Participatory noise mapping

Dr. Ellie D'Hondt & Matthias Stevens

$$
\begin{aligned}
(\langle\overline{\psi}|_A U_k^\dagger \otimes I) \sum_i |i\rangle_A |i\rangle_B &= \sum_{i,j} a_j \langle j|_A (U_k^\dagger \otimes I_B) |i\rangle_A |i\rangle_B \\
&= \sum_{i,j} a_j \langle j|_A (I_A \otimes (U_k^\dagger)^T) |i\rangle_A |i\rangle_B \\
&= \sum_i a_i (U_k^\dagger)^T |i\rangle_B \\
&= (U_k^\dagger)^T |\psi\rangle_B \,.
\end{aligned}
$$

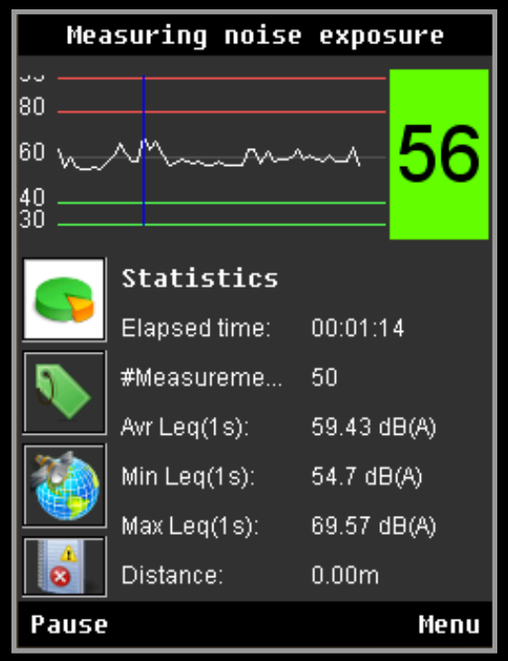
7 years

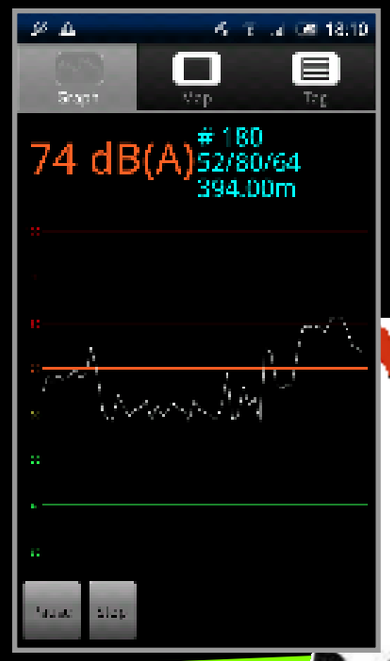
NoiseTube

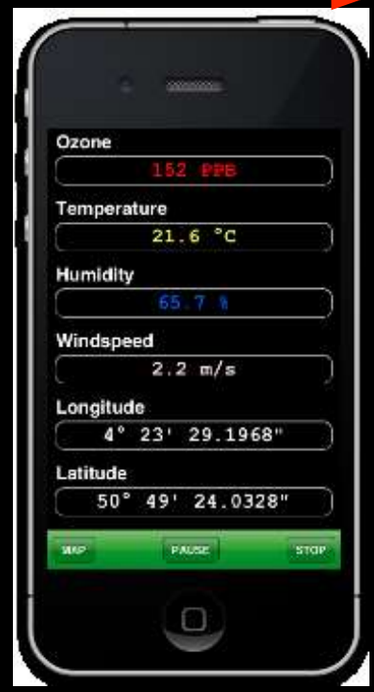
why noise? That's why.

operational

under development







NoiseTube

overview

1. Sustainability in cities
2. Sound & noise
3. Noise maps today
4. Participative sensing & NoiseTube
5. Participative noise maps
6. Next year’s developments

overview

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cities ↔ sustainability

- UN data shows that: [UN2006]
  - In 2005, 49% of the world's population were city dwellers
  - By 2030, this number is expected to hit 60%
- Urbanisation is rising even faster in developing nations [UN2006]
  - In 2005, 74% of all city dwellers lived in the developing world
  - By 2030, developing counties are expected to acc
- Rapid urbanisation threaten life
  - Mobility issues
  - Housing shortage
  - Social injustice
  - Lack of green space
  - Air, soil, water & noise pollution

[UN2006] UN, Dept. of Economic & Social Affairs, Population Division (2006). *World Urbanization Prospects: The 2005 Revision*. Working Paper No. ESA/P/WP/200.


P
TAXIS
50
50

cities ↔ sustainability

- Cities provide a critical arena from which to approach the issues of sustainability and climate change because:

1. Urban areas are responsible for approximately 75 percent of all greenhouse gas emissions in the world;
2. local policies can be effective where broader policies might not be feasible;
3. cities, like universities, are learning laboratories.

M. E. Kahn (2006). *Green Cities: Urban Growth and the Environment*, Brookings Institution Press

computer science ↔ sustainability

- Environmental simulations: to get better predictions of the future and thus encourage the need for action
- Distributed computation: for better exploitation of available computing resources and the development of energy-efficient soft- and hardware solutions

- Improve the granularity and quality of environmental measurement data (think Internet of Things)
- Increase awareness of citizens about the conditions in their environment and thus provide support for political action

L. Steels (2009), *Participatory Mapping and Social Networking for a Sustainable World*. Sony CSL Open House 2009 Symposium talk.

Participatory Sensing & Sustainability

Opportunity:

+

+

(Time Magazine, 2006)

Platform:

Ever more popular, cheaper "<u>smart phones</u>"

- Significant computational power
- Semi-permanent Internet access WiFi, GPRS/EGDE, 3G
- Integrated sensors
- Camera's, GPS, motion, touch, ...

Cultural shift (*Web 2.0*):

User-generated content, participation

The (mobile) Web continues to change how we create, share and consume information...

Concerns:

Growing interest for environmental/sustainability issues

Climate change (*Inconvenient truth*, IPCC), desertification, global migration, urbanisation, mobility, energy efficiency, air pollution (e.g. fine particles), ...

participatory/urban sensing

Burke et al. (2006). *Participatory Sensing*. WSW'06 at SenSys '06, ACM Press.

Cuff et al. (2008). *Urban sensing: Out of the woods*. Comm. of the ACM, 51(3): p.24-33.





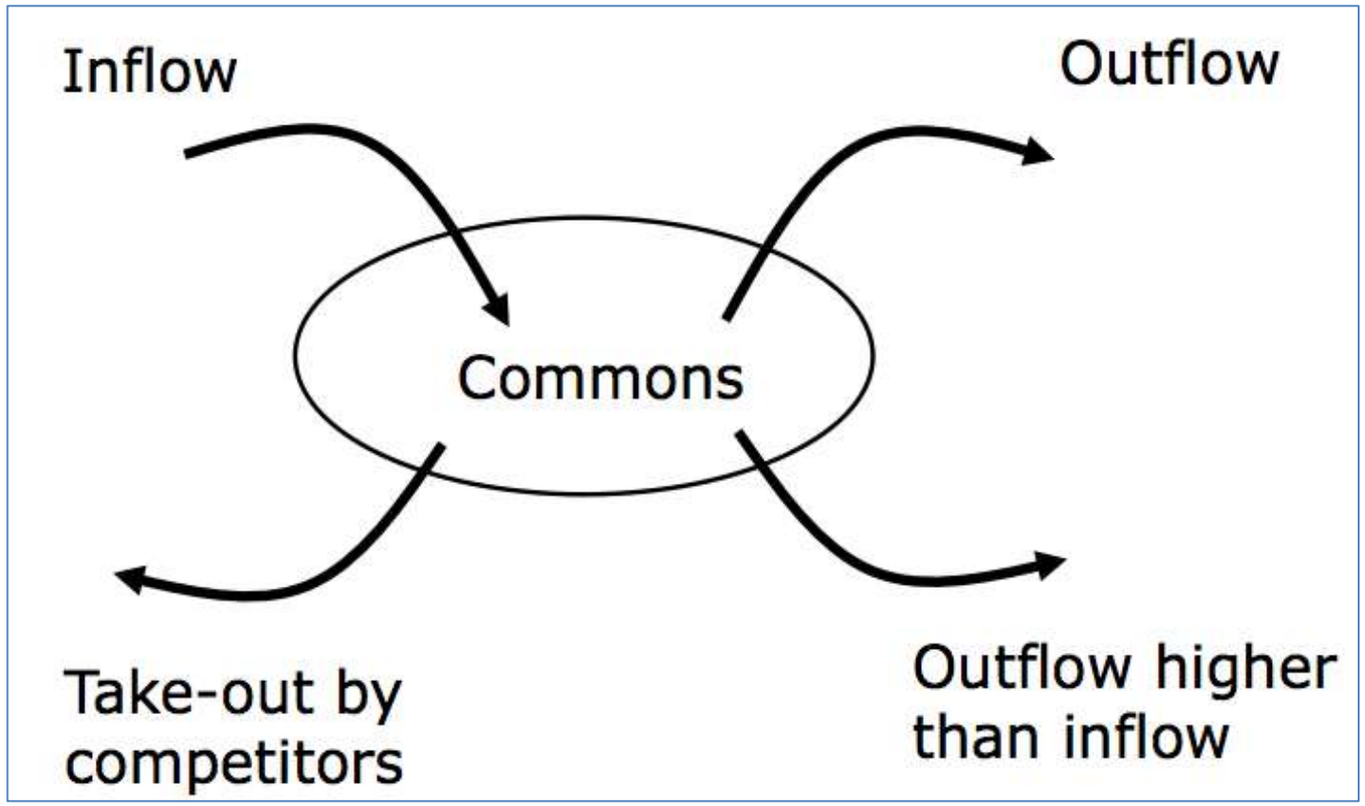



tragedy of the commons

- **= over-exploitation of common resources which are not replenished**

"No one owns the Earth's atmosphere. Therefore, it is treated as a common dump into which everyone may discharge wastes. Among the unwanted consequences of this behaviour are acid rain, the greenhouse effect, and the erosion of the Earth's protective ozone layer."

"Industries and even nations are apt to regard the cleansing of industrial discharges as prohibitively expensive. The oceans are also treated as a common dump. Yet continuing to defend the freedom to pollute will ultimately lead to ruin for all. Nations are just beginning to evolve controls to limit this damage."



More examples: irrigation systems, space in streets, **noise** ↔ **silence**, forests ↔ logging, …

G. Hardin (1968). *The Tragedy of the Commons*. Science, 162(3859): p.1243-1248.

managing common pool resources

1. Clearly defined boundaries
2. Congruence between appropriation and provision rules and local conditions
3. Collective-choice arrangements allowing for the participation of most of the appropriators in the decision making process
4. Effective monitoring by monitors who are part of or accountable to the appropriators
5. Graduated sanctions for appropriators who do not respect community rules
6. Conflict-resolution mechanisms which are cheap and easy of access
7. Minimal recognition of rights to organize

Elinor Ostrom (1990). *Governing the Commons. The Evolution of Institutions for Collective Action*. Cambridge University Press.

community memories

- Early predecessors:
  - Bulletin boards [Colstad1975]
  - Open expert systems [Steels1986]

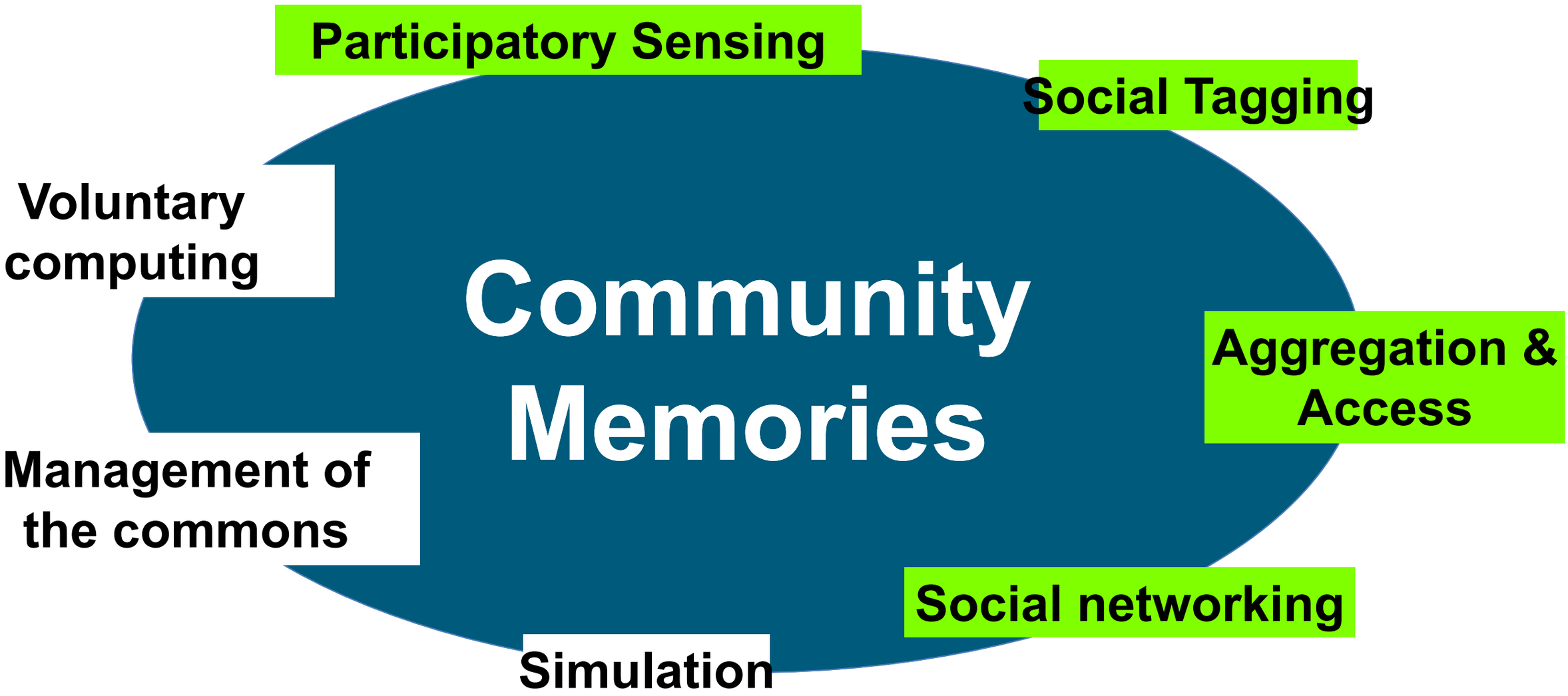
= collection of ICT tools to collectively manage common pool resources, e.g. our environment

- Technological advances have enabled many new ingredients:
  - Mobile, participatory sensing
  - Social tagging
  - Geo-localisation
  - Aggregation, simulation and visualisation

[Colstad1975] K. Colstad & E. Lipkin (1975). *Community Memory: a public information network*. ACM SIGCAS Computers and Society, 6(4): p.6-7.

[Steels1986] L. Steels (1986). *From Expert Systems to Community Memories*. In T. Bernold (ed.), Expert Systems and Knowledge Engineering. Conf., G. Duttweiler Institute, Ruschlikon, Switzerland. p.17-29.

potential ingredients



L. Steels (2009), *Participatory Mapping and Social Networking for a Sustainable World*. Sony CSL Open House 2009 Symposium talk.

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

Dr. Ellie D'Hondt & Matthias Stevens

BrusSense

● *Department of Computer Science* ●

Vrije Universiteit Brussel

Participatory sensing for sustainable urban living

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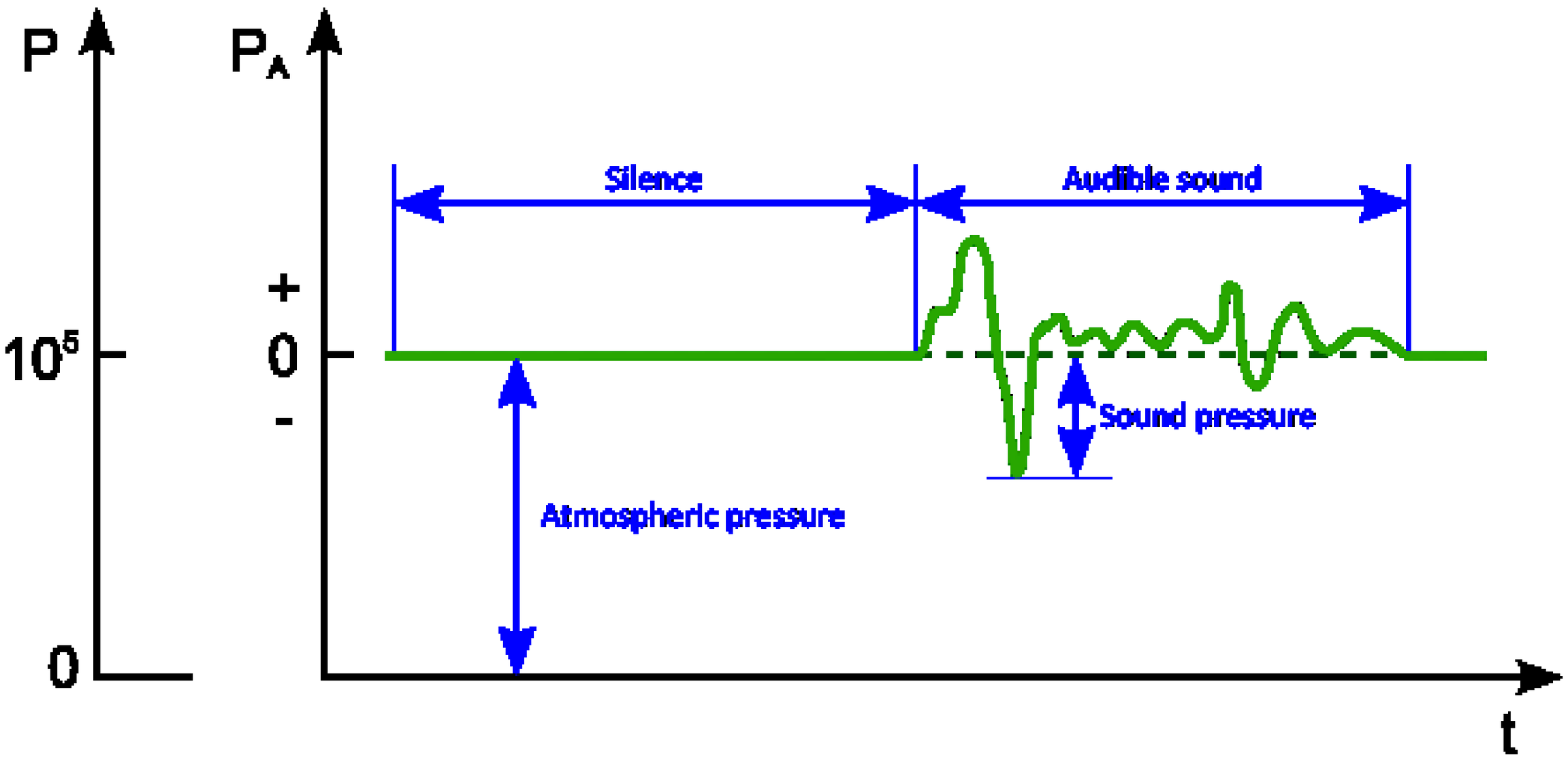
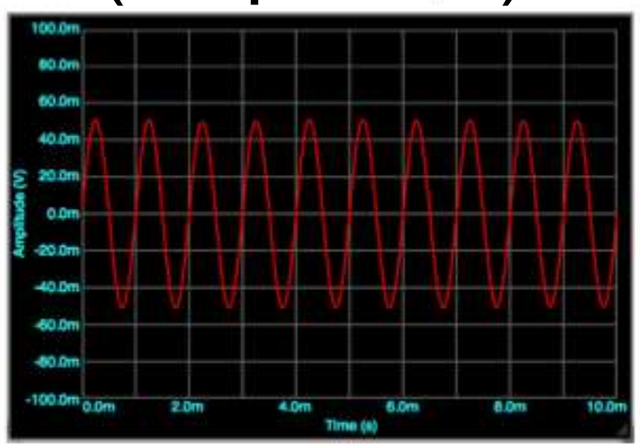
sound

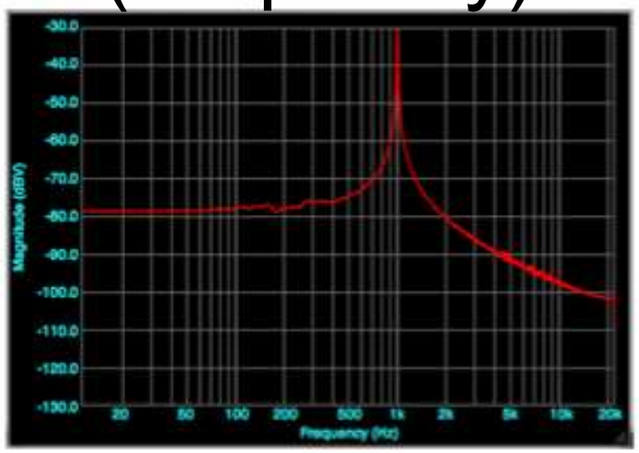

P
P_A
10^5
0
+
0
-
Silence
Audible sound
Sound pressure
Atmospheric pressure
t

typical sounds

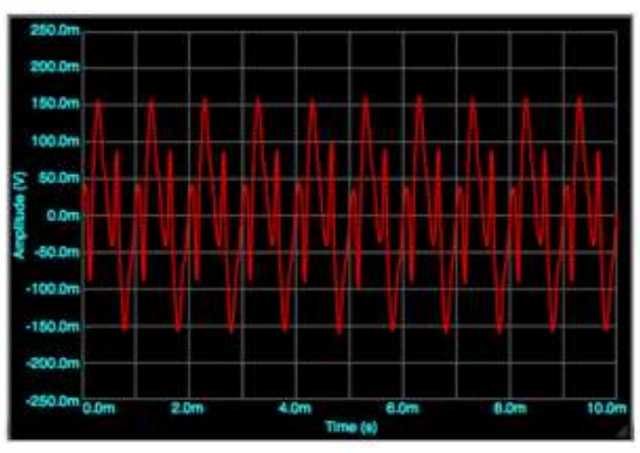
time evolution (amplitude)

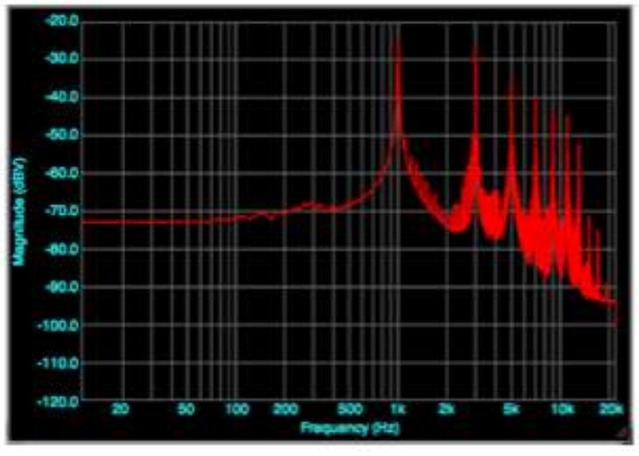
spectrum (frequency)



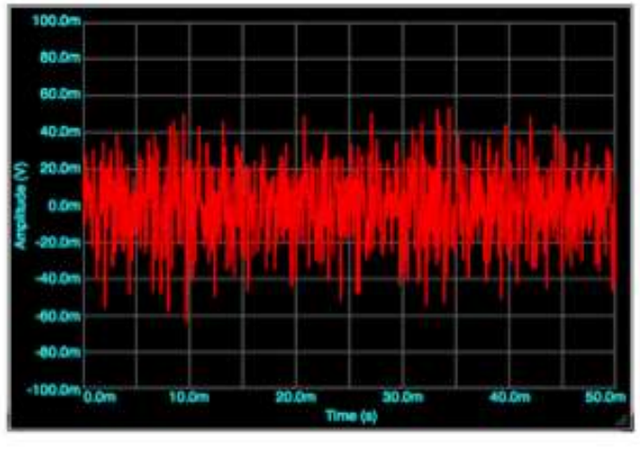


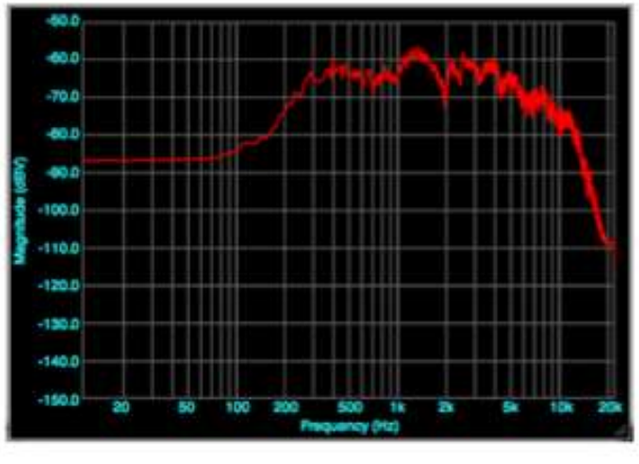
pure tone (note)





