Perception and annoyance: application to transportation noise

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Introduction

- To the question during survey: “What do you think is the most worrying problem in your city?” People put noise first

54 % of inhabitants from cities of more than 50 000 inhabitants say that noise annoy them at home (INSEE, 2001)

- After air pollution, exposure to environmental noise constitutes the largest burden of disease in Europe (WHO, 2013)

Impact of noise on health

- Auditory effects of noise on health

 - on middle ear (stapedian muscle due to deflagration)

 - on inner ear (long exposure to noise higher than 80 dB(A))

- non auditory effects on health

due to hormones and corticoids (as in case of fear):

 - on cardiovascular system

 - on respiratory system

 - on digestive system

 - on endocrine system

 - on immune system

 - on sleep patterns

(*cf*. Marquis-Favre *et al.,* Acta Acust. united Acust. 2005)

Other direct non auditory effects:

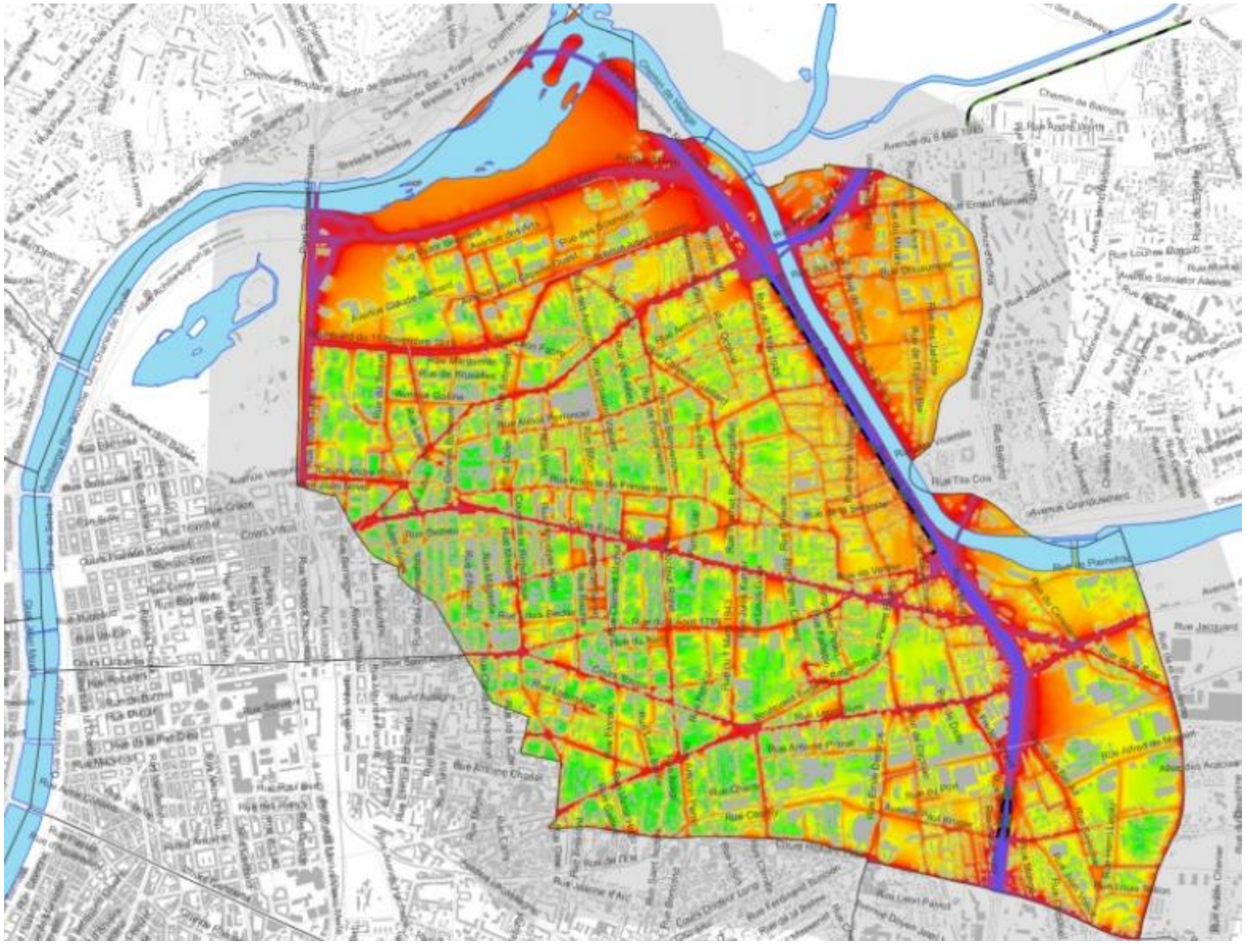
- on productivity, mental performance, vigilance
- Intellectual and emotional development of children
- annoyance

And non direct effects due to noise: medicine, decrease in price for landed properties and real estate, limited use of private space

➡ Five risks due to environmental noise: cardiovascular disease, cognitive impairment in children, sleep disturbance, tinnitus and annoyance (WHO, 2011).

- Strategic noise maps with L_{den} for European Union (E.U.)

European Guideline 2002/49/CE



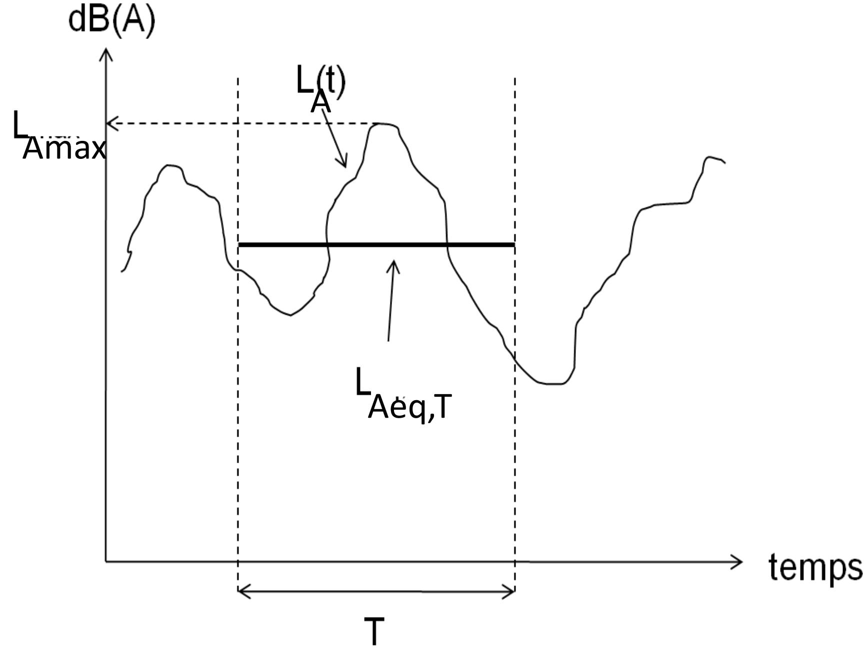
VILLEURBANNE (cf. http://bruit.grandlyon.com/)

L_{DEN} or L_{den} , *day-evening-night level*

$$L_{den} = 10 \log_{10} \frac{1}{24} \left[\int_{day=12H} 10^{L_A/10} dt + \int_{evening=4H} 10^{(L_A+5)/10} dt + \int_{night=8H} 10^{(L_A+10)/10} dt \right] \quad (dB(A))$$

Mean energy based index

constructed using the L_{Aeq} index



- E.U.'s dose-effect relationships = F(L_{den})

i.e. relationship between L_{den} and health impact due to noise

e.g. for sleep disturbance or annoyance

What is noise annoyance? How to assess it?

