Modélisation numérique et caractérisation expérimentale des effets de la rugosité de surface sur la propagation acoustique

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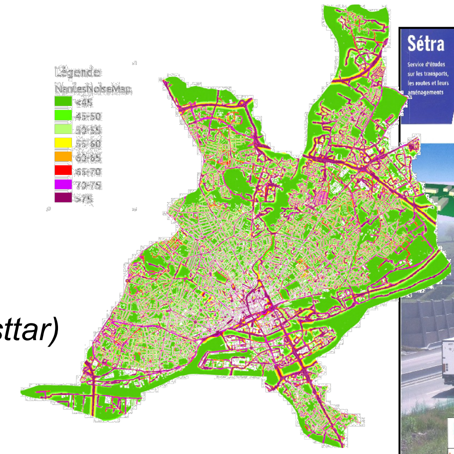
Avant-propos

Modèles de référence *vs* modèles d'ingénierie

> Modèles utilisés dans le domaine de l'ingénierie

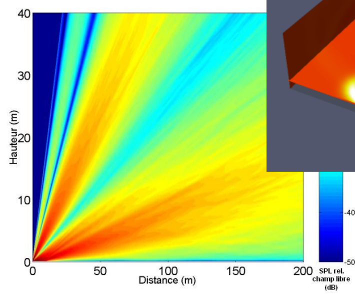
- Rapidité de calcul >> grande échelle
- Type NMPB08, ISO 9613, Nord 2000, CNOSSOS, *etc.*
- Prise en compte partielle des phénomènes physiques
- Outils logiciels (IHM)
- Nouveaux outils logiciels libres : NoiseM@p/OrbisGis *(IRSTV/ifsttar)*

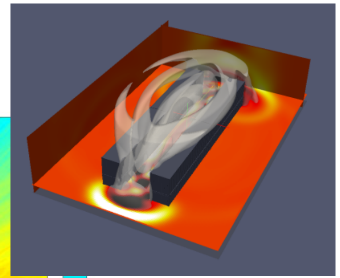


http://noisemap.orbisgis.org/

> Modèles de référence ou de laboratoire

- Temps CPU/GPU important >> petite échelle
- Prise en compte quasi-exhaustive des phénomènes physiques
- Méthodes analytiques et numériques (PE, BEM, FDTD, TLM, etc.)
- Utilisation délicate (sensibilité aux paramètres), diffusion restreinte
- Couplage/chainage avec modèles météo/QA
- Validation (!) : comparaison mesures/calculs, benchmarks inter-modèles de propagation acoustique
- >> BdD numériques de référence pour validation des modèles de référence… et d'ingénierie !
- Thèse O. Faure : intégration des effets de la rugosité dans les modèles de référence… et d'ingénierie ?



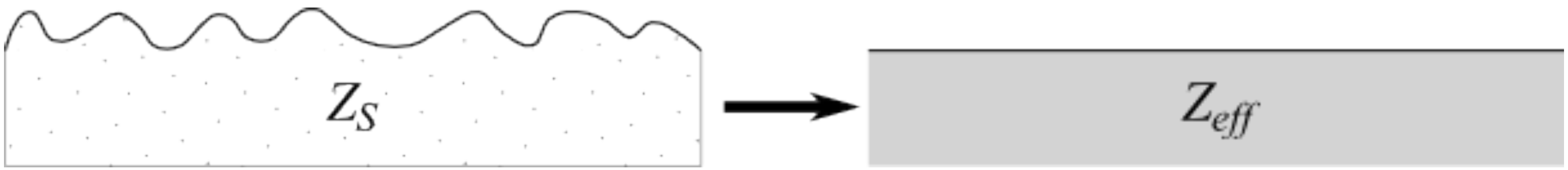


Introduction

• Context : modelling of outdoor sound propagation in an heterogeneous medium.

• Realistic cases include :
- time variability of the propagation medium properties
- geometric irregularities due to the complexity of the ground
- measurement uncertainties

• Modelling the effects of small geometry irregularities compared to wavelength (« roughness ») using an effective impedance :



Introduction

- Boss model for a roughness formed by cylindrical scatterers[1]

$$1/Z_{eff} = \beta_{eff} = \beta_s + \boxed{\beta_R(size, spacing, shape, etc.)}$$

→ Experimentally[1] and numerically validated[2] (and impemented in time-domain methods)

- Model for a random roughness ?

→ Objectives : experimental validation of an effective impedance model for random roughness with measurements in semi-anechoic chamber

[1] P. Boulanger, K. Attenborough, Q.Qin, "Effective impedance of surfaces with porous roughness: Models and data", Journal of the Acoustical Society of America, 117(3), 1146-1156 (2005).

[2] O. Faure, B. G., F. J., and P. L., Effective impedance models for rough surfaces in time-domain propagation methods, In Proceedings of Internoise 2013, Innsbruck, Austria.

I. MPP effective impedance model

I.1 – Definition

• In electromagnetism, an effective impedance model for rough surfaces is obtained using the Small Perturbation Method (MPP), taking into account the **roughness spectrum** of the surface and its statistical properties[3]

• Transposed to acoustics for an absorbing rough surface :

$$1/Z_{eff} = \beta_{eff} = \beta_S + \int_{-\infty}^{+\infty} \frac{d\kappa'}{k_0 k_z(\kappa')} \left(k_0^2 - \kappa\kappa'\right) W\left(\kappa - \kappa'\right) \quad \text{with} \quad k_z(\kappa) = \sqrt{k_0^2 - \kappa^2}$$

• Models the mean effects of ground roughness on sound propagation

• Reformulation possible to get rid of the pole[3] for an easy numerical integration

• Used with the **Weyl-Van der Pol formula** for obtaining analytical solutions

[3] Y. Brelet and C. Bourlier, "SPM numerical results from an effective surface impedance for a one-dimensional perfectly-conducting rough sea surface," *Progress in Electromagnetics Research-pier*, vol. PIER 81, pp. 413–436, 2008.