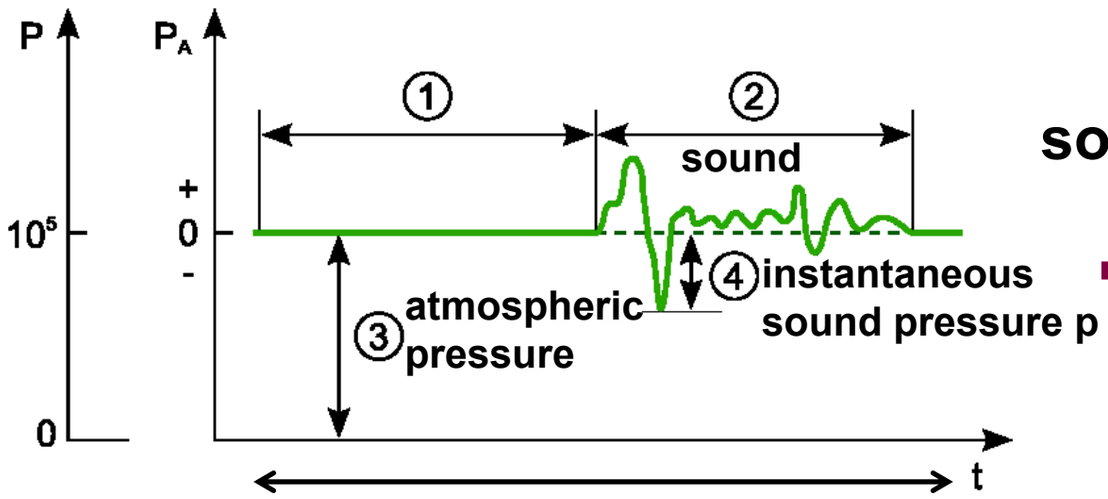
complexe tone (chord)





noise

sound level

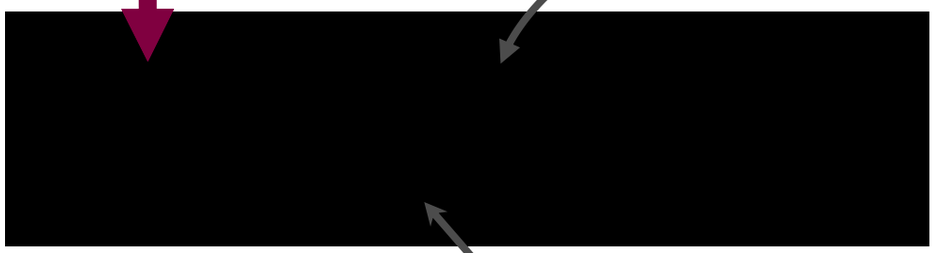


sound pressure level

threshold human hearing = 20.10^{-6} Pa

make all amplitudes positive

average sound pressure level

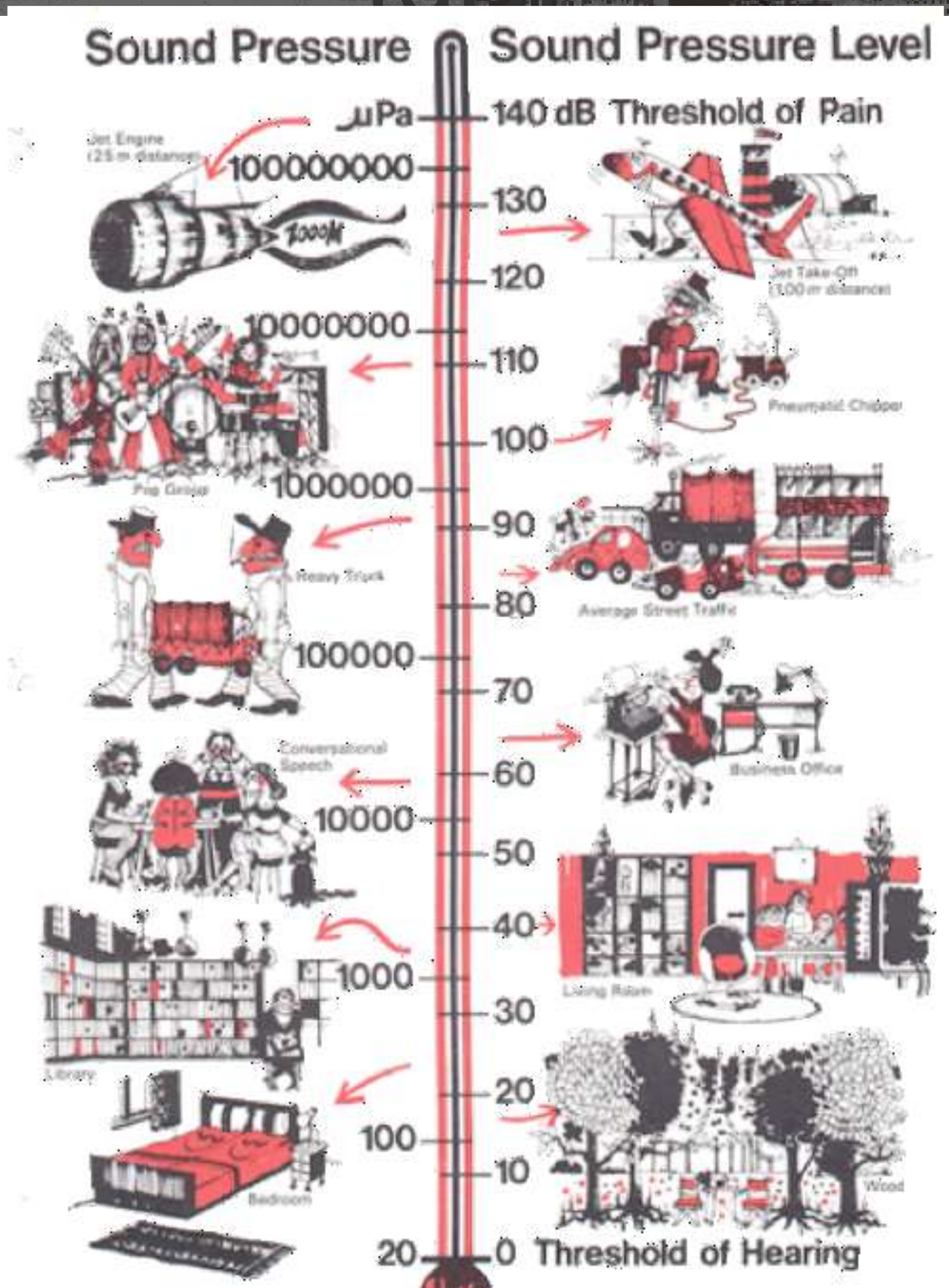


integraal = sum over all values

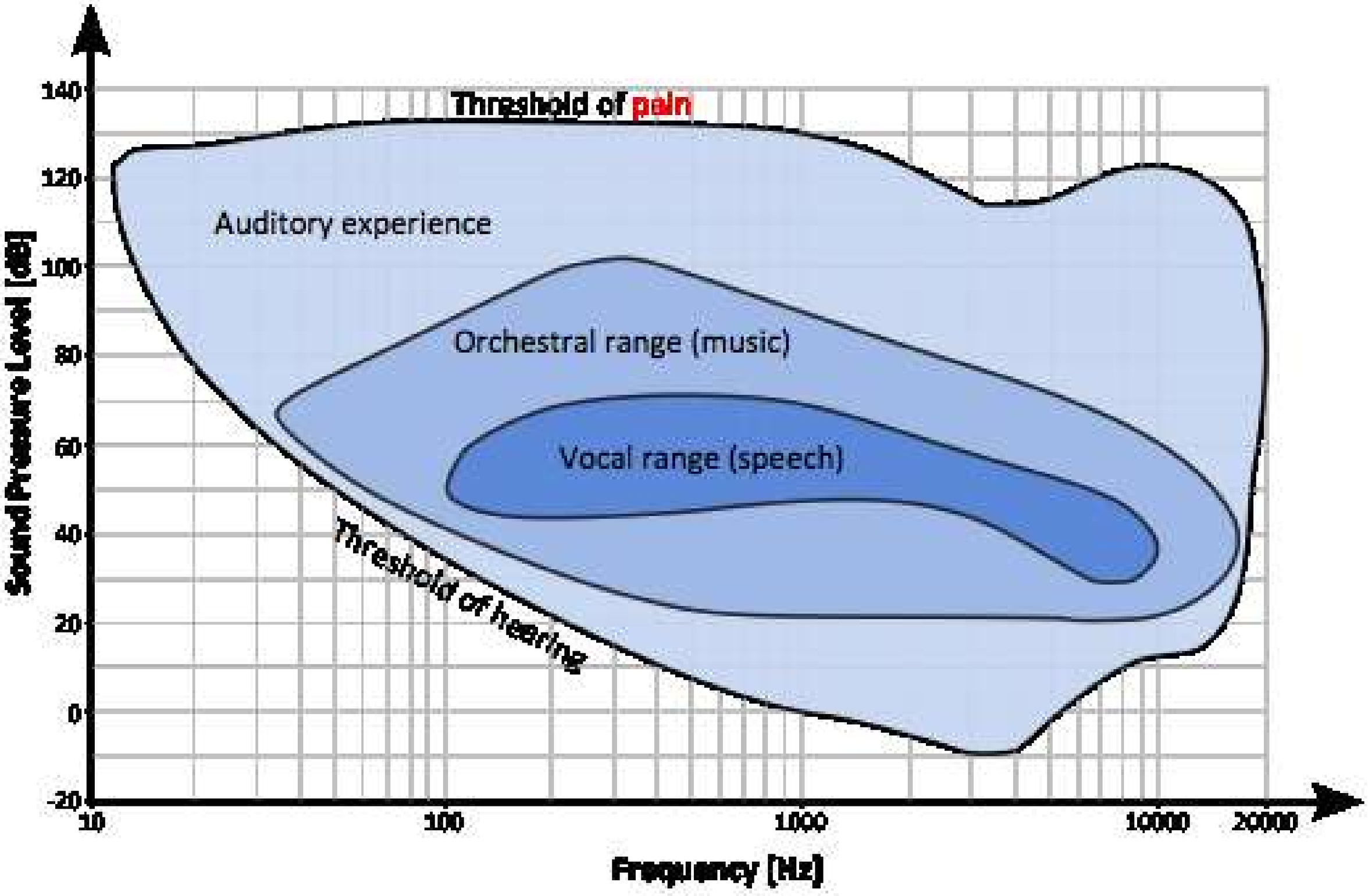
= average

divided by time interval

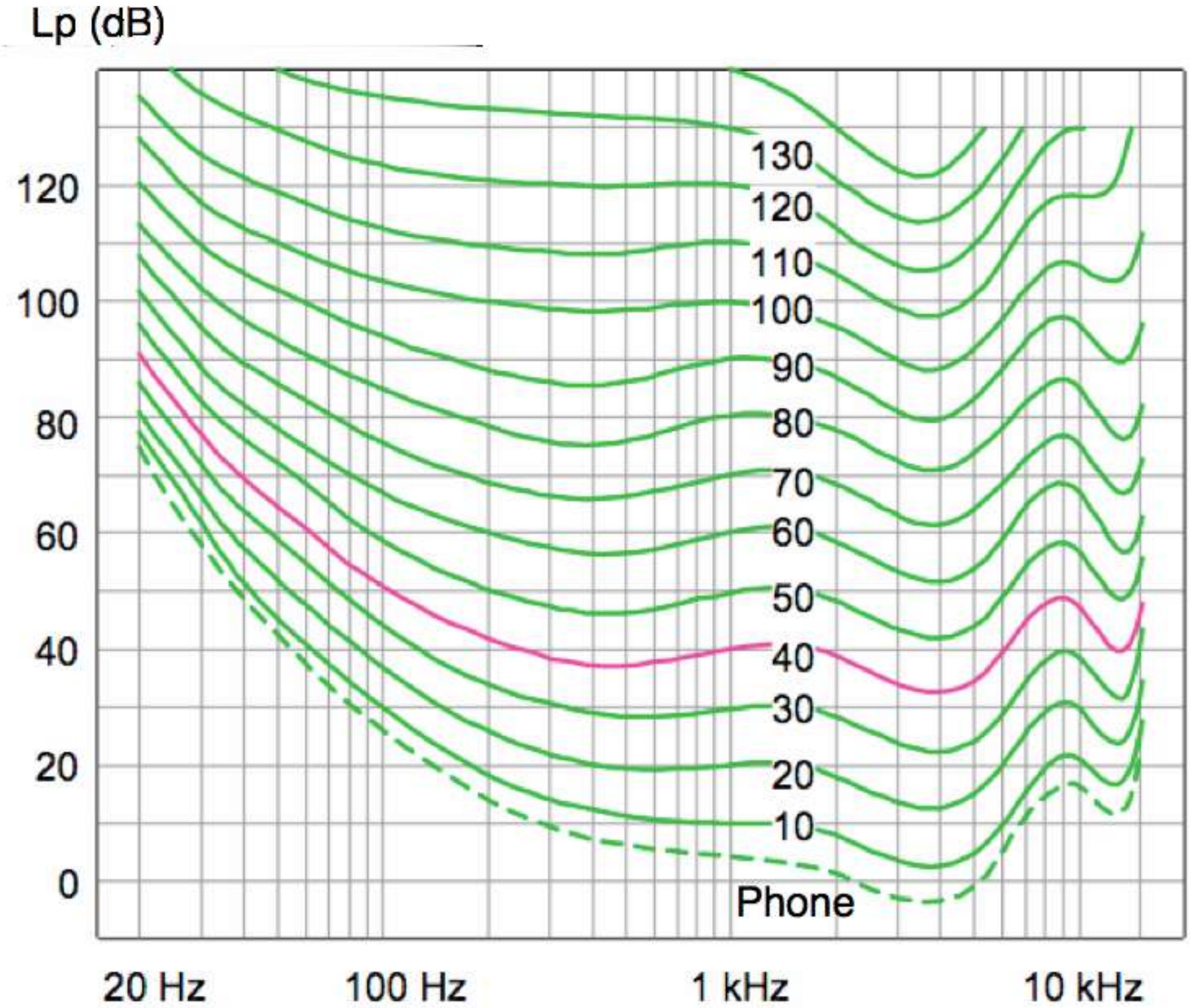
pressure [Pa] ↔ sound pressure level [dB]



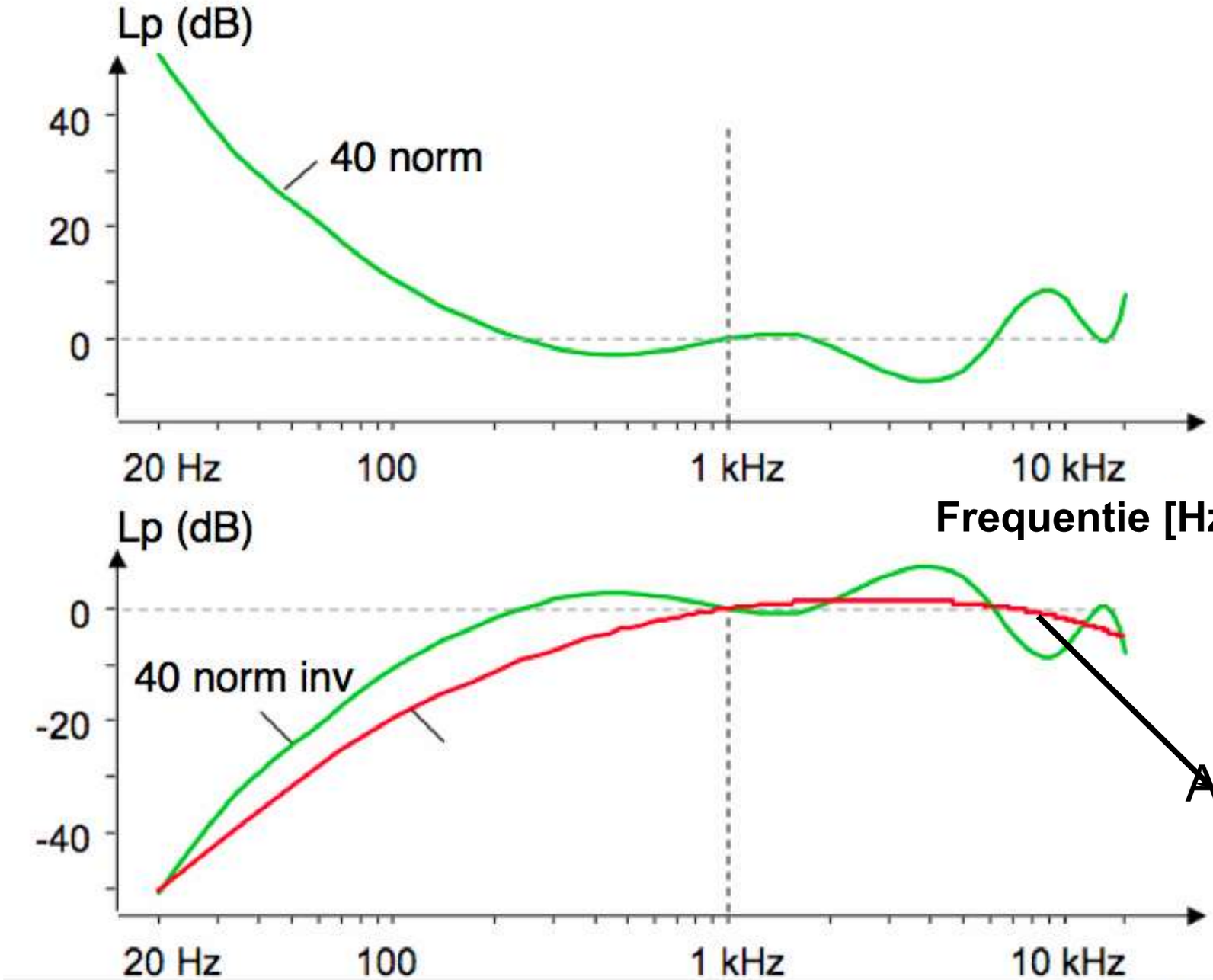
range of human hearing



frequency dependence



A-weighting [dB(A)]



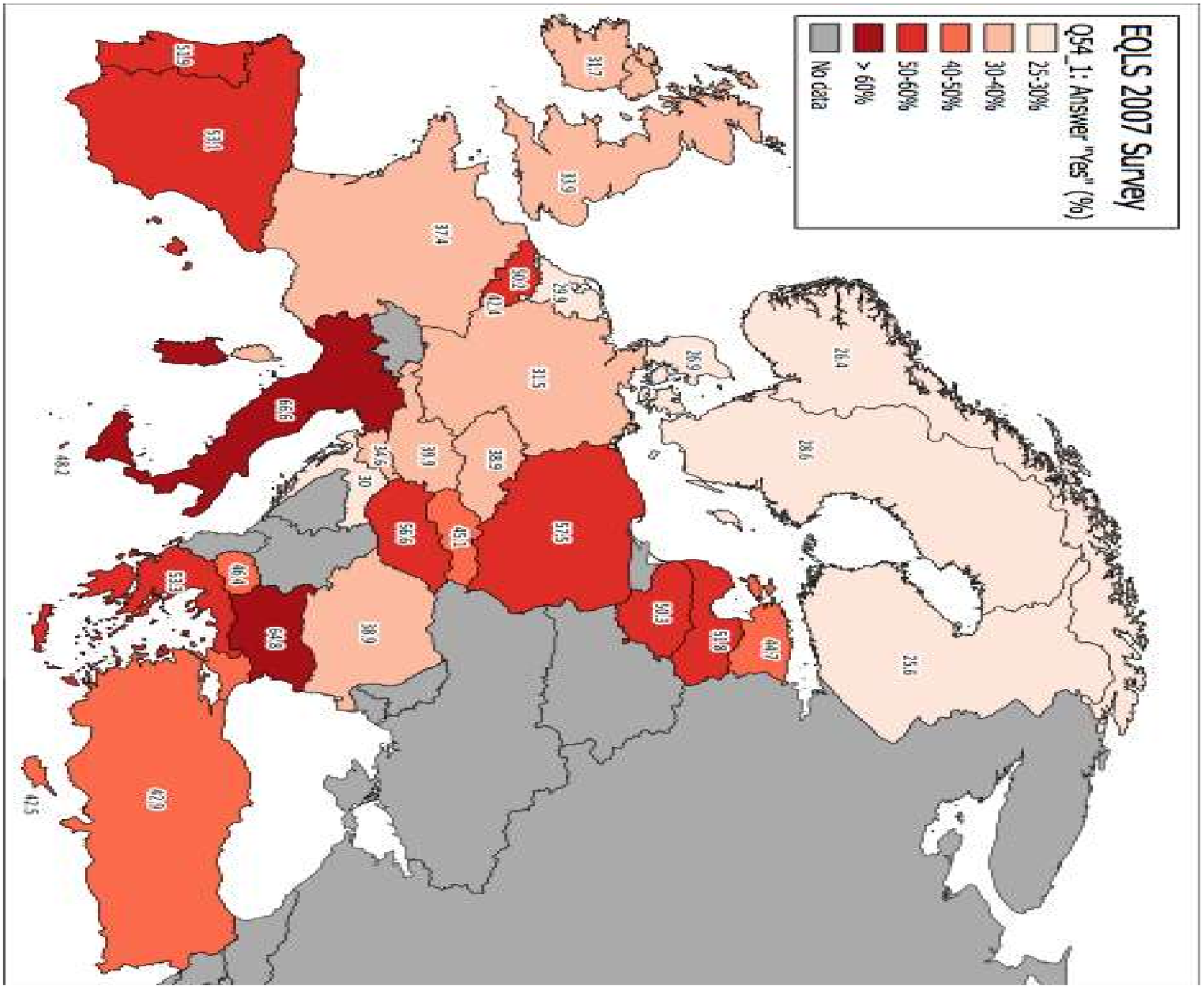
$$L_{eq} + \text{A-weighting} = L_{Aeq} \quad (\text{dB(A)})$$

Heathrow,
UK

Brussels,
Belgium

noise is a real problem in cities all over the world

noise survey in the EU



A map of Europe showing the per-country percentage of respondents answering ”Yes” to the question: ”In the immediate neighbourhood of your home, do you have reason to complain about noise?”