"Unpleasantness sensation due to an environmental factor that the individual knows has an impact on health" (WHO)
("*Sensation de désagrément provoquée par un facteur de l'environnement dont l'individu connaît le pouvoir d'affecter la santé*")

Health: "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (WHO)

Noise annoyance: **one of the most significant effects of noise on health for noise exposure with non critical values** (AFSSE's report, 2004)

Examples of noise annoyance assessment

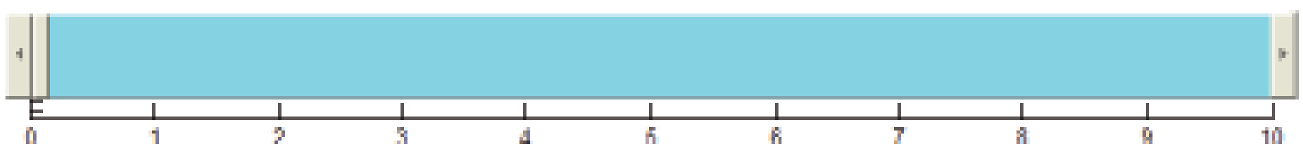
• *numerical ordinal scale*:

"Does the aircraft noise annoy you?"

1=Not at all; 2 ; 3 ; ... ; 7= extremely

• *continuous interval scale with numerical and verbal labels*:

"Does the tramway noise annoy you?" (Trollé *et al.*, AAA 2014)



Not at all Extremely

Since 2003, there has been an **ISO standard (ISO/TS 15666, 2003)** with common phrasing of questions and common rating scales for international comparisons

4 types of scales in psychophysics:

- nominal scale: categories of objects according to their identity, with no order (the lowest level of measurement)

- category scale (ordinal scale): order between objects

- interval scale: order and distance between objects

- ratio scale: order, distance properties and absolute zero

Scale type ➡ mathematical properties of the collected data

⬇

appropriate analysis technique

E.U.'s dose-effect relationships for annoyance

Single exposure annoyance model by (Miedema and Oudshoorn, 2001)

- For a participant i of a survey j:

$$A_{ij} = \beta_0 + \beta_1 \times L_{den} + u_{0j} + \epsilon_{ij}$$

- The percentages of people whose annoyance is greater than C:

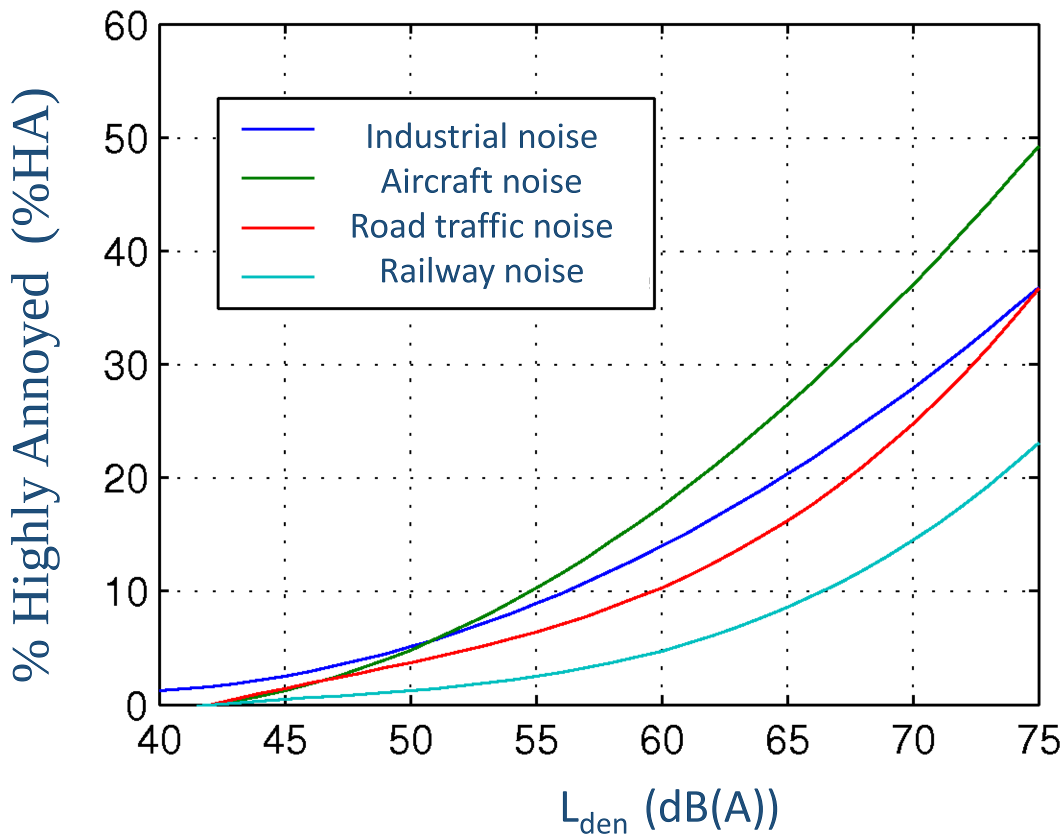
$$100.p_C(L_{\mathrm{den}}) = 100 \times \left(1 - \phi\left(\frac{C - \beta_0 - \beta_1 \times L_{\mathrm{den}}}{\sqrt{\sigma_0^2 + \sigma_e^2}}\right)\right)$$

with ϕ the cumulative standard normal distribution.