I. MPP effective impedance model

I.2 – Roughness power spectrum

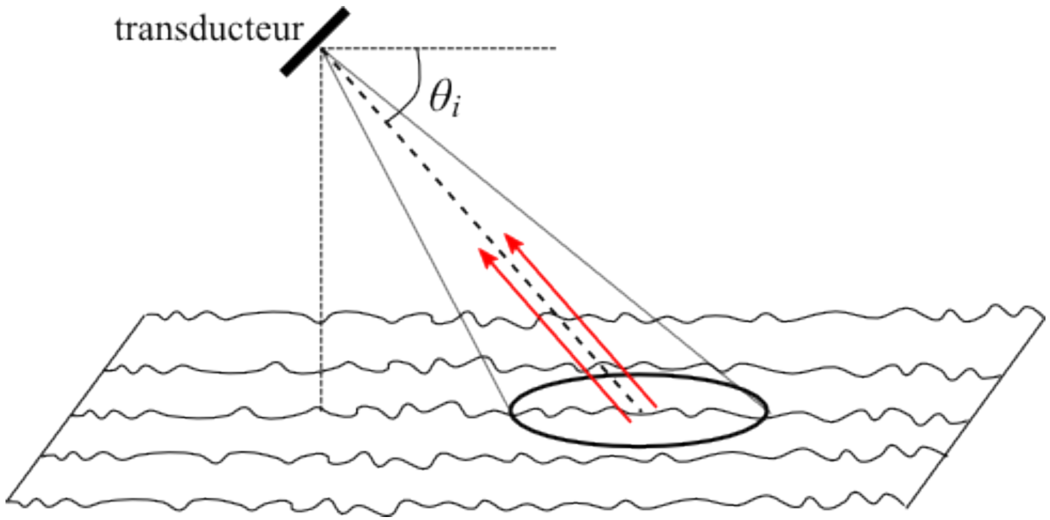
• For an area of a surface whose height profile ζ is known :

$$W(k_x, k_y) = \left|\Im\left[\zeta(x, y)\right]\right|^2$$

• For a surface statistically defined by an autocorrelation function C_ζ :

$$W(k_x, k_y) = \iint e^{-i\vec{k}.\vec{x}} C_\zeta(x, y)\,dxdy$$

• For a rough sea surface or a rough ground, the roughness power spectrum can be estimated by backscattering measurements[4]

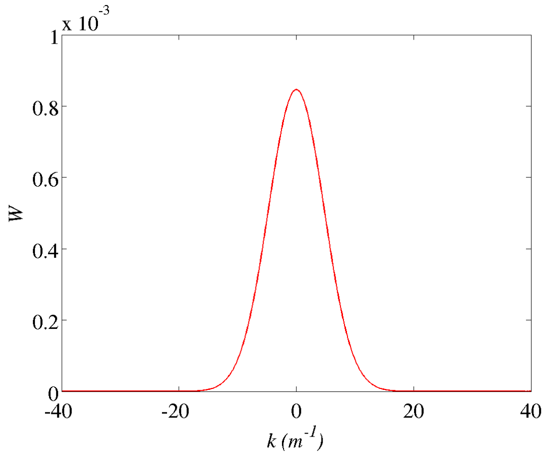


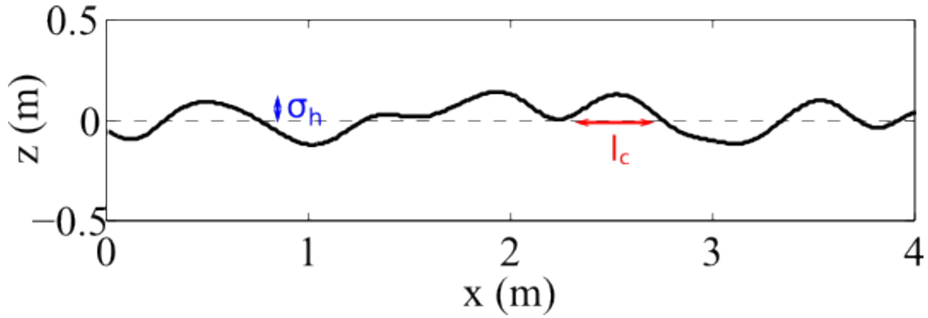
[4] M.L.Oelze, J.M. Sabatier, R..Raspet, "Application of an acoustic backscatter technique for characterizing the roughness of porous soil", Journal of the Acoustical Society of America, 111(4), 1565-1577 (2002).

II.1 – Gaussian roughness spectrum

- A 1D gaussian roughness spectrum is defined by : $$W(K) = \frac{\sigma_h^2 l_c}{2\sqrt{\pi}} e^{-\frac{K^2 l_c^2}{4}}$$

e.g. σ_h=0.1m and l_c=0.3m





- Experimental rough surfaces defined with a gaussian spectrum :

