Uncertainties and variability

Celya Summer School 'Atmospheric sound propagation'

14-06-2018

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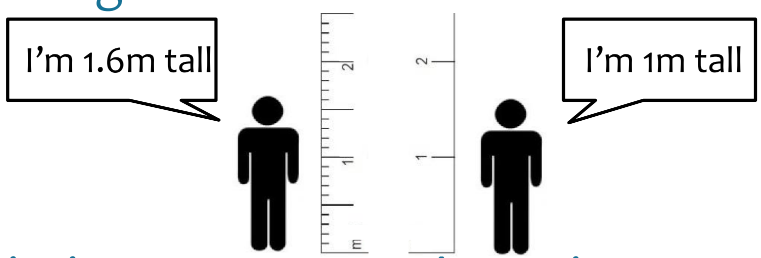
UMRAE

Introduction

- **A start with a few truisms** **(… but not always considered as such)**

  - It is impossible to measure (or predict) EXACTLY a physical quantity (even if you are Nobel prize in metrology)

  - A measurement result given without its associated uncertainty should make no sense



Who is right ?

Both !

  - Several dB uncertainties are common in environmental acoustics (depending on the quantity observed)

Introduction

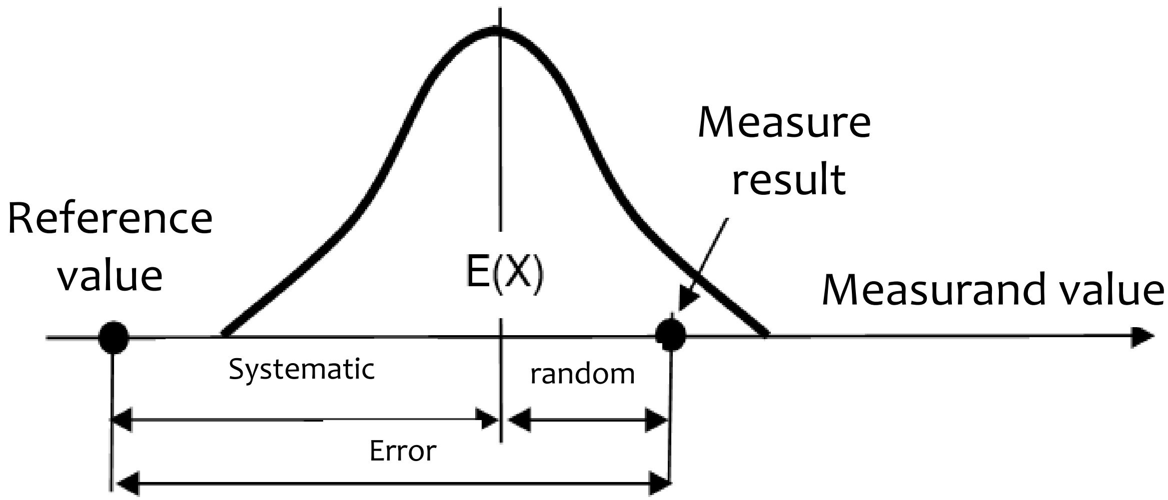
- **Uncertainties : where are they come from?**

  - Epistemic uncertainties : unknown (or bad known) parameters
  - Model limitations, measuring instrument uncertainties, methodology uncertainty …
  - ‘Natural’ variability of the observed quantity, sampling uncertainty

Introduction

○ Uncertainties : what is it ?

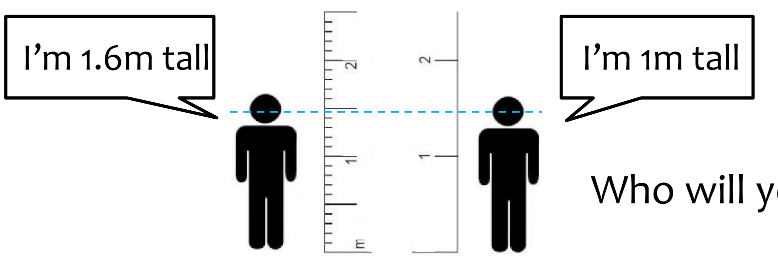
- Measurement (or prediction) -> measurement (or prediction) error



Introduction

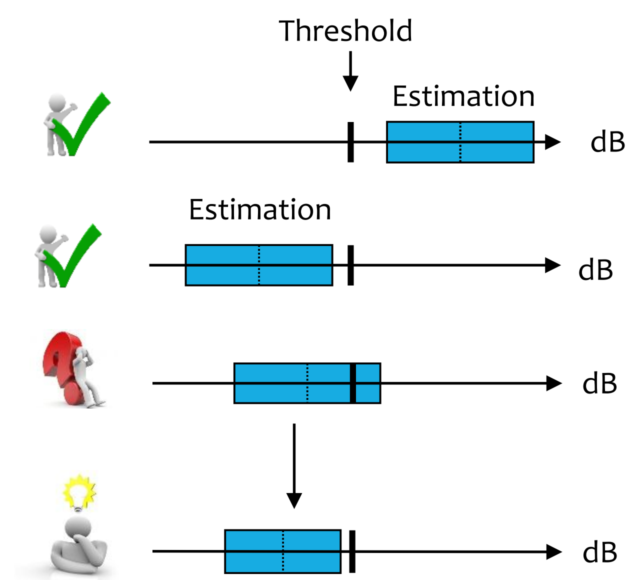
- **Uncertainties: what do I do with them? what do I need it for?**

  - Uncertainty information = information on the quality of its measurement/calculation against a defined requirement



Who will you trust in ?

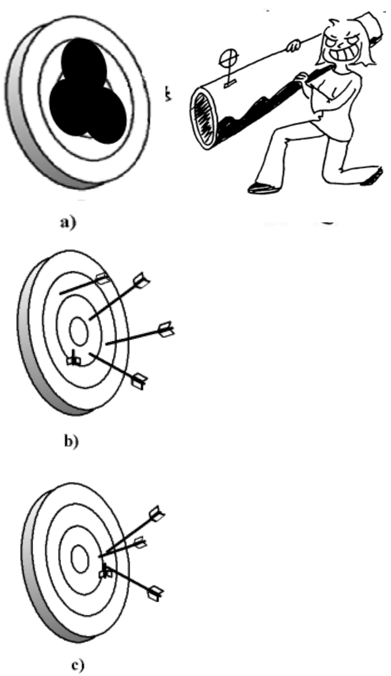
  - Comparison to a threshold

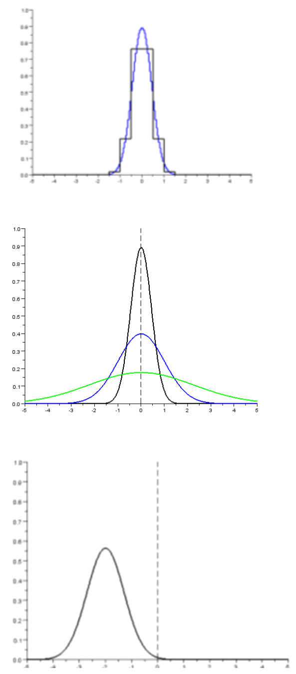


Introduction

○ Several kinds of uncertainties

- Accuracy
  - *e.g. d*ue to the instrument resolution
- Dispersion
- Systematic error (trueness)





-> Uncertainty is a combination of all of these

Methodology

- **Roadmap**

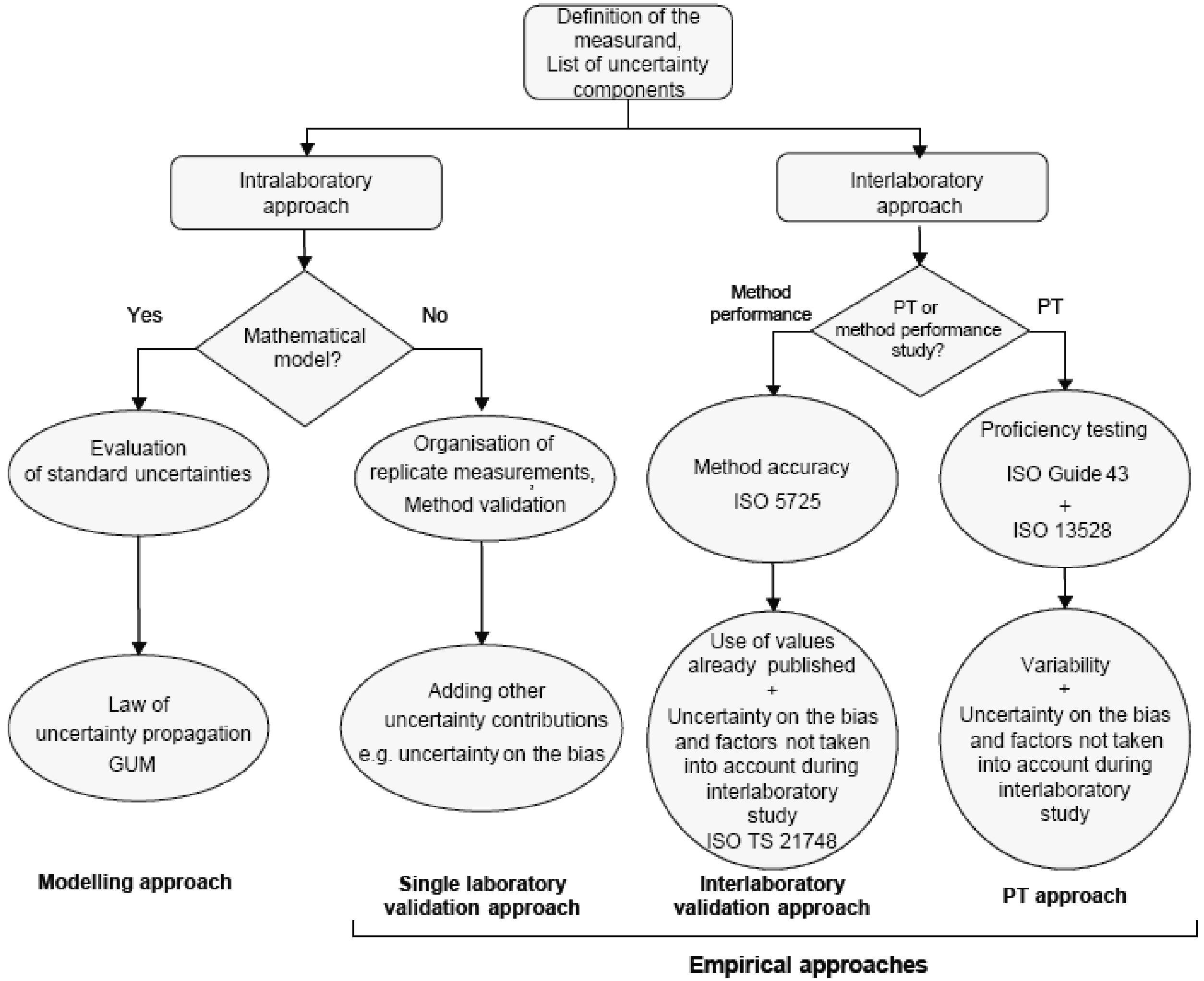
  - Define precisely the quantity of interest

  - Investigate the measurement process to identify the possible causes of error (if possible)

  - Choose a method for estimating standard uncertainties :
    - Depending on the knowledge we have of the measurement process
    - Depending on the possibility to model the process
    - Depending on whether the measurement process can be repeated easily or not

  - Calculate the expanded uncertainty and a confidence interval

Methodology

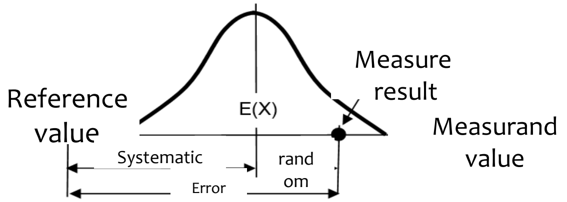


[Désenfant, Priel, A road map for uncertainty estimation approaches, 2006]

Methodology

- Bias, expanded standard uncertainty, confidence interval

  - Result:



$$L_c = L_{mes} - b$$

in the x% confidence interval: $[L_C - U_{\min} \; ; L_C + U_{\max} \;]$

- b : bias (systematic error)
- U_{min} et U_{max} : expanded standard uncertainty

$$u_{\min} = t_{\min} u$$

$$u_{\max} = t_{\max} u$$

-- u : standard uncertainty (standard deviation)

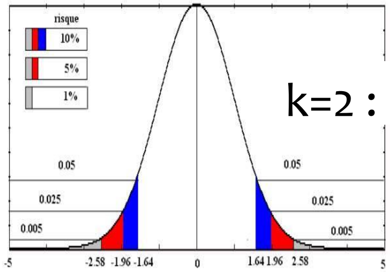


Figure 10.5 : densité de la loi normale et valeurs critiques.

k=2 : IC 95%

Methods : GUM

- **GUM method (ISO/CEI Guide 98-3) – analytical approach (errors propagation law)**
  - An analytical model is required: $Y = f(X_1, X_2, ..., X_N)$
    - Estimations: $y = f(x_1, x_2, ..., x_N)$
    - Combined uncertainty: $u^2 = \sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i} \right)^2 \sigma_{x_i}^2 + 2 \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \left(\frac{\partial f}{\partial x_i} \right) \left(\frac{\partial f}{\partial x_j} \right) \sigma_{x_i, x_j}$
    - If influence quantities Xi are not correlated: $u^2 = \sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i} \right)^2 \sigma_{x_i}^2$

Methods : GUM

- In France : new standard XP S 31-115 (GUM compliant)

- General process

  a) identification of influence quantities
  b) bias induced by each influence quantity
  c) standard uncertainty induced by each influence quantity
  d) calculation of combined uncertainty and total bias
  e) calculation of the expanded uncertainty and confidence interval
  f) presentation of the measurement result and uncertainty information

Methods : GUM

- a) Main influence quantities

Instrumentation	Implementation and environmental conditions
- Microphone Directivity - Linearity of levels - Frequency weighting and frequency linearity (A, C, Z) - Air temperature and humidity - Ambient air pressure - Field standard level - Wind screen - Power supply - Proper noise of the instrumentation - Time Weighting (F, S, I)	- Duration of measurement; - Post-treatment ; - Local weather conditions at the microphone (wind, rain,…) ; - Electromagnetic fields outside the acoustic measuring device

