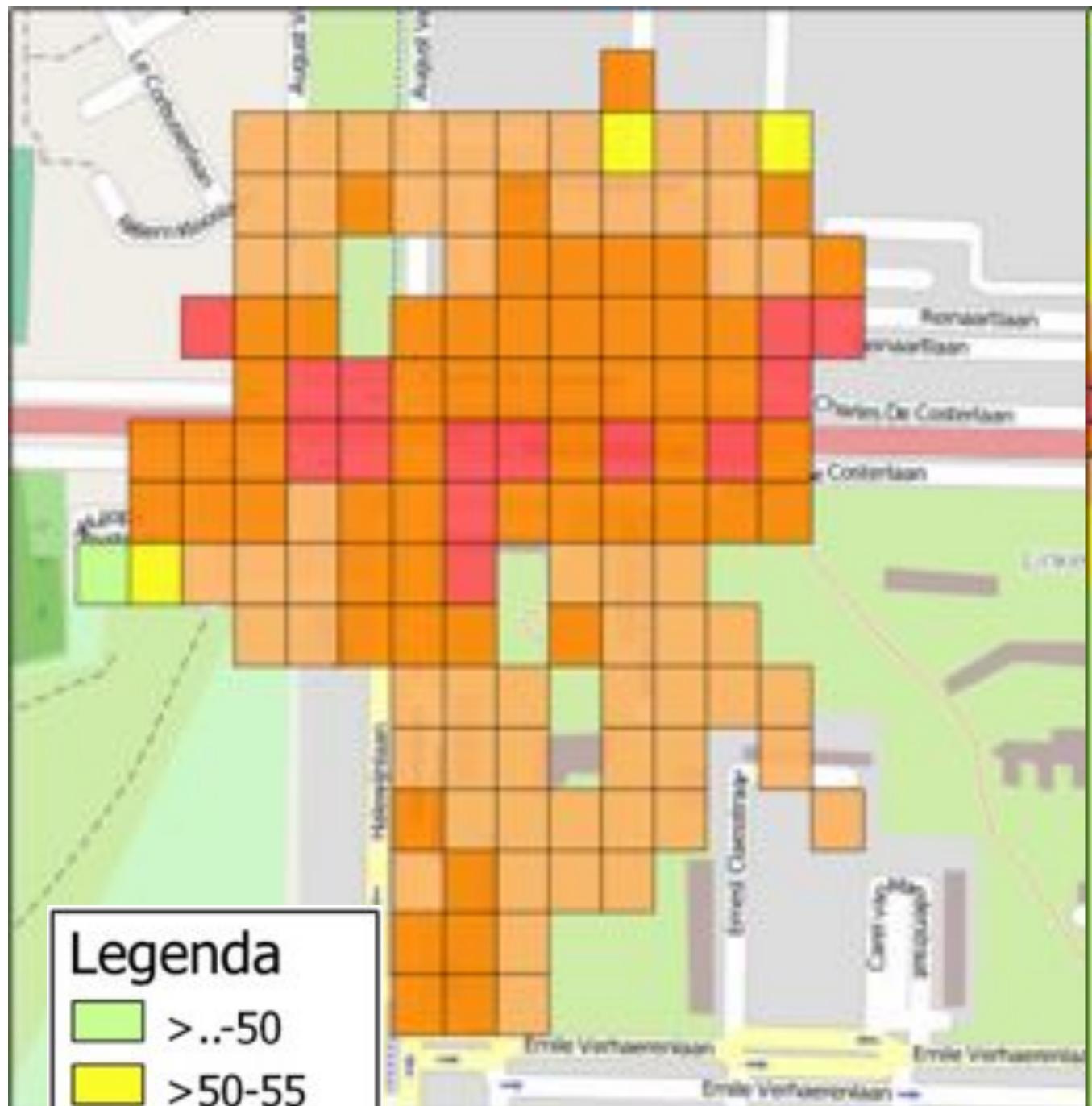
results: # measurements



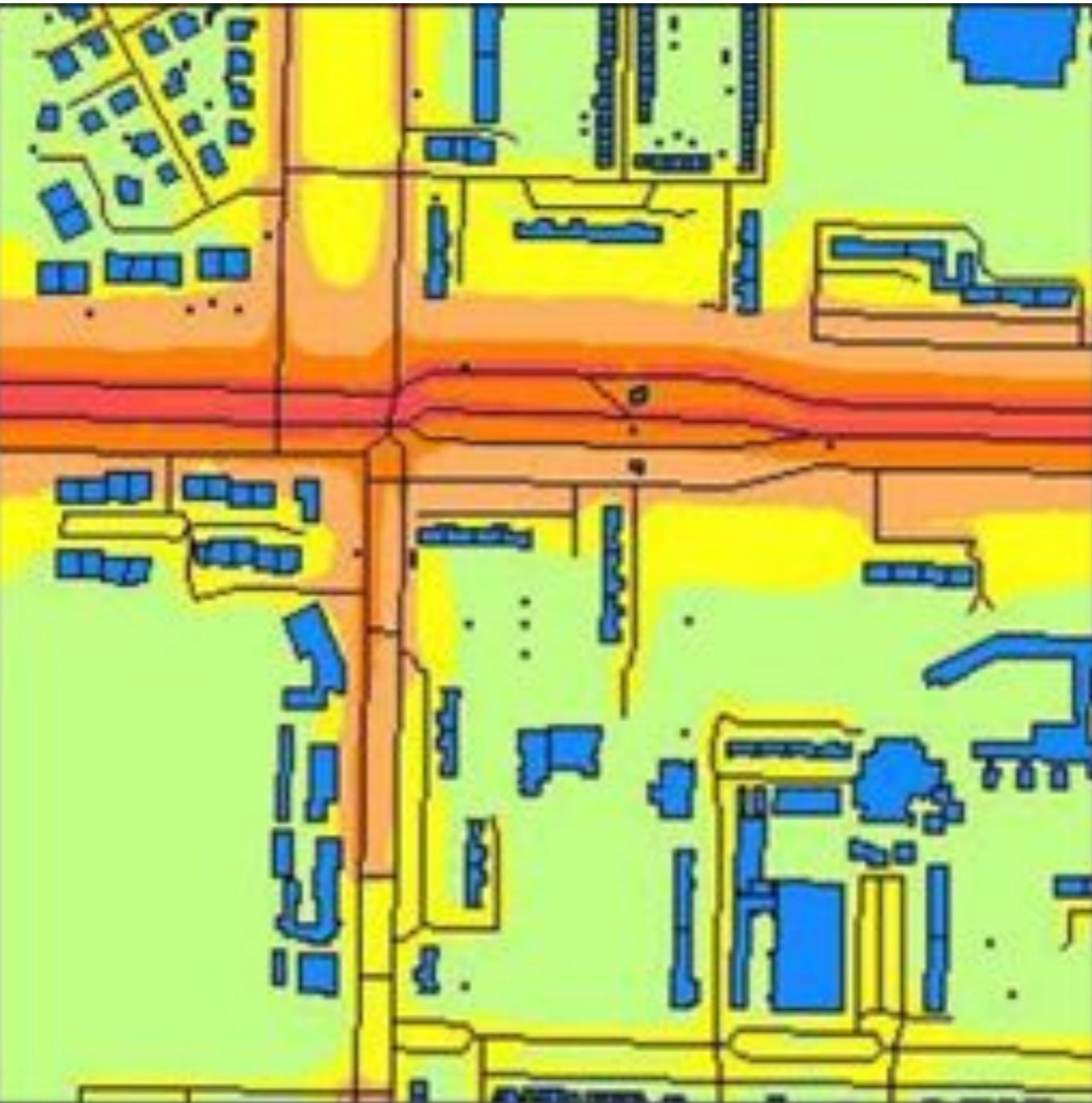