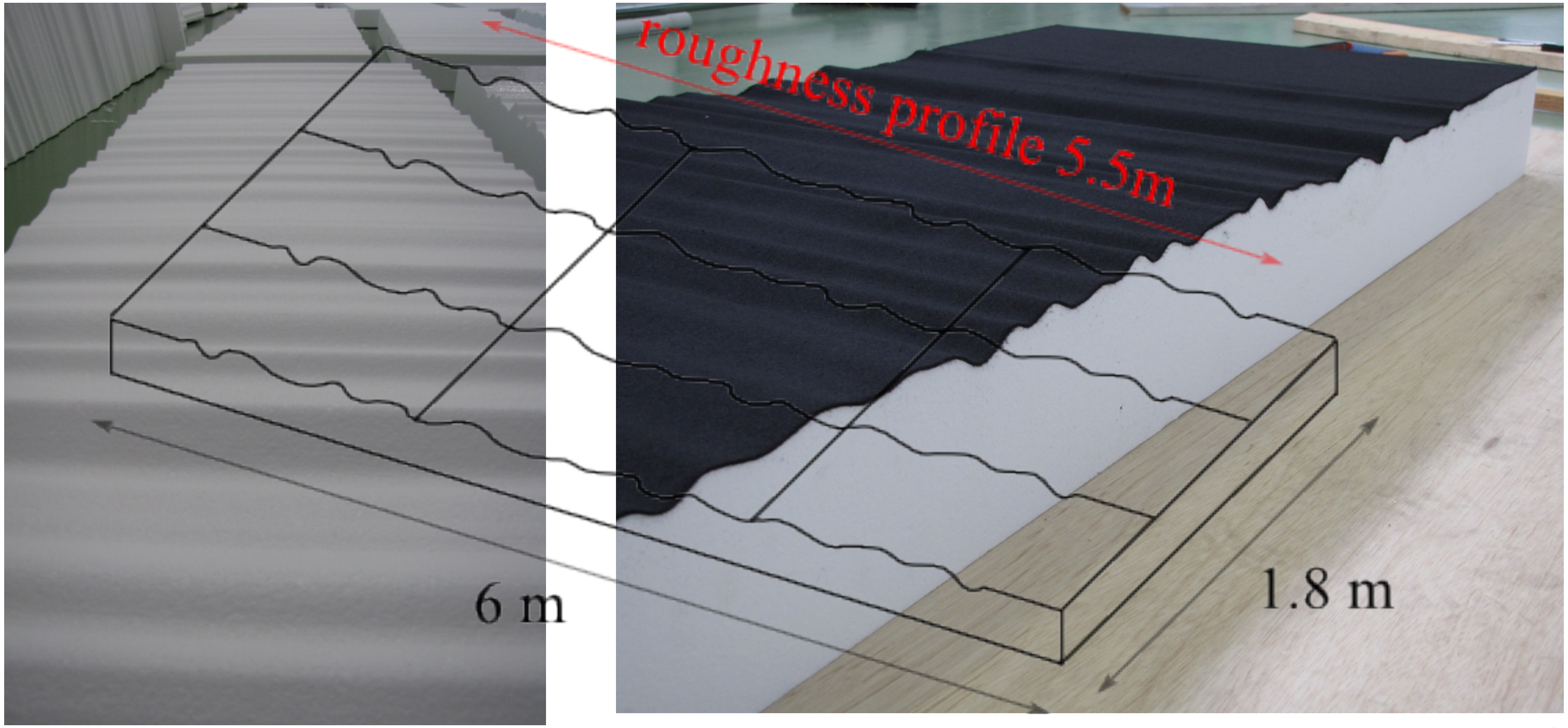
  -σ_h=0.05m

  - l_c=0.2m

II.2 – Rough surfaces

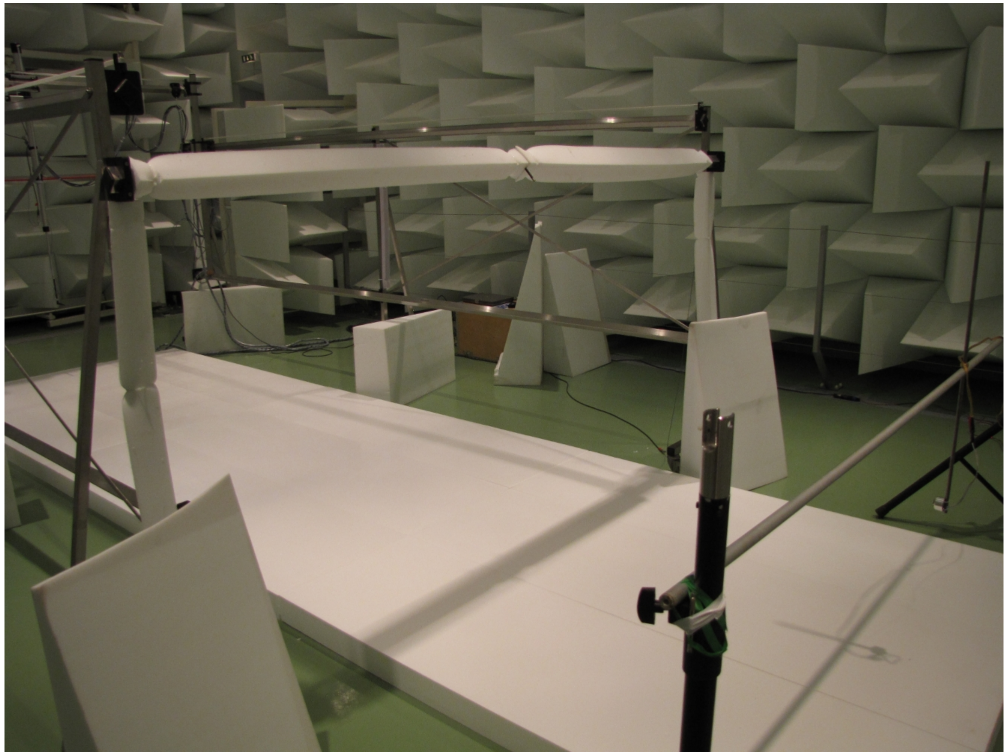
• 55m gaussian rough profile carved at scale 1/10 in two sets of polystirene boards (1 set = 9 boards, 2m x 0.6m)

• The two sets of rough boards are coated with epoxy resin. One is left uncovered to make it reflective, the other one is covered with 1mm layer of felt to make it absorbing.



II.3 – Flat surfaces

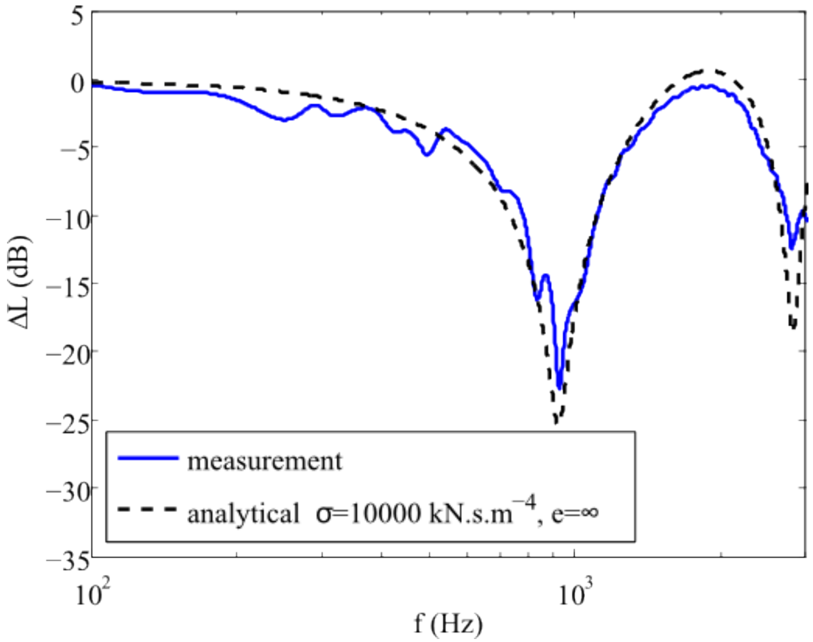
- Flat reflective and absorbing surfaces are also considered



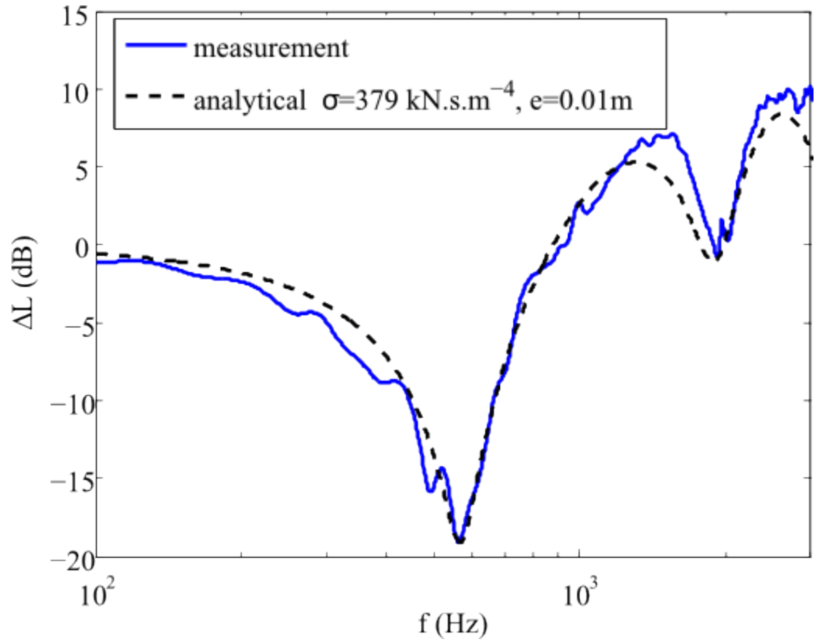
III.1 – Preliminary measurements

• The impedance of the flat surfaces is measured by a two-microphone technique, reproduced at scale 1/10.
• Miki model with thickness is considered.