Methods : GUM

- b) and c) bias and standard uncertainty of each influence quantity
  - Standard uncertainty estimated by standard deviation

- (d) total bias and combined uncertainty
  - Total Bias : $b = \sum_i b_i$

    -> biases can compensate each other (and the total bias can be null)

  - Combined uncertainty (decorrelated quantities) : $u_C = \sqrt{\sum_i u_i^2}$

    -> standard uncertainties do not compensate each other (the composed standard uncertainty cannot be zero)

Methods : GUM

- e) Expanded uncertainty and confidence level

  - Expanded uncertainty

$$U = k.u_C(y)$$

k=coverage factor (depend on the confidence level)

  - Confidence interval

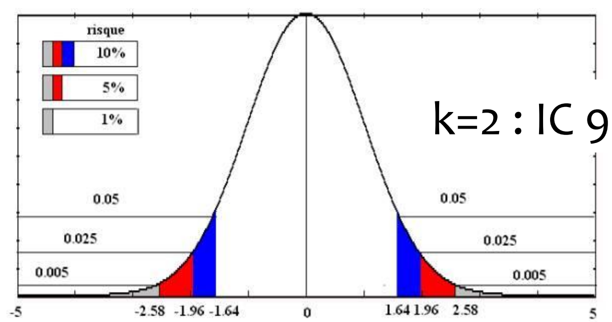


Figure 10.5 : densité de la loi normale et valeurs critiques.

k=2 : IC 95%

Methods : GUM

- Values for standard uncertainties

  - Standard values (overestimation)
    - Standard (ISO/CEI 61672 for ex.)
    - Technical spec., publications

  - Specific value
    - Estimated by the user

Methods : GUM

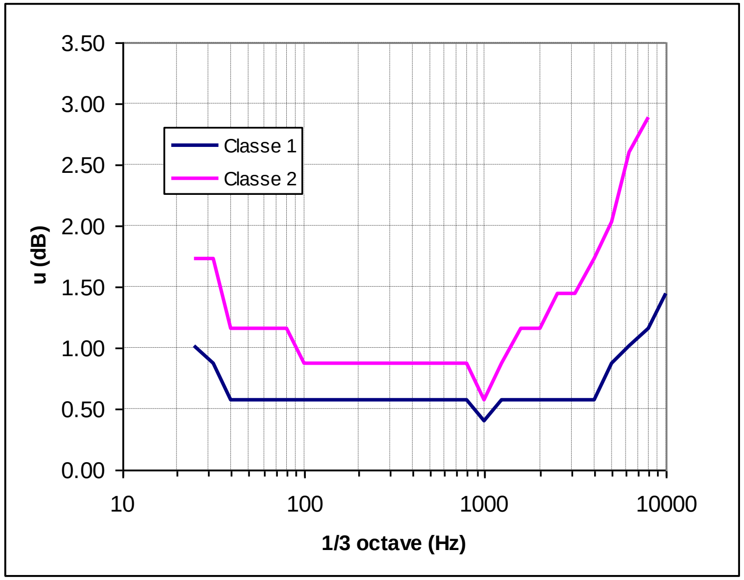
- Ex : from NF EN 61672-1 (sound level meter spec.) for class I

Influence quantity		u (dB)
Level linearity error		0.46
Supply voltage		0.06
Static air pressure	85 kPa à 108 kPa	0.23
	65 kPa à 85 kPa	0.52
Air temperature	-10 à + 50°C	0.28
	0 à + 40°C	-
Air humidity	20% à 90%	0.28
Electromagnetic fields		0.57
Calibrator		0.17
Wind screen	63 Hz à 2 kHz	0.28
	2 kHz à 8 kHz	0.46
Time weighting F and S		0.06
Leq measurement		0.06
Rounding of the measurement		0.03
Adjustment		0.01
Measurement of C-weighted peak sound pressure levels		1.15

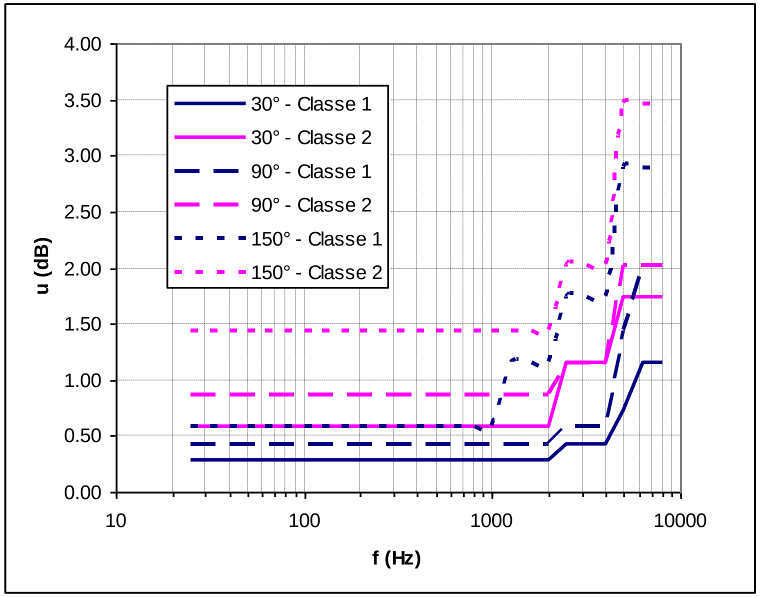
Methods : GUM

- Ex : from NF EN 61672-1 (sound level meter spec.)

‘A’ frequency weighting

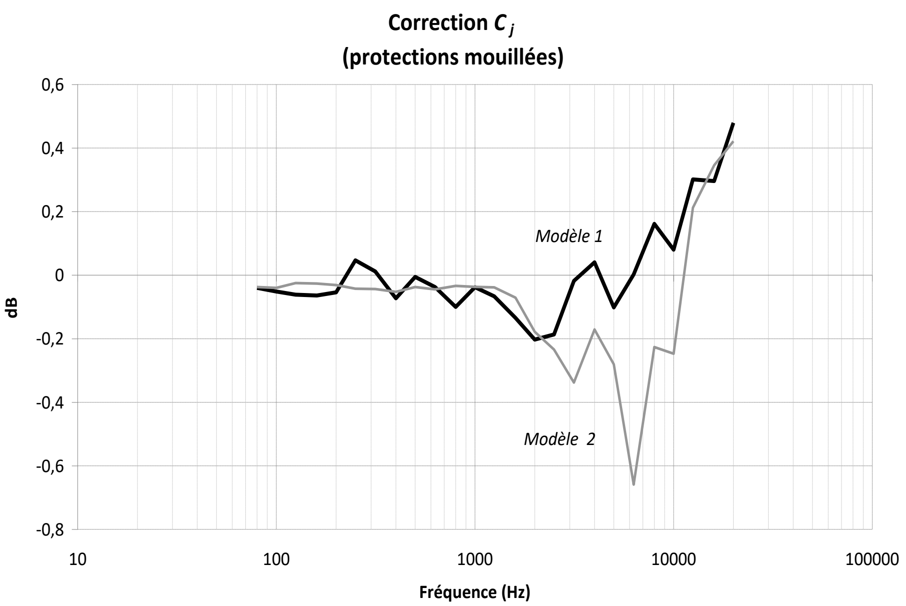


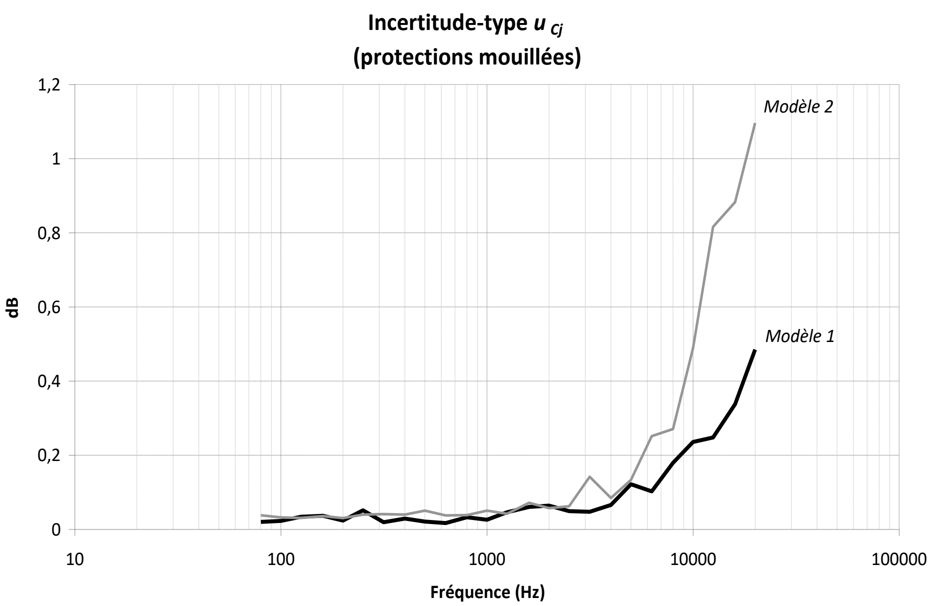
Microphone directivity



Methods : GUM

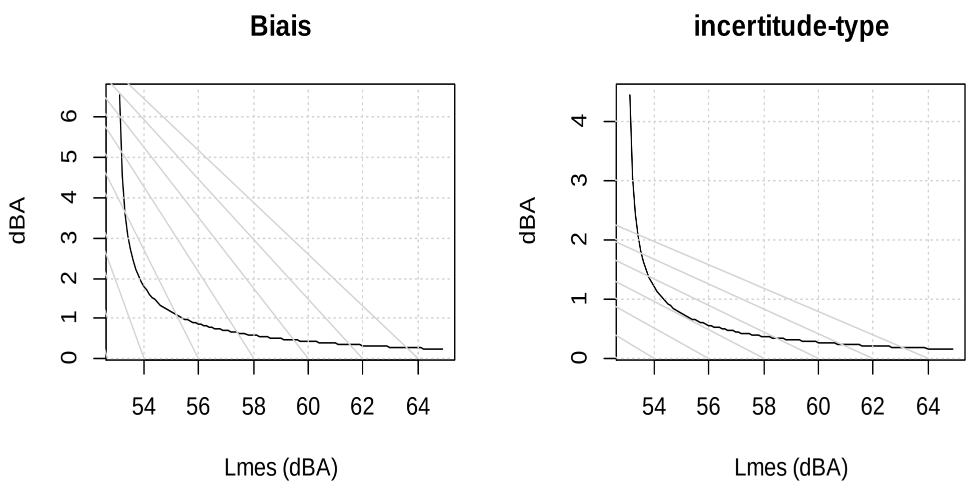
- Wet wind screen [Ribeiro, Ecotière *et al*, 2014] [XP S 31-115]





Methods : GUM

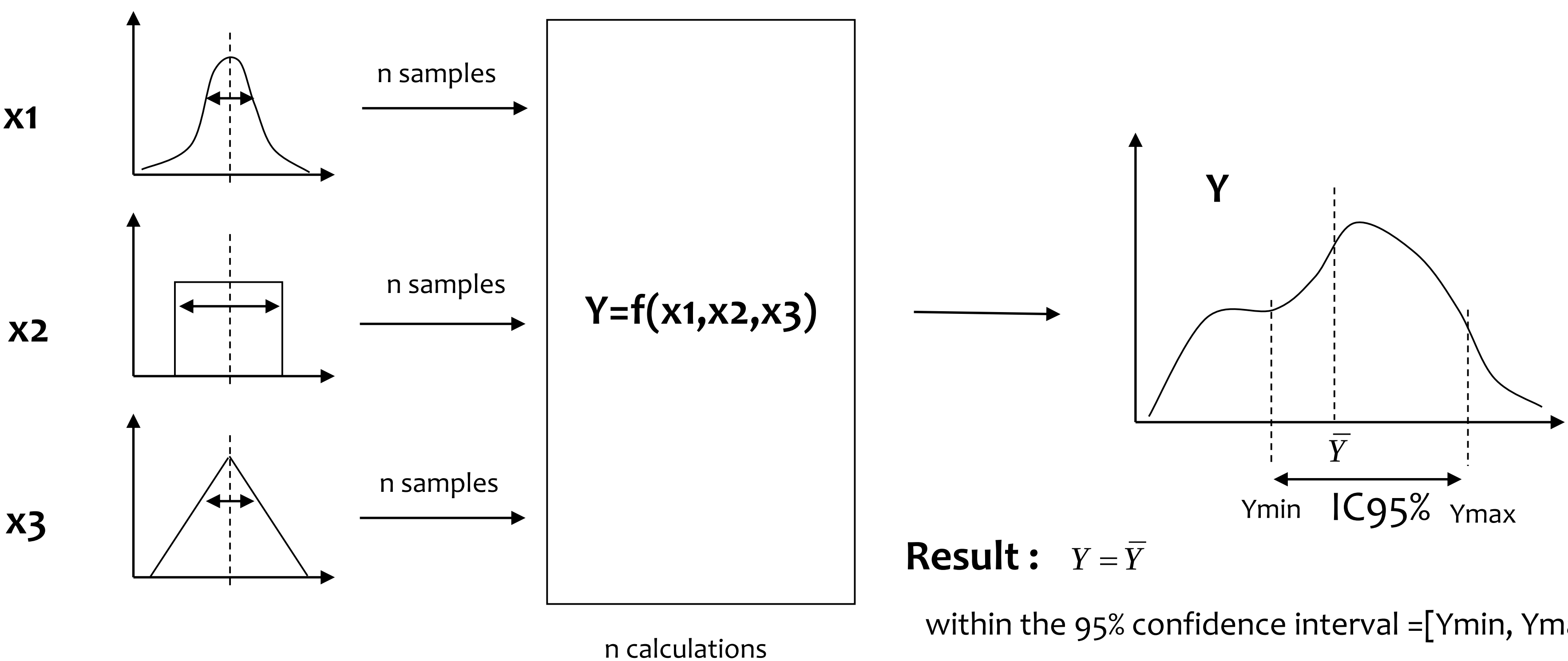
- Wind induced noise [Ecotière, Rumeau *et al.* 2012, 2018] [XP S 31-115]
  - Bias : $$b_{wid} = a_{b,1} + \frac{a_{b,2}}{\sqrt{L_{mes} - L_0}}$$
  - Standard uncertainty : $$u_{wind} = \sqrt{\left(a_{u,1} + \frac{a_{u,2}}{\sqrt{L_{mes} - L_0}}\right)^2 + u_{wind,mod}^2}$$



Ex : wind speed 5/m/s, microphone height 1.5m.