results: # measurements



results: comparison



statistical analysis



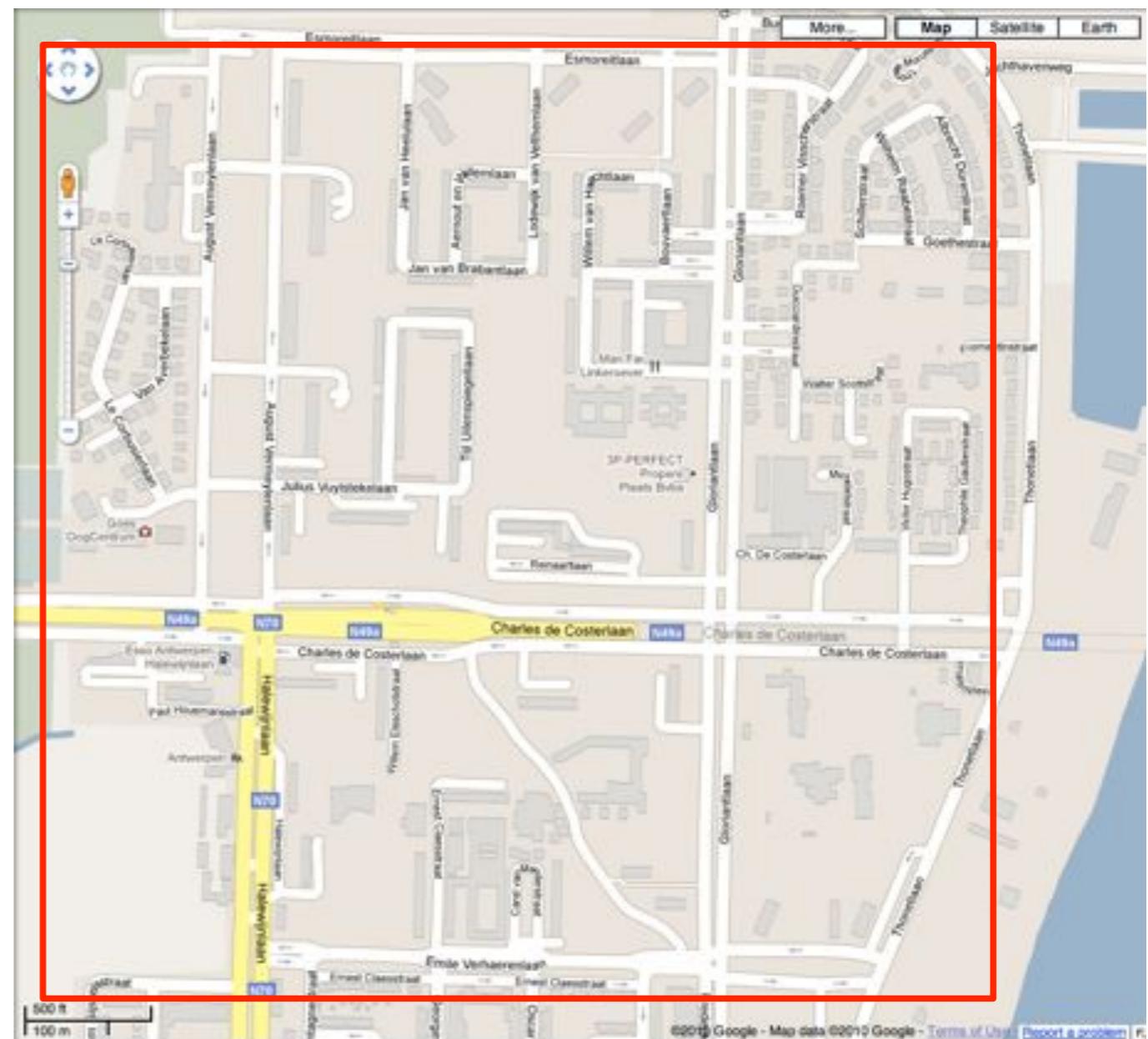