Reflective flat surface

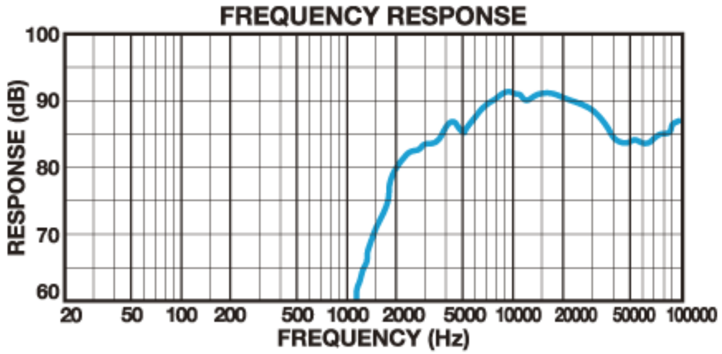


Absorbing flat surface



III.2 – Devices

- Source : Clarion SRH292HX tweeter

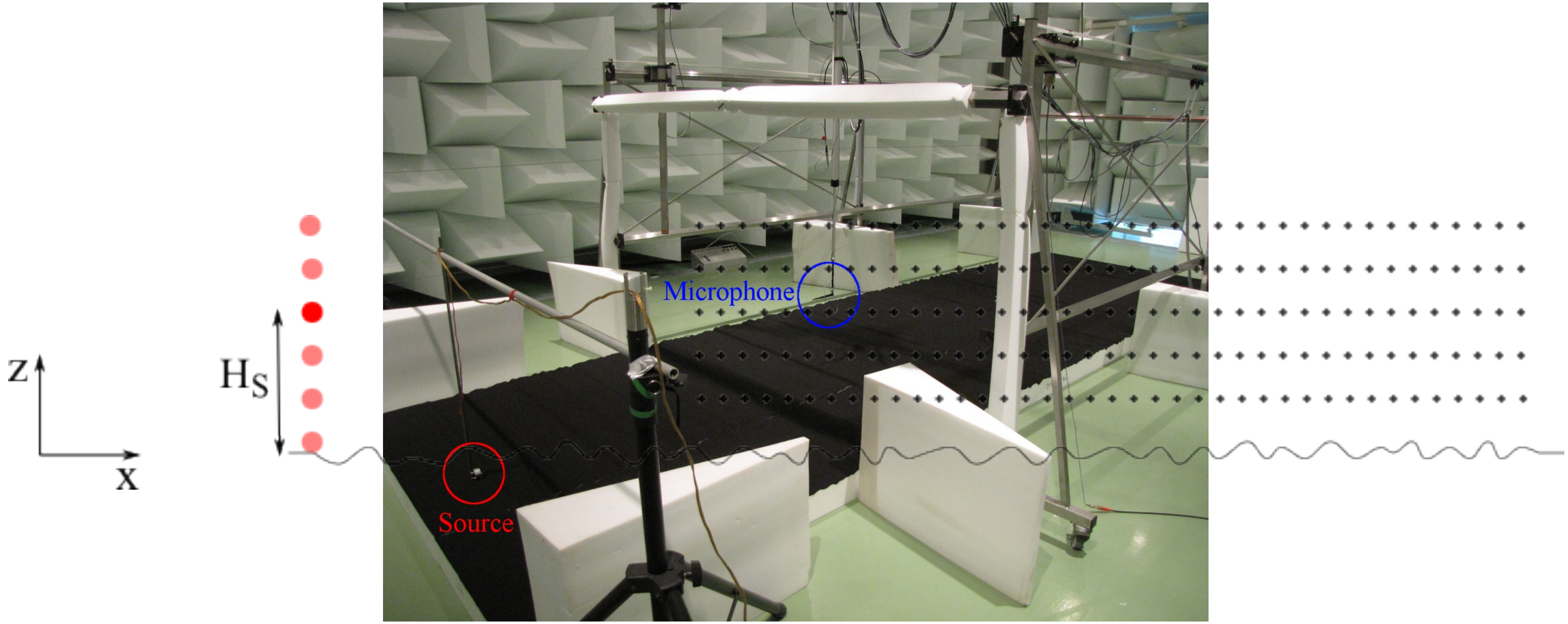


- Microphone : ¼” B&K 4961 multi-fields

Sensibility : 60 mV/Pa
Frenquency range : 5 Hz -20 kHz
Dynamic : 20 -130 dB

- White noise emitted, impulse responses obtained using B&K PULSE LabShop
- Frequency range of interest at full scale 200Hz-2000Hz

III.3 – Measurements configuration



- 6 source heights H_S : 0.2, 1, 2, 3, 4, 5m
- The microphone position is controled by an automatic system
- 5 microphone heights H_R : 1, 2, 3, 4, 5m
- For each source height : d=17, 18, …54, 55m (all distances expressed at full scale)
- In total 1170 measurement points for each surfaces (reflecting and absorbing)

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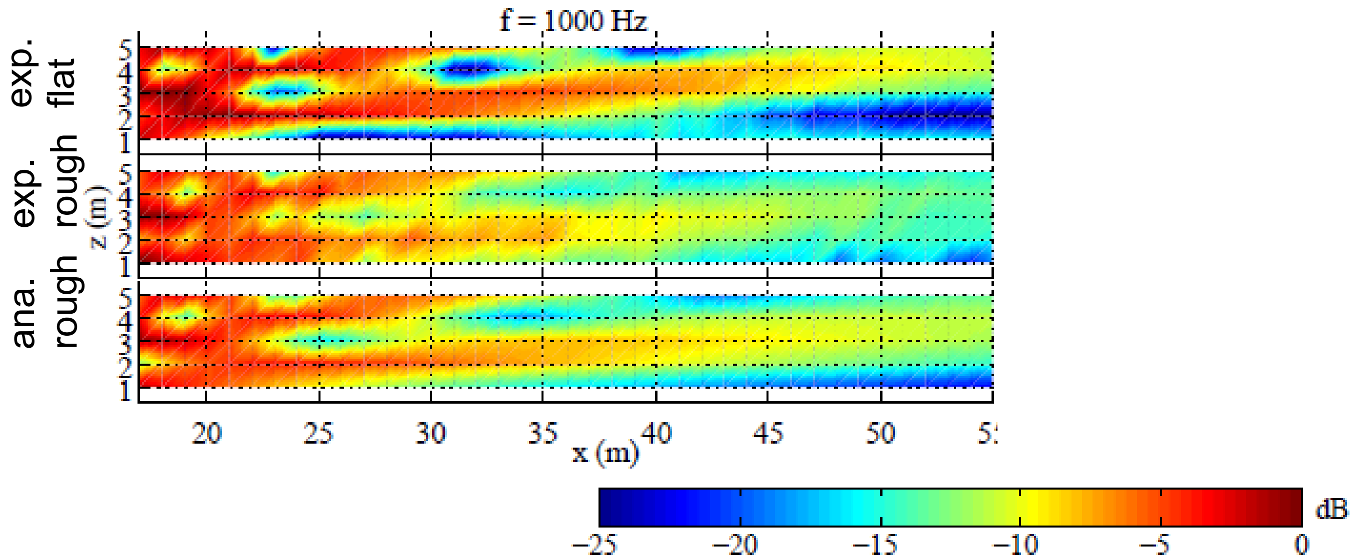
IV. Results in frequency-domain