WHO guidelines

- How loud is too loud?
- < 30 dB(A) in bedrooms for a good night's sleep
- < 35 dB(A) in classrooms for good cognitive performance
- < 40 dB(A) yearly average sound pressure level in and around bedrooms required to prevent health effects due to noise
- How many people are exposed to excessive noise?
- ± 40% of the EU population is exposed to traffic noise > 55db(A);
- 20% is exposed to > 65 dB(A) during the day
- > 30% is exposed to > 55 dB(A) at night.

consequences for quality of life

Traffic related noise exposure in Western Europe costs the society at least 1 million healthy life years per year [WHO2011, Burden of disease from environmental noise]

- Aspects studied:
- cardiovascular disease
- cognitive impairment in children
- sleep disturbance
- tinnitus
- general annoyance

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EU norms

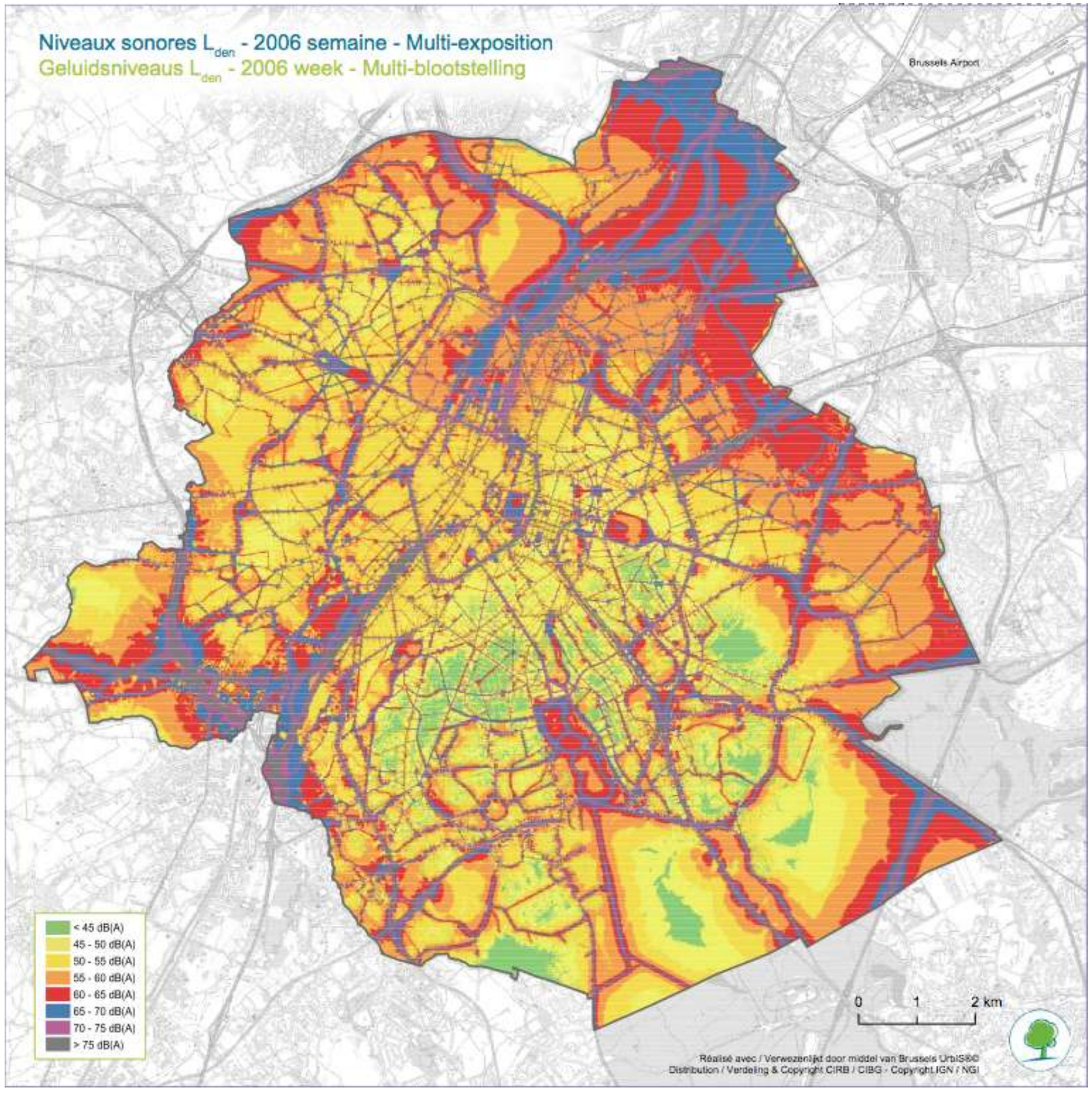
- Noise maps obligatory for
  - cities > 250 000 inhabitants
  - roads > 6 million vehicles per year
  - railways > 60 000 passages per year
  - and this every 5 years from 2012 onwards

- by simulation and/or measurement

EU norms

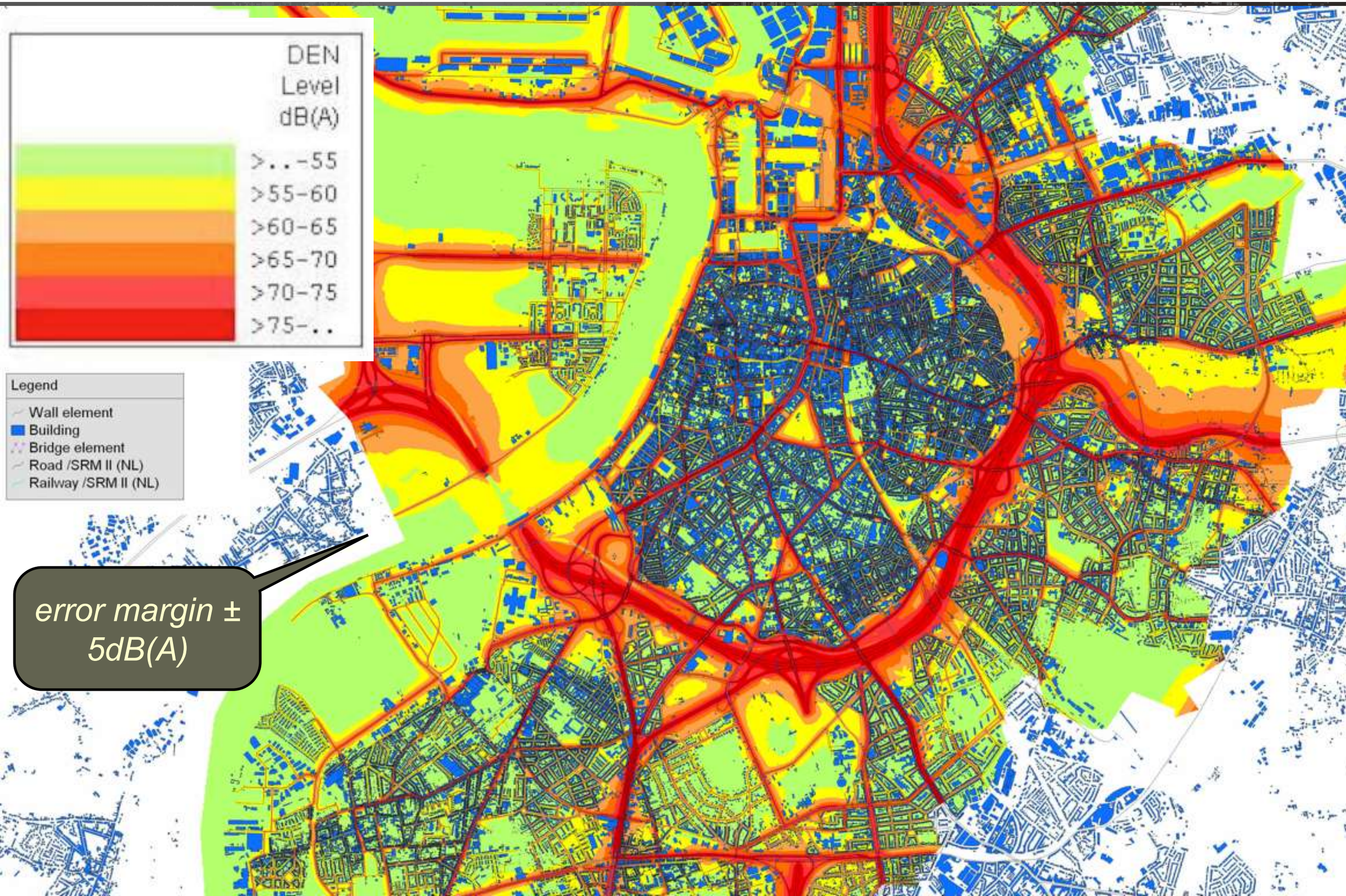
- where day: 7-19, evening: 19-23, night: 23-7
- each L is a time average over these periods
- needed: # people exposed to L_{den} and L_{night} values
  - within 5dB bands between 55 and 75 dB and > 75dB
  - at 4 m above the ground on the most exposed façade
- separate value for road, rail, air traffic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

official noise maps

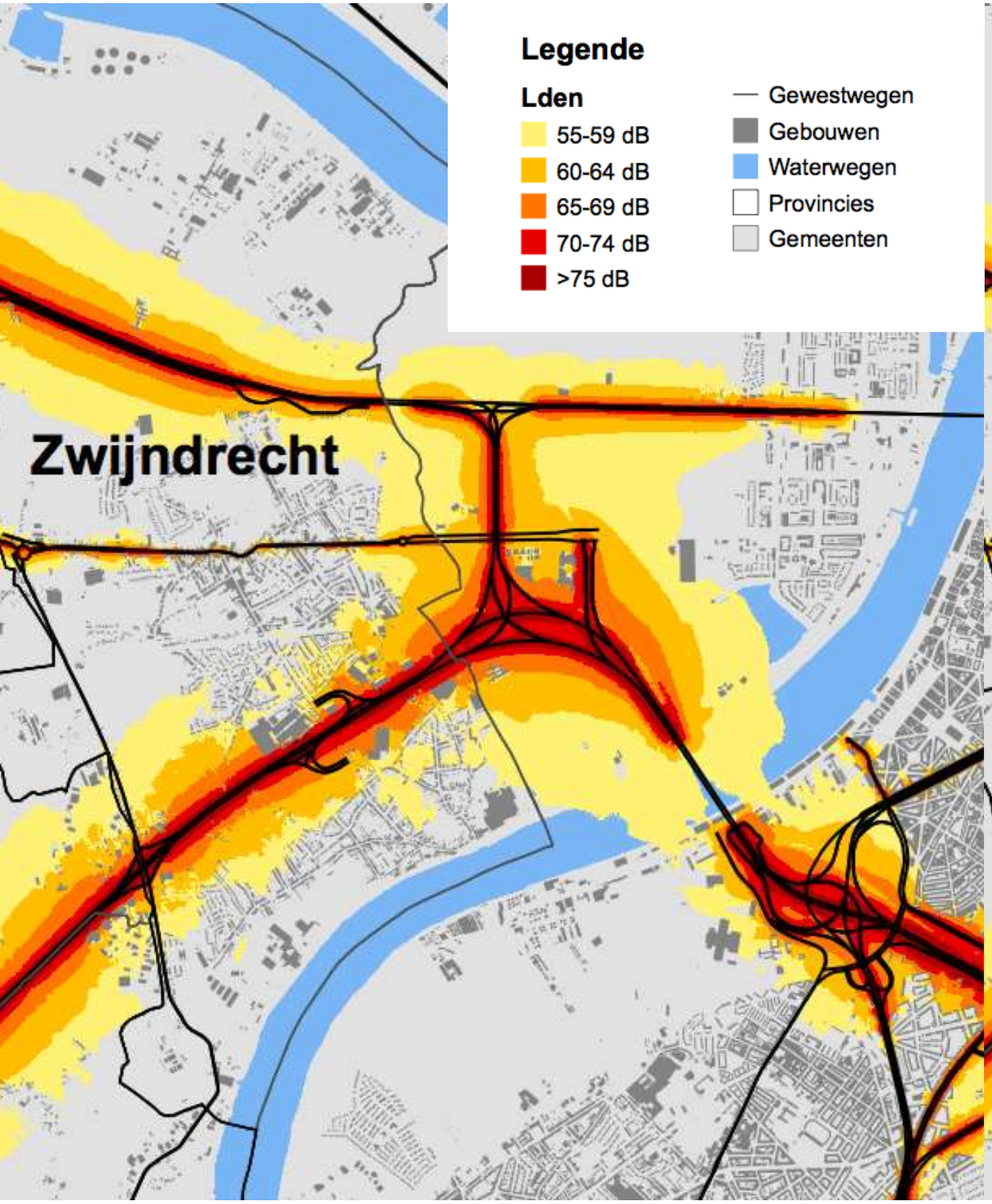


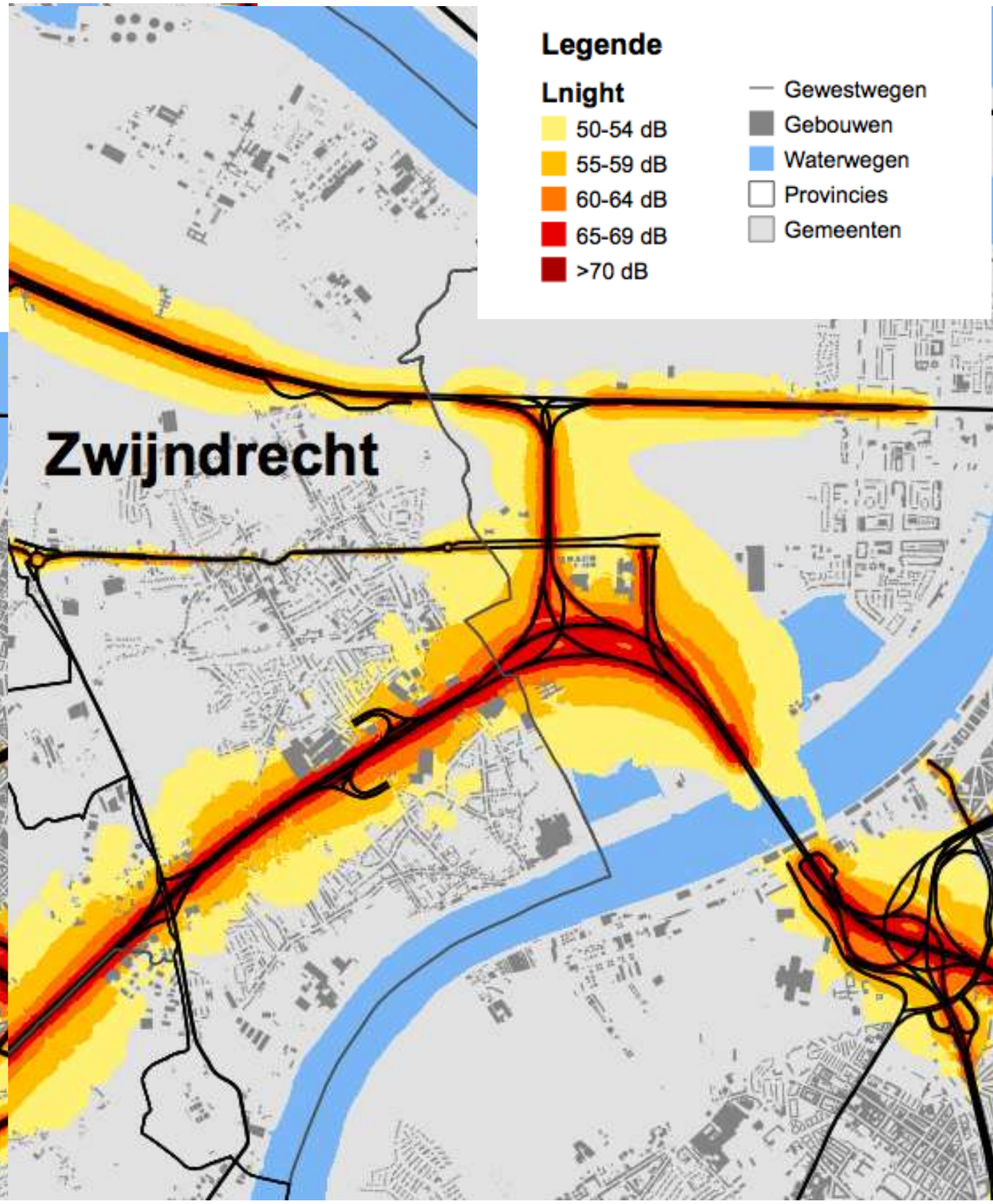
WHO norms:
day <55 dB(A)
night: < 40 dB(A).

official noise maps



Lden vs. Lnight





http://www.lne.be/themas/hinder-en-risicos/geluidshinder/Geluidskaarten

VeniceNoise.org

Home | Data Tools | About Us | App Prototype | Project Website

official noise data

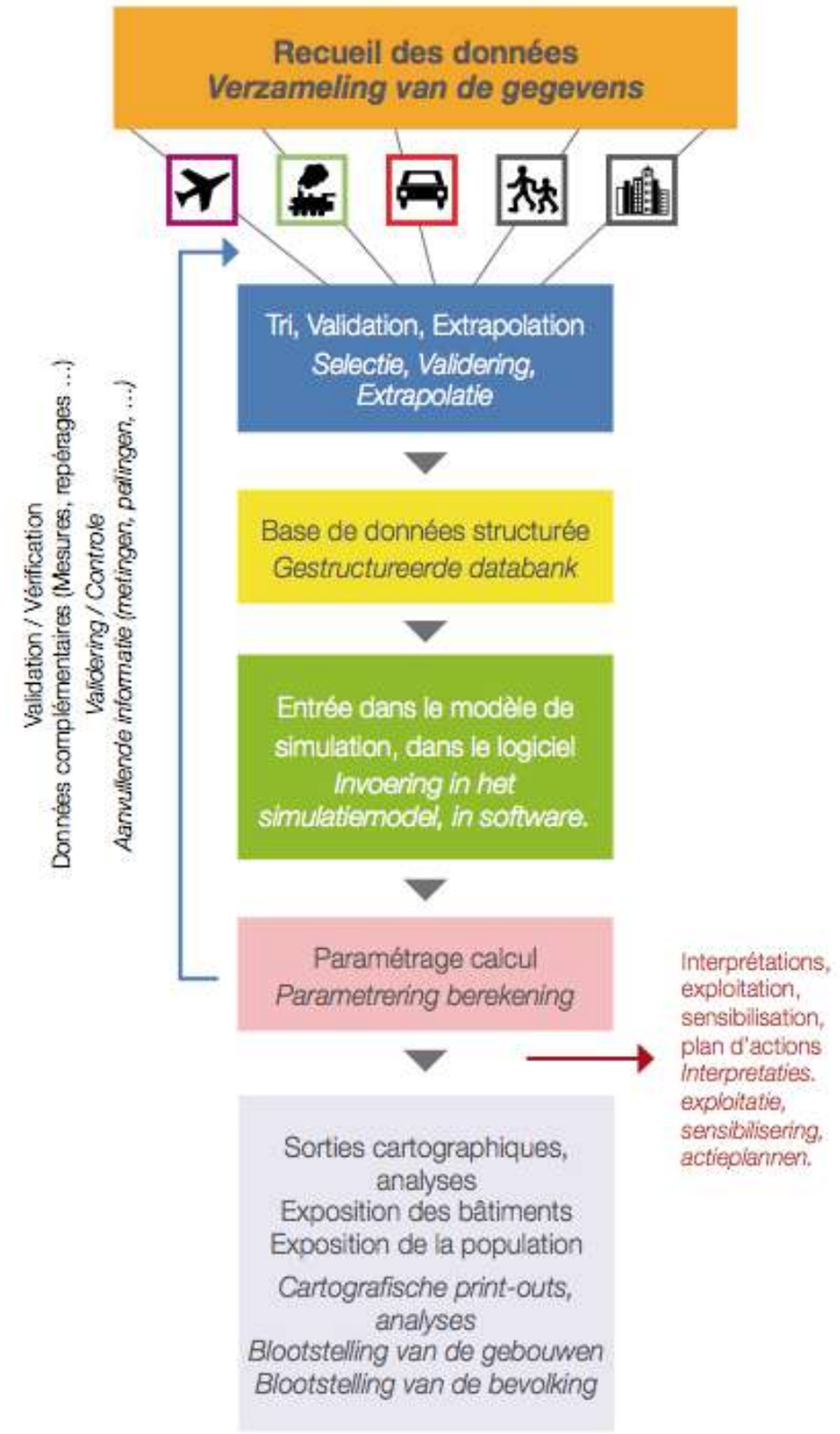
L_{den}				
Niveaux sonores [dB(A)]	Nombre d'habitations Aantal woningen	% des habitations % van het totaal aantal woningen	Habitations avec façade calme Aantal woningen met een rustige gevel	% des habitations soumises aux niveaux sonores précités et bénéficiant d'une façade calme % van het aantal woningen blootgesteld aan geluidniveaus 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)	48758	27%	1	0%
60 - 65 dB(A)	31053	17%	25	0%
65 - 70 dB(A)	15804	8%	446	3%
70 - 75 dB(A)	3891	2%	557	14%
> 75 dB(A)	581	0%	134	24%

interpretation

Sensation moyenne Gemiddelde geluidsbeleving	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 stedelijk lawaai	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



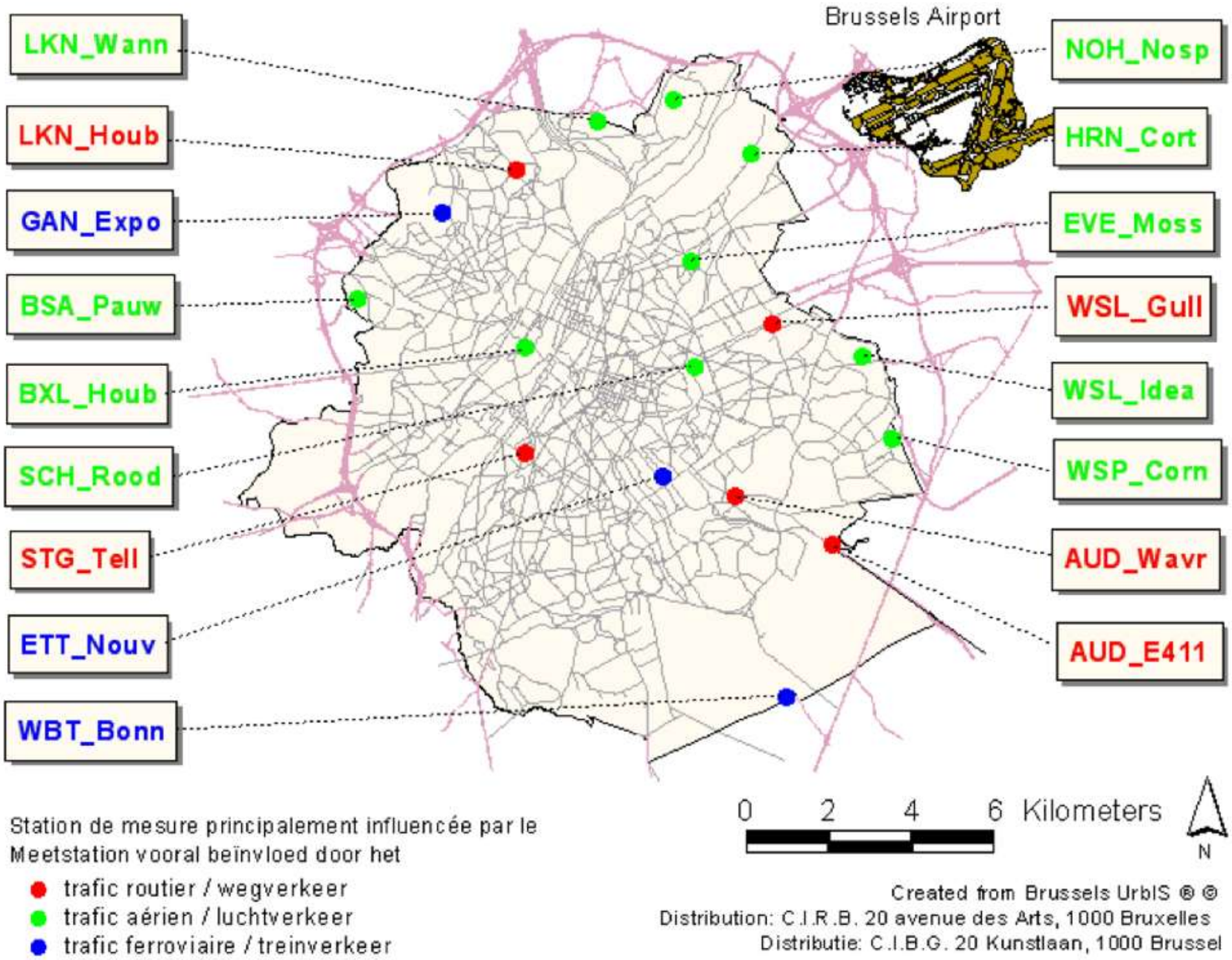
- sources covered:
  - traffic, train, industry, airports
- limited measurement
- data + propagation model →noise map

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 simulation



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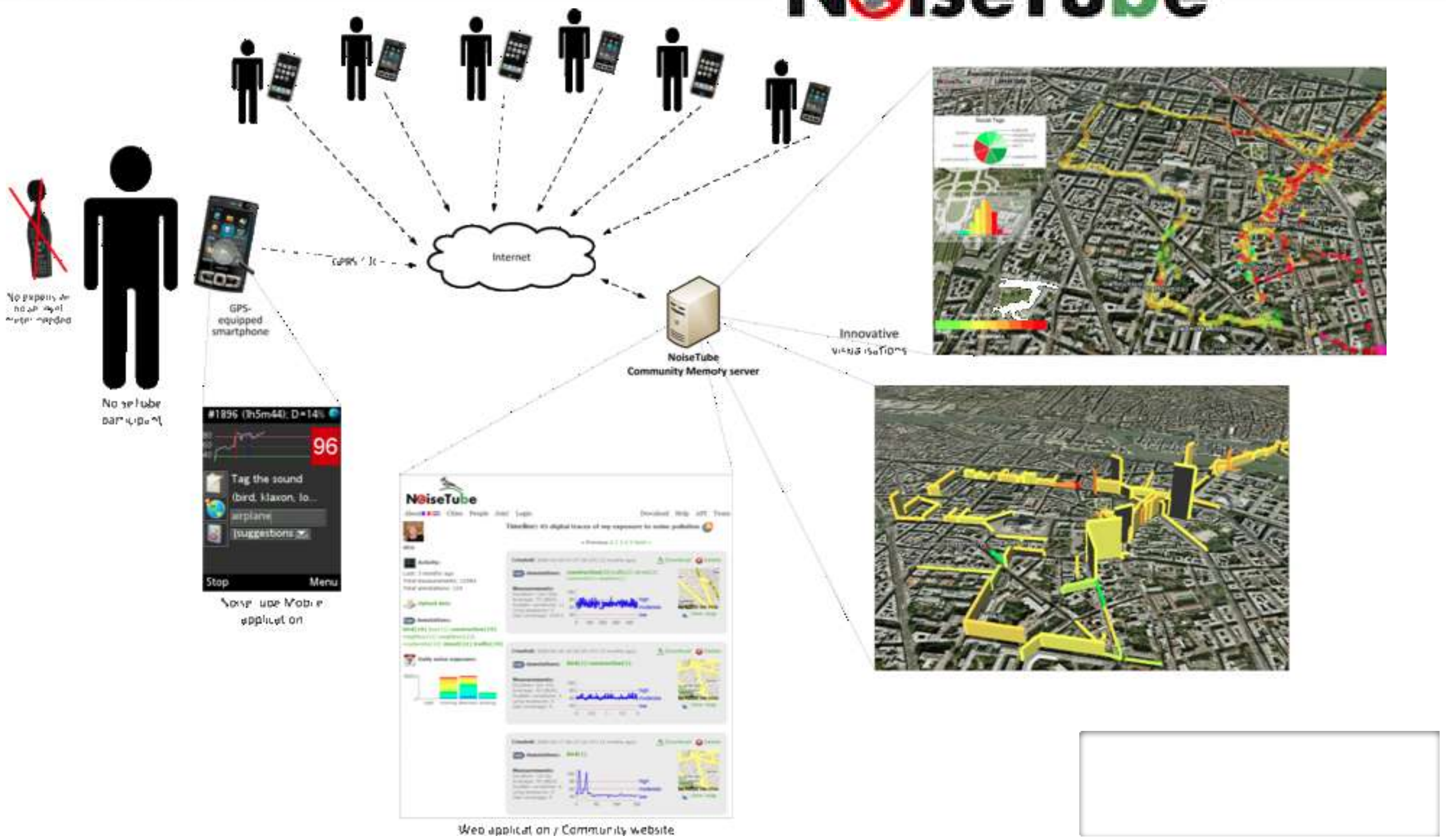
state of the art:



Nicolas Maisonneuve, Matthias Stevens & Bartek Ochab. *Participatory noise pollution monitoring using mobile phones*. Information Polity, 15(1-2):51-71, Aug 2010. DOI: 10.3233/IP-2010-0200.

state of the art: apps

	platform	availability	measurements	architecture
Ear-Phone	Java ME	private	continuous	app only
NoiseSPY	Symbian C++	private	continuous	app+server
NoiseTube	Java ME-Android-iPhone	public	continuous	app+server
WideNoise	iPhone	public	on demand	app+server

Rana &al, Ear-Phone: An End-to-End Participatory Urban Noise Mapping, Proc. 9th Int. Conf. on Information Processing in Sensor Networks, 2010

Kanjo, NoiseSPY: A Real-Time Mobile Phone Platform for Urban Noise Monitoring and Mapping, J. Mobile Networks and Appl., Vol. 15(4), 2010

Stevens &al. Participatory noise pollution monitoring using mobile phones. Information Polity, 15(1-2):51-71, Aug 2010.