GIS development

comparison

wild mapping

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

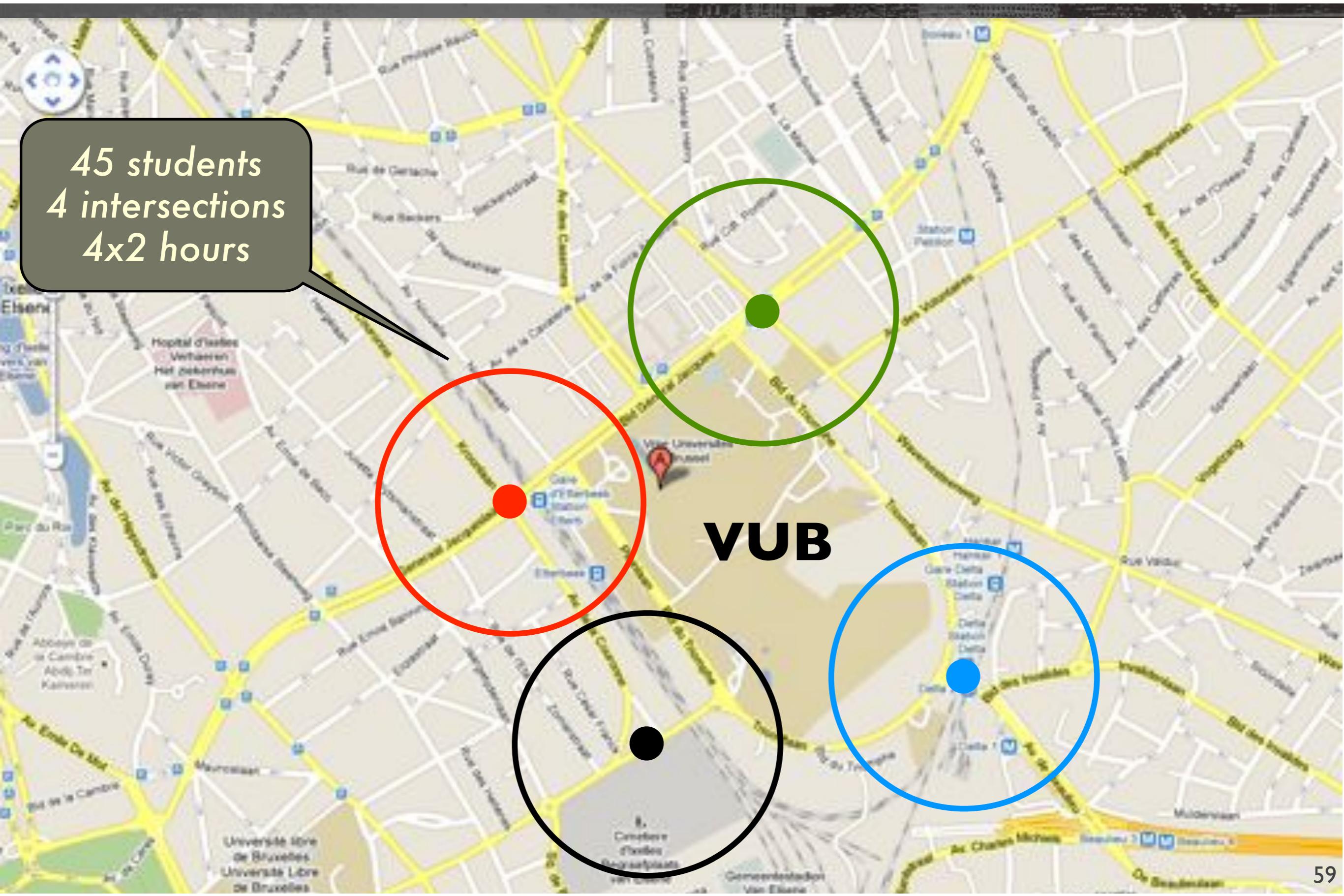
- any time of day
- 10 volunteers
- > 1 hour per day
- within fixed area
of 1 km²