IV.1 – Reflective surfaces

- H_S=2 m

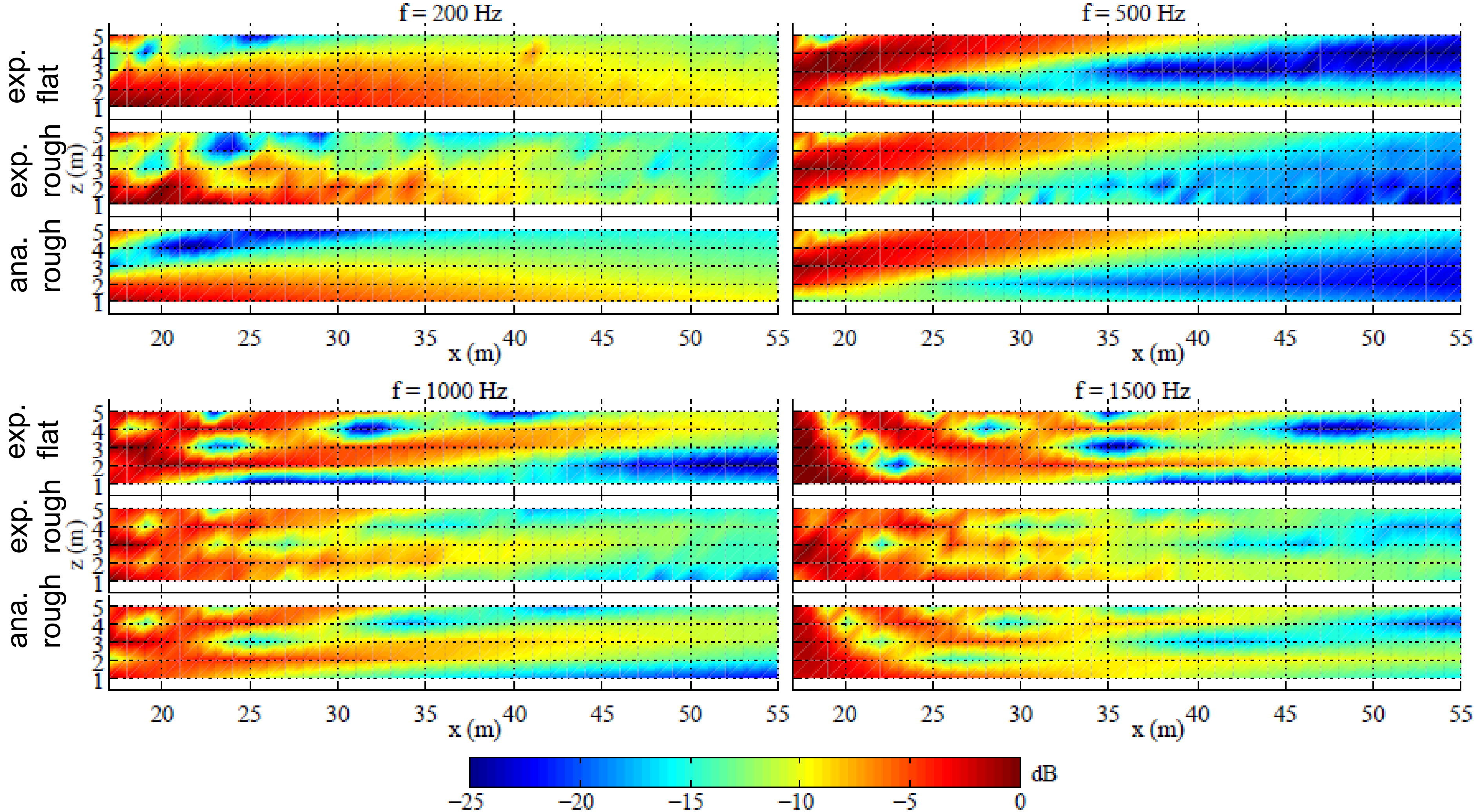


SPL relative to free field at 1m

IV. Results in frequency-domain

IV.1 – Reflective surfaces

- H_S=2 m



SPL relative to free field at 1m

IV. Results in frequency-domain

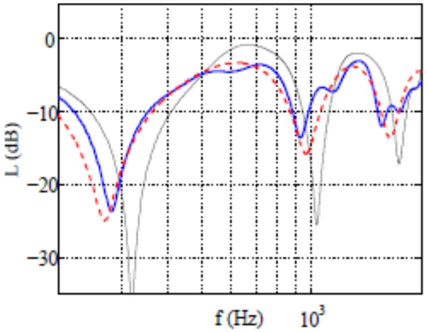
IV.1 – Reflective surfaces

- H_S=2 m