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


OPSM
SUNGLASSES
423

environmental social tagging

- = adding context to numeric pollution data to facilitate interpretation

- Sources of noise
- subjective perception
- activity
- .... anything goes!

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

L. Steels & E. Tiselli (2008). *Social Tagging in Community Memories*. Proceedings of the AAAI Spring Symposium on Social Information Processing.

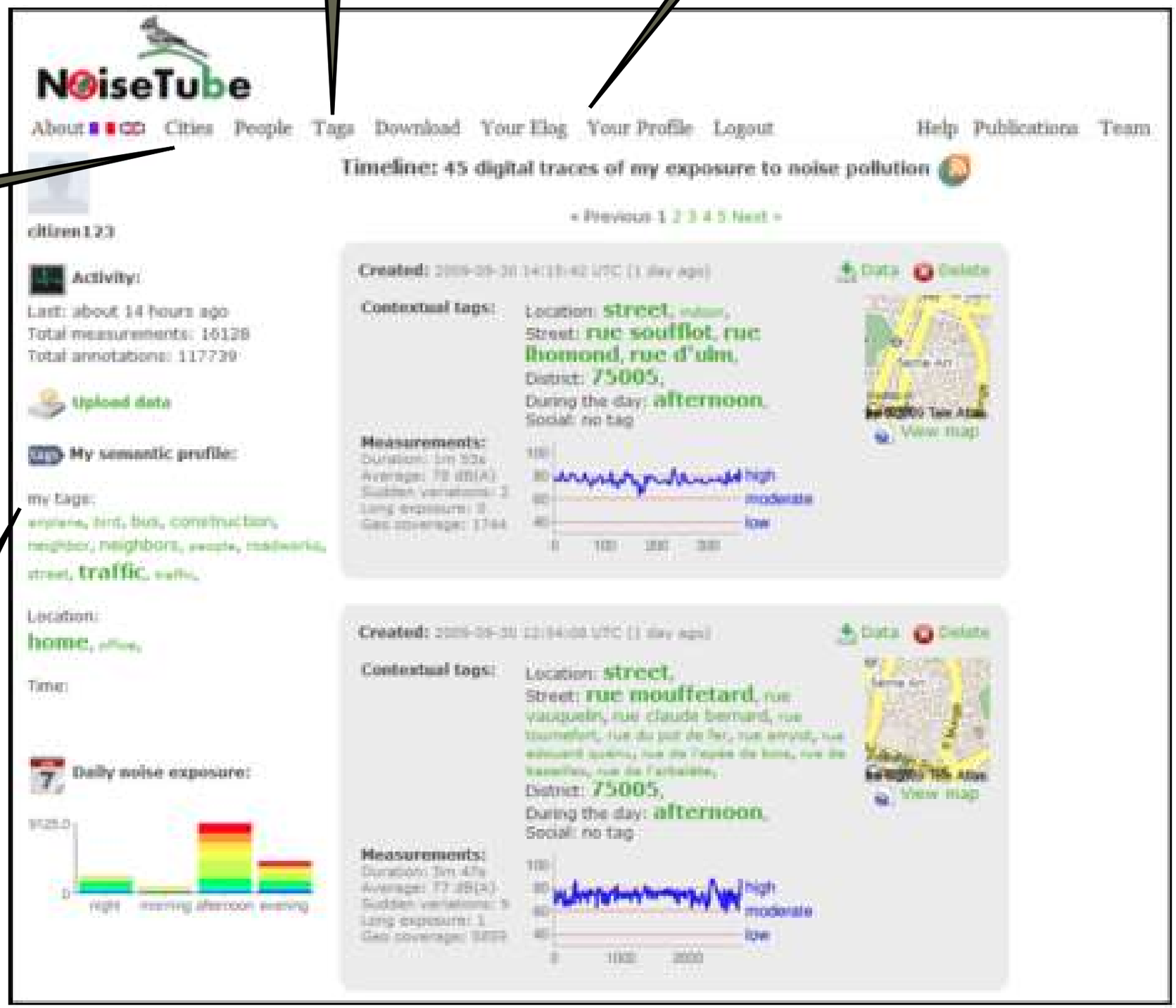
web-based community memory

tag-based search & exploration

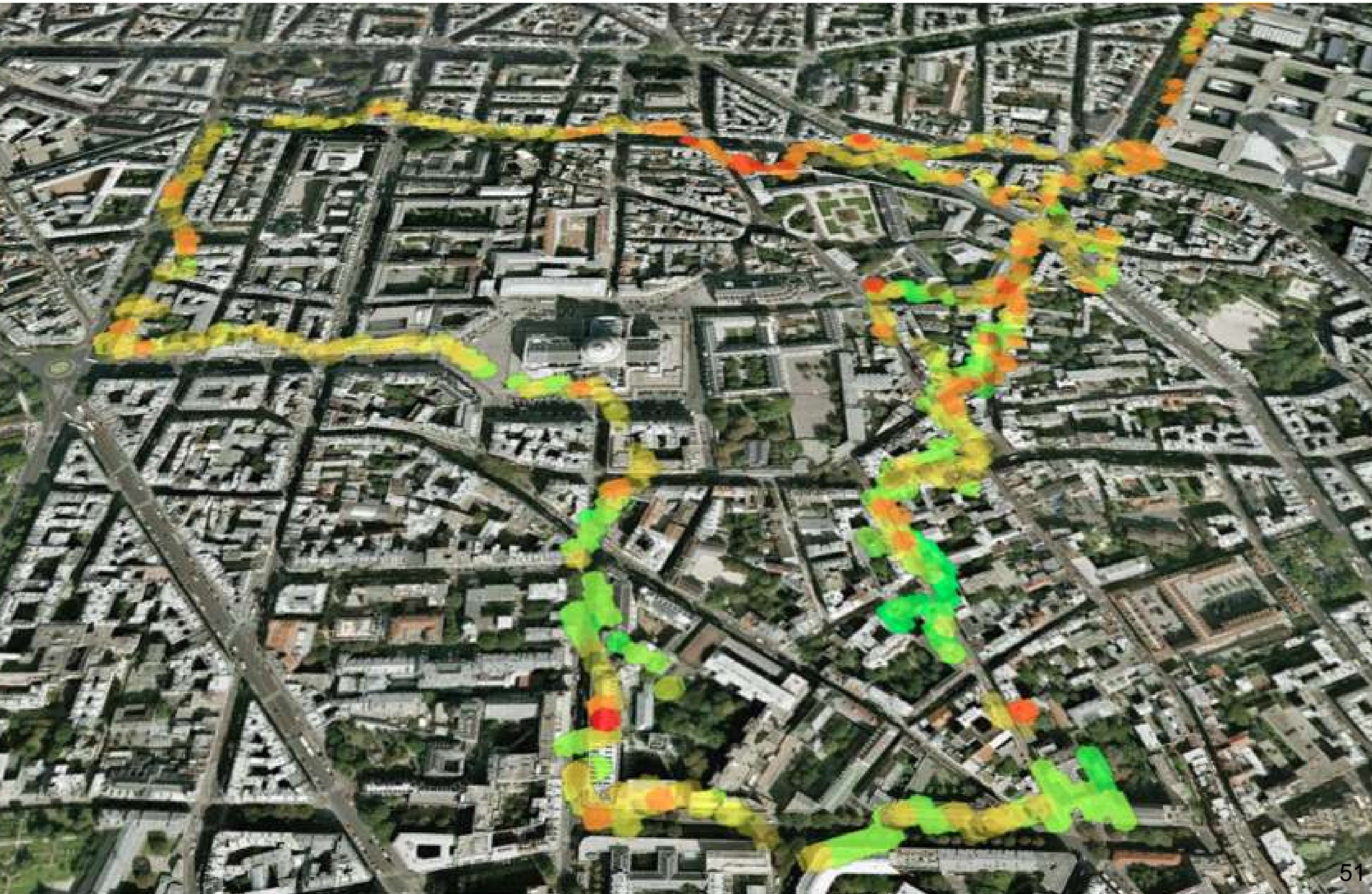
user profiles (“elog”)

collective maps

social networking

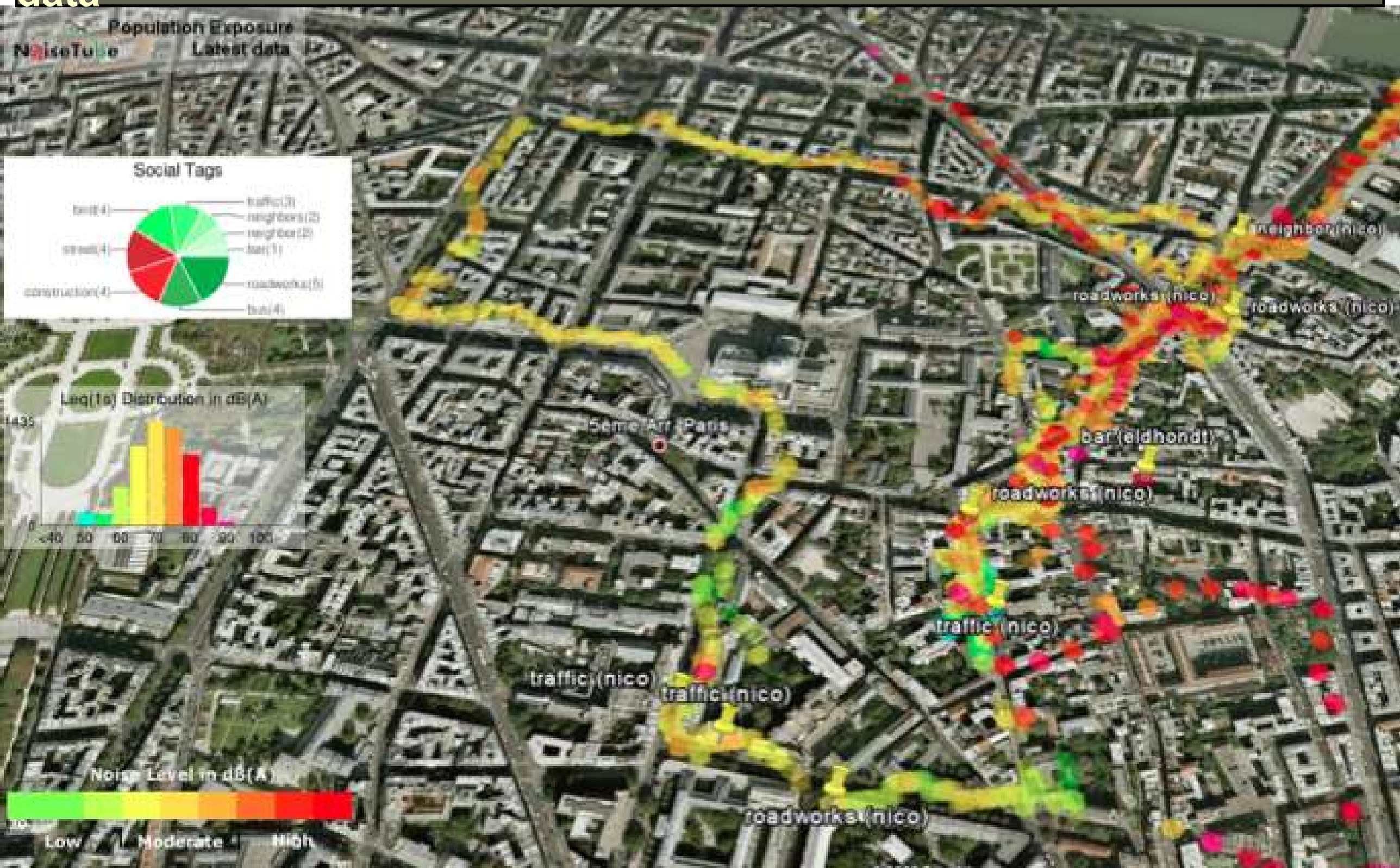


individual tracks



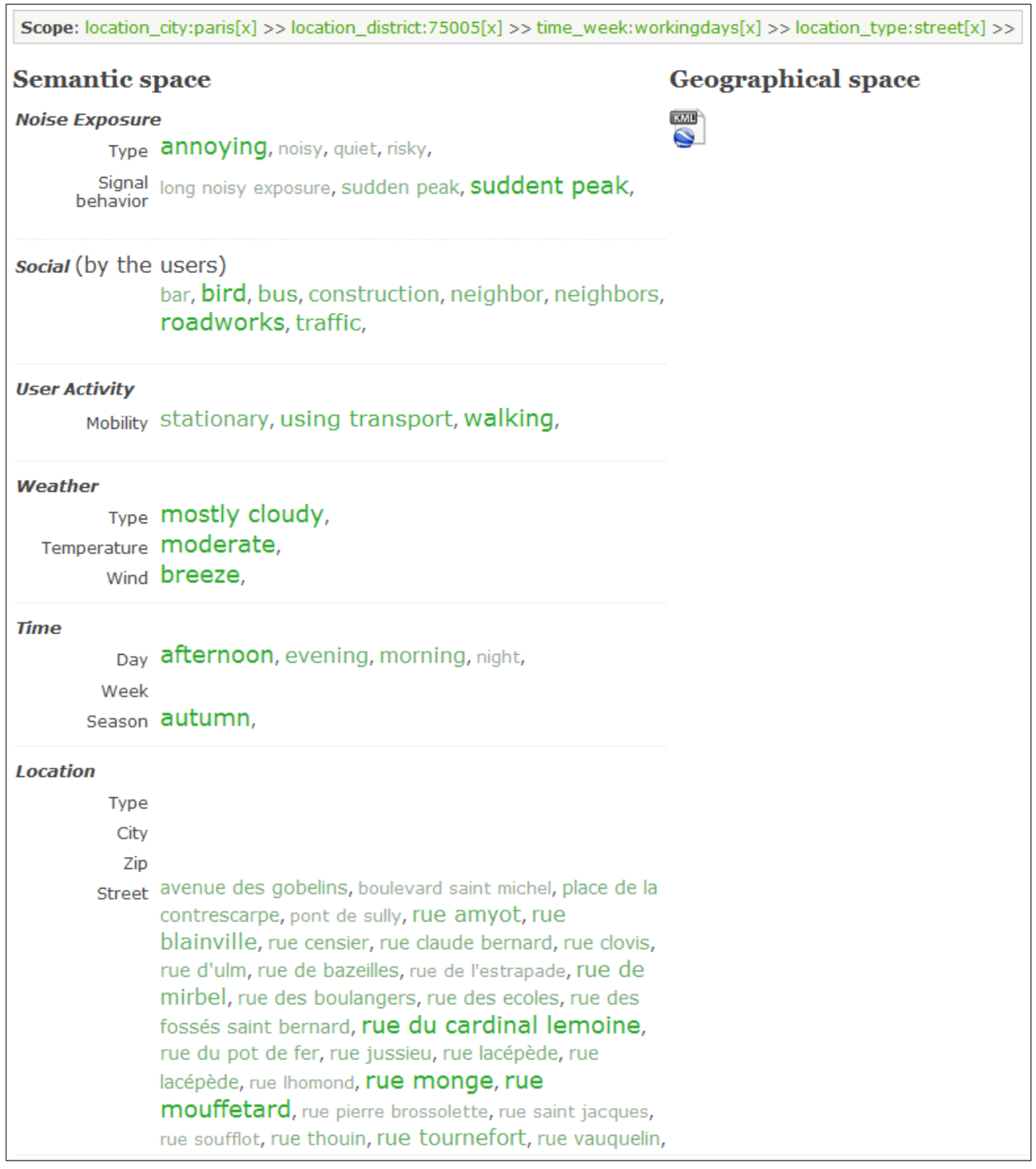
collective maps

dynamic aggregated maps per city, combining all shared exposure data



semantic exploration

- Social & automatic contextual tagging allows semantic search through large data sets
- Bookmarkable tag queries



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

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

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3. Noise maps today
4. Participative sensing & NoiseTube
5. **Participative noise maps**
6. Next year’s developments

research question

implementation

data aggregation

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

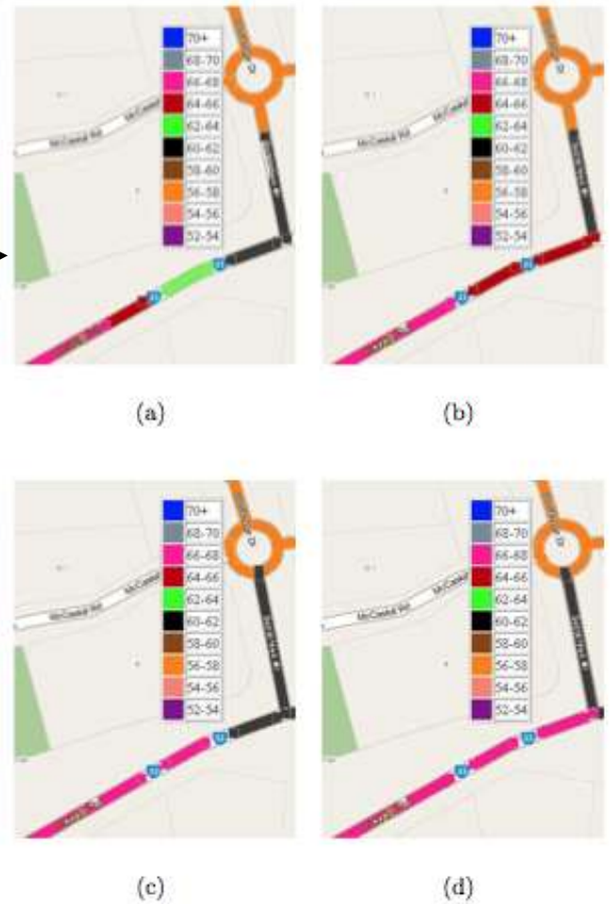
How do these maps compare to current environmental surveying methods, which are simulation-based (and rely only on a limited amount of measured data)?

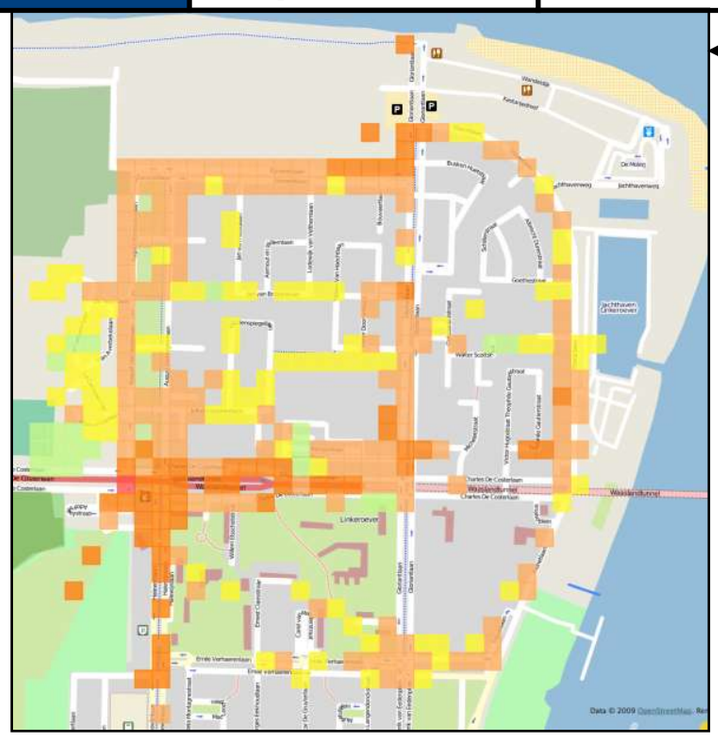
analysis & interpretation

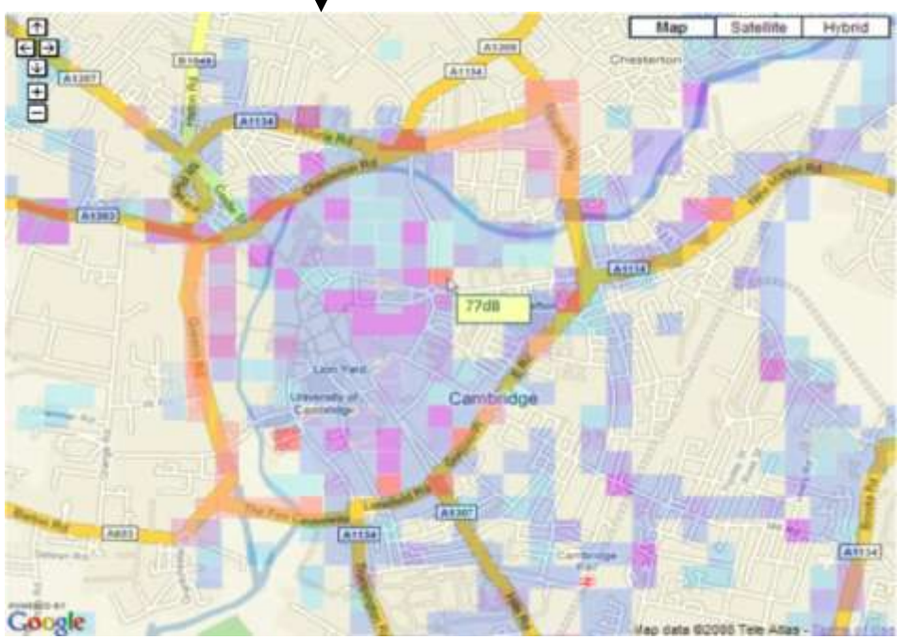
EU-norms

state of the art: maps

	measure-ments	focus	maps
Ear-Phone	street	compressive sensing	street
NoiseSPY	city	Cambridge	city
NoiseTube	world	accuracy, norms	city areas
WideNoise	discrete points	?	-