Methods : GUM

- **GUM method (ISO/CEI Guide 98-3) – stochastic approach (distributions propagation, Monte Carlo)**

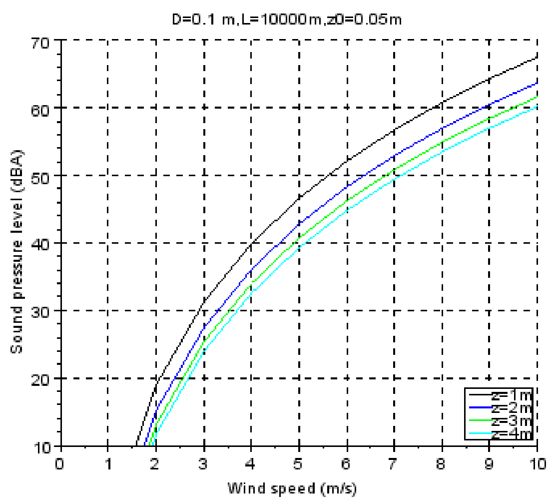


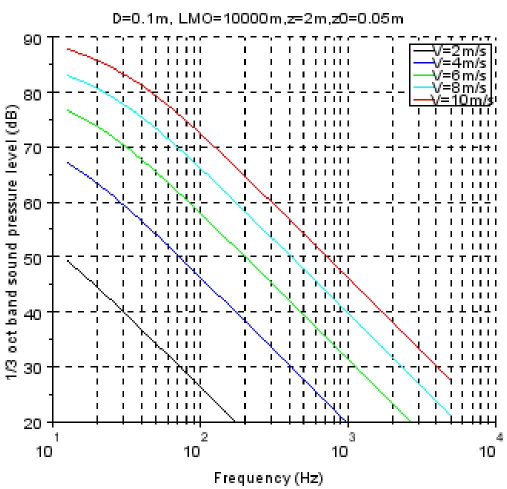
Result : $Y = \bar{Y}$

within the 95% confidence interval =[Ymin, Ymax]

Methods : GUM

- An example of Monte Carlo application : uncertainties of wind induced noise in a screened microphone





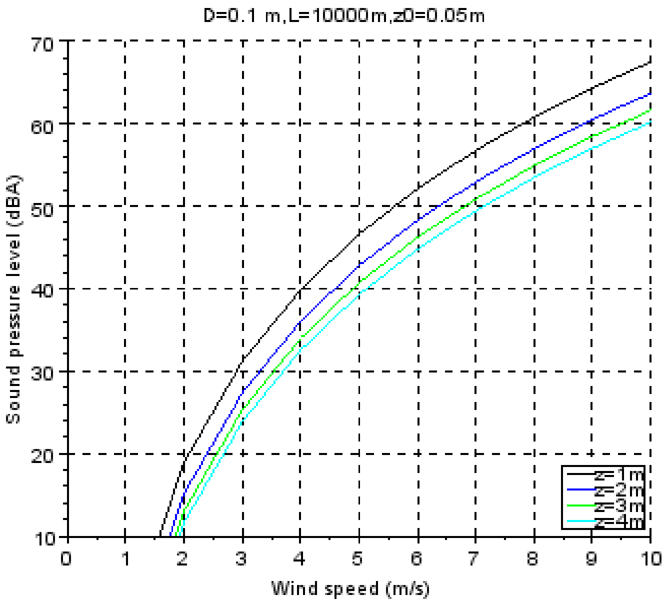
Methods : GUM

- **An example of Monte Carlo application : uncertainties of wind induced noise in a screened microphone**

[van den Berg, 2006]

$$L_{at,A} = 69{,}4\log(V/V_0) - 26{,}7\log(D/l_0) + F(z) + C(\alpha) - 74{,}8$$

$$f_c = V/(3D),$$
$$F(z) = -20\log\{(z/D)^{1/3}[\ln(z/z_0) - \Psi]\},$$
$$C(\alpha) = 20\log(0.215\kappa\alpha\rho V_0^2 / p_0).$$



Input parameters :

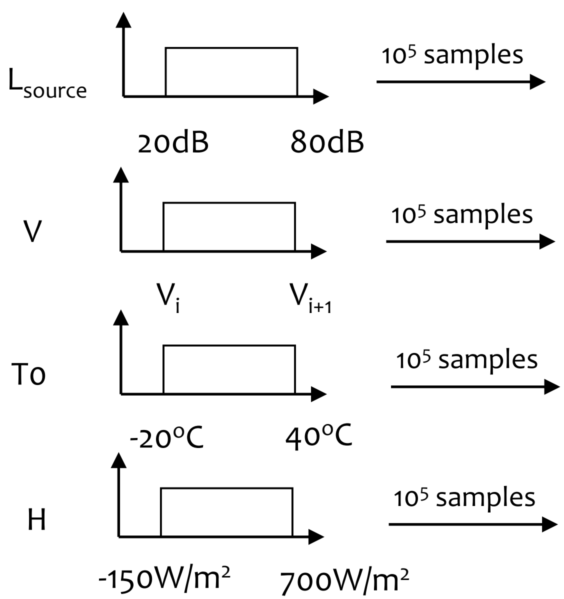
Wind screen: $D,\ \alpha,\ z$

Environment: $V,\ z_0,\ T_0, H$

Methods : GUM

- Bias and bias uncertainty estimation by Monte Carlo technique

[Ecotière,2012, 2018]



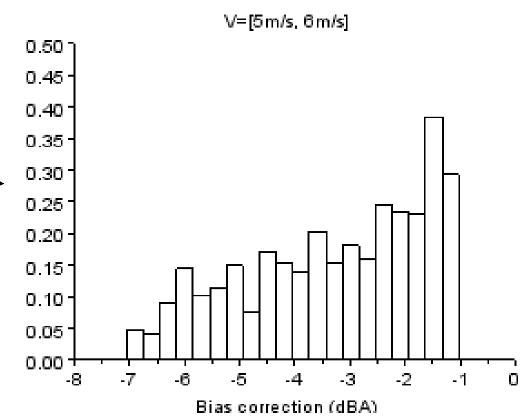
Monte Carlo method

$$C = L_{source} - L_{mes}$$

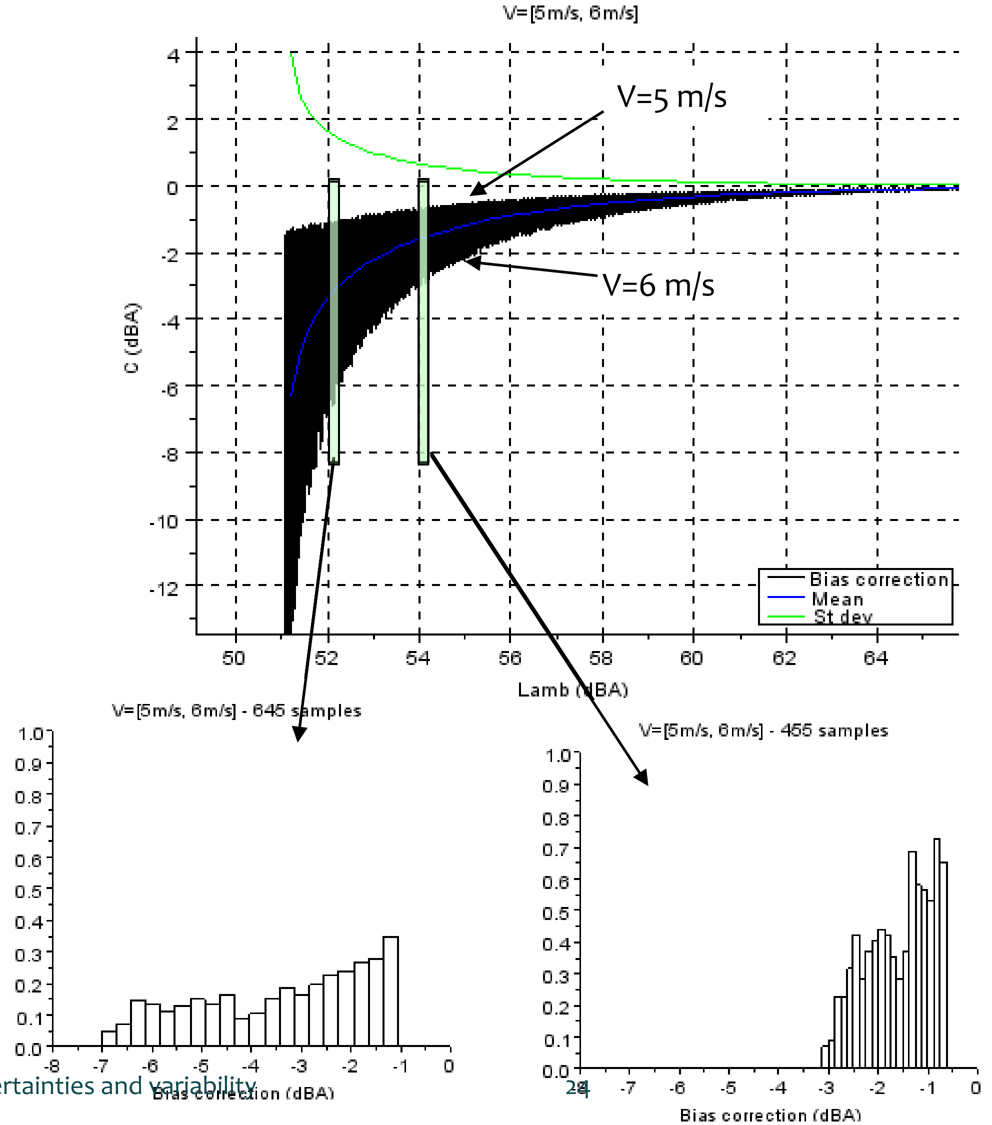
$$L_{mes} = 10\log\left(10^{L_{wind}/10} + 10^{L_{source}/10}\right)$$

L_{wind} : van den Berg model

10^5 calculations for each wind class



Methods : GUM



V=[5m/s, 6m/s]
V=5 m/s
V=6 m/s
C (dBA)
Lamb (dBA)
Bias correction
Mean
St dev
V=[5m/s, 6m/s] - 645 samples
V=[5m/s, 6m/s] - 455 samples
Bias correction (dBA)
Bias correction (dBA)

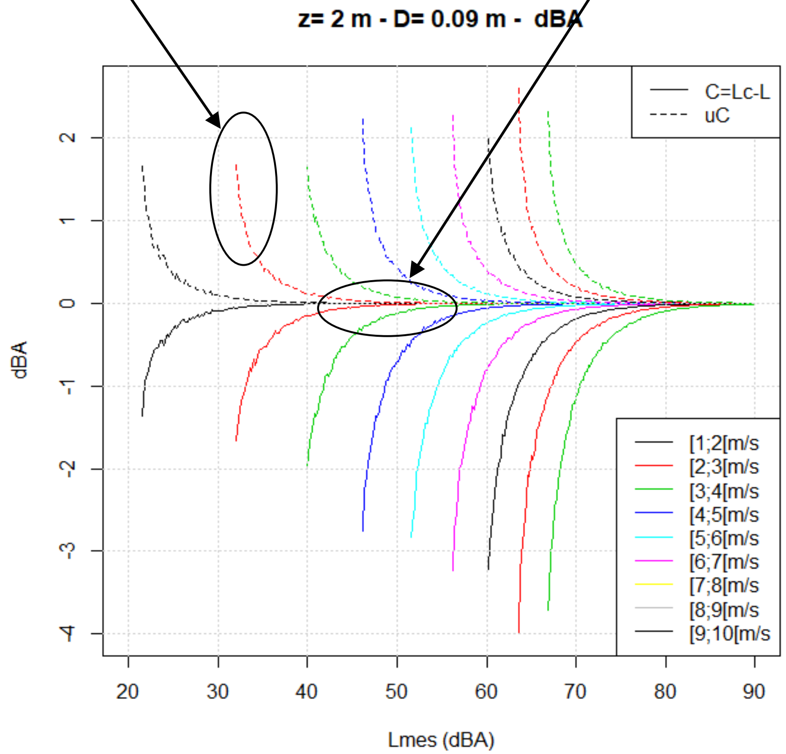
Methods : GUM

- Bias and bias uncertainty

[Ecotière,2012, 2018]

Big uncertainty

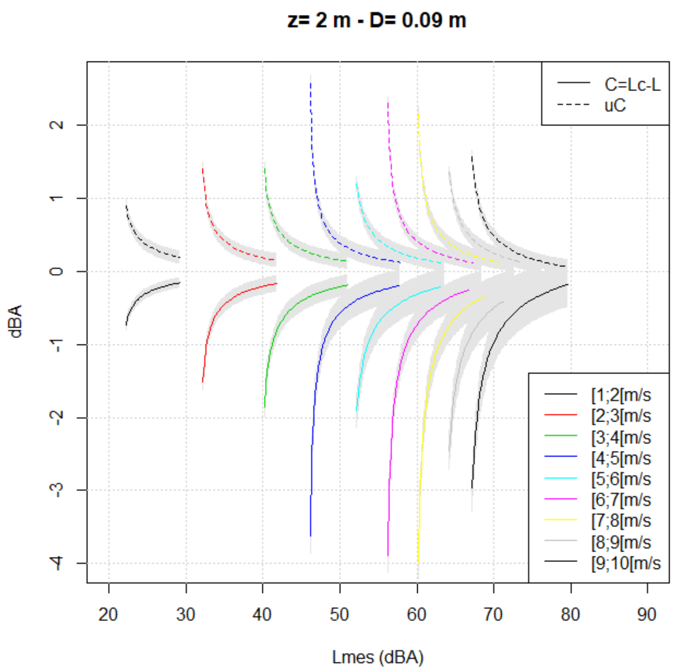
negligible bias



Methods : GUM

- Bias and standard uncertainty for wind induced noise

[Ecotière,2018]



$$b_{wid} = a_{b,1} + \frac{a_{b,2}}{\sqrt{L_{mes} - L_0}}$$

$$u_{wind} = \sqrt{\left(a_{u,1} + \frac{a_{u,2}}{\sqrt{L_{mes} - L_0}}\right)^2 + u_{wind,mod}^2}$$