$\text{C} \geq 28: \textit{percentage of at least a little annoyed people } (\%\boldsymbol{LA})$

$\text{C} \geq 50: \textit{percentage of annoyed people } (\%\boldsymbol{A})$

$\text{C} \geq 72: \textit{percentage of highly annoyed people } (\%\boldsymbol{HA})$



Data from Miedema and Vos, JASA, 2004
Figure from Le Nost, 2007

Their testing using recent noise annoyance data

collected in France by Ecotière *et al*. (2014) according to ISO/TS 15666, 2003

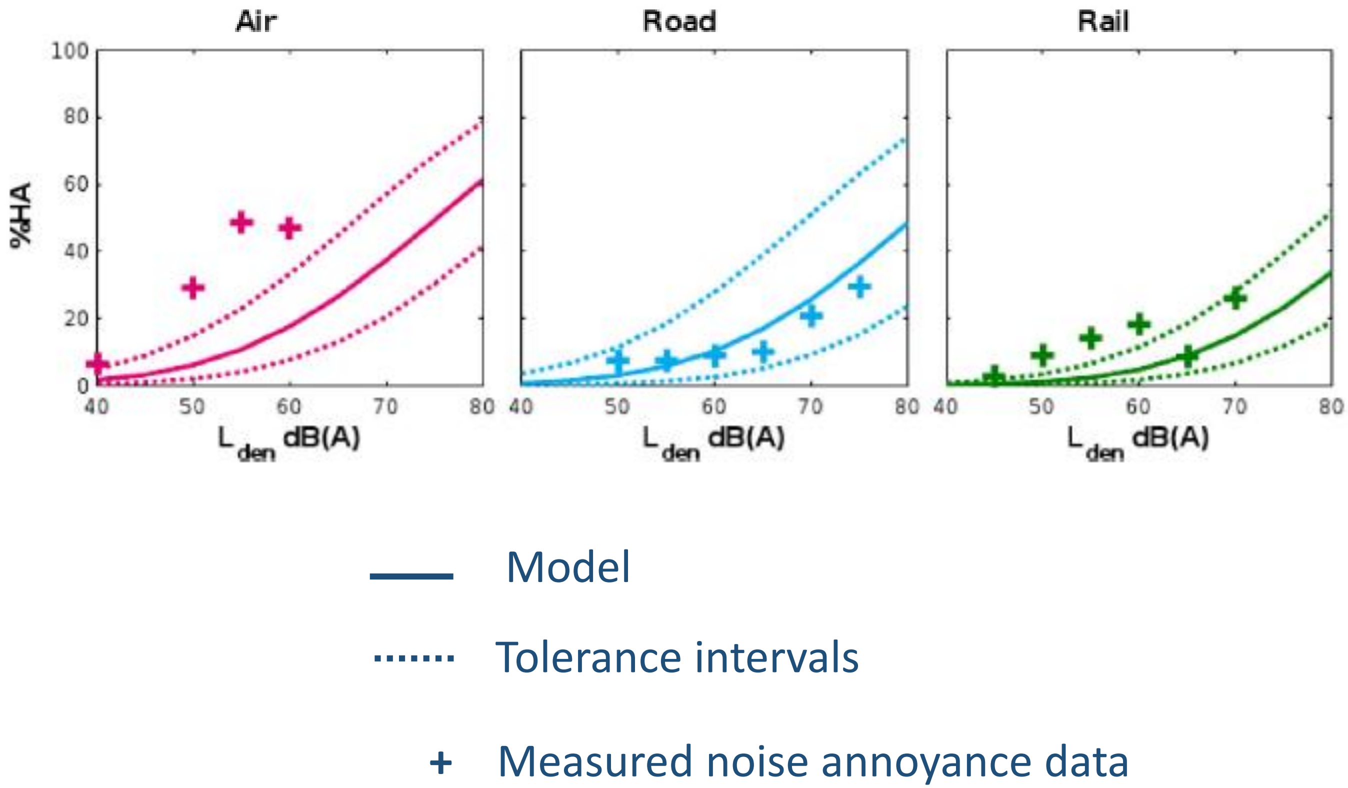
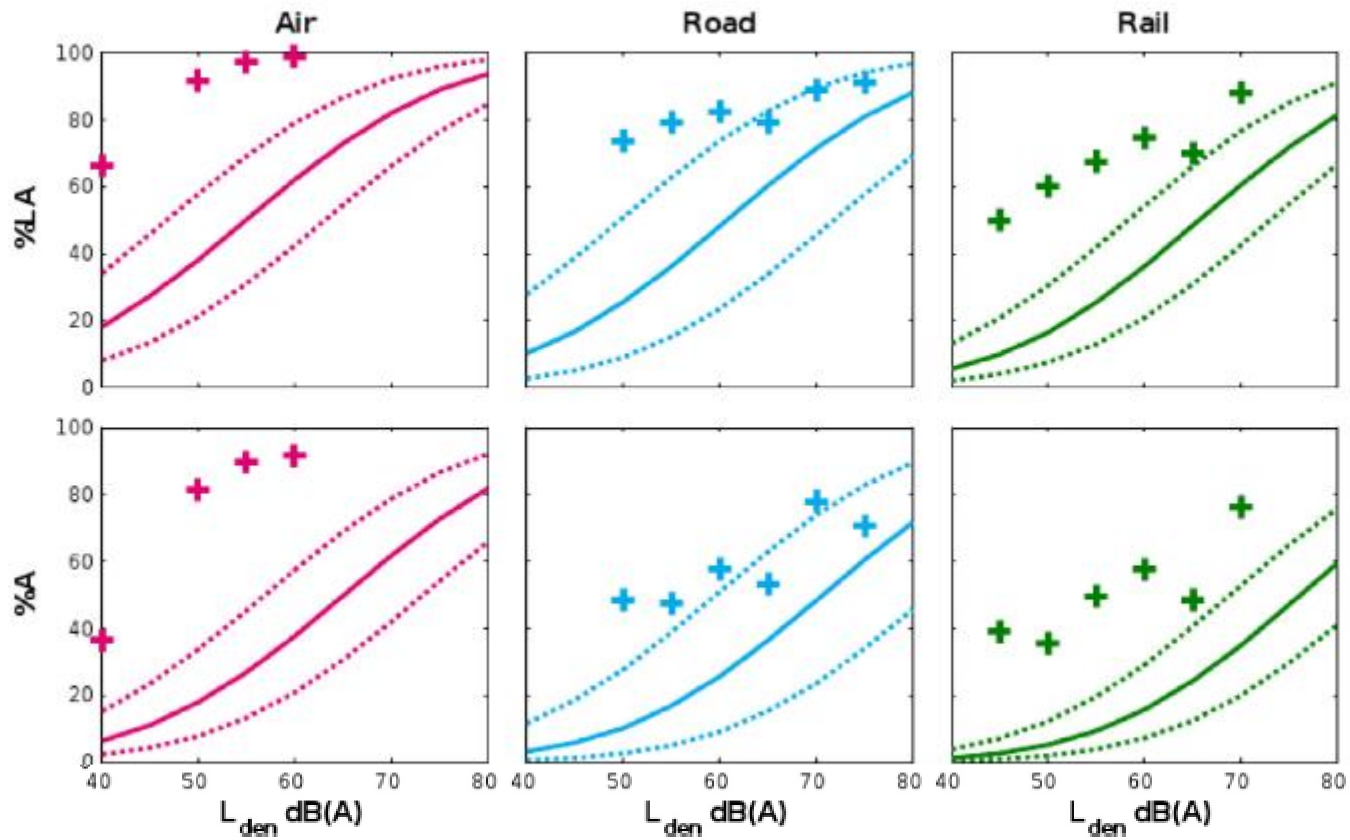