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 issu

measurement equipment

10x

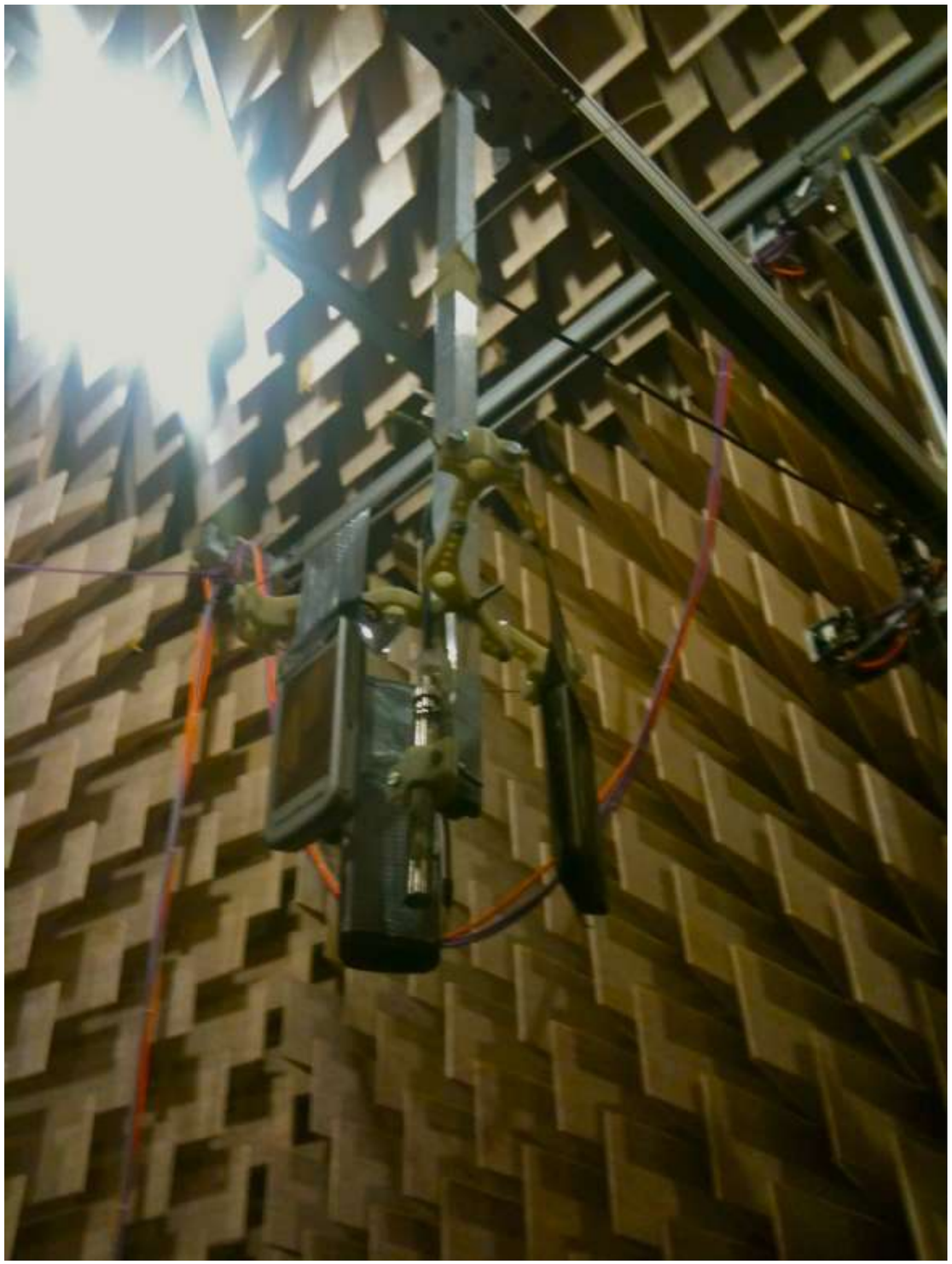
+

EU-norms:

- 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

realistic set of phones (from eBay)

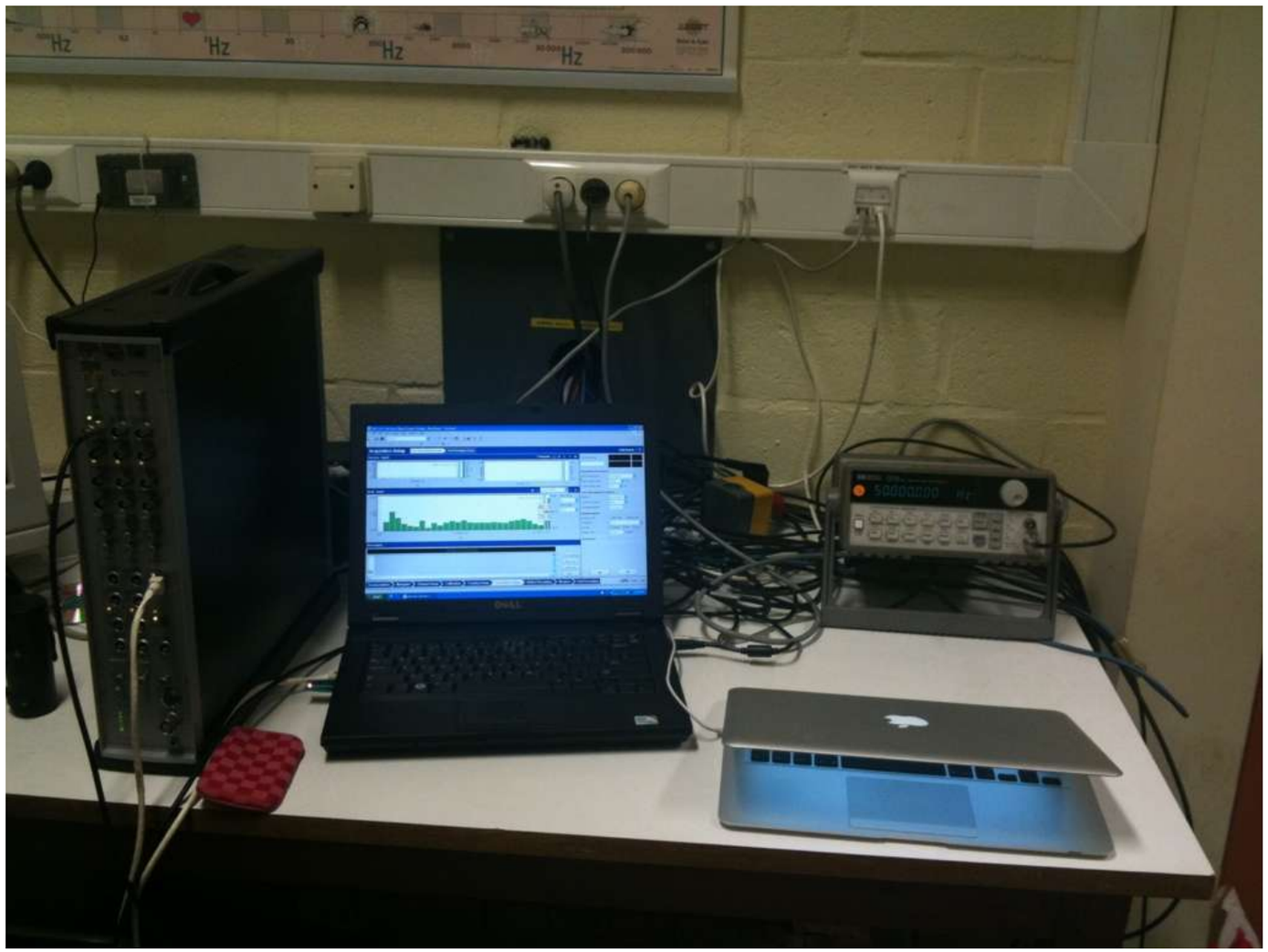
calibration

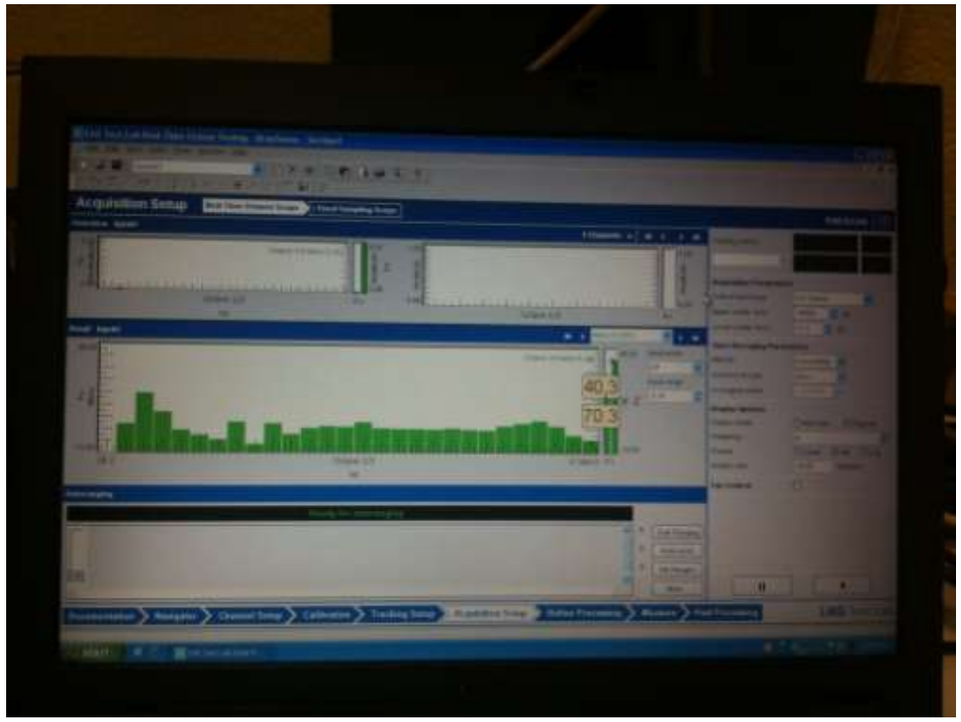


Calibration work carried out in collaboration with Prof. Guillaume, Acoustics & Vibration Group, Applied Sciences, VUB.