Methods : ISO 5725

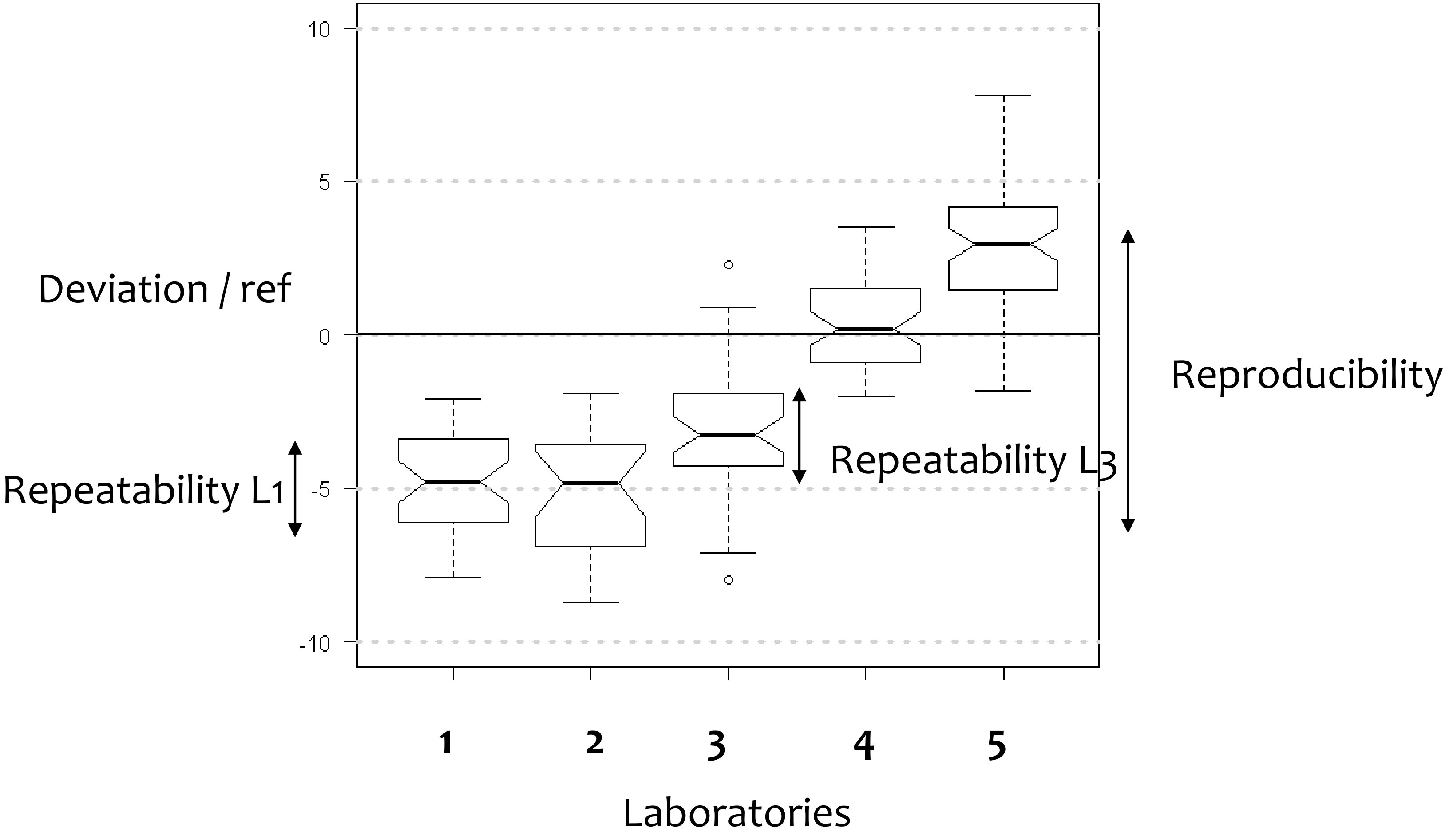
○ Interlaboratory approach (CEI Guide 98-3) – approach

- Requires numerous experimental trials with several labs
- Based on a statistical method of analysis of variance (ANOVA)
- Allows the estimation of 2 uncertainties :
  - Repeatability: u_r
  - Reproducibility: u_R
  - Final Uncertainty: $\mathrm{u}^2 = \mathrm{u}_\mathrm{r}^2 + u_R^2$

- Possibility to calculate intermediate precision (repeat. per lab, per operator, etc.)

Methods : ISO 5725

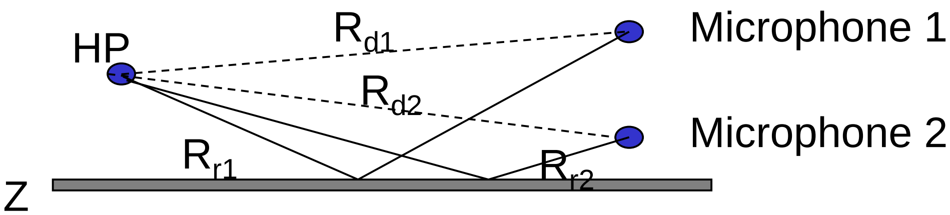
Ex of interlab. approach



Methods : ISO 5725

- **An example of ISO 5725 application : uncertainties of an *in situ* method for measuring ground acoustic impedance**

  - **A 2 mic. Method** [Hess,1990] [Sabatier,1990] [Sabatier,1993][**Guillaume,2015**]



- Measurement of the spectrum transfer function between 2 points

$$\Delta L = 10\log_{10}\left|\frac{p_1}{p_2}\right|^2$$

- Estimation of the Z parameters by fitting calc/measured of *ΔL*

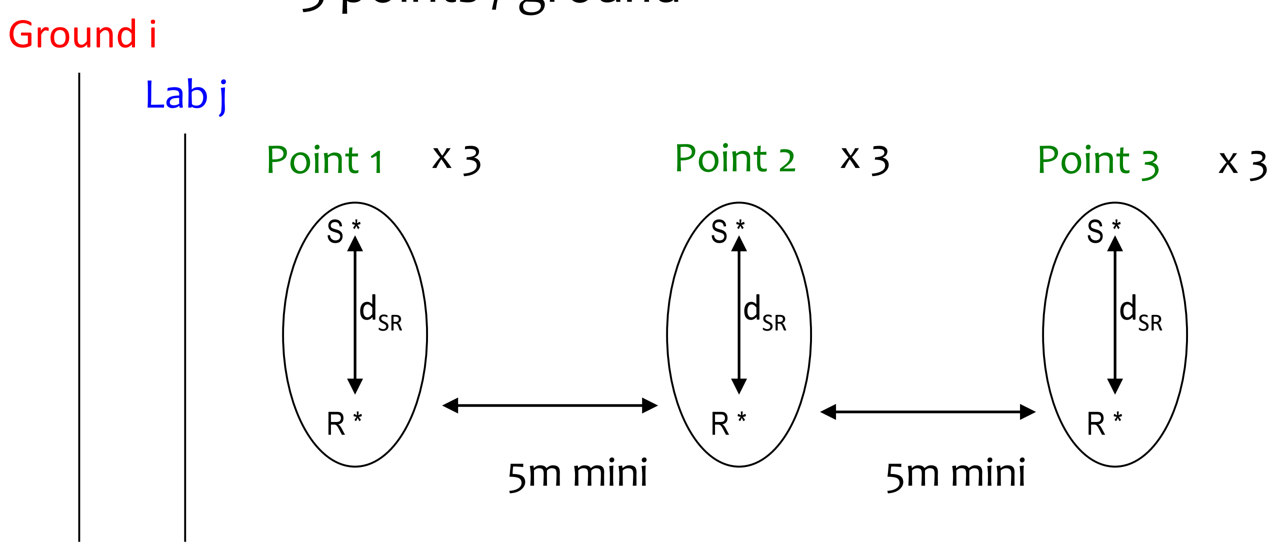
Methods : ISO 5725

- The round robin test : protocol

[Ecotière, Glé *et al* 2015]

-5 laboratories, whith the same kind of exp. device
-3 repetitions / point

-5 outdoor grounds
-3 points / ground



Methods : ISO 5725

- The round robin test : ground samples


Synthetic lawn


Natural lawn

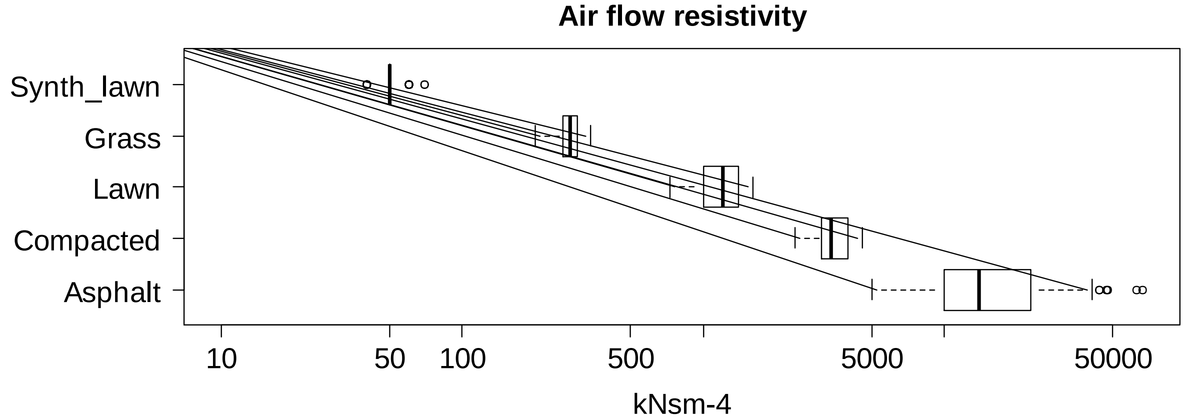

Natural grass


Compacted ground


Non porous asphalt

Methods : ISO 5725

- Reprod. and repeat. vs ground type



Air flow resistivity ($kNsm^{-4}$)	Mean	s_R (reprod.)	S_r (repeat.)	s_L (interlab.)
Non porous Asphalt	19 609	15 070	13 065	7 510
Compacted ground	3 519	567	512	245
Natural lawn	1 154	248	217	119
Grass	277	34	34	6
Synthetic lawn	51	7	5	5

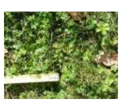
Methods : ISO 5725

- Uncertainties on sound levels estimation

Maximum type-uncertainty of SPL 1/3rd octave band
(under **reproducibility** conditions)

example for hr=2m, d=1:200m and f=100:5000 Hz





	hs=0.05 m	**hs=1 m**	**hs=3 m**	**hs=10 m**
σ =3 519	1,7 dB	2,1 dB	1,2 dB	1 dB
σ = 1 154	2,1 dB	2,3 dB	1,6 dB	1 dB
σ = 277	2,6 dB	2,9 dB	2,2 dB	1 dB

Standard uncertainty (1/3rd oct bands) <3 dB

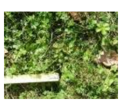
Methods : ISO 5725

- Uncertainties on sound levels estimation

Maximum type-uncertainty of SPL 1/3rd octave band
(under **repeatability** conditions)

example for hr=2m, d=1:200m and f=100:5000 Hz

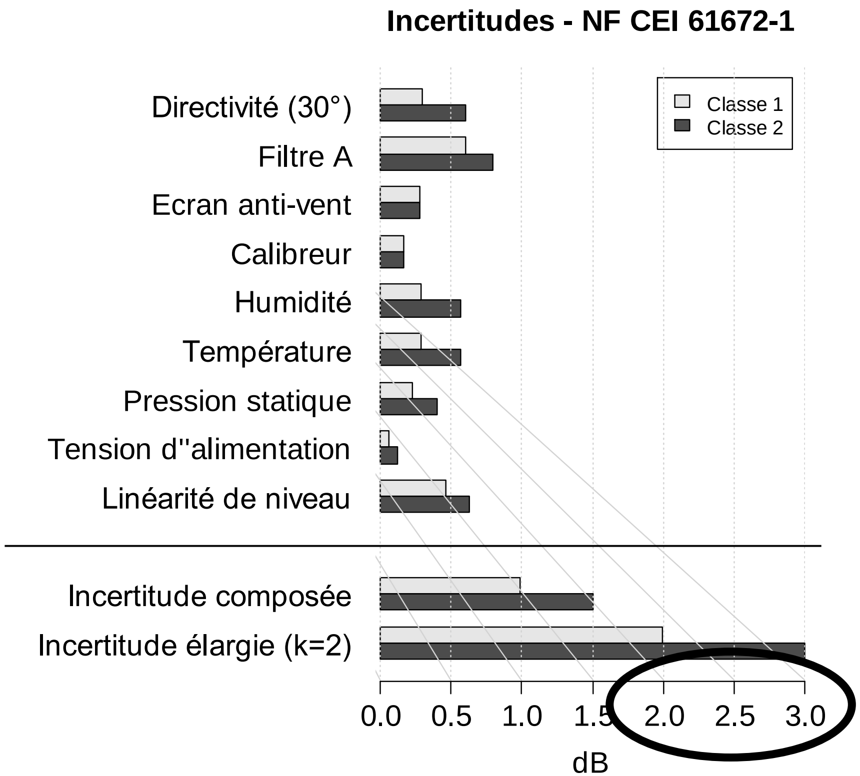




	hs=0.05 m	hs=1 m	hs=3 m	hs=10 m
σ =3 519	0,7	1	0,6	0,6
σ = 1 154	1	1,2	0,8	0,6
σ = 277	1,2	1,3	1,3	0,6