$d = 25$ m $\quad$ $d = 40$ m $\quad$ $d = 55$ m

$H_R = 5$ m

$H_R = 3$ m



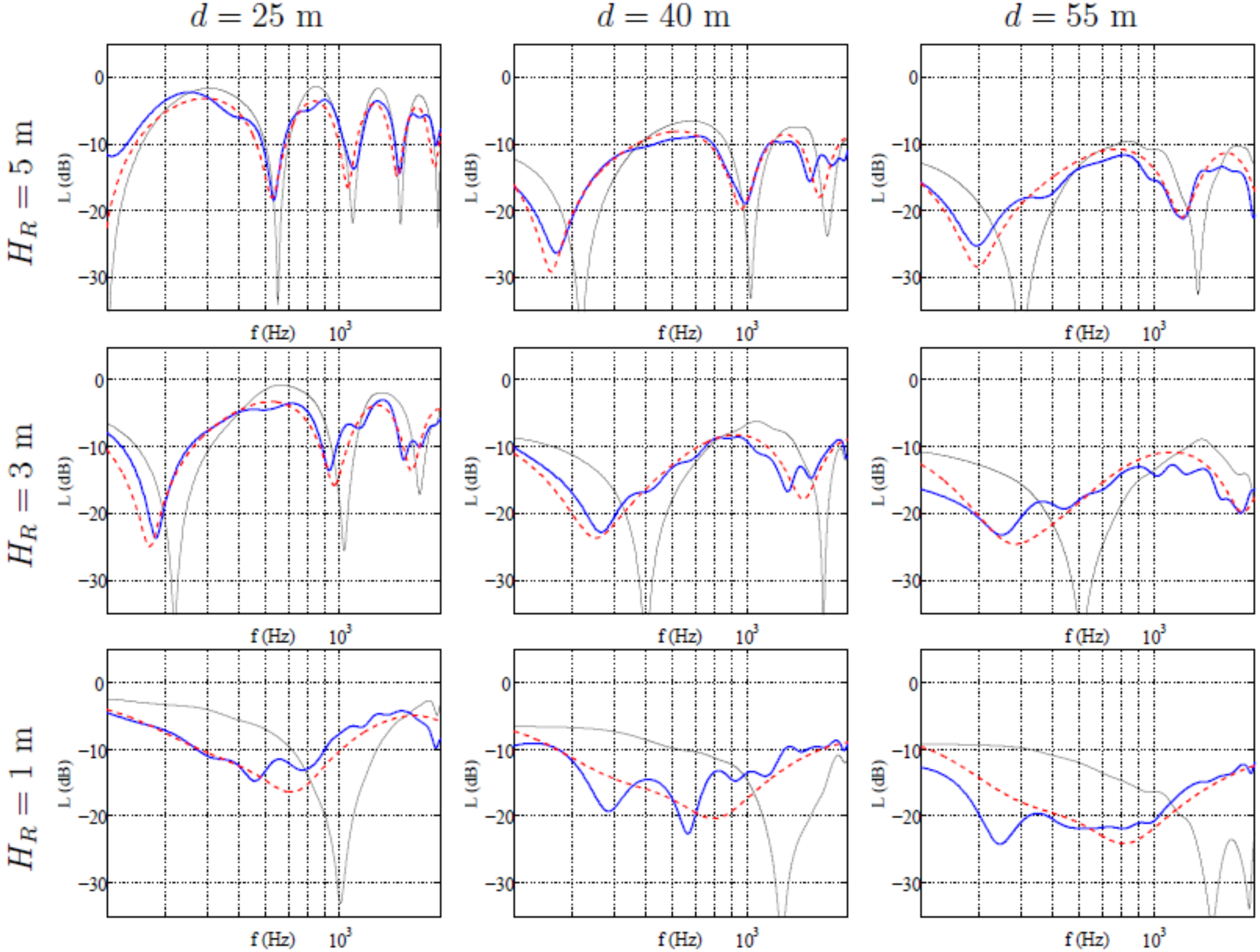
$H_R = 1$ m

SPL relative to free field at 1m

IV. Results in frequency-domain

IV.1 – Reflective surfaces

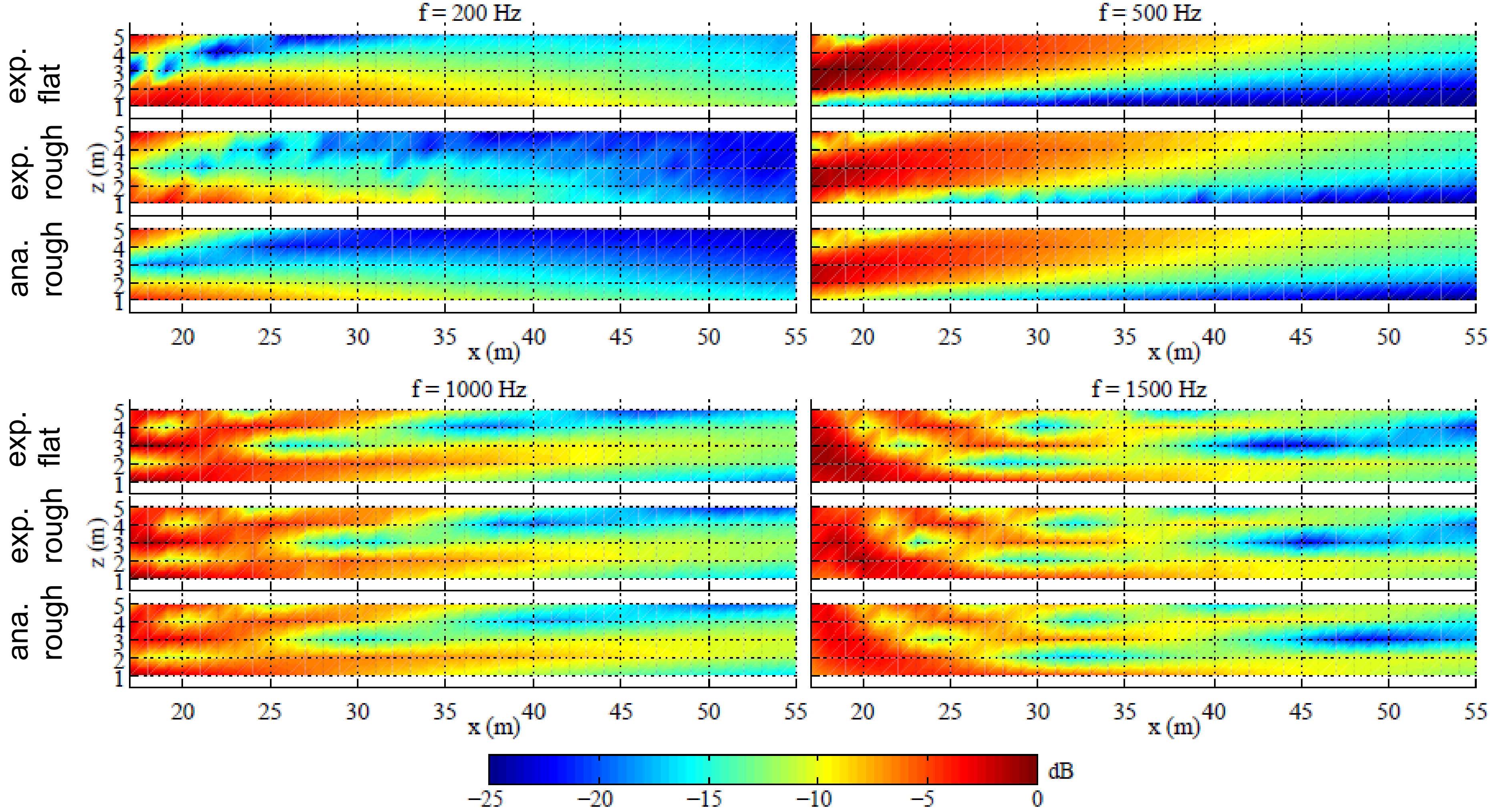
- H_S=2 m



SPL relative to free field at 1m

IV.2 – Absorbing surfaces

- Elevated source (H_S=2 m)