Figure from Gille *et al*., Environment International 2016



Cf. Gille *et al.*, Environment International 2016

Underestimation: *Cf.* also Klæboe *et al*. (AA, 2004) for road traffic in Norway
Lim *et al*. (JASA, 2006) for railway in Korea,
Lim *et al.* (JSV, 2007) for aircraft in Korea

Different reasons for this prediction quality:

- Models built from surveys published between 1965 and 1993 and based on different scales (3-pt to 11-pt scales) and indices (e.g. L_{dn} , L_{Aeq})

Thus

- Relationships need to be revised using recent surveys based on ISO 2003 and common indices

- L_{den}: often in question to characterize noise annoyance
- Mean acoustical energy, taken into account by energy-based index such as L_{Aeq} or L_{den}, only explains *30%* of annoyance variance
- They are the only indicators used nowadays…

- Various factors influence noise annoyance such as:
  - acoustical factors (*e.g*. spectral content, fluctuation, modulation)
  - non acoustical factors (*e.g*. noise sensitivity)

➡ Need to enhance noise annoyance indicators (*cf*. Grenelle de l'Environnement, 2007)

Main factors influencing annoyance

(*cf*. Job, JASA 1988; Marquis-Favre *et al*., Acta Acust. united Acust. 2005)

a) Acoustic factors

- *Mean sound intensity* (ex: L_{Aeq}): dominant acoustical factor
- *Spectral content*

e.g. tonal component

- *Temporal content*

e.g. irregular fluctuation

e.g. amplitude modulation

e.g. impulsiveness

b) Non acoustic factors

❖ Main attitude factors

- *Fear of danger*
- *Attitude of the person towards the sound source*
- ***Sensitivity to noise***

About 1/3 of people mention to be sensitive or very sensitive to noise (Öhrström *et al*., JSV 2006)

- *Activity during exposure*
- *Perception of neighbourhood* (ex: public services)
- *Global perception of environment* (ex: smell): notion of environmental load

❖Main socio-demographic and situational factors

- *Time spent at home* (ex: social isolation)
- *Exposure to noise at work* and its effect on annoyance felt at home (*sound exposure over time*)
- ***Sound proofing of windows***
- ***time of year or time of day***
- Controversial factors (*e.g. age, gender, education level)*

Other indices accounting for sound intensity

- L_{Amax}, $L_{Aeq,\,1s}$
- Statistical indices

  Examples : L_{10} , L_{50} , L_{90}

 sound pressure level exceeded 10%, 50 %, 90 % of the time

(*e.g.* Aumond *et al*. AAA, 2017)

- Loudness N : N_{mean}, N_5, etc.

They are well correlated with annoyance responses for different types of environmental noise

Indices accounting for spectral content

- **Sharpness S**

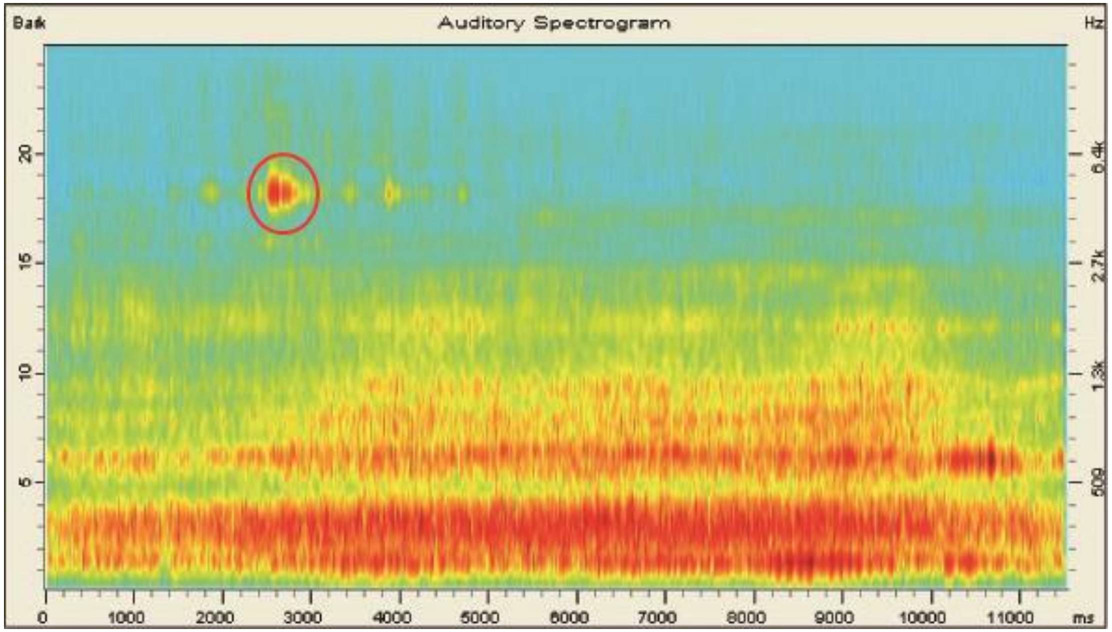
a measure of the high frequency content of a sound
Noise annoyance is felt for high frequency content noise

But sharpness is not correlated with annoyance responses due to various environmental transportation noises

Tramway noise

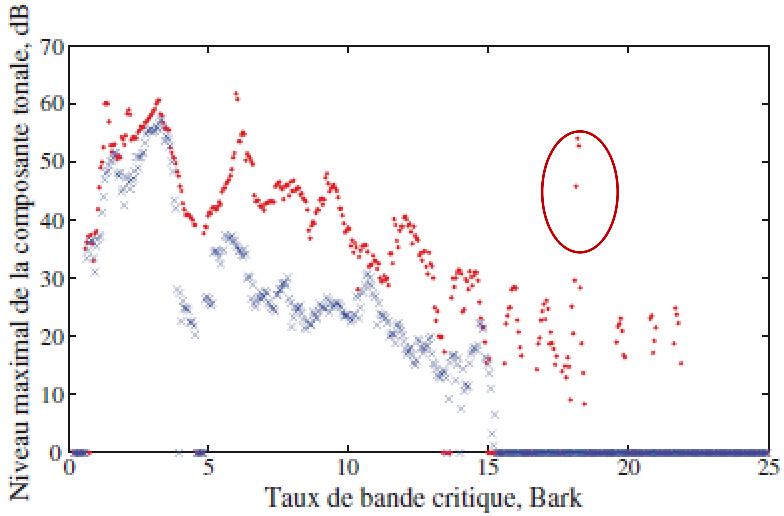
- Annoying tonal components: High Frequency (HF) content

  « squealing noise »