Standard uncertainty (1/3rd oct bands) <1,3 dB

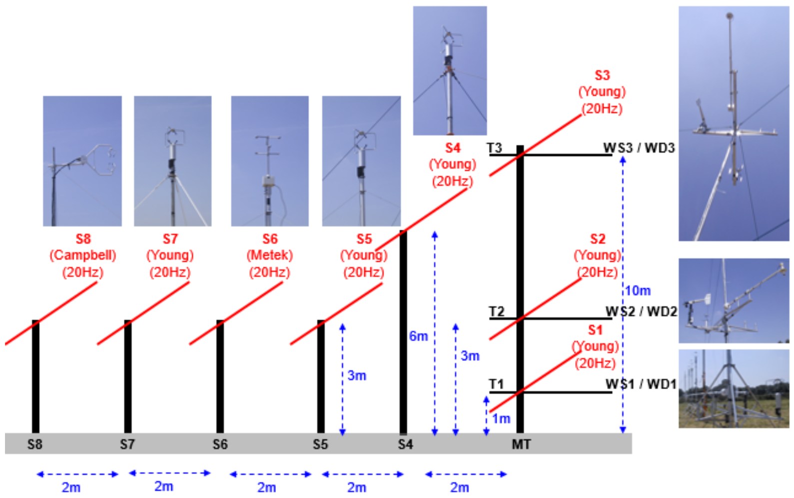
About sound level measurement uncertainties



Sound level meter : minimum
± 2dB (class I)
± 3dB (class II)

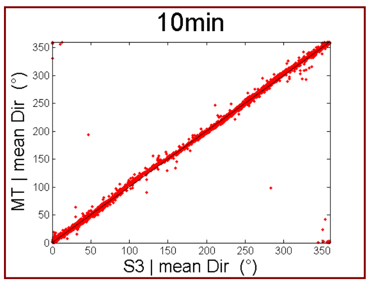
Uncertainties due to meas. processes

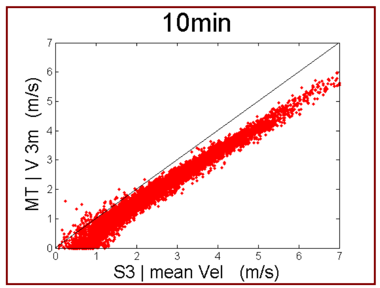
- Ex of vertical sound speed gradient measurement
  - Influence of method : sonic vs mast
  - Influence of the devices : sonic vs sonic
  - Influence of the height meas.

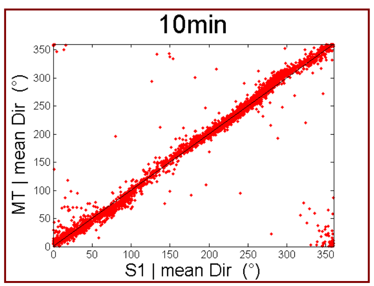


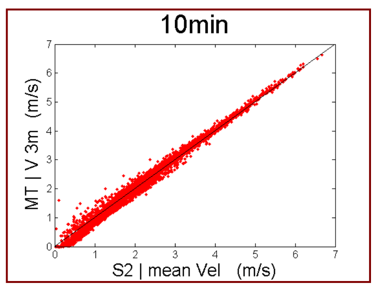
Uncertainties due to meas. processes

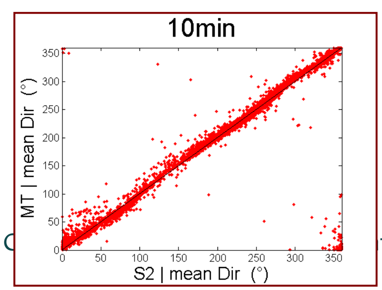
- Ex of vertical sound speed gradient measurement
  - Influence of devices

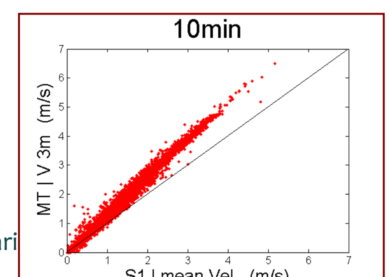


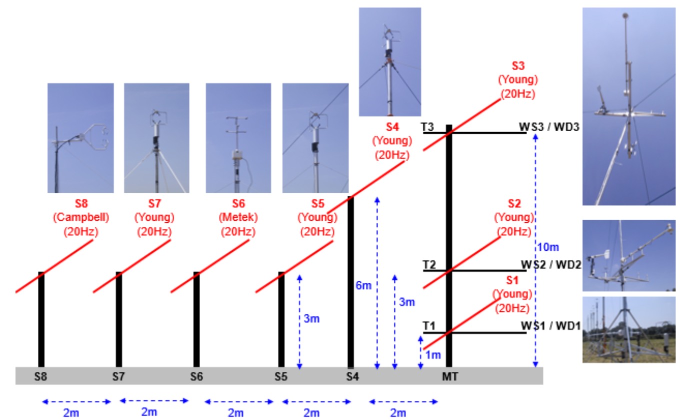


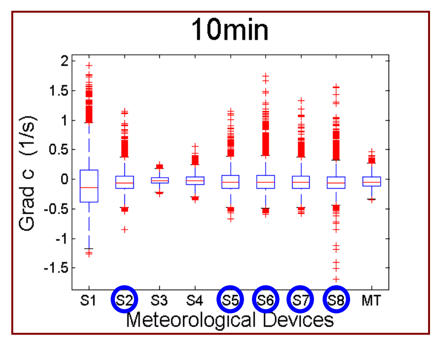


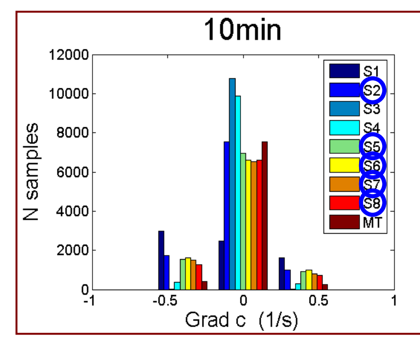












Uncertainties due to meas. processes

- Uncertainties on sound level estimation due to uncertainties on vertical sound speed gradient measurement

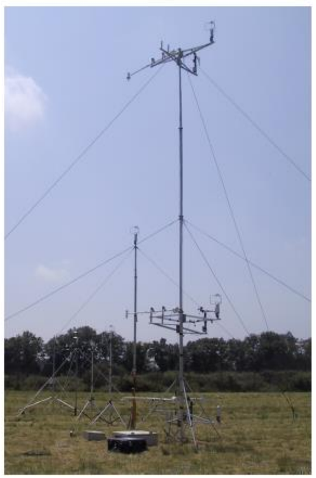


FIGURE: Mât équipé de capteurs météorologiques sur trois hauteurs (1, 3 et 10 m).

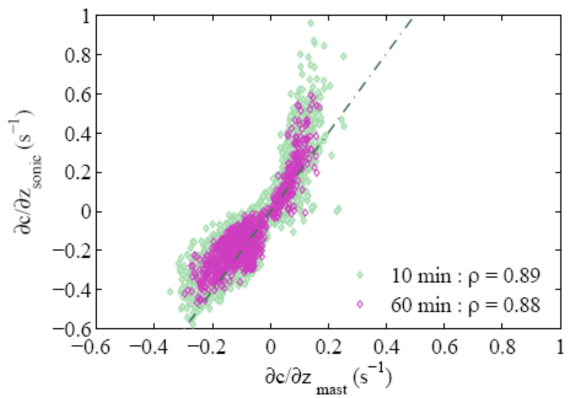
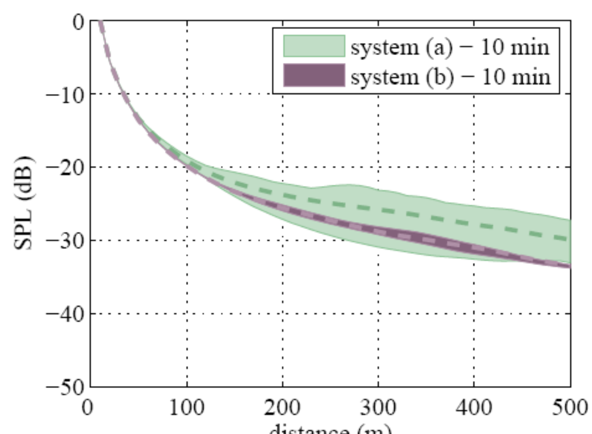


FIGURE: Anémomètre ultrasonique tridimensionnel.



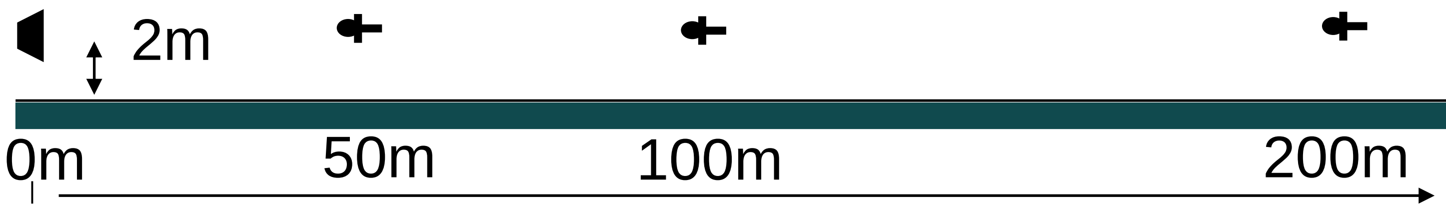
Variability

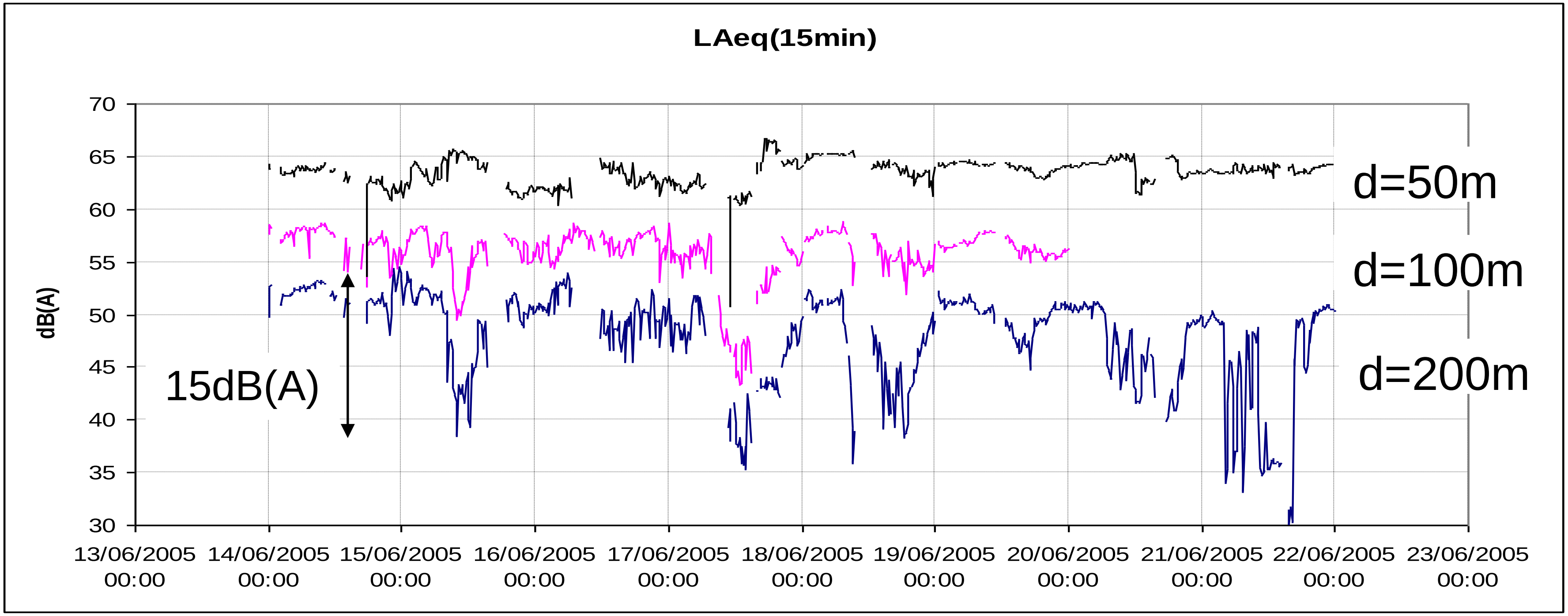
- How my measurement result is representative ?