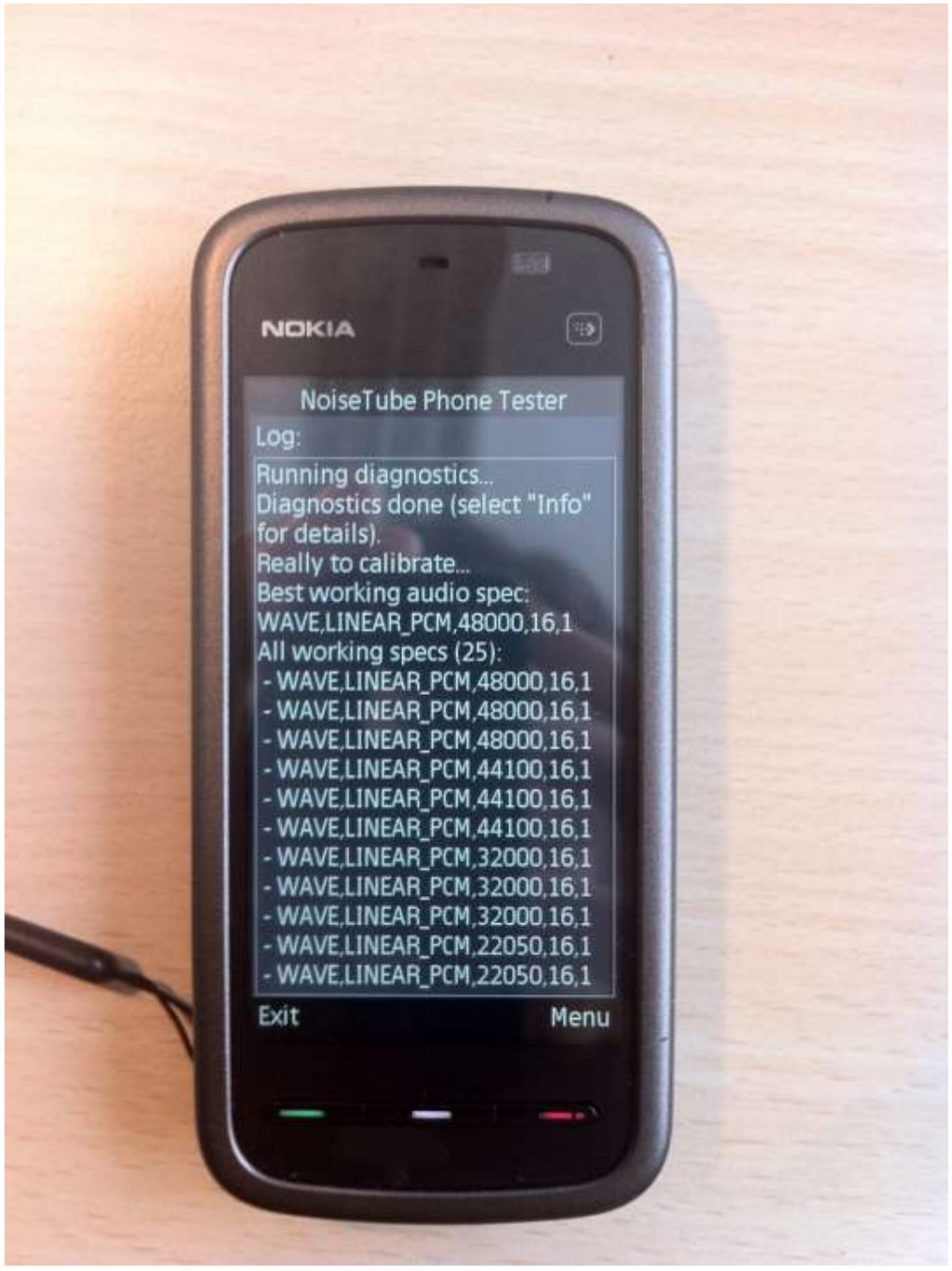
calibration: frequency

2 phones tested



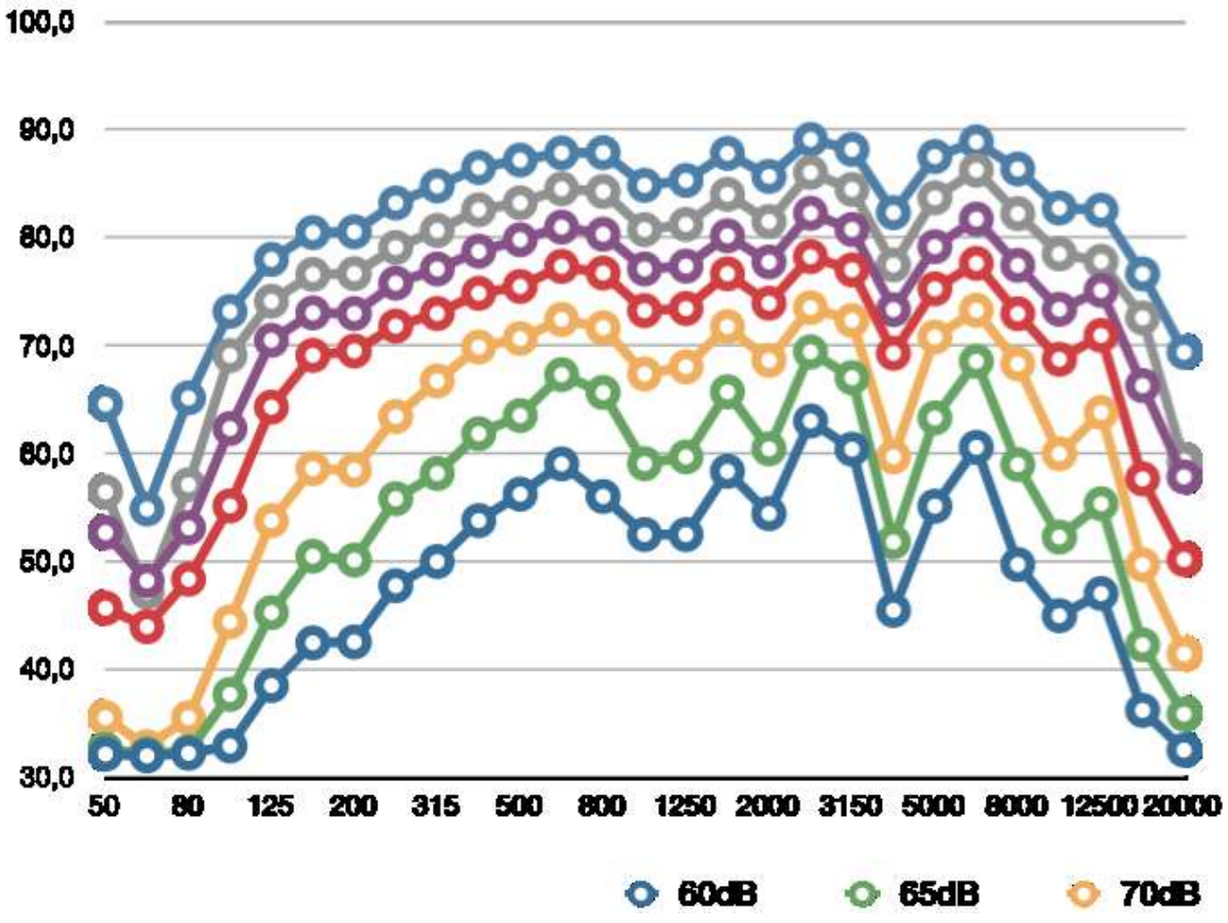


calibration

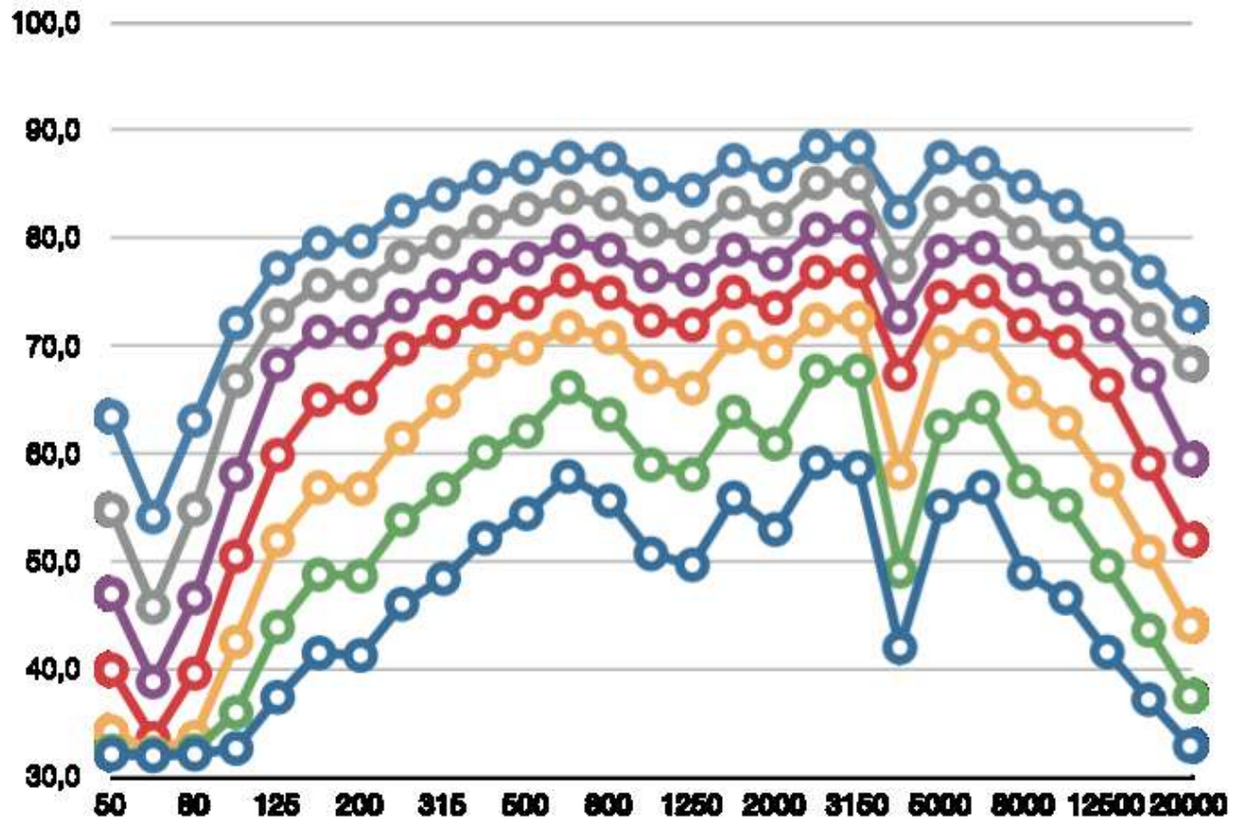


calibration: frequency

Nokia 5230-0



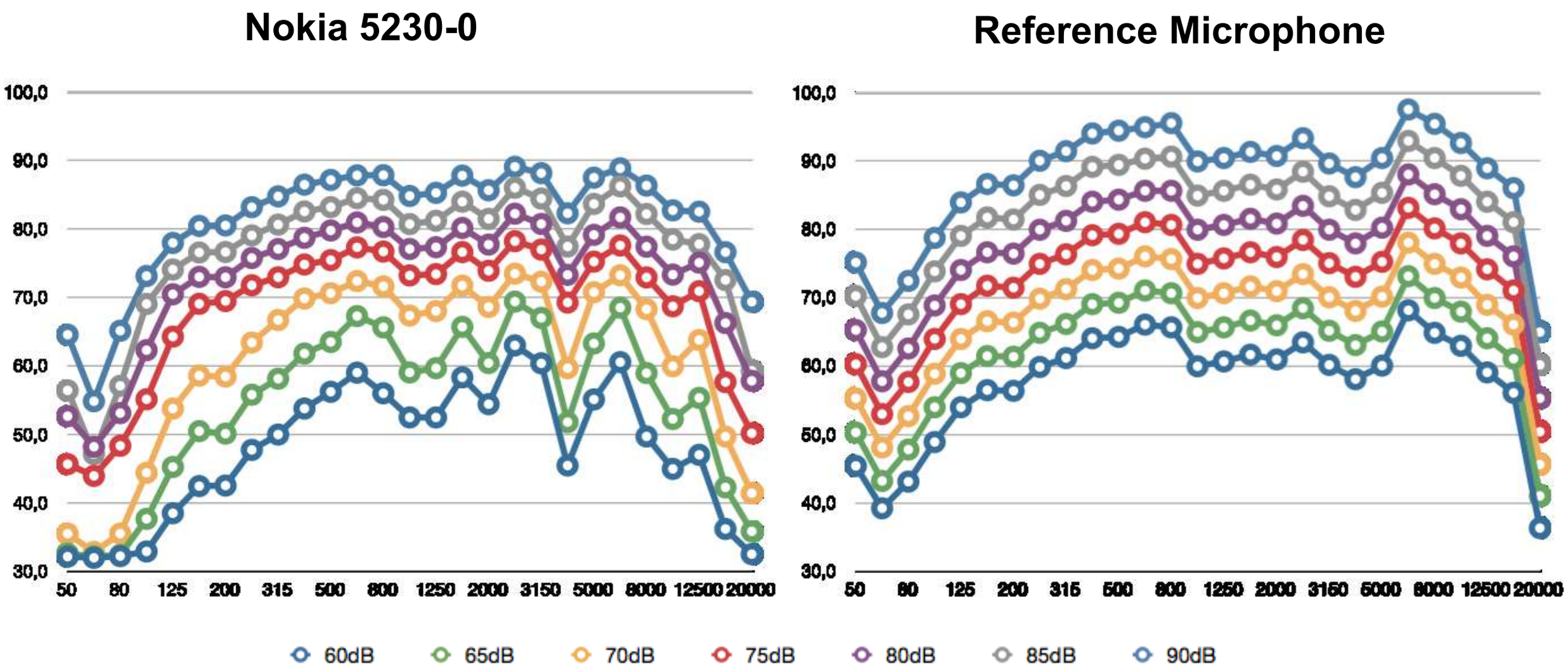
Nokia 5230-1



no significant differe

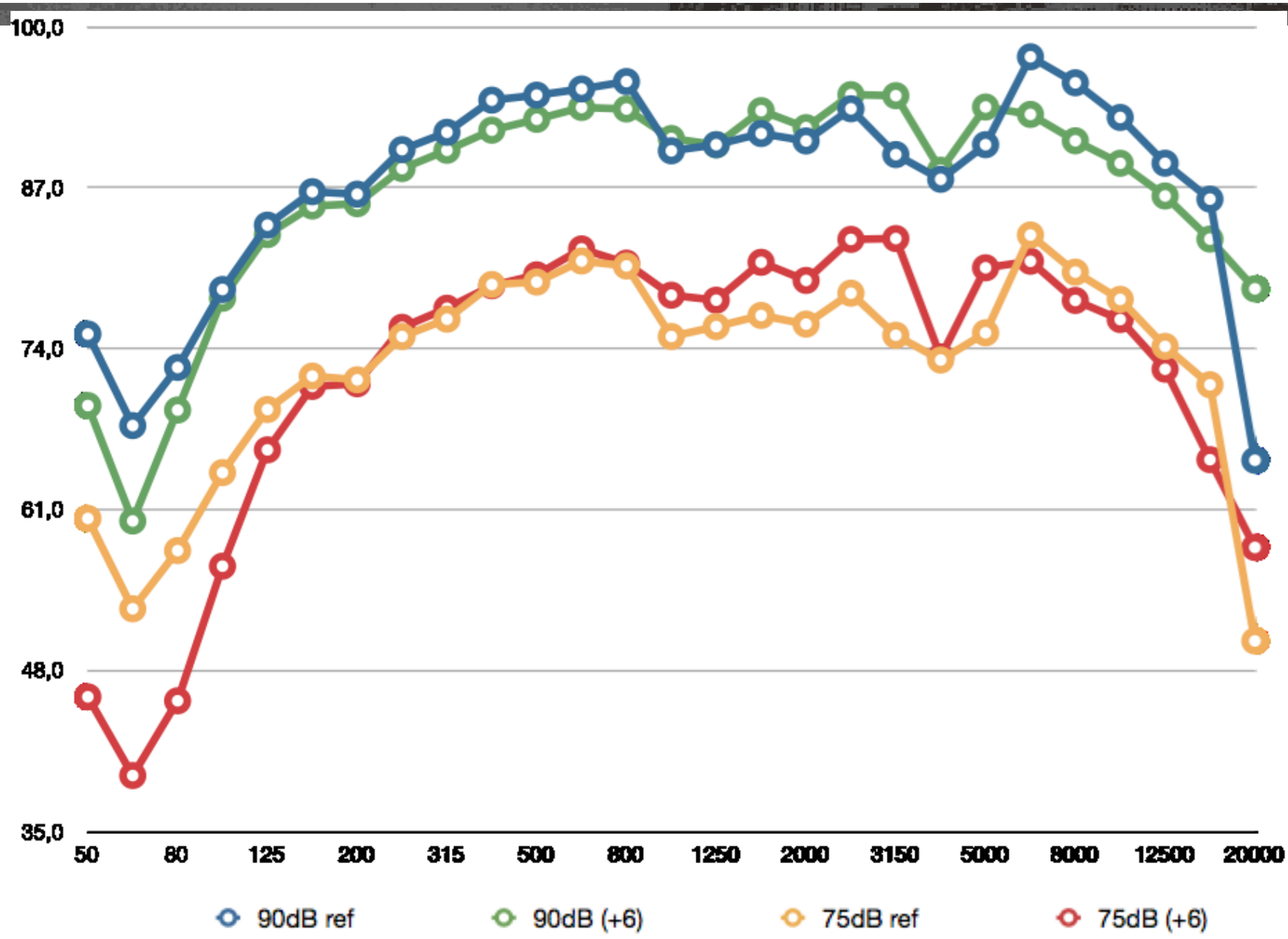
pho

calibration: frequency



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

calibration: frequency



Refere

add 6dB globally

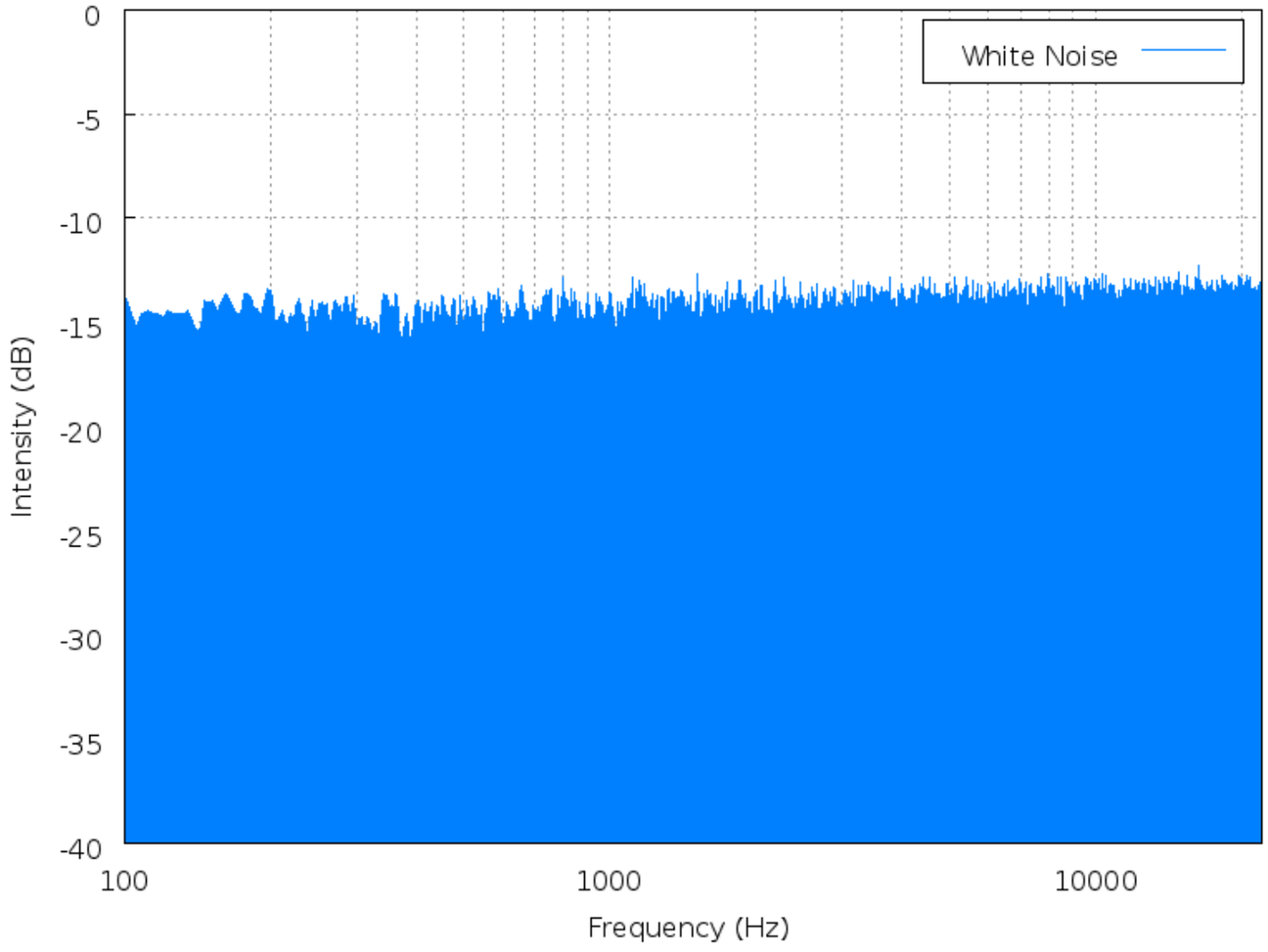
phone follows mike quite well, except for low dB/frequency

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)

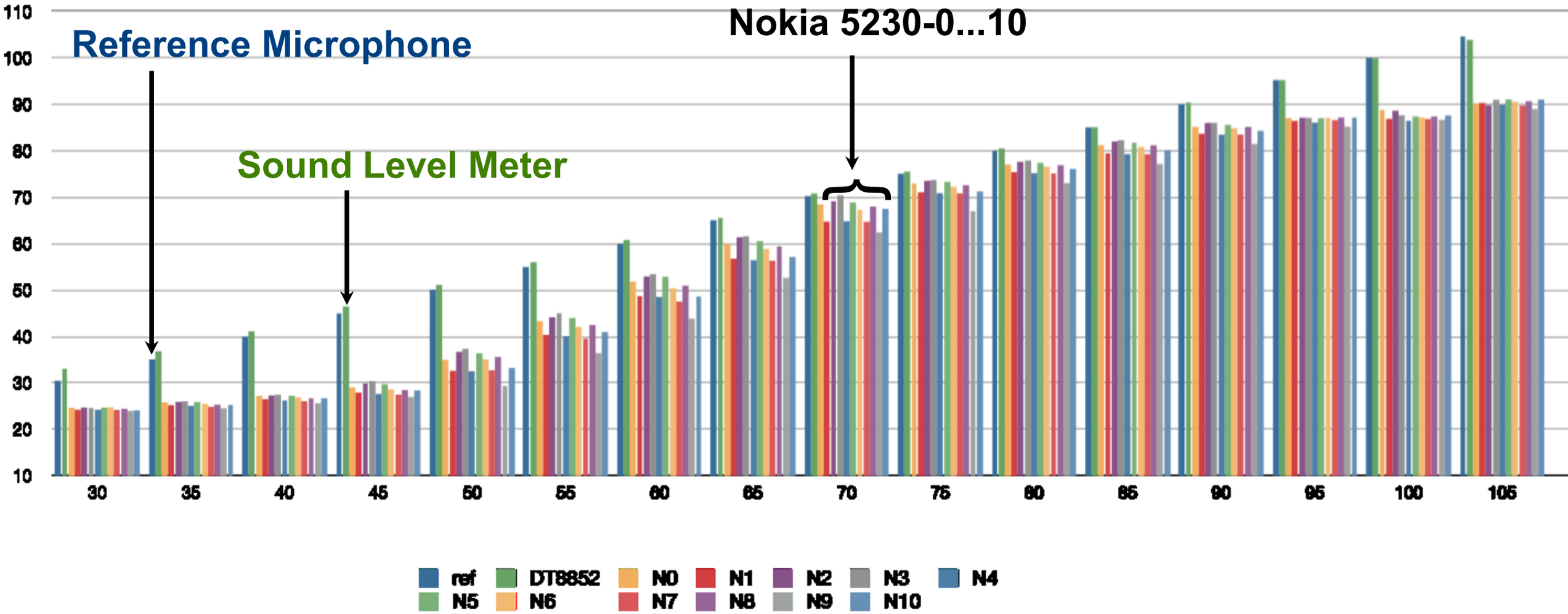
calibration: white noise



white noise = all frequencies equally present

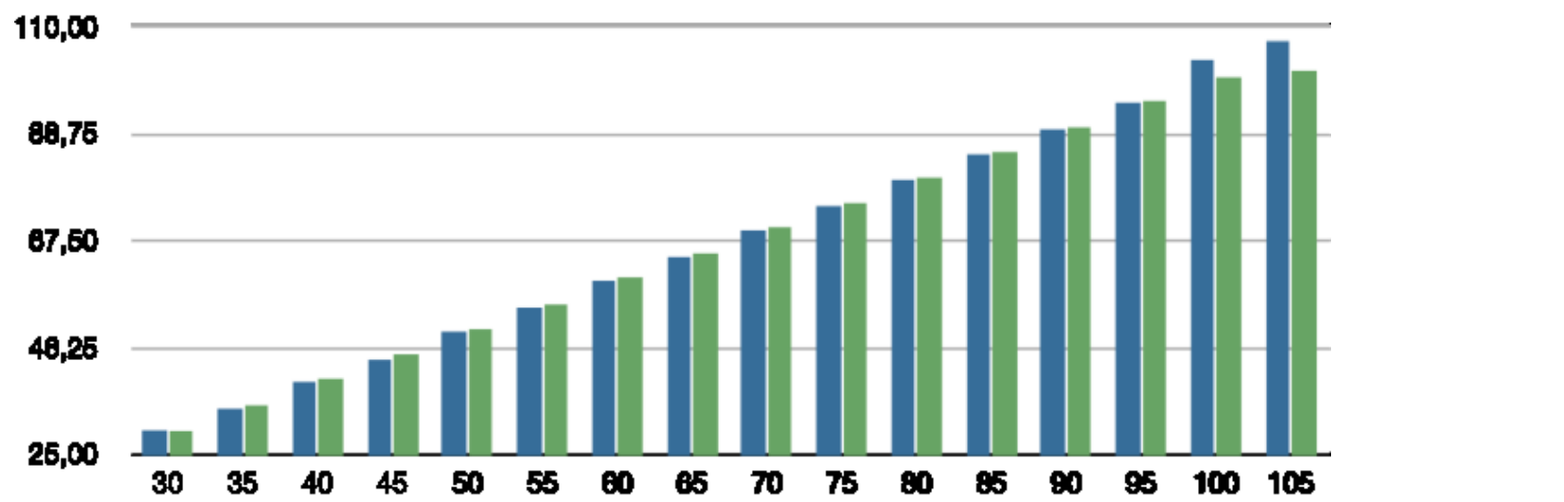
calibration: white noise

10 phones tested



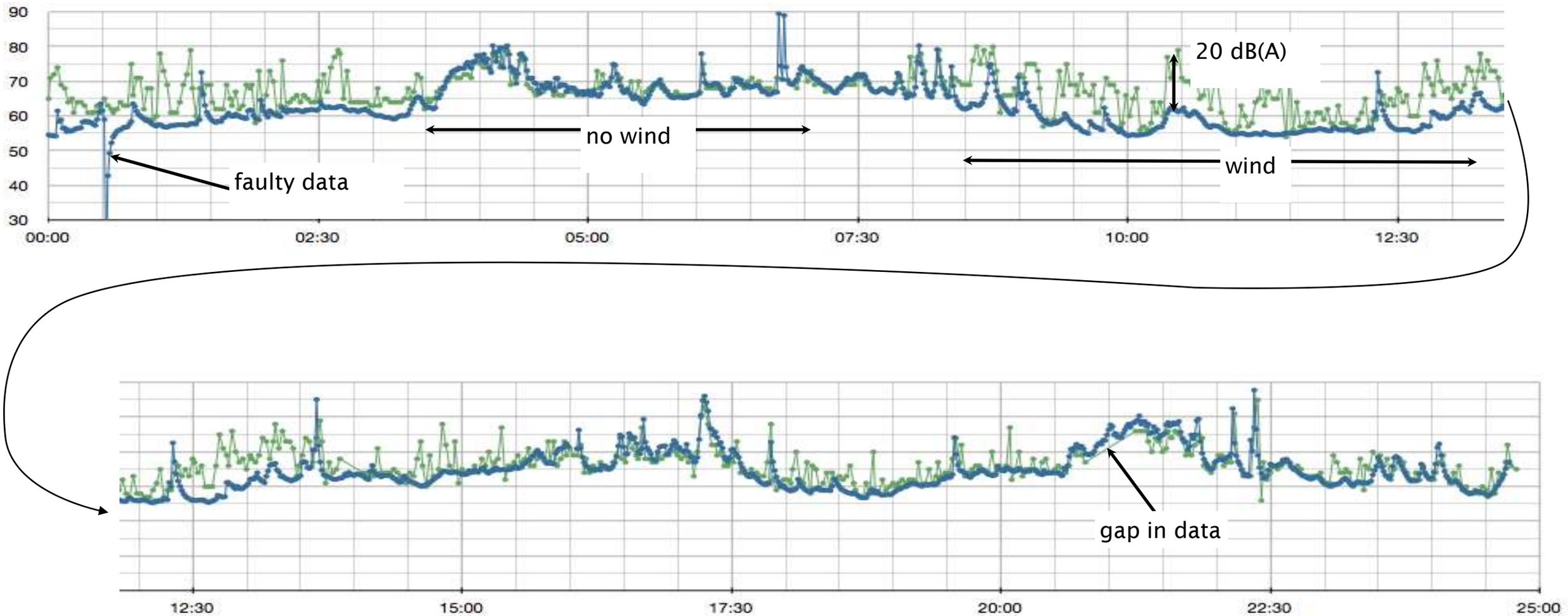
calibration: white noise

NoiseTube +



Nokia 5230-0 dBA dBAref Reference Microphone

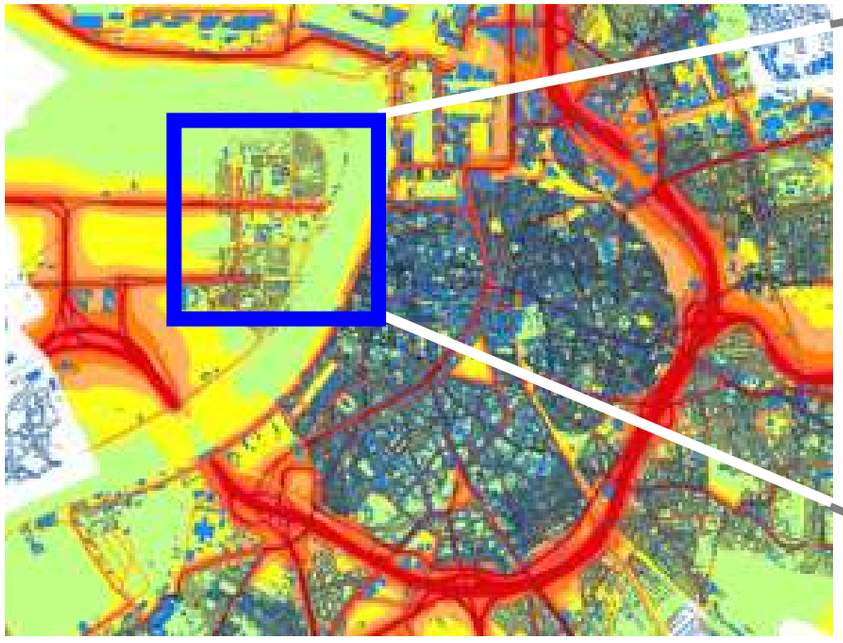
calibration: in the field

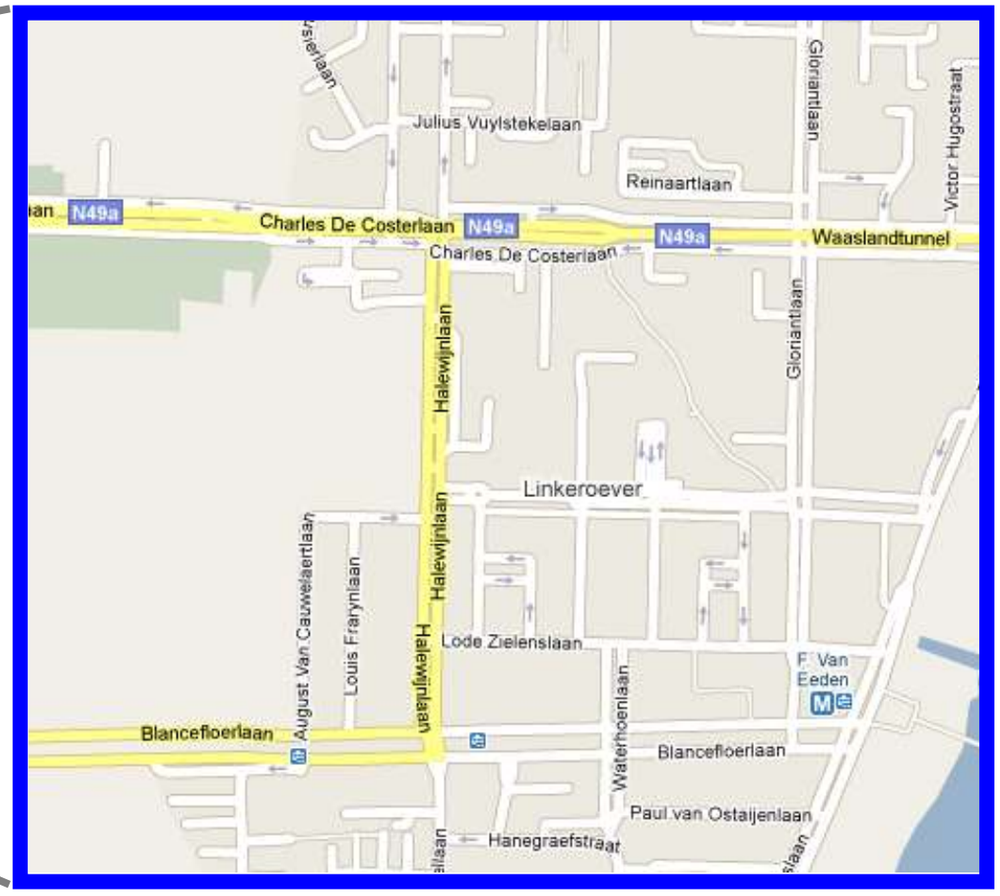


Nokia 5230-0:

Reference Sound Meter:

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.

- 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

analysis: tools

40 tracks in xml → Scheme vector with clean data

(5 21 4 1 66 51.229289850654006 4.380786121046)

...

analysis: grid

Divide the area into a grid...

- choice depends on #measurements and GPS errors
- GPS errors max 8,25m for latitude, 11,41m for longitude as measured at 7 positions in the area
- we use a 40m x 40m matrix grid to have ±100 measurements per cell

analysis: grid

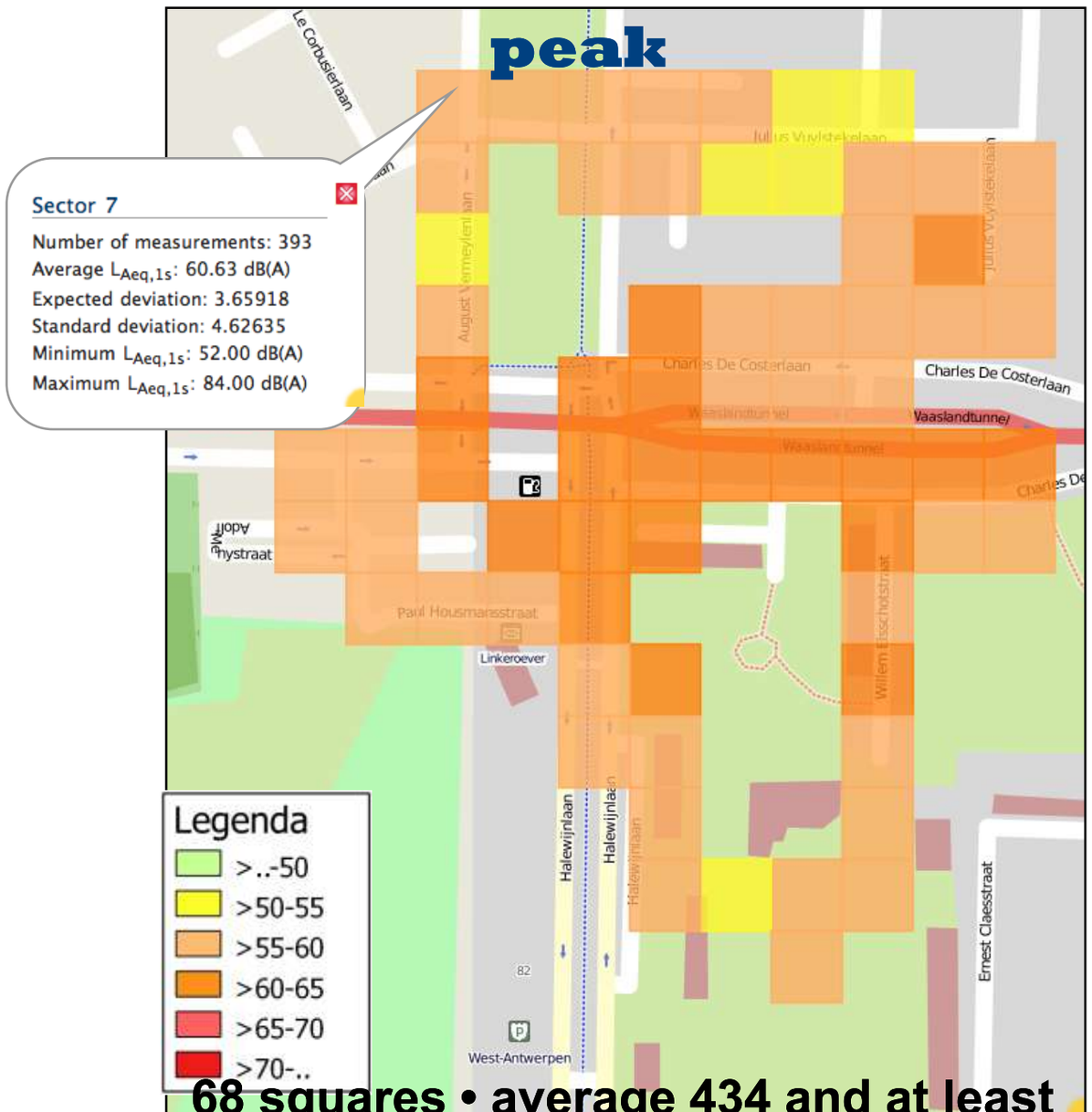
... distribute measurements over the grid ....

analysis: statistics

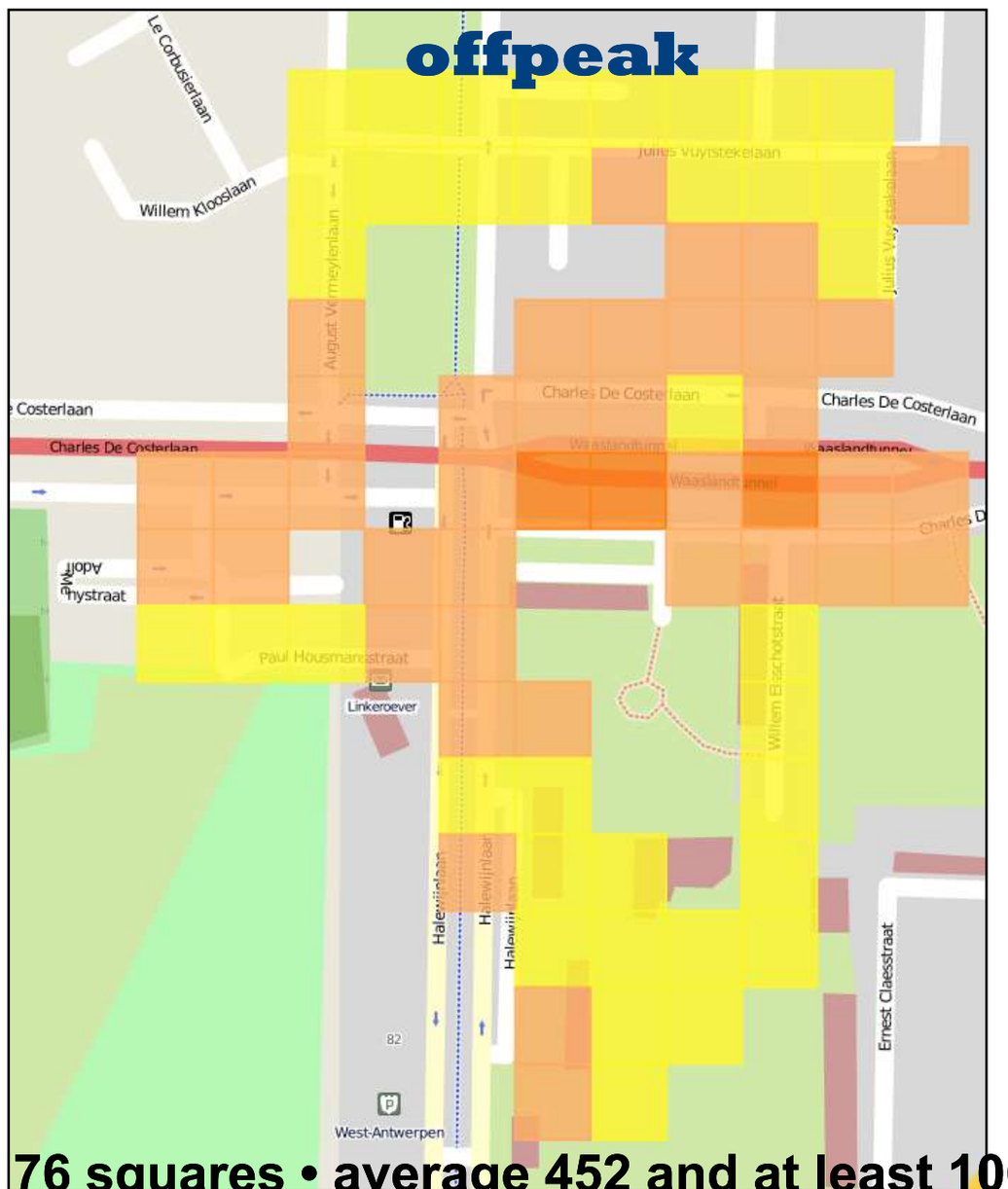
... compute averages &tc per grid element and make ready for map representation

results: noise map

Import in GIS software to obtain noise maps.
(see http://www.brussense.be/experiments/linkeroever/)