Cf. Trollé *et al.*, Acta Acust. Acust., 2014

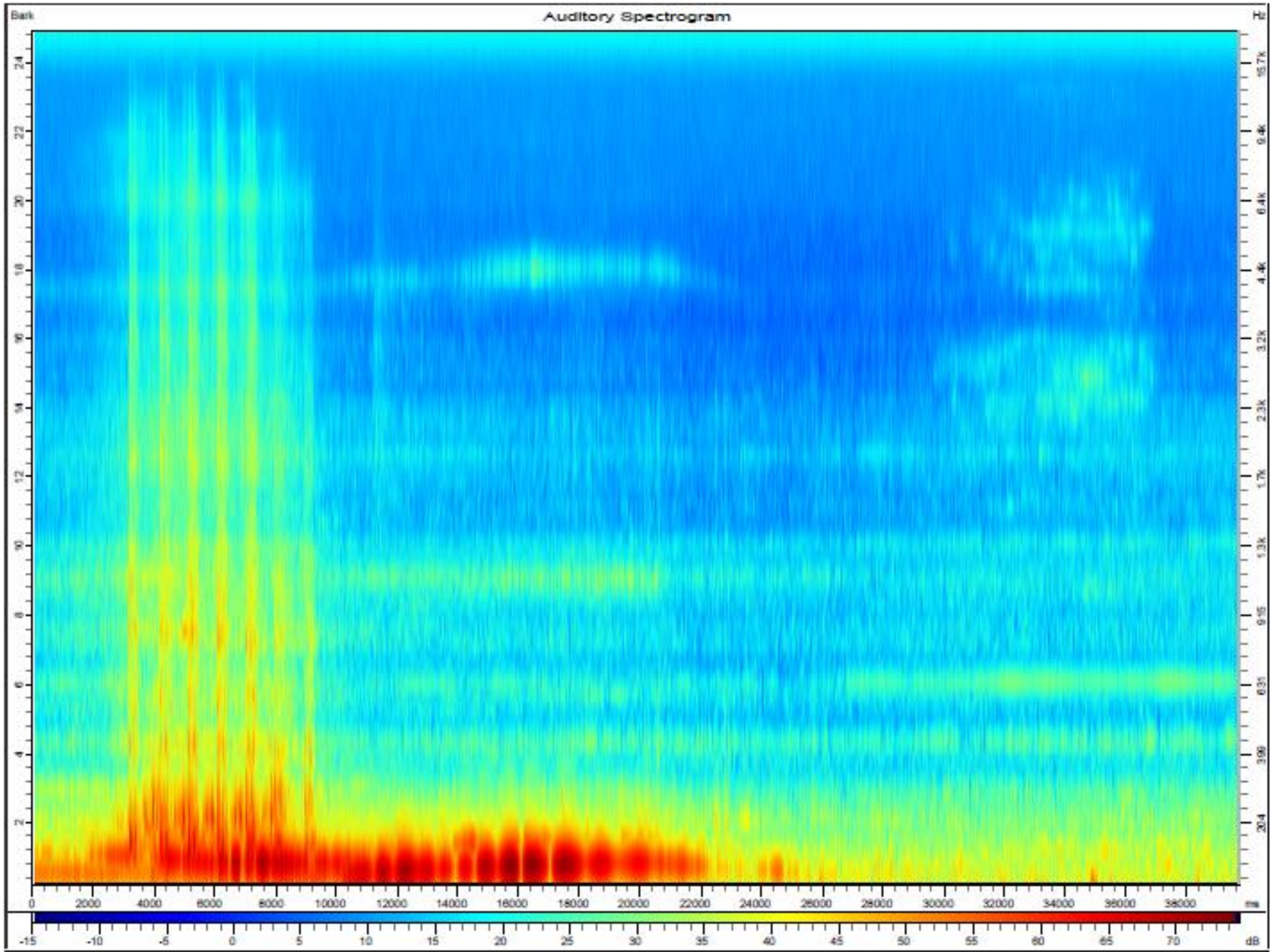
- Index accounting for high frequency tonal components



$$TETC = 10\log_{10}\left(\int_{11}^{24} 10^{\frac{L(z)}{10}}\,dz\right)$$

***Correlation between TETC and annoyance: r* = 0.83, *p* < .001**

Cf. Trollé *et al.*, Acta Acust. Acust., 2014



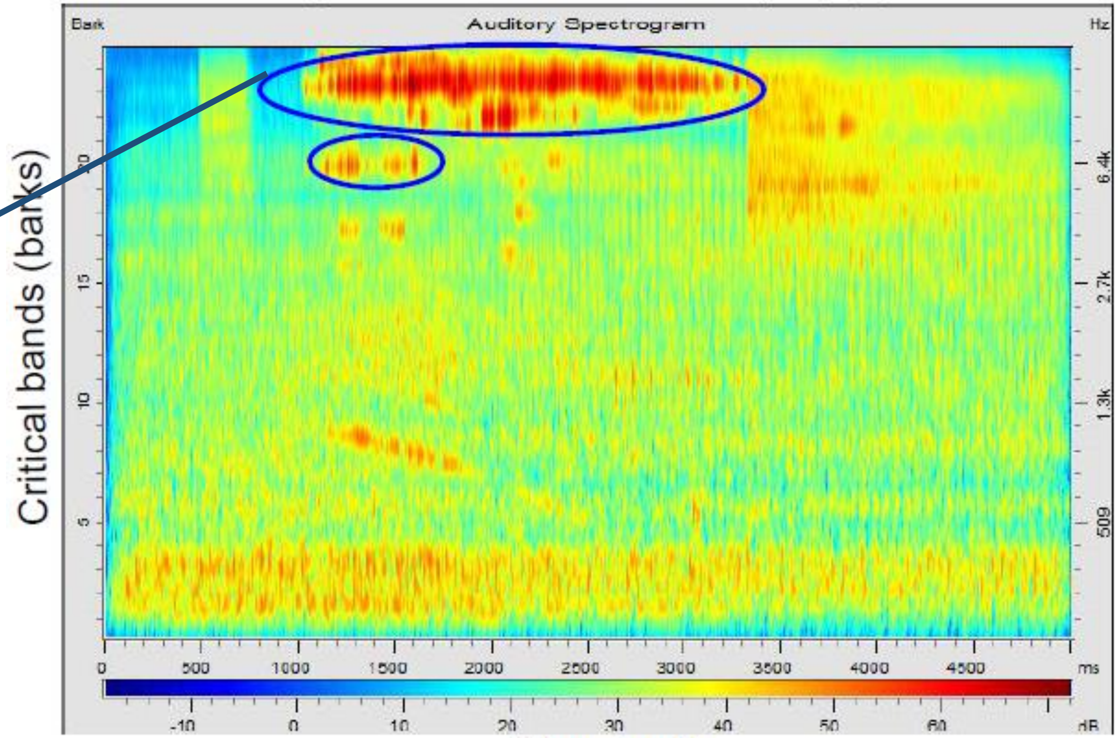
Spectrogram of the train noise N°5 with high frequency content