- 'Natural' variability
  - Source emission variability
  - Meteorological variability
  - Ground properties variability
  - …
  - Spatial and temporal variability

- Sampling uncertainty

Variability due to meteo





Lannemezan 2005 (Junker et al, 2006)

Noise variability due to meteo

○ Estimation of variability due to meteo : LTS method

[Zouboff, 2000][Ecotière 2008]

Step 1

Site data
(geometry, ground …)
+
celerity gradients

↓

Acoustic model (PE)

[Gauvreau, JASA, 2002]

[Lihoreau et al., JASA, 2006]

Step 2

Meteo data measured hourly over x years

↓

Micrometeo model
(Choisnel model based on Monin-Obukhov theory)
[Brunet et al., LRSP, 1996]

↓

$$\partial_z c = g(T)\partial_z T + \partial_z V_{\vec{w}}$$

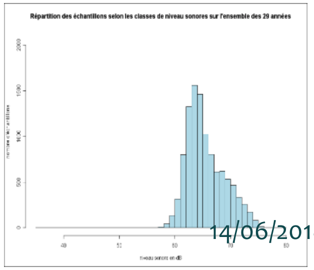
Hourly celerity gradient over x years

$$LAeq = f(\partial_z c)$$

↓

LAeq(1h) over x years →

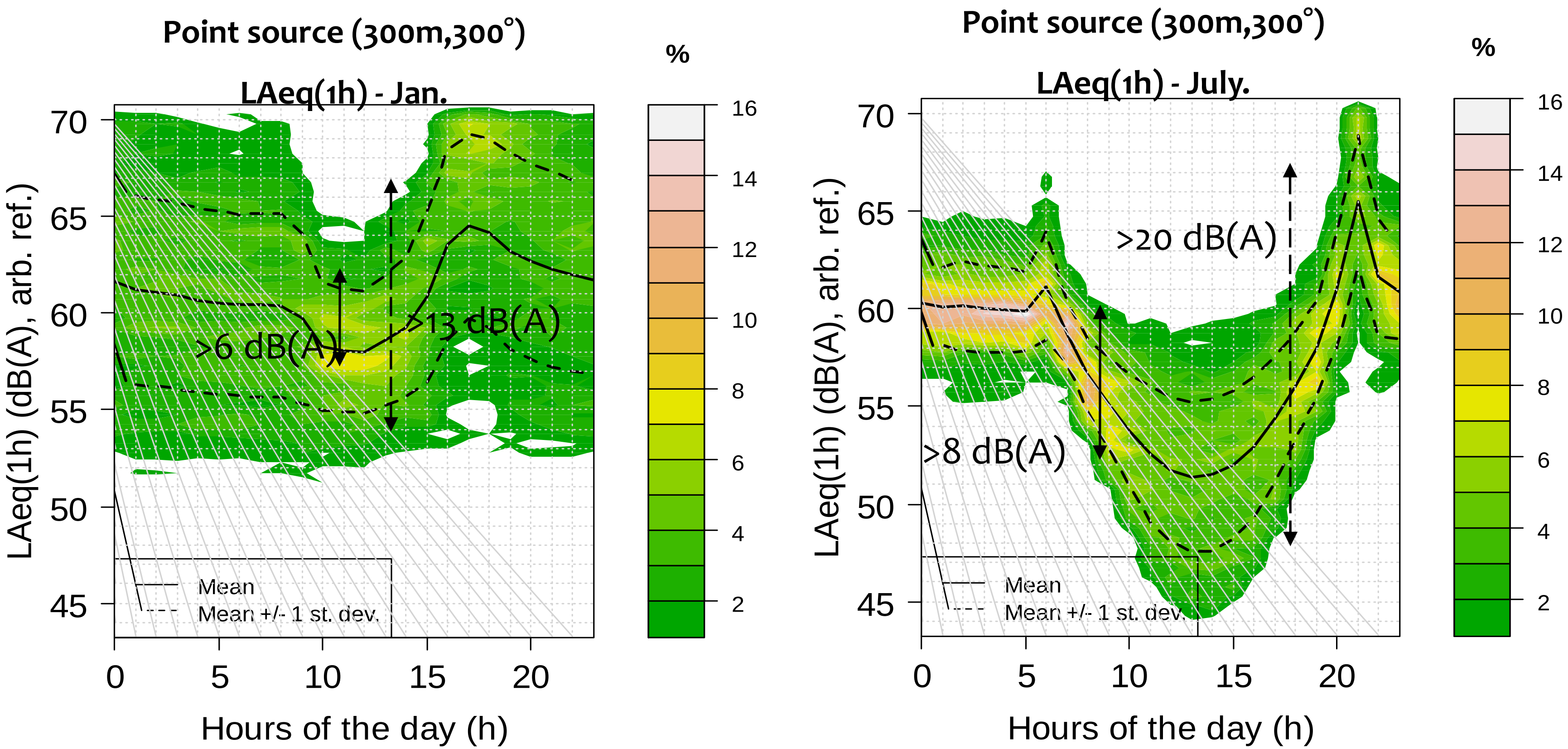
Statistical analysis



Noise variability due to meteo

- Daily fluctuations of LAeq(1h) – seasonal influence

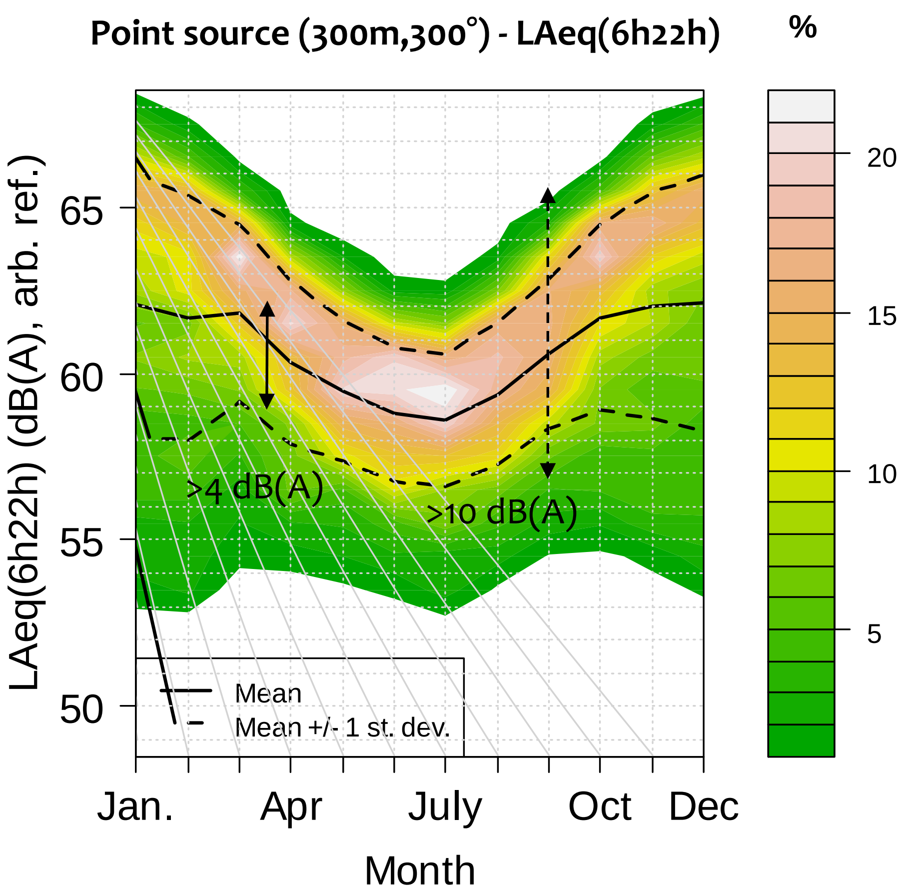
[Ecotière 2008]

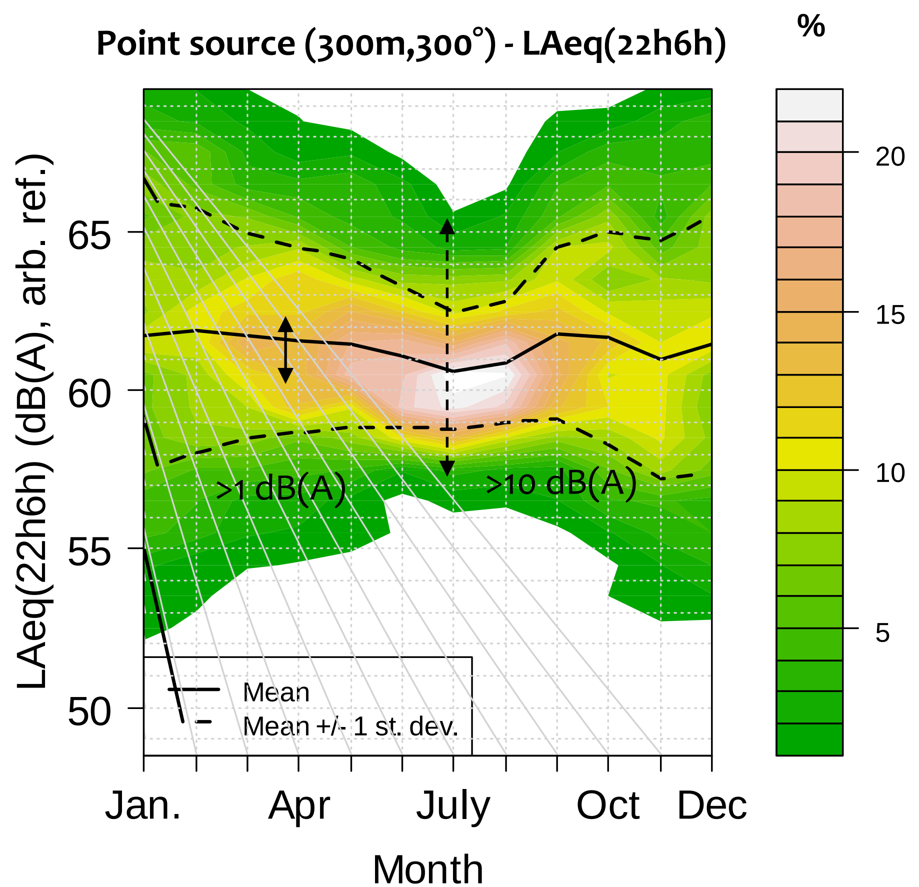


Noise variability due to meteo

- Seasonal fluctuations of LAeq(day/night)

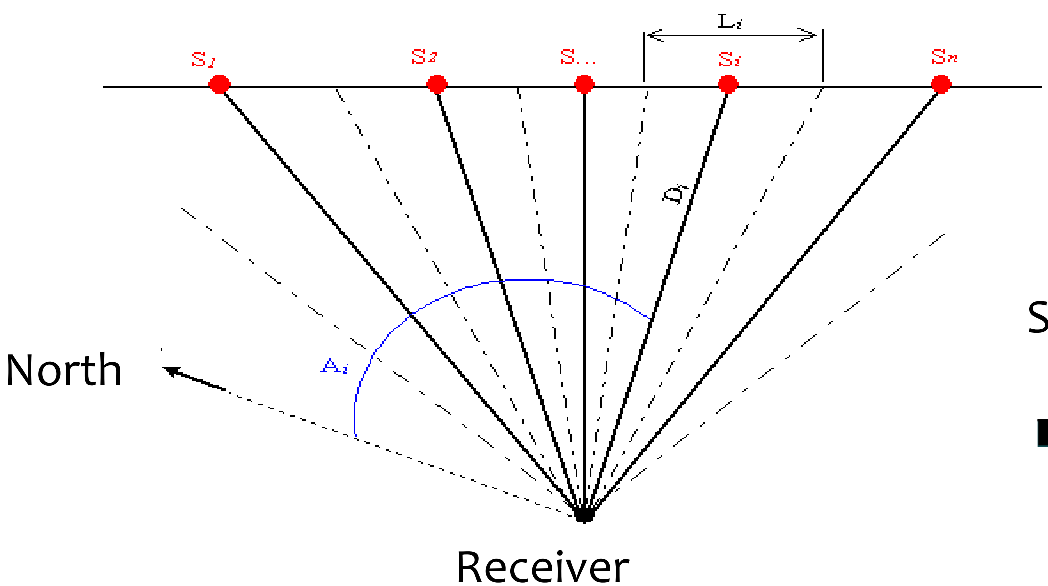
[Ecotière 2008]

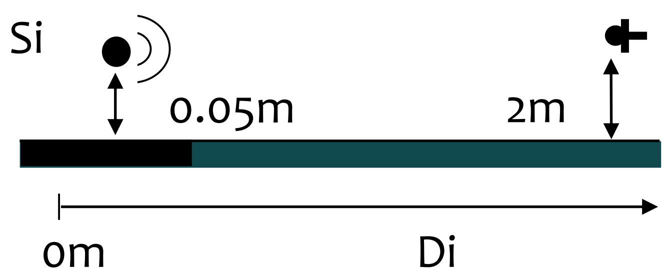




Noise variability due to meteo

- Application for a road source
  - Site : Avrillé (49) - meteo data : 1960 to 1990 (>250 000 samples LAeq(1h))
  - Flat ground, Model of impedance Miky (□=300 kNms-4)
  - Road source - Road noise spectrum