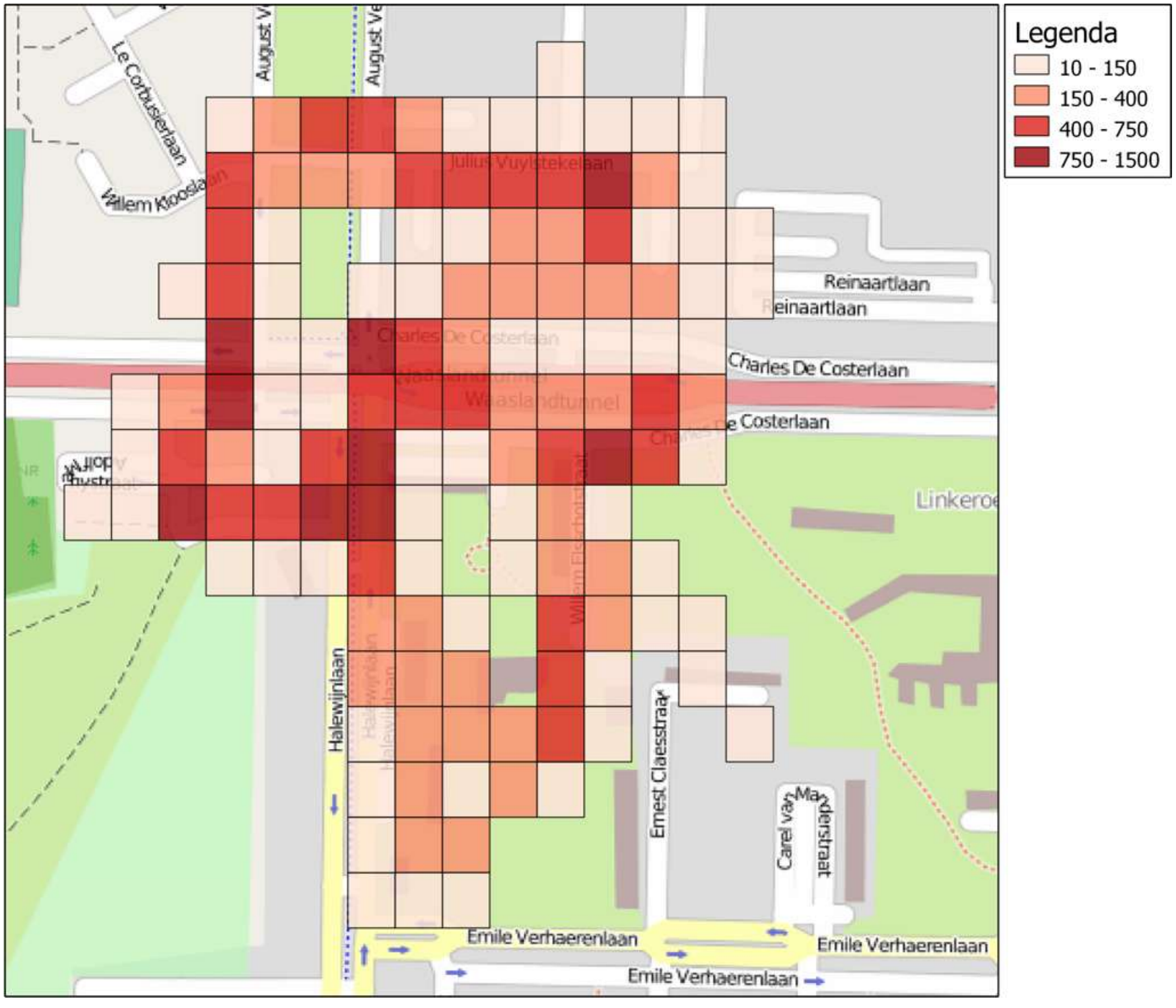


68 squares • average 434 and at least 100 measurements per square • average sound level 63,5 ± 4,2 dB(A)

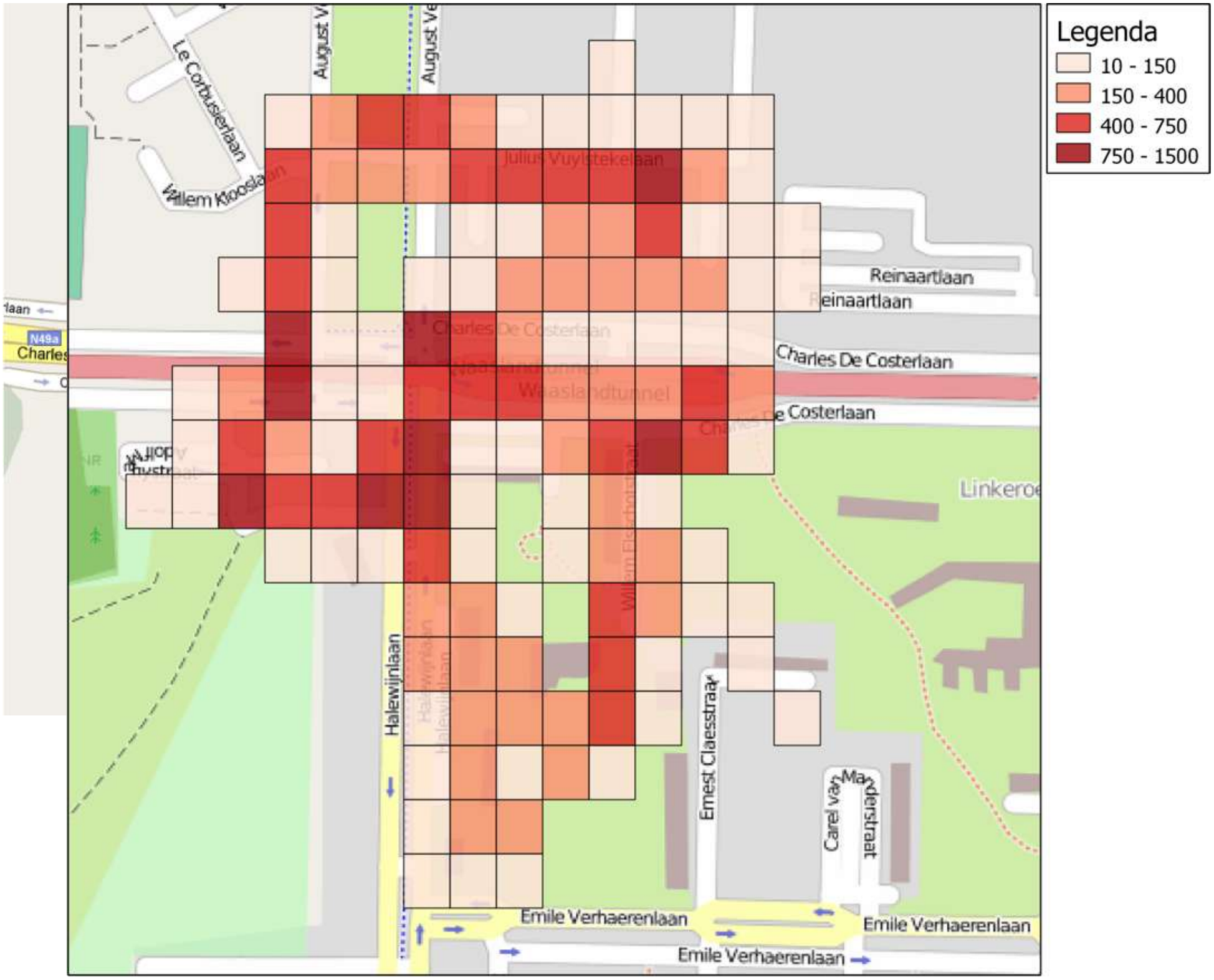


76 squares • average 452 and at least 100 measurements per square • average sound level 60,6 ± 4,1 dB(A)

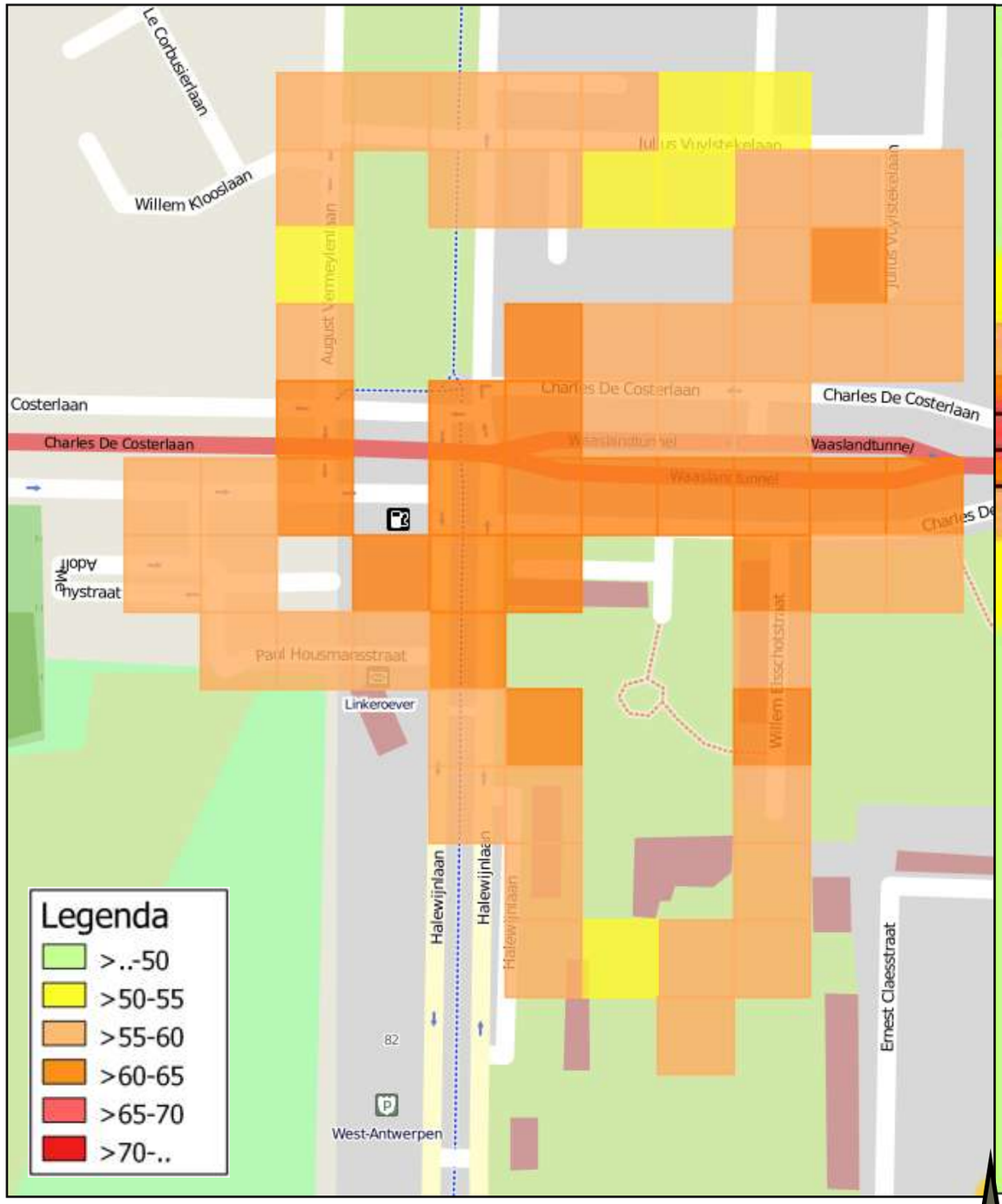
results: # measurements

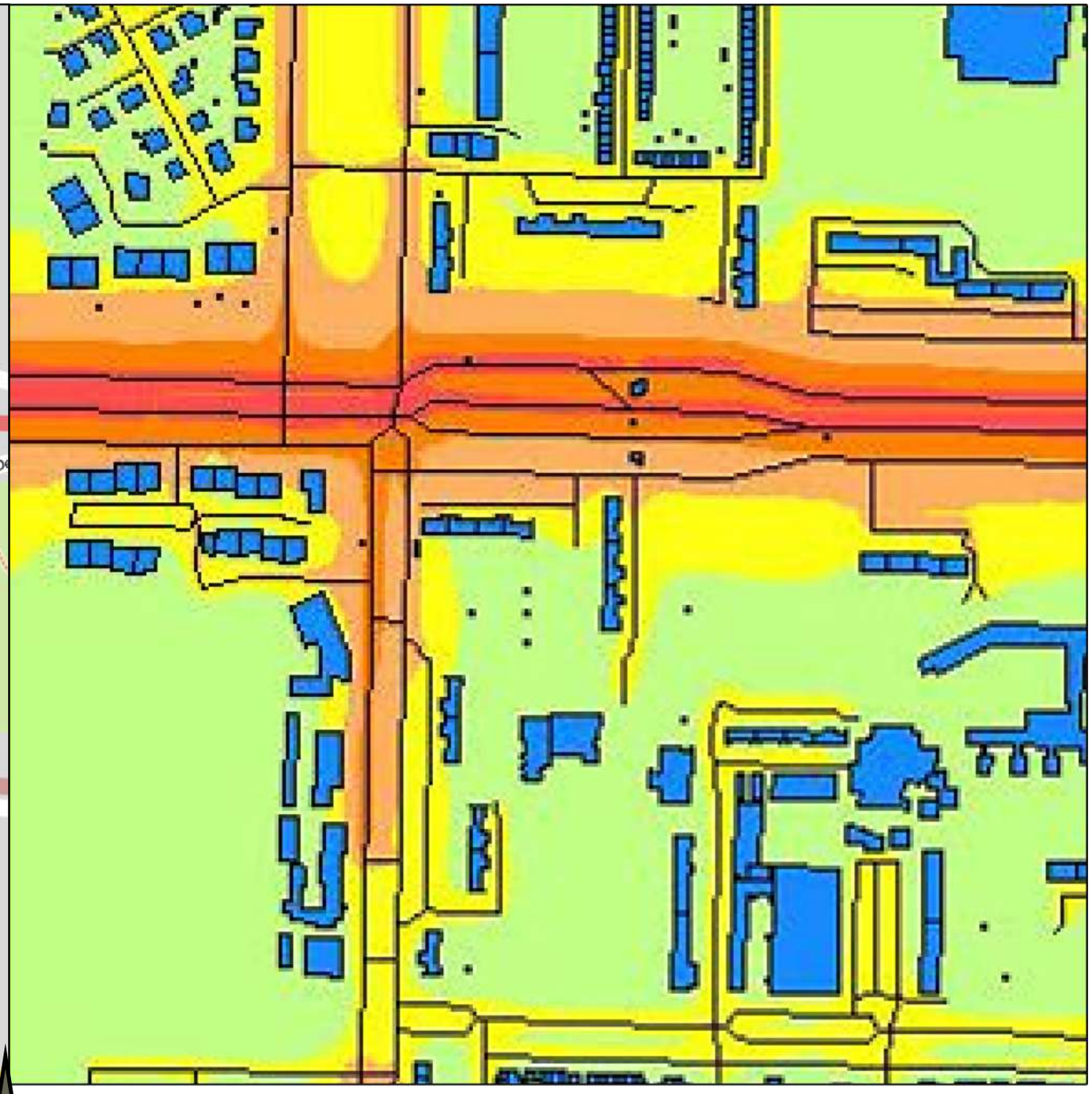


results: # measurements



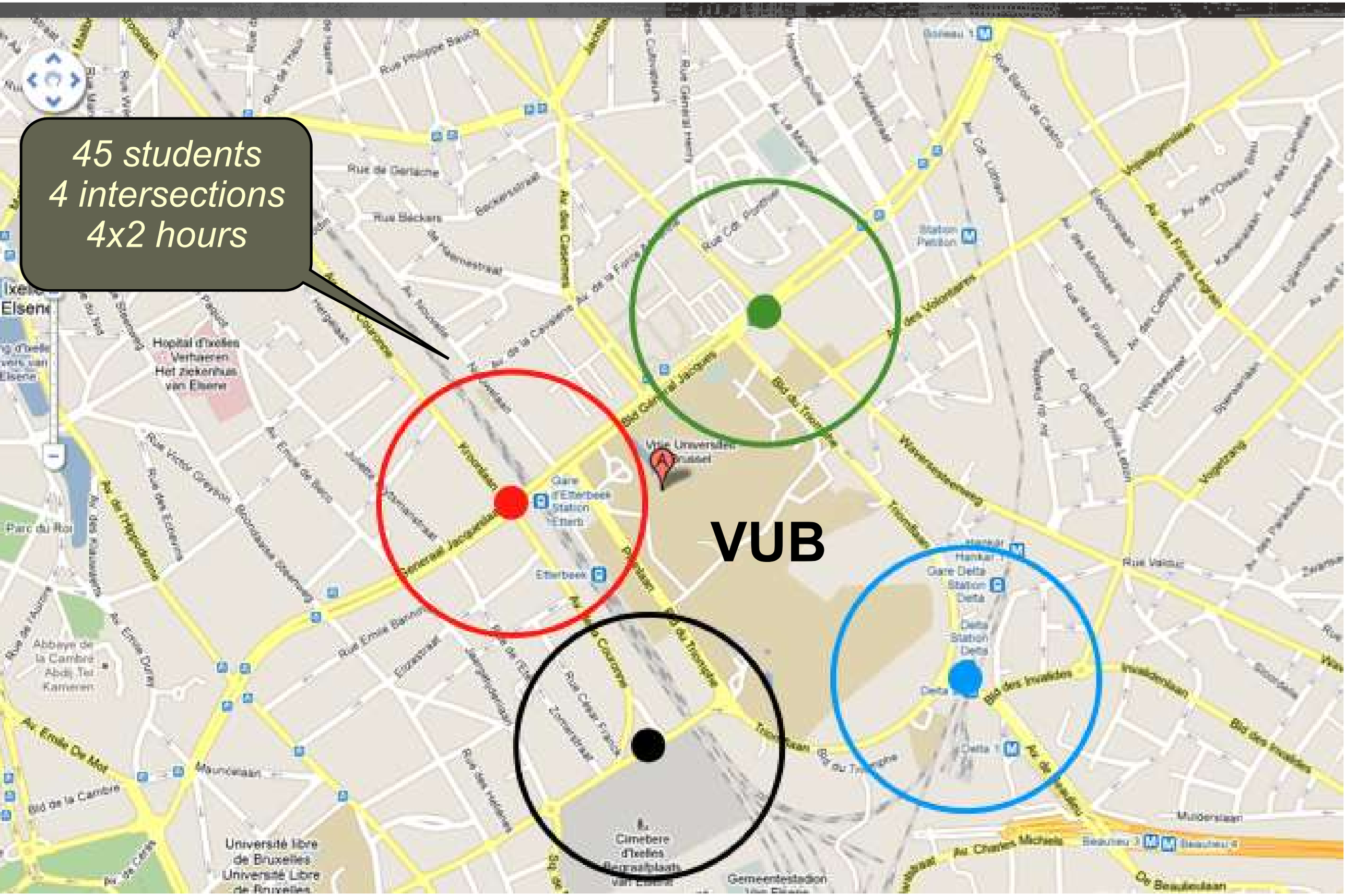
results: comparison





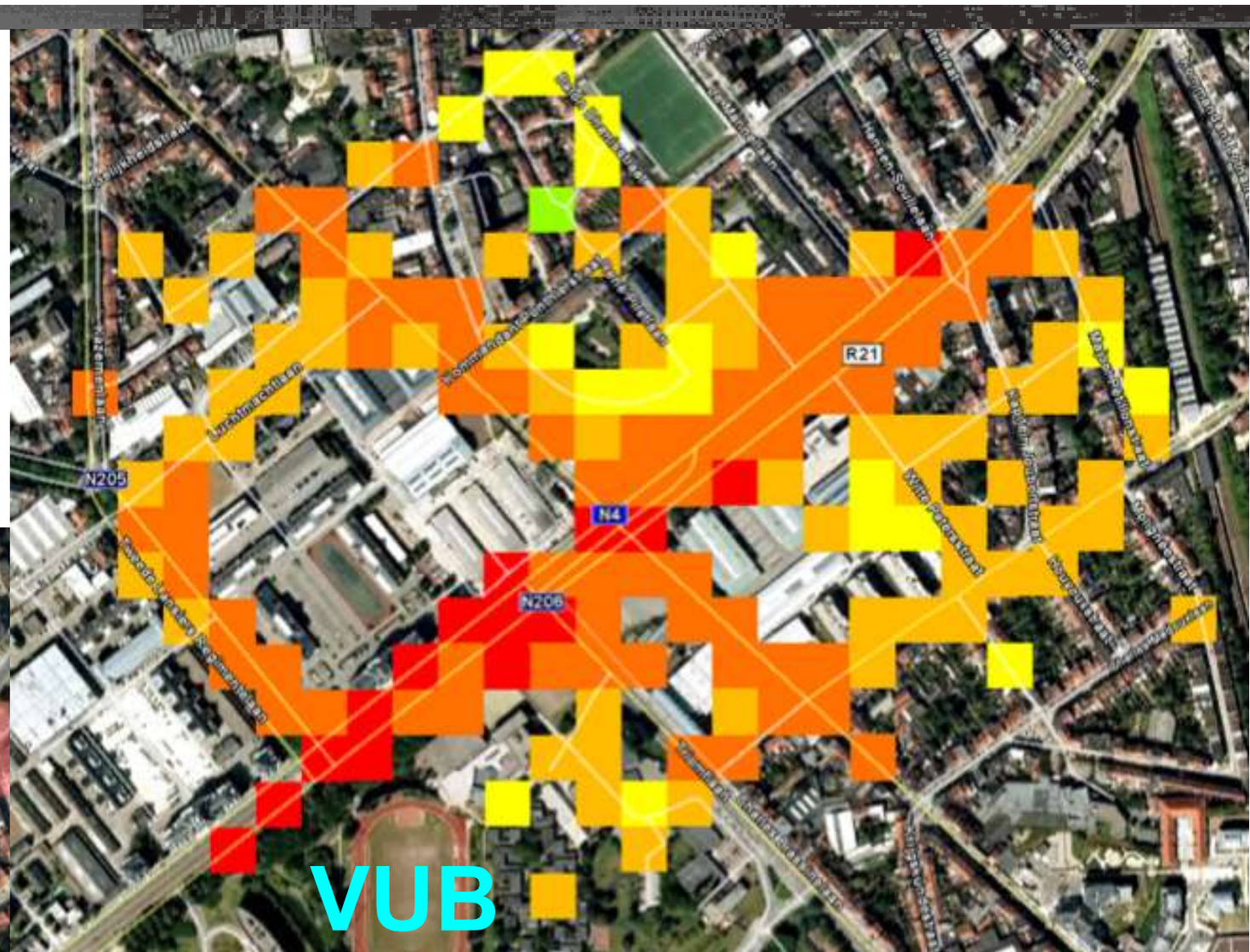
precise data required from city administrations for quantitative analysis