SPL relative to free field at 1m

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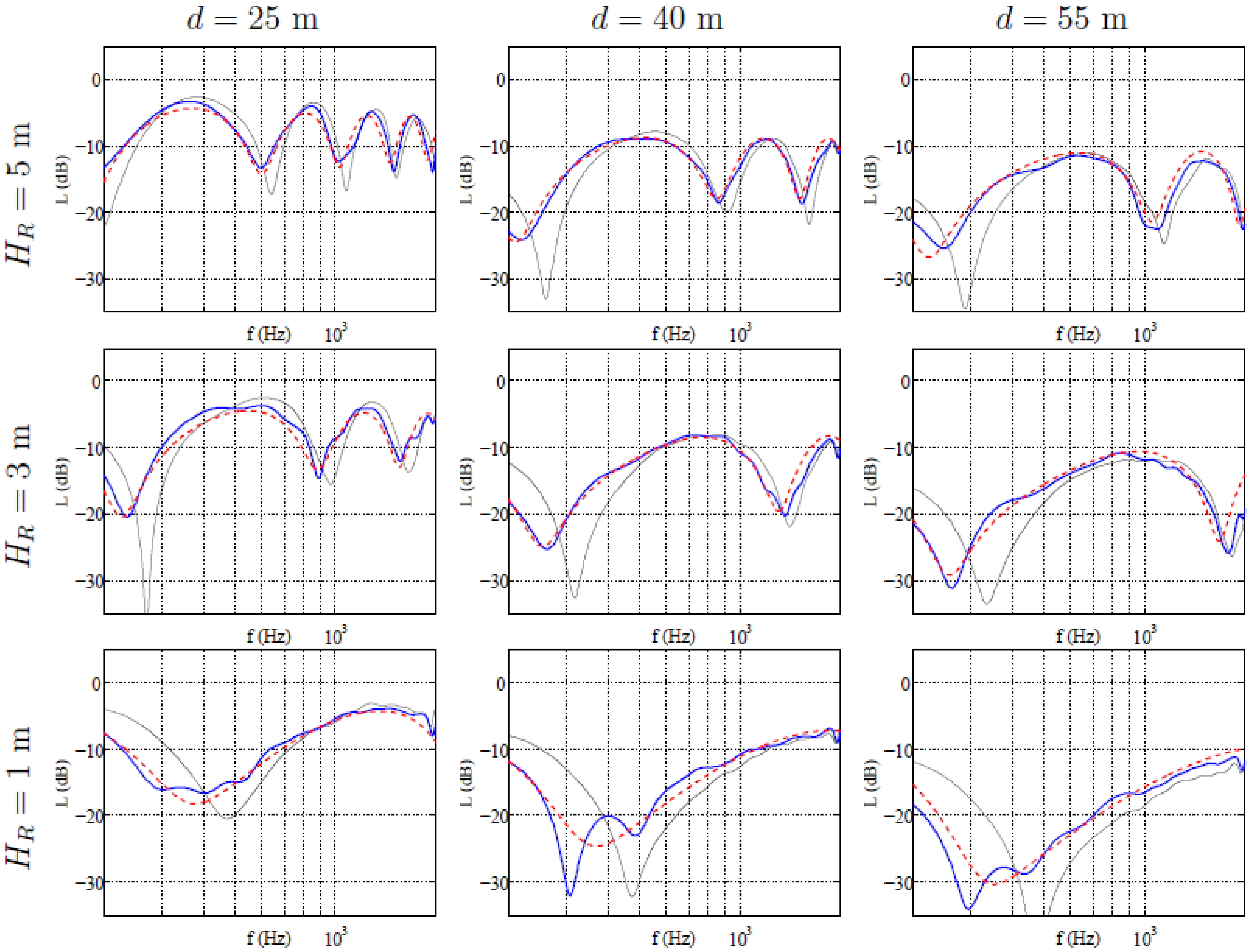
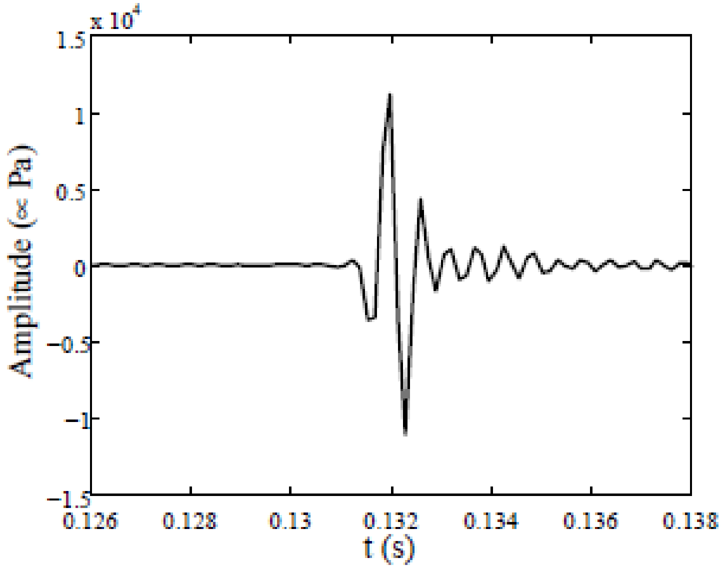


SPL relative to free field at 1m

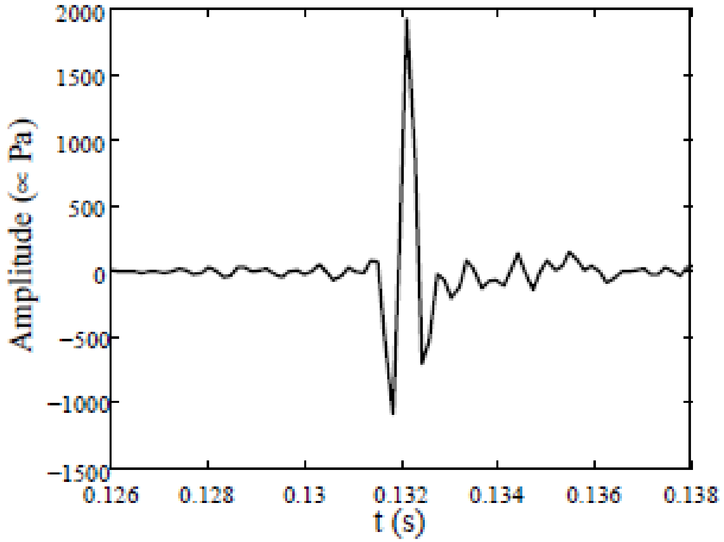
V. Results in time-domain

V.1 – Experimental results (reflective surfaces)