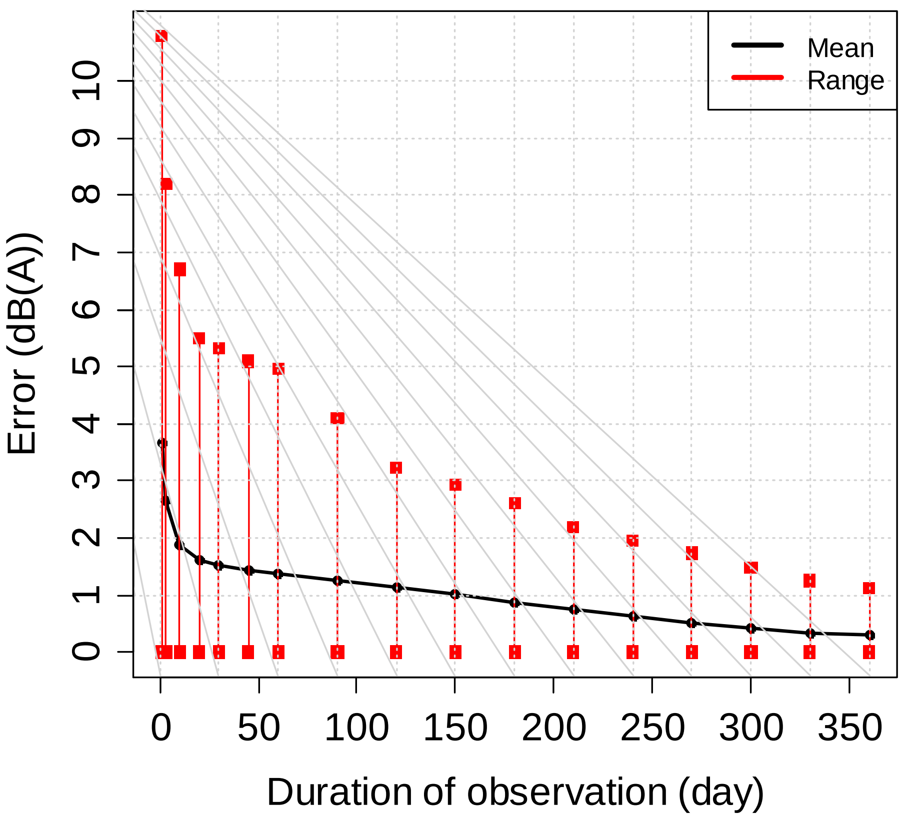




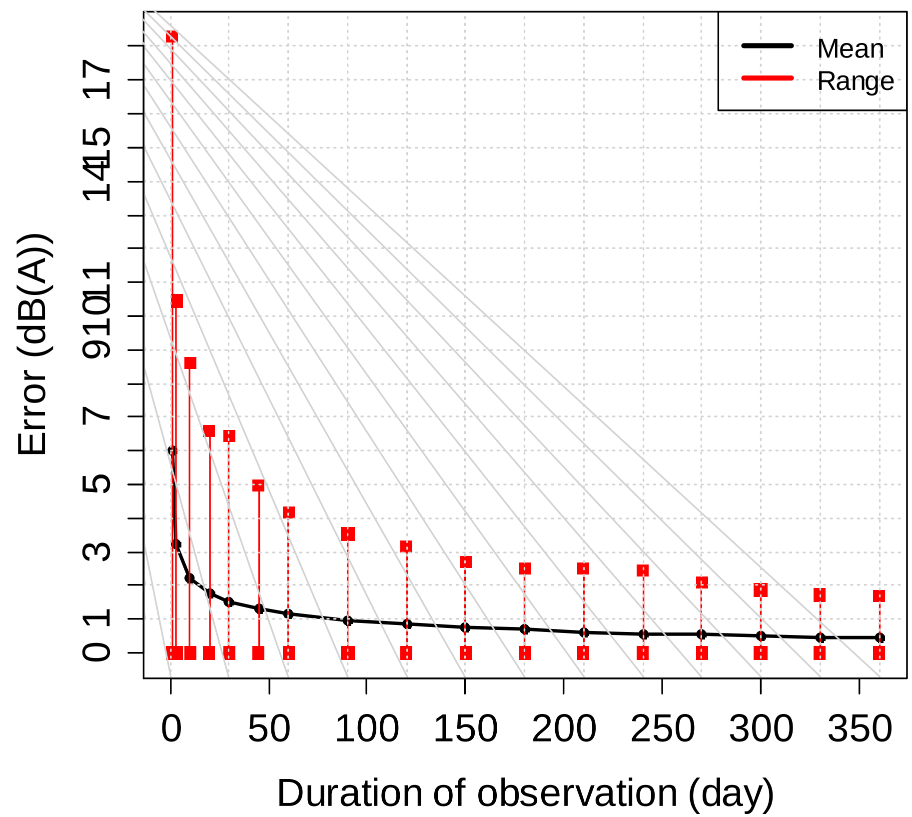
Noise variability due to meteo

- Error of estimation of the LAeq(day/night) – Road source (150m, 0°)

Error of estimation of LAeq(6h22h)

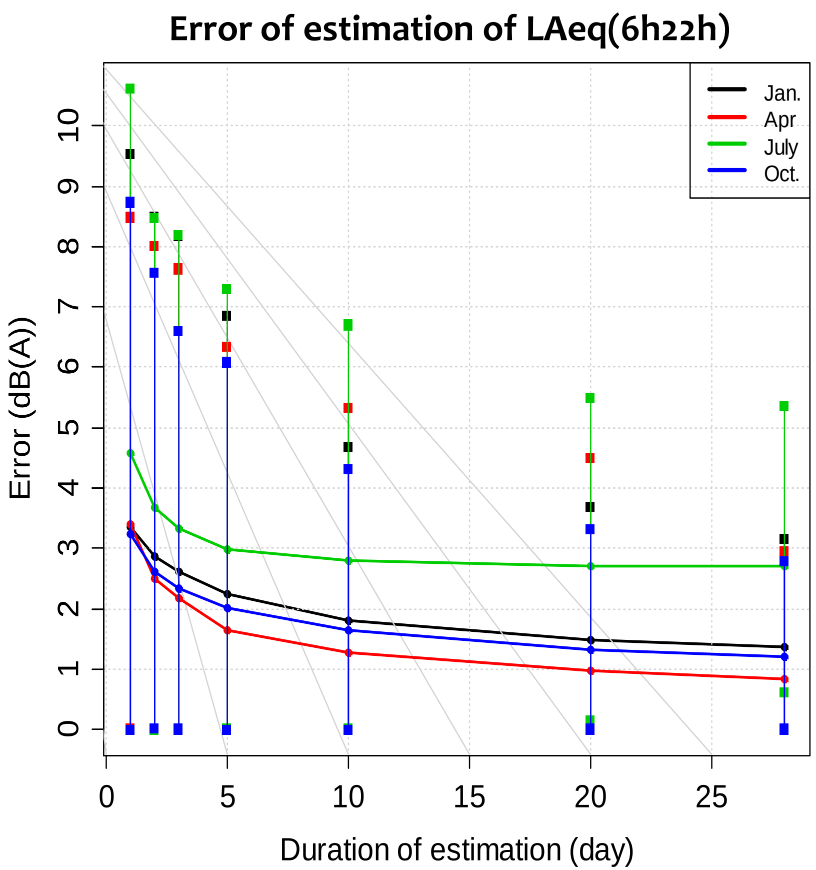


Error of estimation of LAeq(22h6h)



Noise variability due to meteo

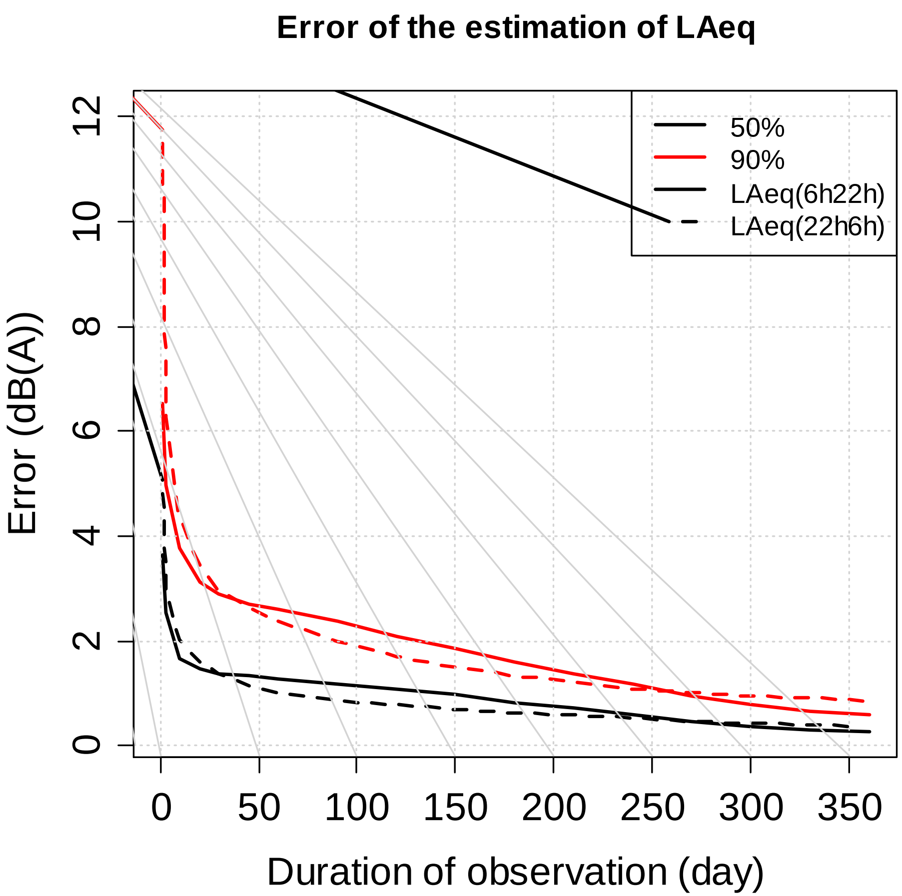
- Error of estimation of the LAeq(day/night) – Road source (150m, 0°)



- Summer : error>2 dB(A)
- Winter : error>1 dB(A)

Noise variability due to meteo

- Error of estimation of the LAeq(day/night) – Road source (150m, 0°)



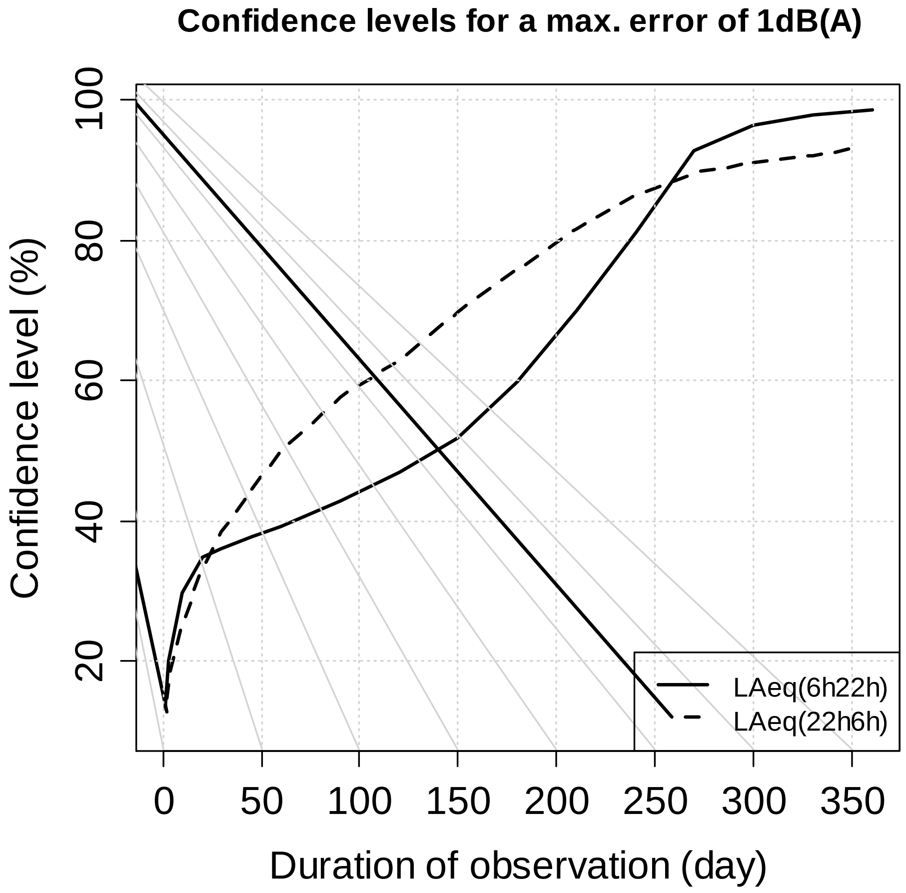
Maximum error - confidence level α and duration of observation

6h22h	α=50%	α=90%
50j	1.5 dB(A)	2.7 dB(A)
100j	1.2 dB(A)	2.4 dB(A)

22h6h	α=50%	α=90%
50j	1.5 dB(A)	2.5 dB(A)
100j	1 dB(A)	1.8 dB(A)

Noise variability due to meteo

- Confidence level - LAeq(day/night) – Road source (150m, 0°)



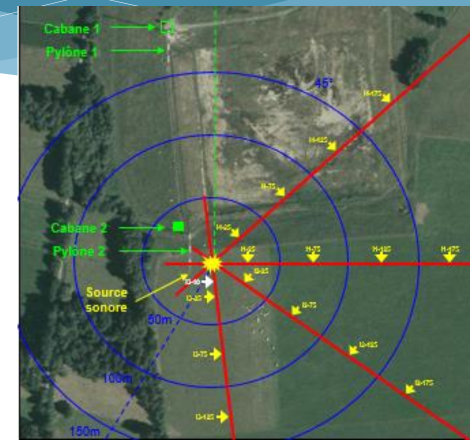
Level confidence as a function of the duration of observation (max error = 1 dB(A))

Minimum number of days to have an error < 1 dB(A) with a confidence level of 50% :

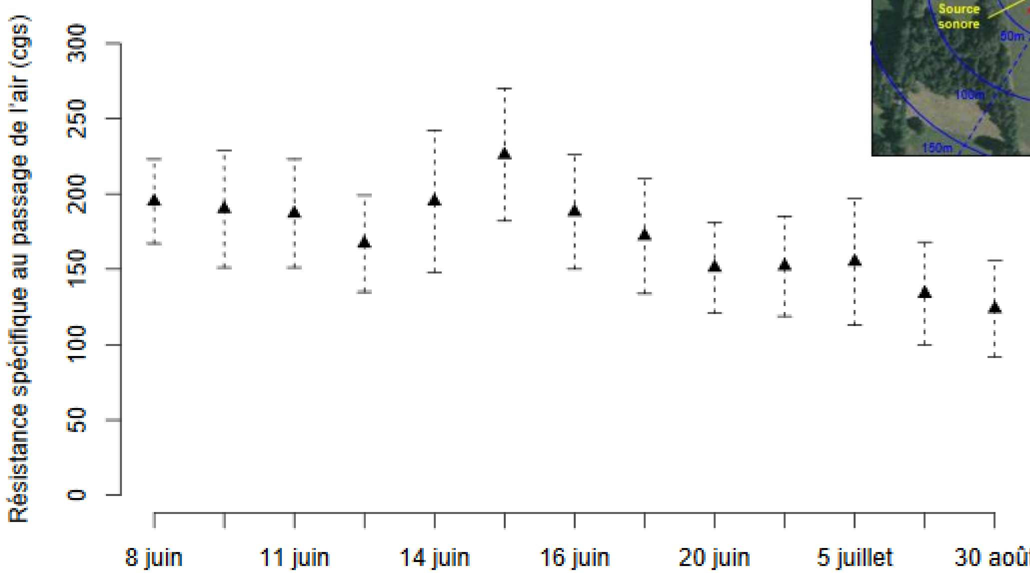
- LAeq(6h22h) : 150 days
- LAeq(22h6h) : 60 days