Cf. Marquis-Favre *et al*., Euronoise, 2018

Breaking noise due to urban road vehicles

Index TETC

Auditory spectrogram of heavy vehicle in deceleration (pdo_6)



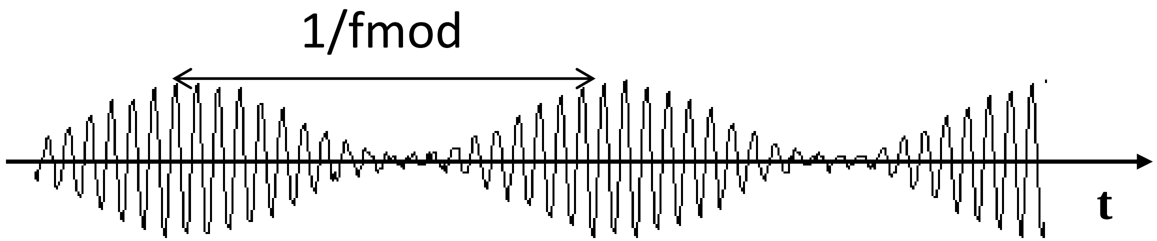
rank correlation coefficients ([a]$p < 0.001$)

	$TETC$	S_{mean}
"annoying"	**0.78**[a]	0.40

Cf. Klein *et al*. (JASA, 2015)

Indices accounting for modulation sensation

Modulated noise



• **Roughness** (*Rugosité)*, in asper, maximum value of the index at 70Hz,
quantifies sensation of rapid amplitude modulation (15-300 Hz)

• **fluctuation strength** *(force de fluctuation*) in vacil, maximum value of the index at 4Hz,
sensation at very low modulation frequencies (<15Hz)

Cf. Zwicker and Fastl (1999)

But they may be not adapted to environmental modulated noises

- **Example for urban road vehicle noises**

"Sputtering"

motorcycle in acceleration (dau_5)

low-frequency modulation

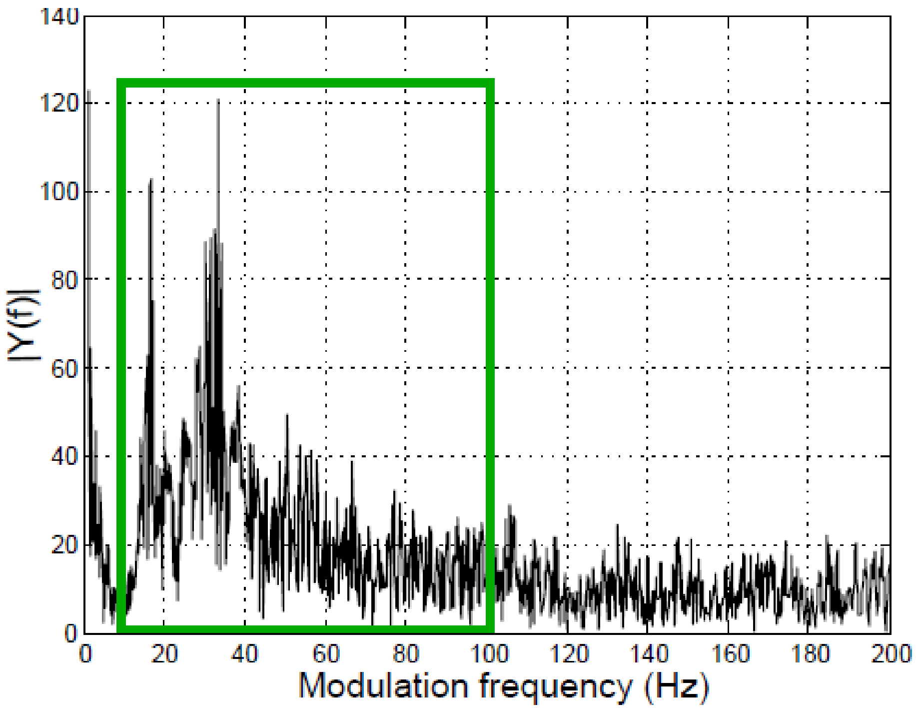
"Nasal"

Scooter in acceleration (dao_2)

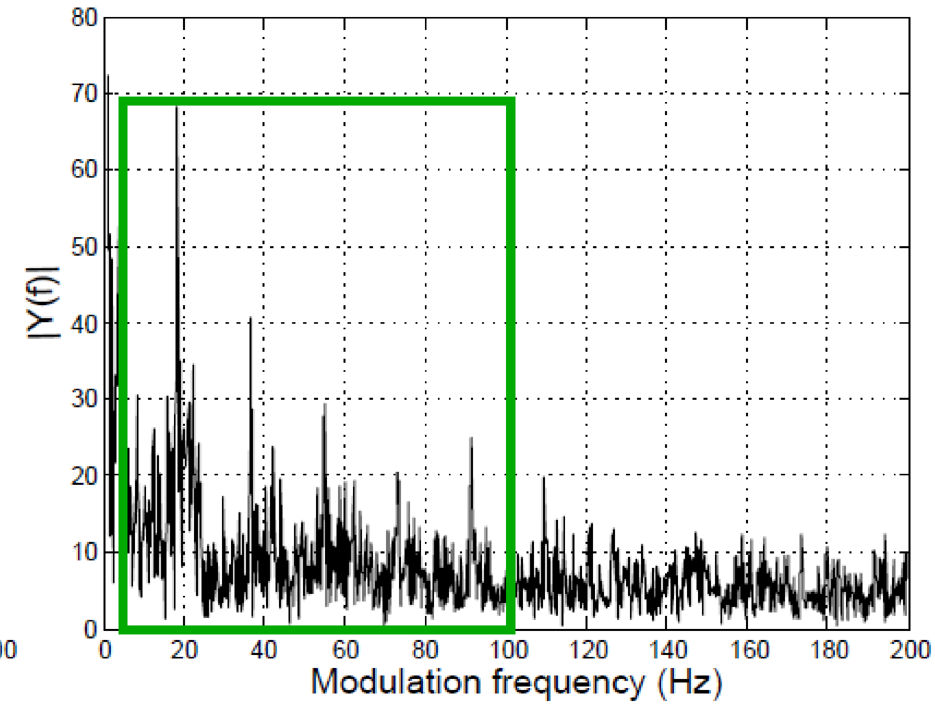
high-frequency modulation

Modulation spectrum: Hilbert transform on the signal then Fourier transform

- Modulation spectrum of two sputtering pass-by noises:



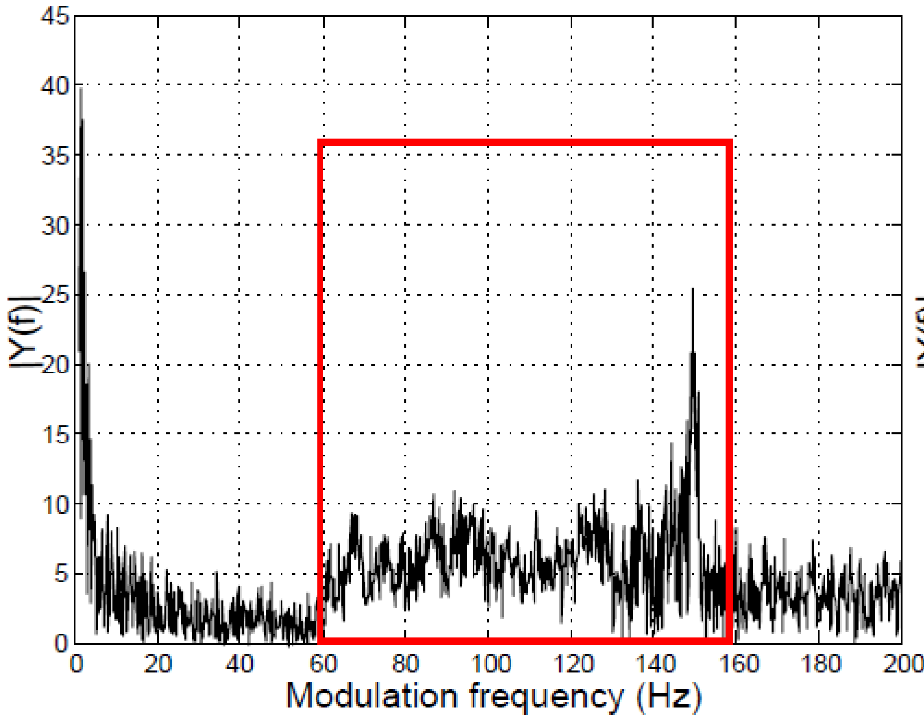
motorcycle in acceleration



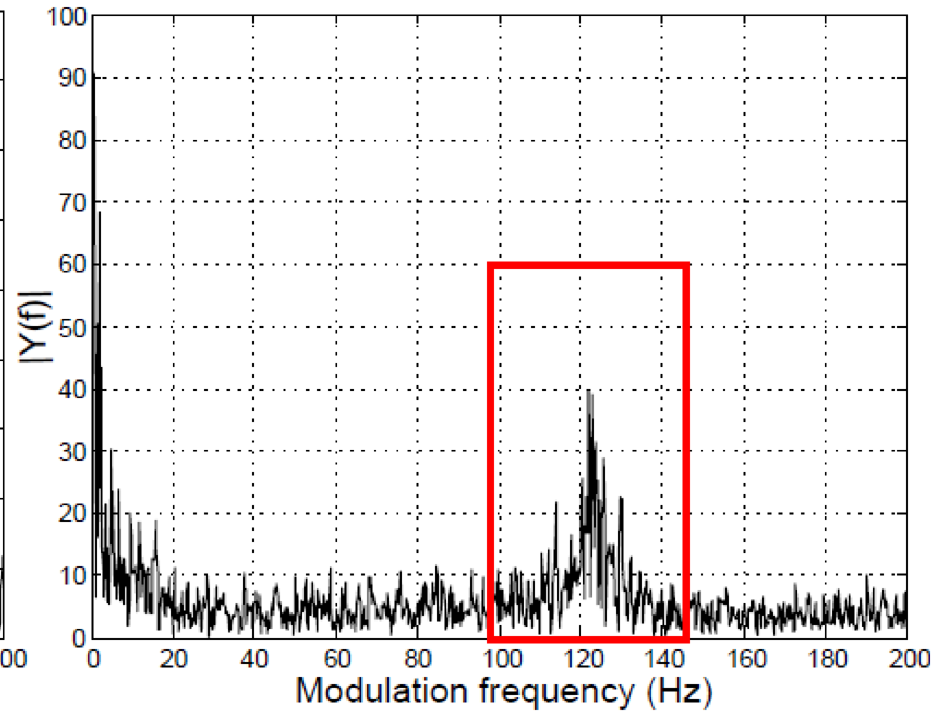
heavy vehicle in deceleration

Cf. Klein *et al*. (JASA, 2015)

- Modulation spectrum of two nasal pass-by noises:



scooter in acceleration



scooter at constant speed

Cf. Klein *et al*. (JASA, 2015)

psychoacoustical indices for modulation sensations:

Roughness (R), Fluctuation strength (F)

Spearman's rank correlation coefficients

($^*p < 0.001$, $^b p < 0.01$, $^c p < 0.05$)

	R_{max}	R_{mean}	R_{10}	F_{max}	F_{mean}	F_{10}
"sputtering" (median)	0.27	0.45	0.27	**0.63^c**	0.41^c	0.61^*
"nasal" (median)	-0.3	-0.22	-0.21	0.71^b	0.66^c	**0.77^b**
"annoying" (median)	0.04	0.22	0.07	0.46	0.25	0.50

!!!

➡ **Physical & perceptual relevance of good significant correlation has to be verified!**

Cf. Klein *et al*. (JASA, 2015)

Roughness (R) and Fluctuation strength (F) are calculated from loudness.

They can be correlated with noise annoyance only due to the loudness correlation with annoyance