confirmation: Brussels



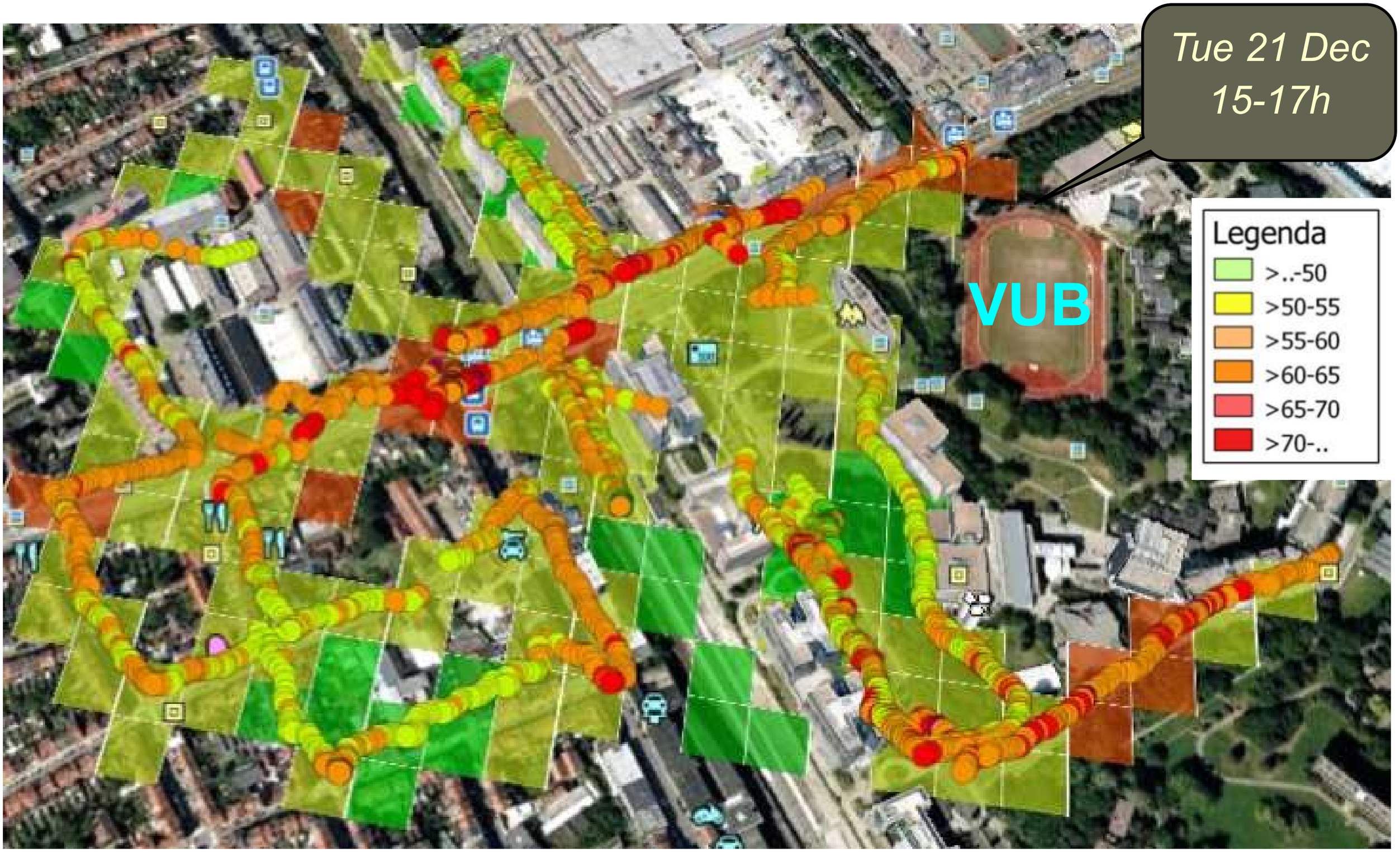
confirmation

Mon. 13 Dec
13-15h



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

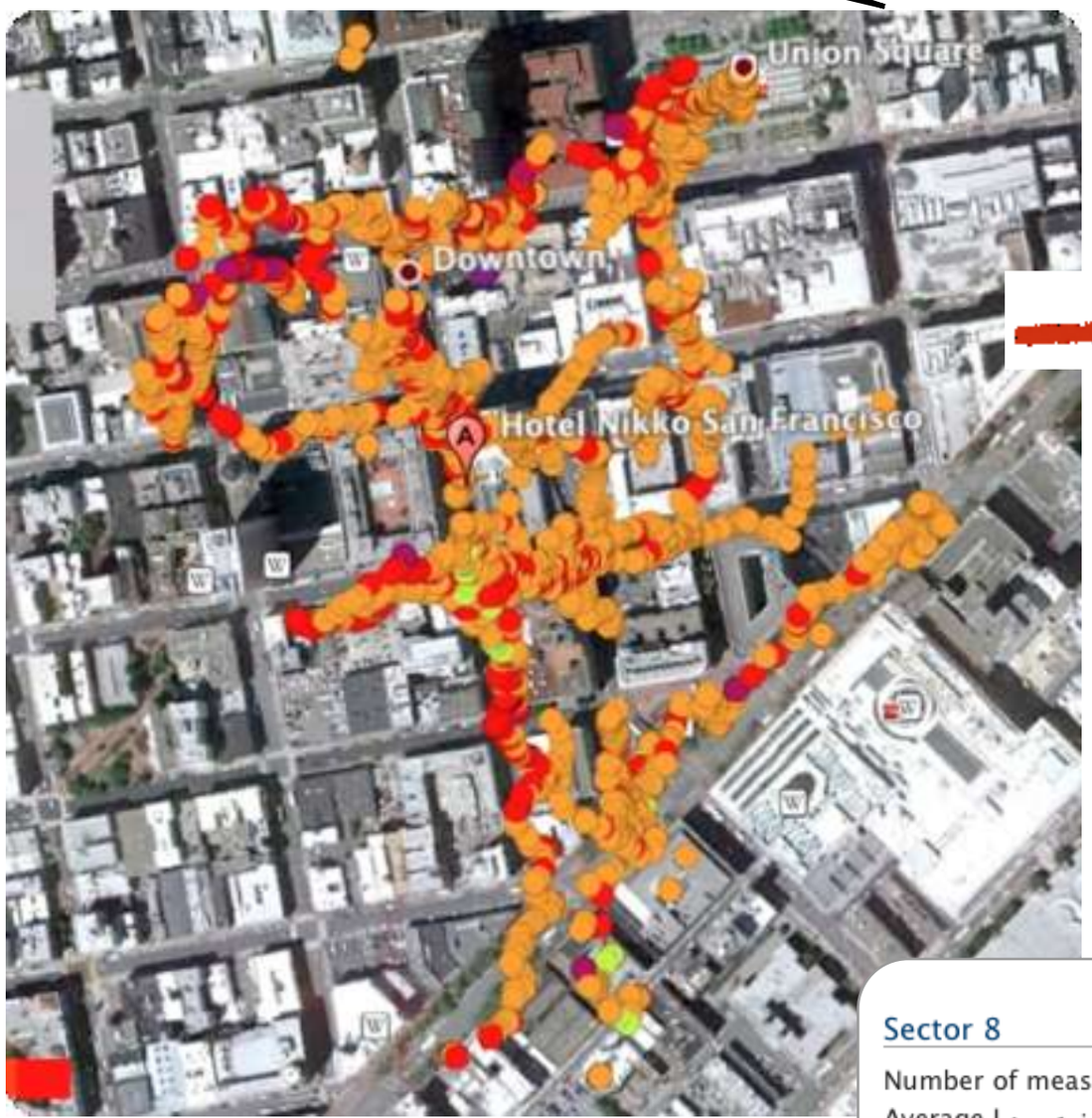
confirmation

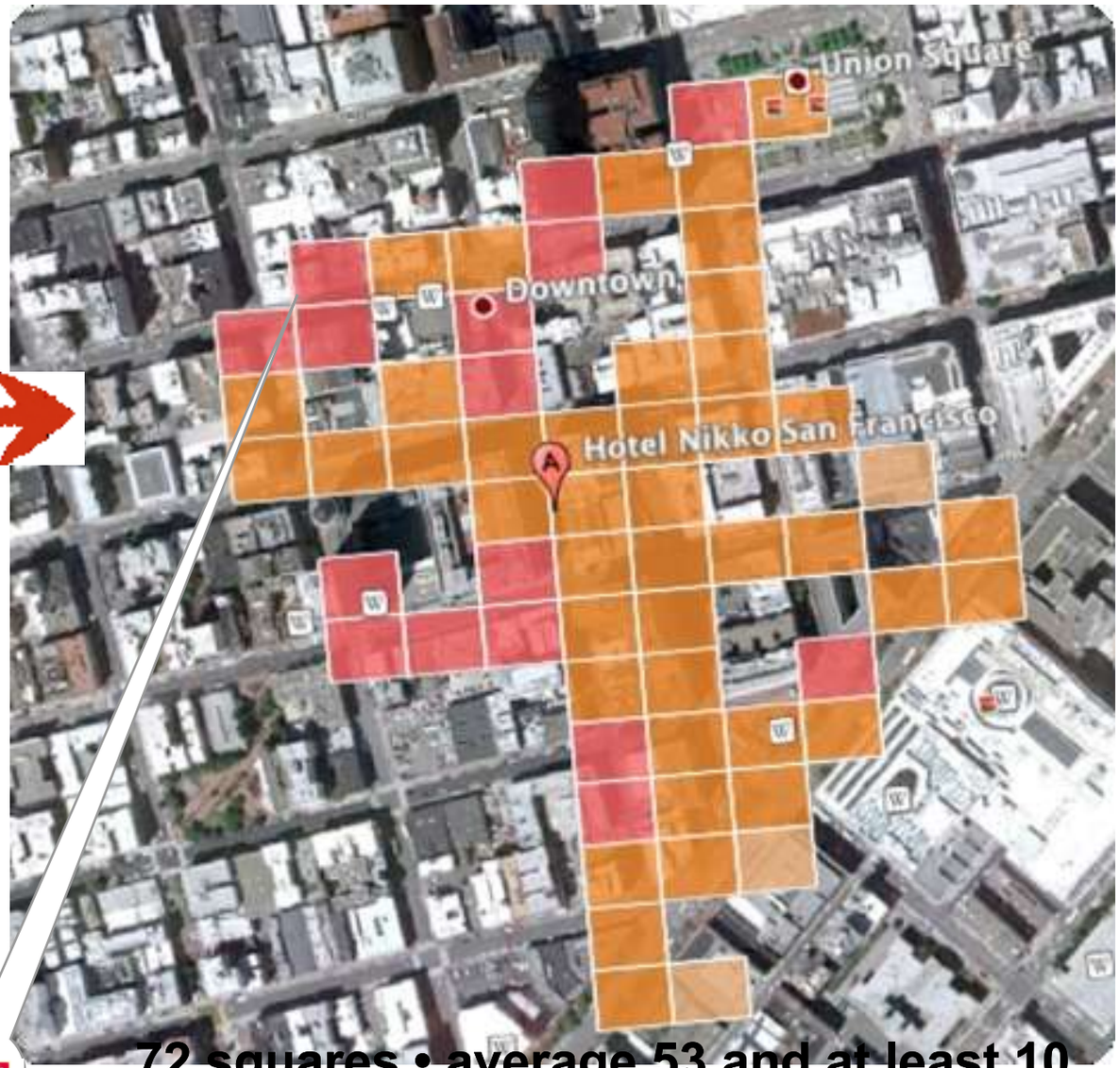


confirmation: San Francisco

1 person
3x 45minutes

see
http://www.brussense.be/experiments/sf/





72 squares • average 53 and at least 10 measurements per square • average sound level 68,88 ± 2,92 dB(A)

Sector 8

Number of measurements: 19
Average $L_{Aeq,1s}$: 73.58 dB(A)
Expected deviation: 3.91228
Standard deviation: 4.40096
Minimum $L_{Aeq,1s}$: 66.00 dB(A)
Maximum $L_{Aeq,1s}$: 80.00 dB(A)

wild mapping

What quality can we achieve with global participation, but without coordination?

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

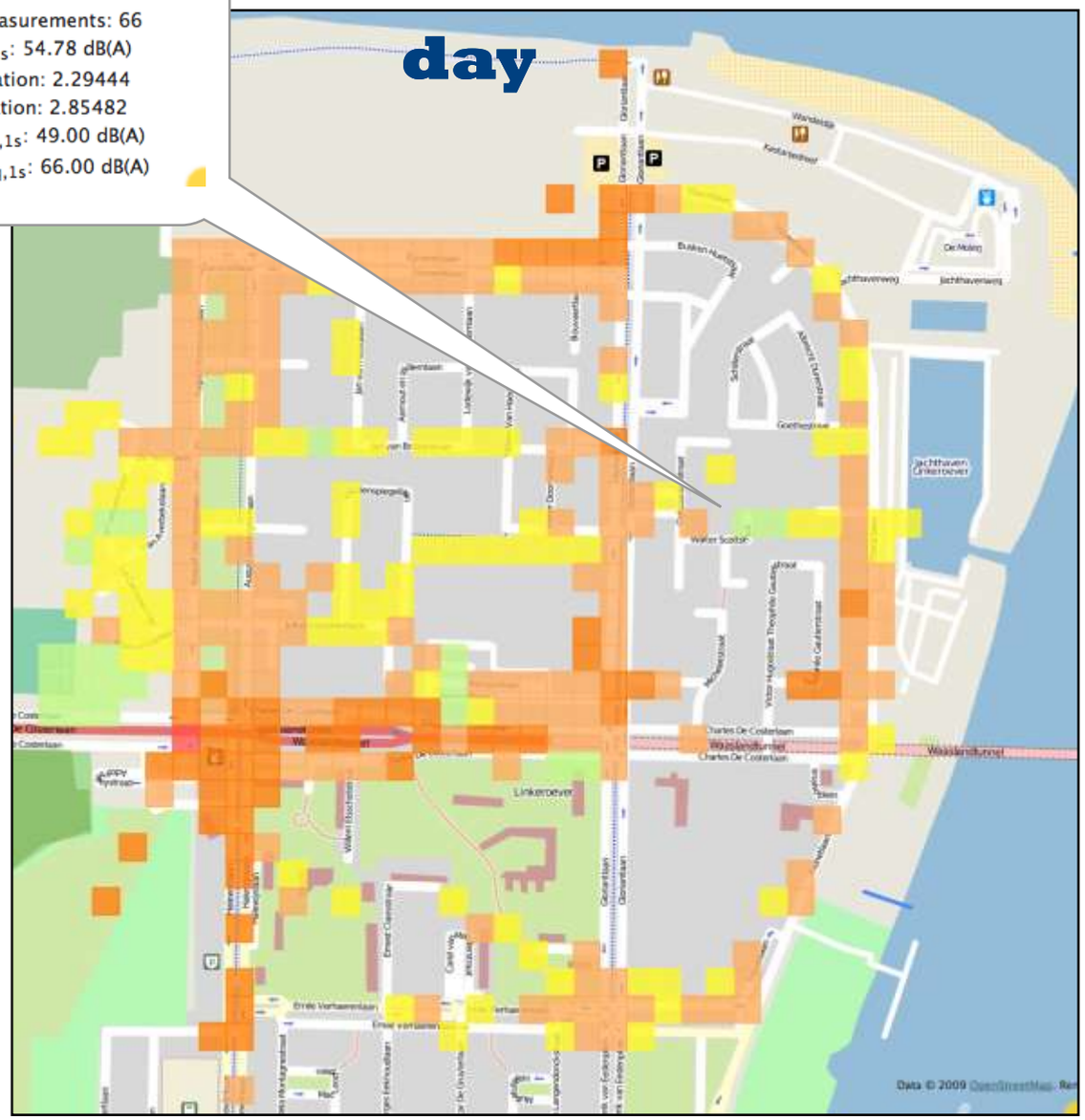
one track


Linkeroever
443 m
Image © 2010 DigitalGlobe
© 2010 Google
©2010 Google

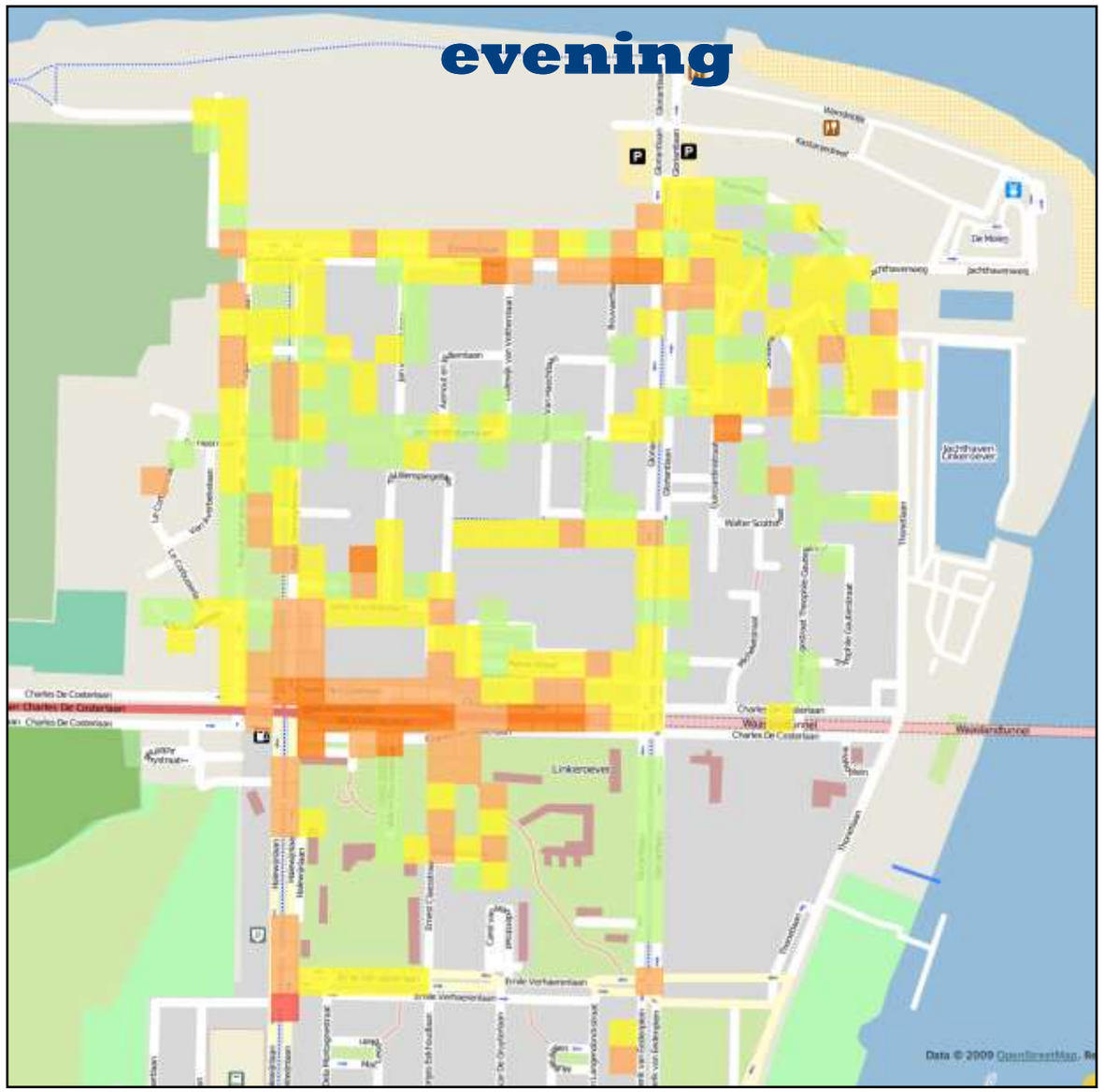
noise maps

Sector 118

Number of measurements: 66
Average $L_{Aeq,1s}$: 54.78 dB(A)
Expected deviation: 2.29444
Standard deviation: 2.85482
Minimum $L_{Aeq,1s}$: 49.00 dB(A)
Maximum $L_{Aeq,1s}$: 66.00 dB(A)



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)

extensions

version 2.0

calibration

NoiseTube

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

context-aware participatory sensing

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

environmental participatory sensing

Surround

NoiseTube

+

Development work carried out in the context of supervised Bachelor (1) & Master Thesis project (2).

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
24 > 30 janvier 2011

crosstalks

CIRB
CIBG

Leefmilieu Brussel
Bruxelles Environnement

3sat
ZDF ORF SRG ARD

MICT
UNIVERSITEIT GENT

vito
vision on technology

MRTE
Mobilités, réseaux, territoires et environnement

Stadspiratie
Congres Stedelijk Netwerken

Scholengroep Brussel
onderwijs van de Vlaamse Gemeenschap

IDEA
Intelligent Distributed Environmental Assessment

CITY BEAT

CeBIT

TEDx Brussels

UBICOMP2010

PERVASIVE 2011
San Francisco, CA, USA
June 12-15, 2011

overview

1. Sustainability in cities
2. Sound & noise
3. Noise maps today
4. Participative sensing & NoiseTube
5. Participative noise maps
6. **Next year’s developments**

I-SCOPE

interoperable Smart City services through an Open Platform for urban Ecosystems

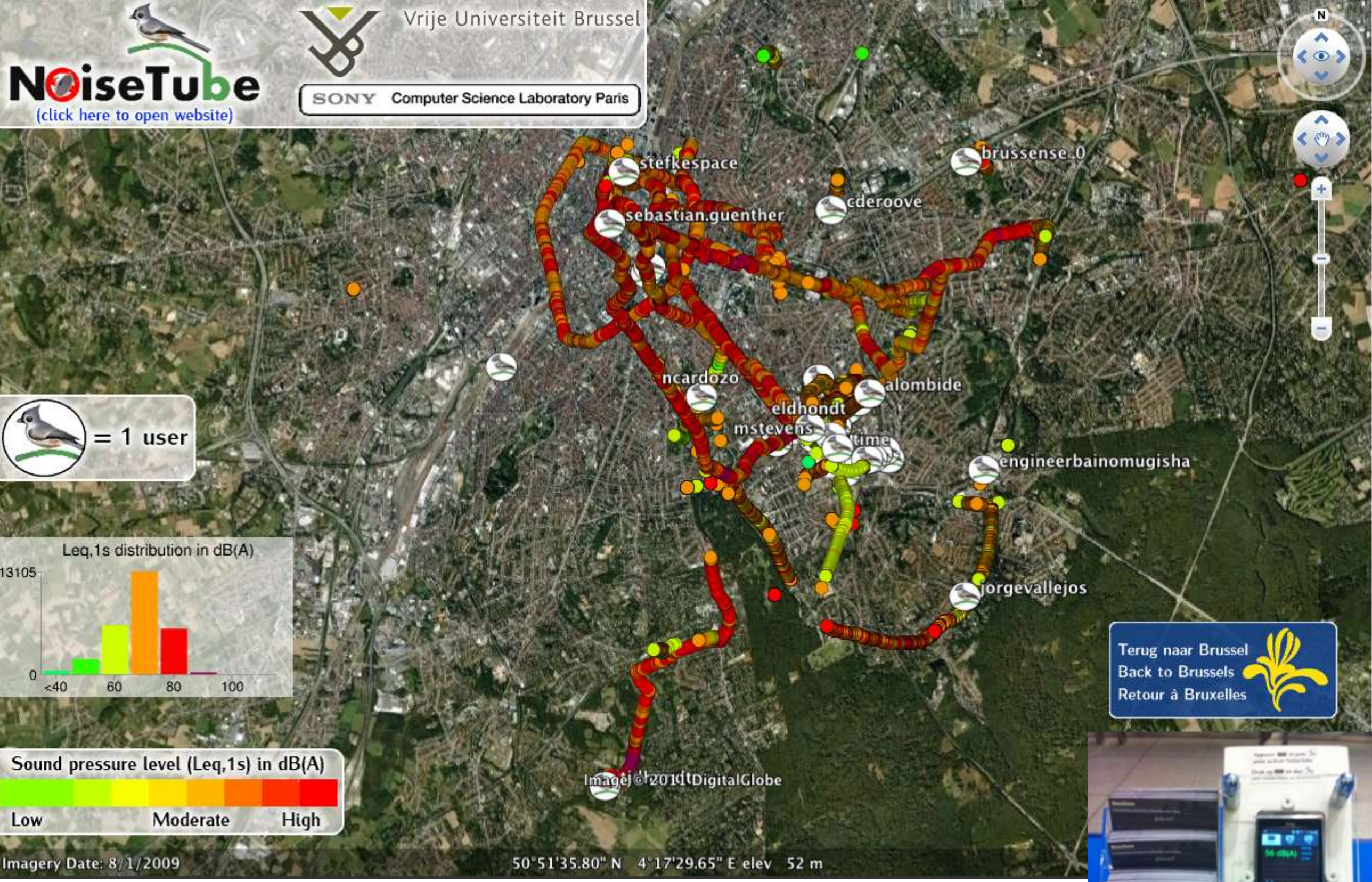
- policy support programme call for *Open Innovation for Internet-enabled services in smart cities*
- 23 partners: 12 city/region councils, 8 companies, 3 research institutes
- important step towards large-scale adoption

pilot locations

See http://www.iscopeproject.net/

in our planning

- substantial upgrade of web app to tackle efficiency & usability issues and conform to standards
- Participatory environmental mapping: campaign with 5-10 people & Body Area Network (BAN) setup focussing on noise, microclimate, and air pollution
- Facilitate community-driven participatory sensing through the website
  - community-building functionalities: geographical (neighbourhood concerns), through common interests (how do peak hours in different cities compare?) or task-oriented (your boss at city hall asks you to evaluate how street works affect the commune)
  - private or public campaigns
  - targeted data analysis



~~Exposition setup on a multitouch table & HTC Hero, gathering measurements in~~ Brussels for October. See http://bxl.noisetube.net/expo. At Brussel Innoveert!, Oct. 2011. 300000 shopping centre visitors, 772 student visits, 480 guided tour enrollments

BrusSense

Participatory sensing for sustainable urban living

Join us!!

Register at www.noisetube.net and download NoiseTube from the following locations:

Android: Market
Java ME: www.noisetube.net/downloads
iPhone: App Store as of Dec 1st

Contact us:

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