Noise variability due to the ground

- **Spatial and temporal ground variability**



Temporal variability

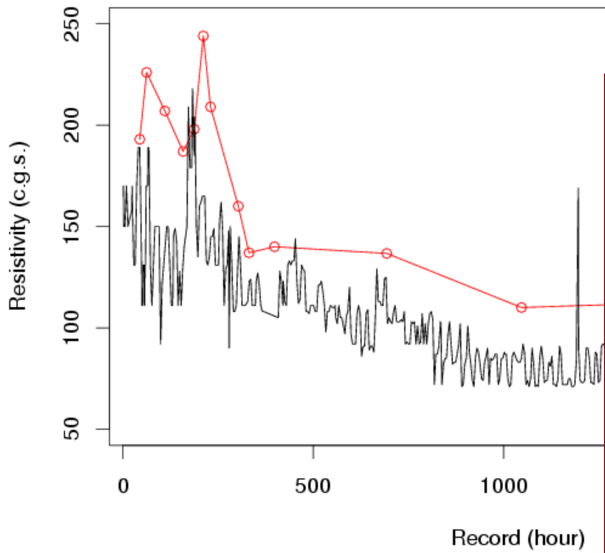


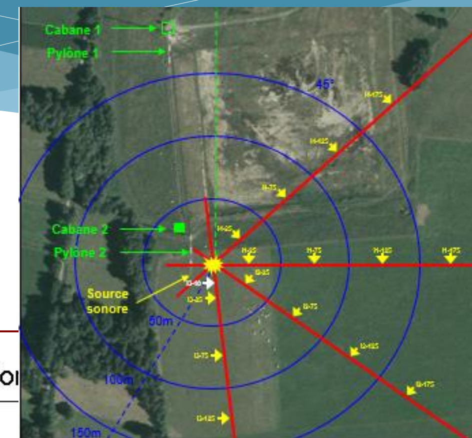
Spatial variability

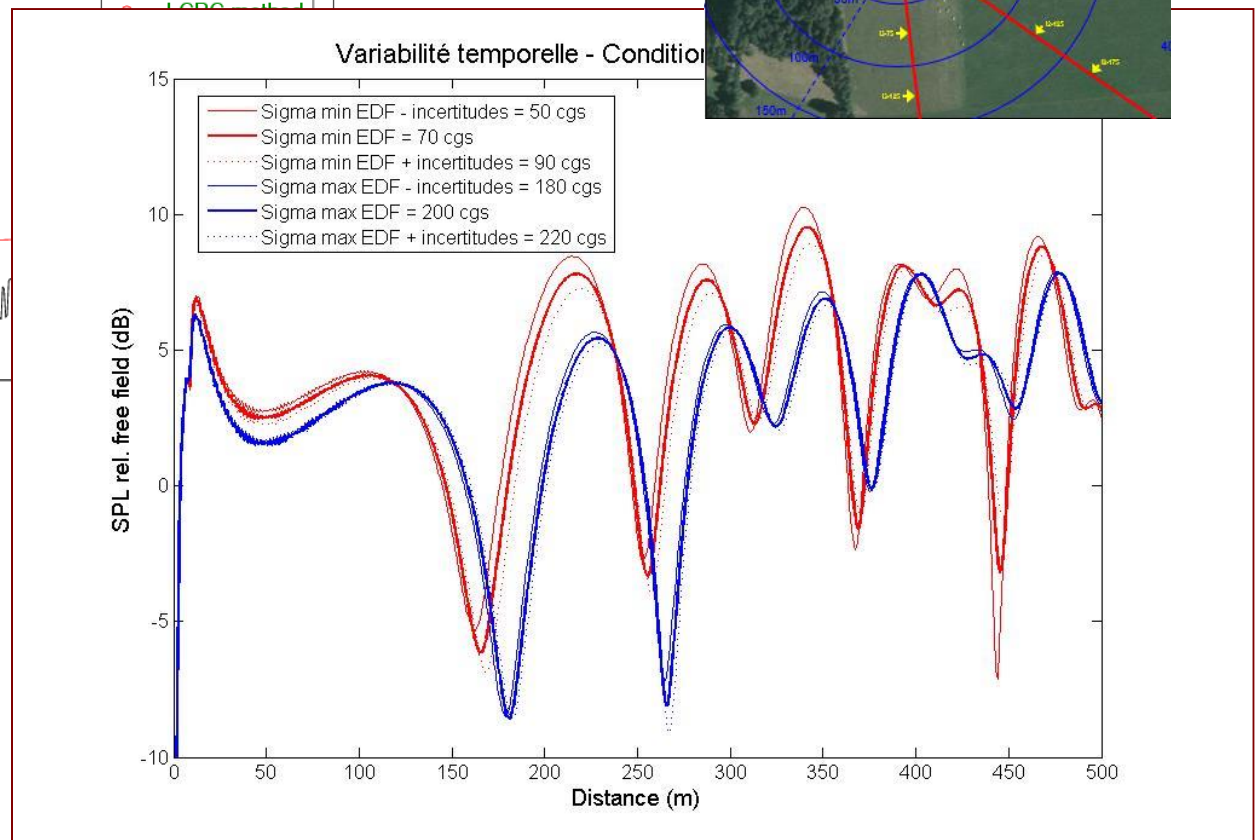
[Junker *et al*, 2006][Baume 2006]

Noise variability due to the ground

- **Temporal ground variability**



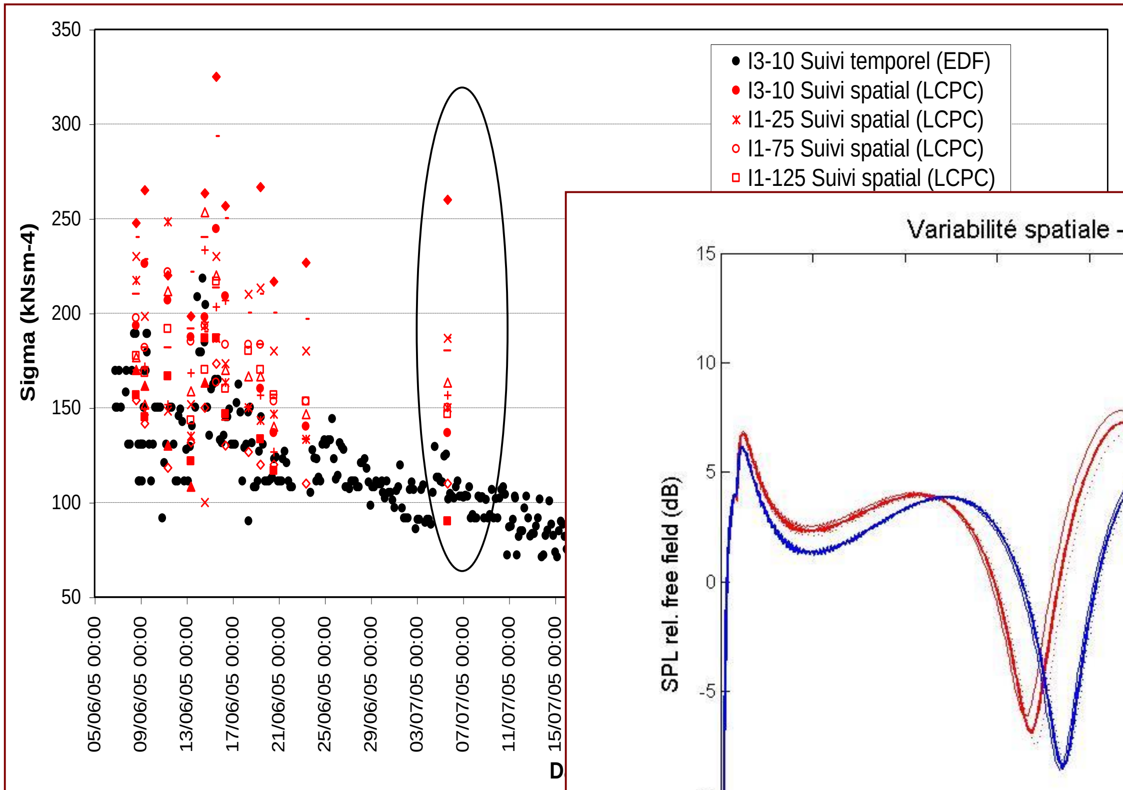


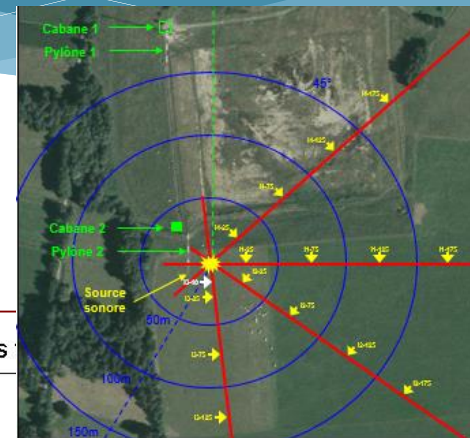


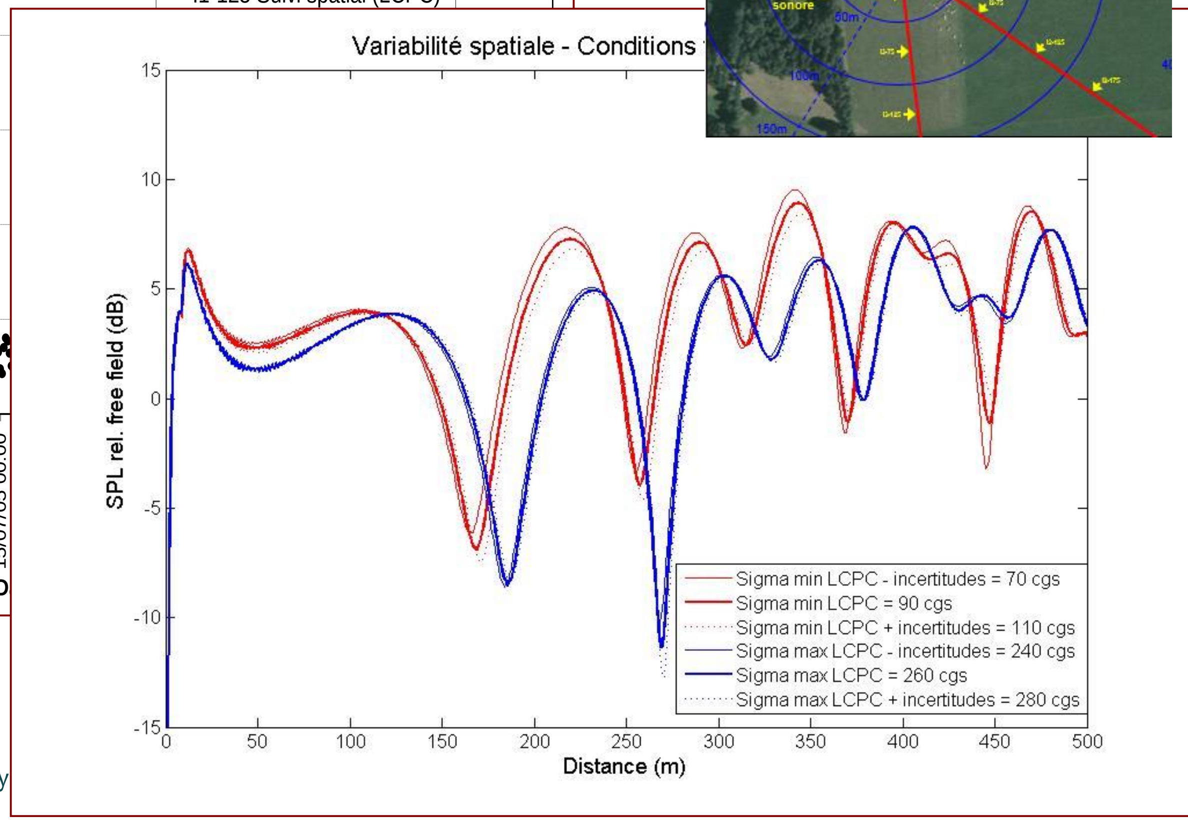
[Junker *et al*, 2006][Baume 2006]

Noise variability due to the ground

○ Spatial ground variability







[Junker *et al*, 2006][Baume 2006]

Noise variability due to ground

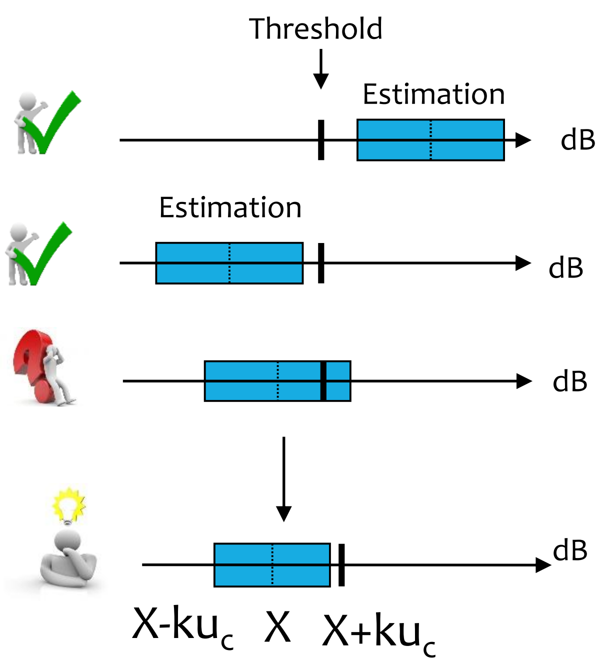
- **Spatial ground variability**

[Junker *et al*, 2006][Baume 2006]

Conclusion

○ Uncertainties: what do I do with them?

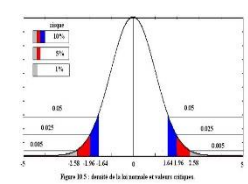
- Comparison to a threshold



Lower uncertainty

and/or

Lower confidence level



IC 95%, 75% …

Conclusions

- The real world is uncertain, uncertainties will always exist and you can't do without it
- Uncertainties of several dB are common in environmental acoustics
- Confidence level : uncertainties are a tool for risk management

Thank you for your attention!

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