one track

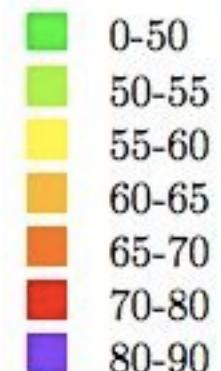
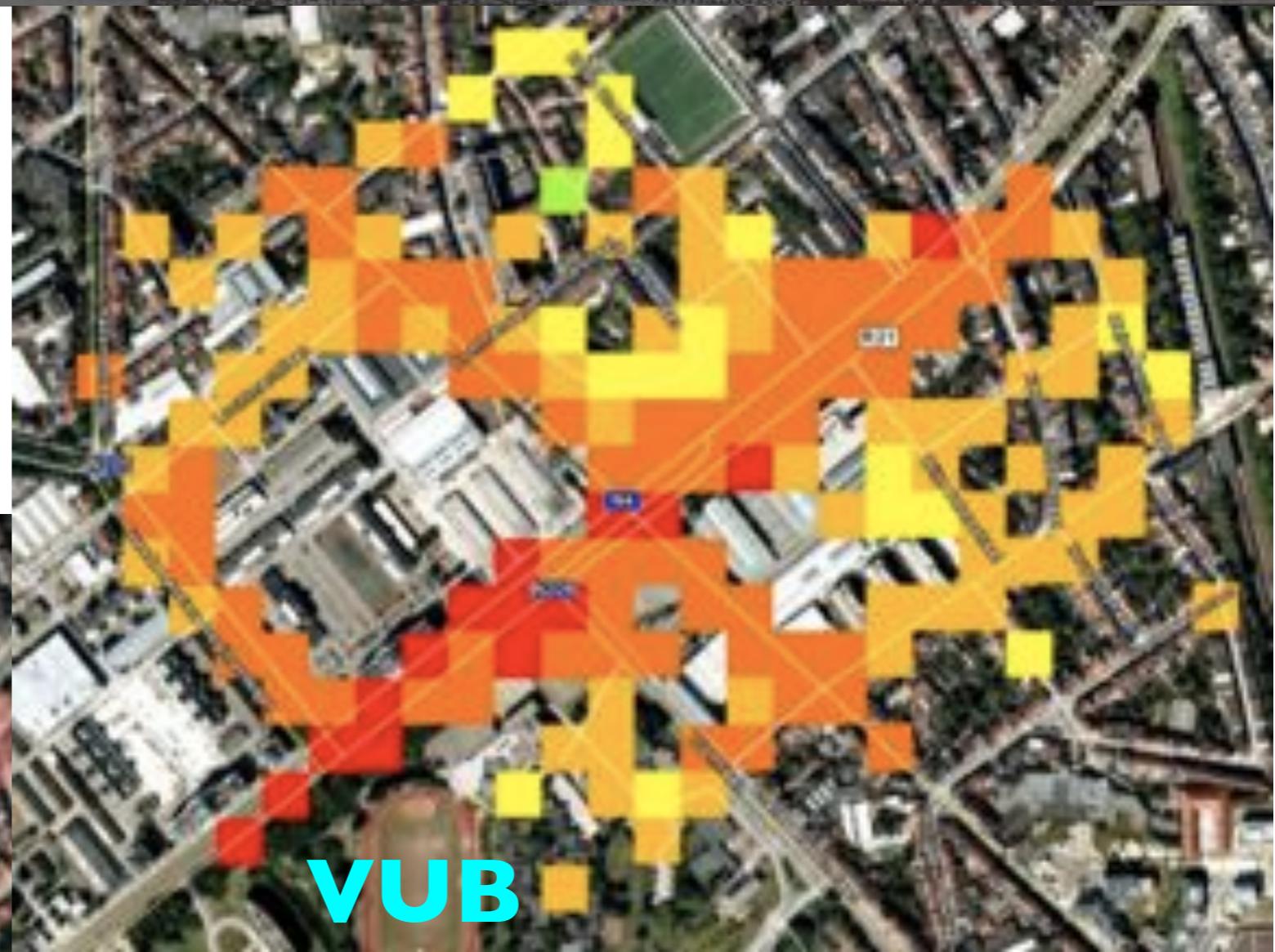