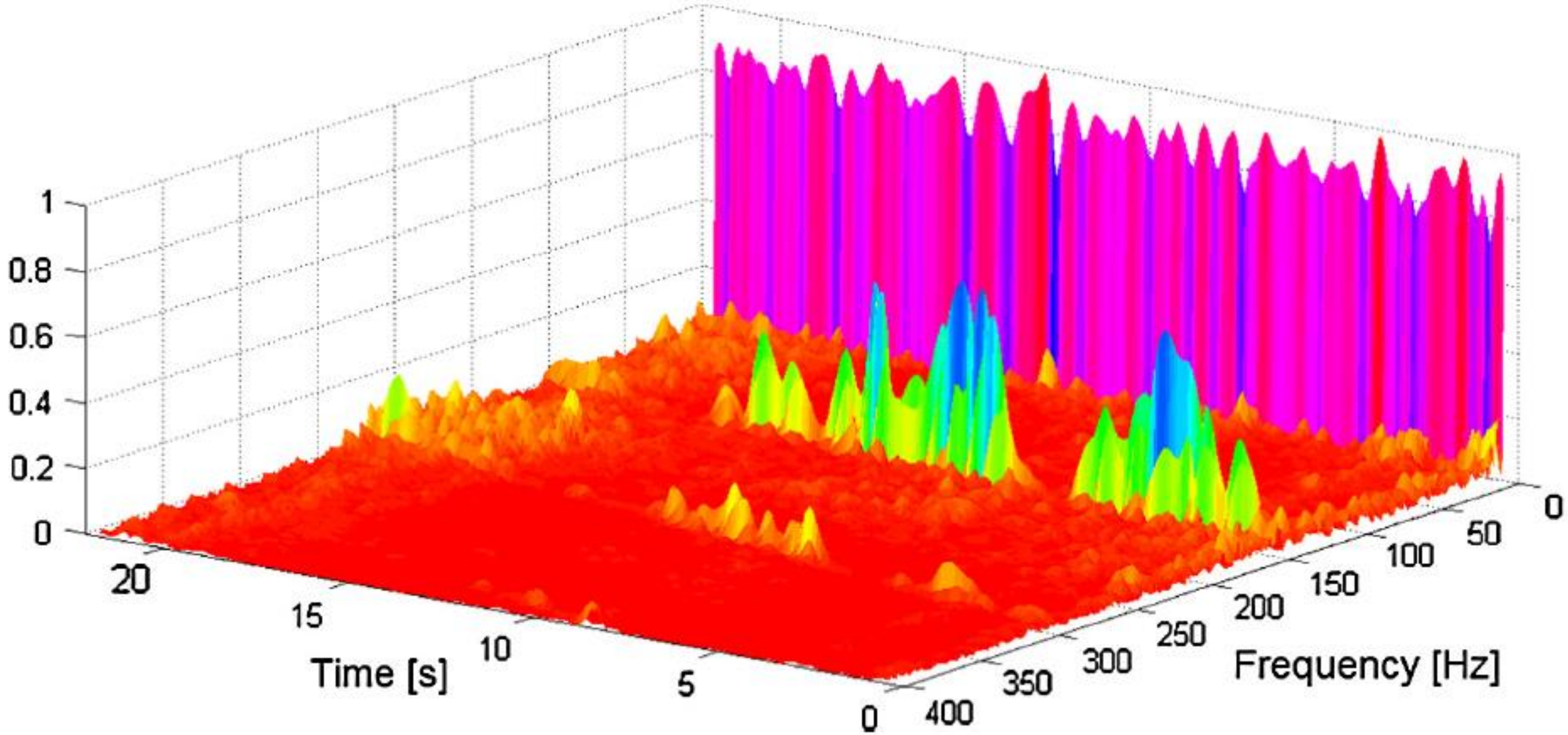
- **Example for aircraft noise**

Correlation with annoyance ratings:

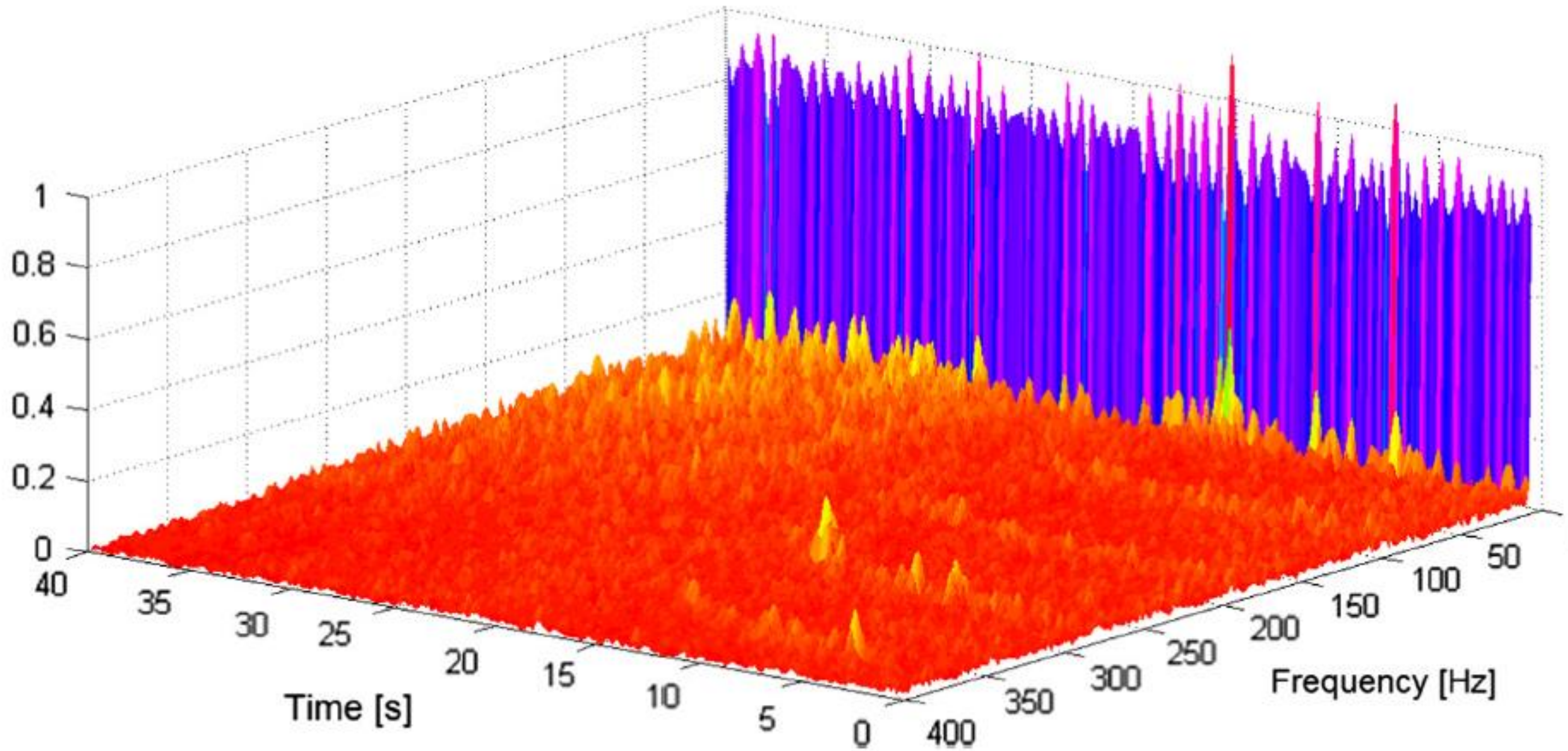
r ($^{a}p < 0.001$, $^{c}p < 0.05$)

N_{1-12}	S
0.88^{a}	0.30
R	F
0.96^{a}	0.66^{c}

(*cf*. Gille *et al*., Applied Acoustics, 2017)



Modulation spectrogram for one of the least annoying aircraft noises of the experiment
(*cf*. Gille *et al*., Applied Acoustics, 2017)



Modulation spectrogram for one of the most annoying aircraft noises of the experiment (*cf*. Gille *et al*., Applied Acoustics, 2017)

Conclusion and future research works

More efforts have to be made :

- to improve both acoustical and psychoacoustical indices to better account for annoying sensations caused by environmental/transportation noises
- To better predict noise annoyance
- To link this prediction with noise maps as a tool for urban planners