confirmation



confirmation

Mon. 13 Dec
13-15h



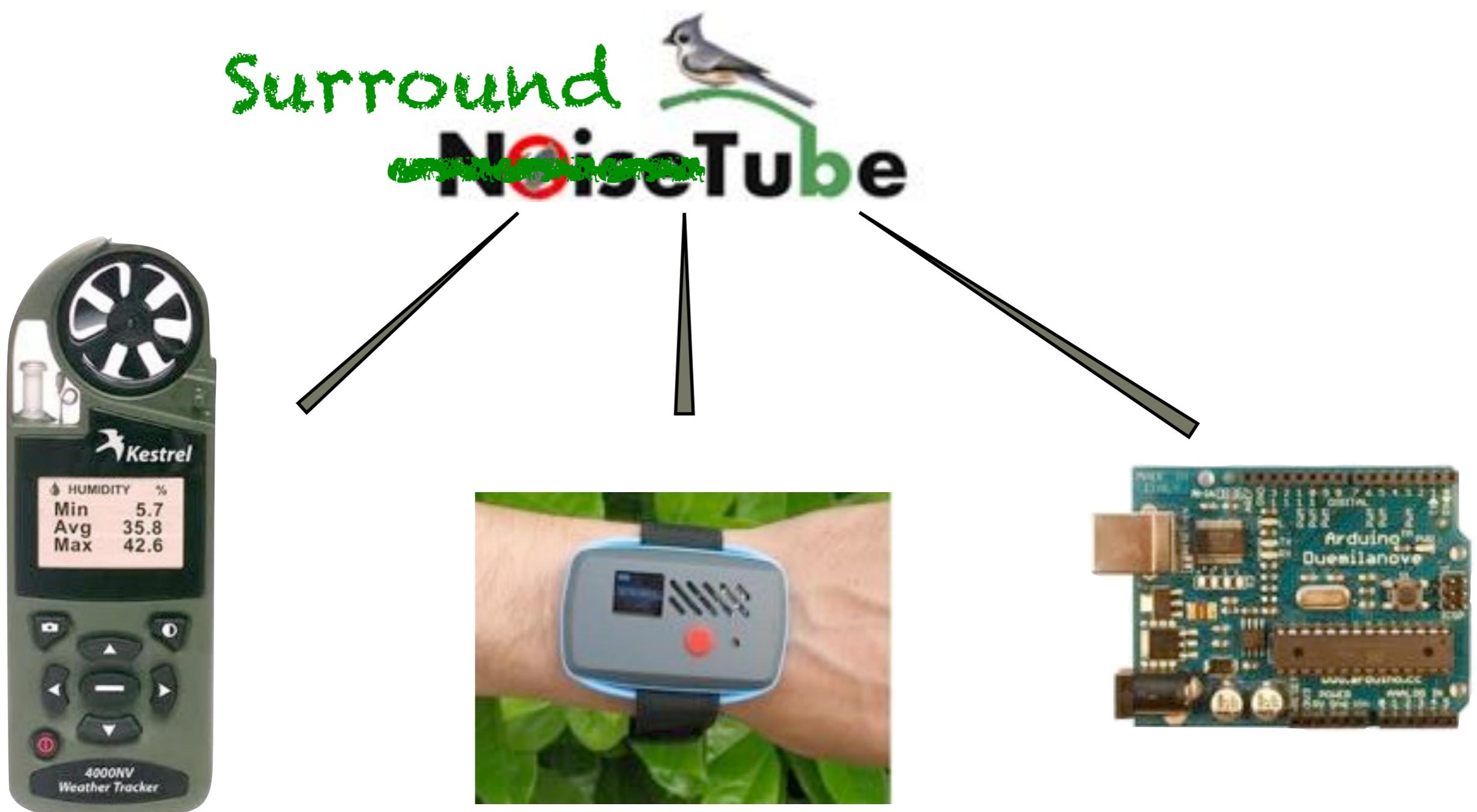
confirmation



extensions



environmental participatory sensing



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

context-aware participatory sensing



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

dissemination

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



Exploratory Workshop:
IoT for a Sustainable Future



Leefmilieu
Brussel
Bruxelles
Environnement



crosstalks



TEDx Brussels

UBICOMP2010

publications

1. E. D'Hondt and Y. Vandriessche, 2010 (online version), *Int. J. Nat. Comp.*, Special Issue on Unconventional Computation, Eds. J.F. Costa and N. Dershowitz, ISSN 1567–7818, Springer.
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 INNOV 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-I)*, Ed. S. Easterbrook, part of Onward! 2009 (co-located with OOPSLA 2009) in Orlando, FL, USA, October 26, 2009.