Flat reflective

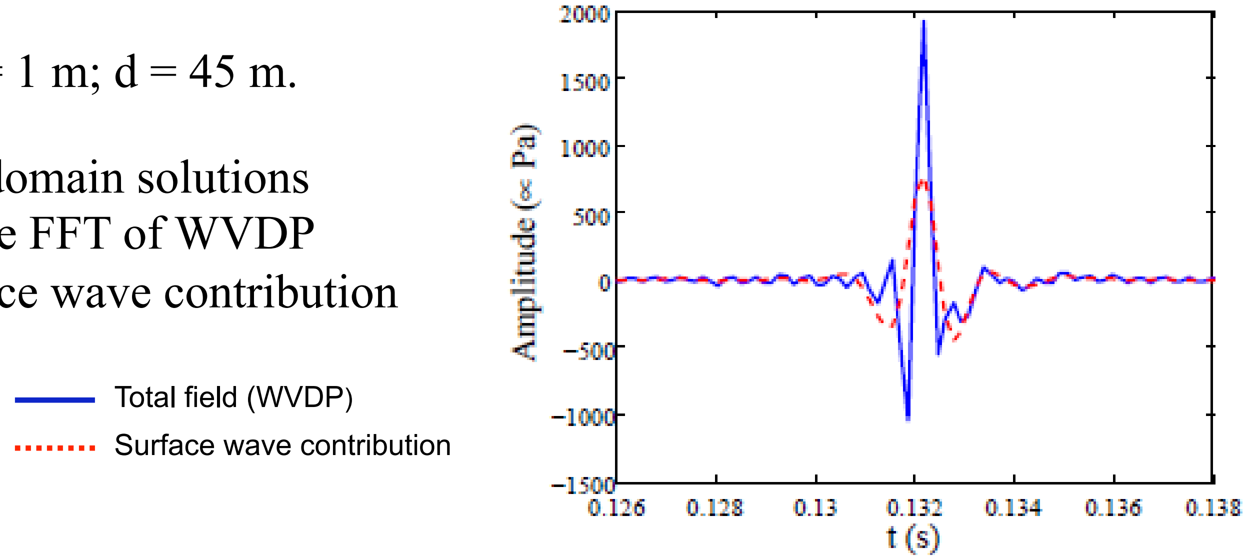


Rough reflective



- H_S = 0.2 m; H_R = 1 m; d = 45 m.

- Analytical time-domain solutions obtained by inverse FFT of WVDP equation and surface wave contribution

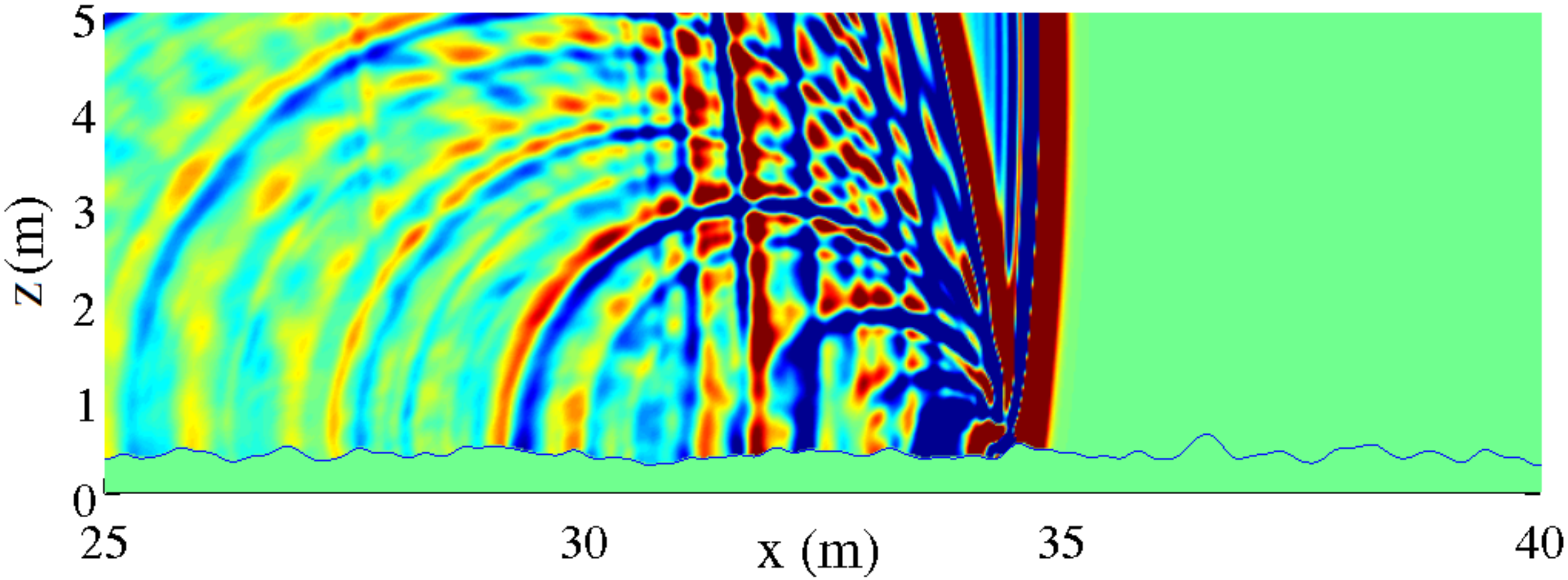


V.2 – Complementary numerical simulations (1/2)

- 2D TLM simulations[5] of a pulse propagation above a gaussian rough profile have been performed, in order to identify the roughness induced surface wave

- More pronounced roughness considered : σ_h=0.1m and l_c=0.2m

- Acoustically hard surface



[5] G. Guillaume and B. Gauvreau, Effect of input data in the impact studies of road traffic noise in a time-domaine model, In Proceedings of Internoise 2014, Melbourne, Australia

Conclusions

• The SPM effective impedance model takes into account the mean effects of a random roughness (defined by a roughness spectrum)

• A measurements campaign above a rough surfaces was performed in semi-anechoic chamber in order to validate this model

• The effects of roughness on SPL are correctly modeled (even for one random realization of a rough profile)

• The deformation of the signal shape and the roughness induced surface wave are correctly taken into account

Perspectives :

→ Application to 3D cases and with mean flows

→ SPM model can be used in reference numerical models and engineering methods

→ Need for data on ground roughness

→ Propagation above sea (Elfouhaily sea spectrum)

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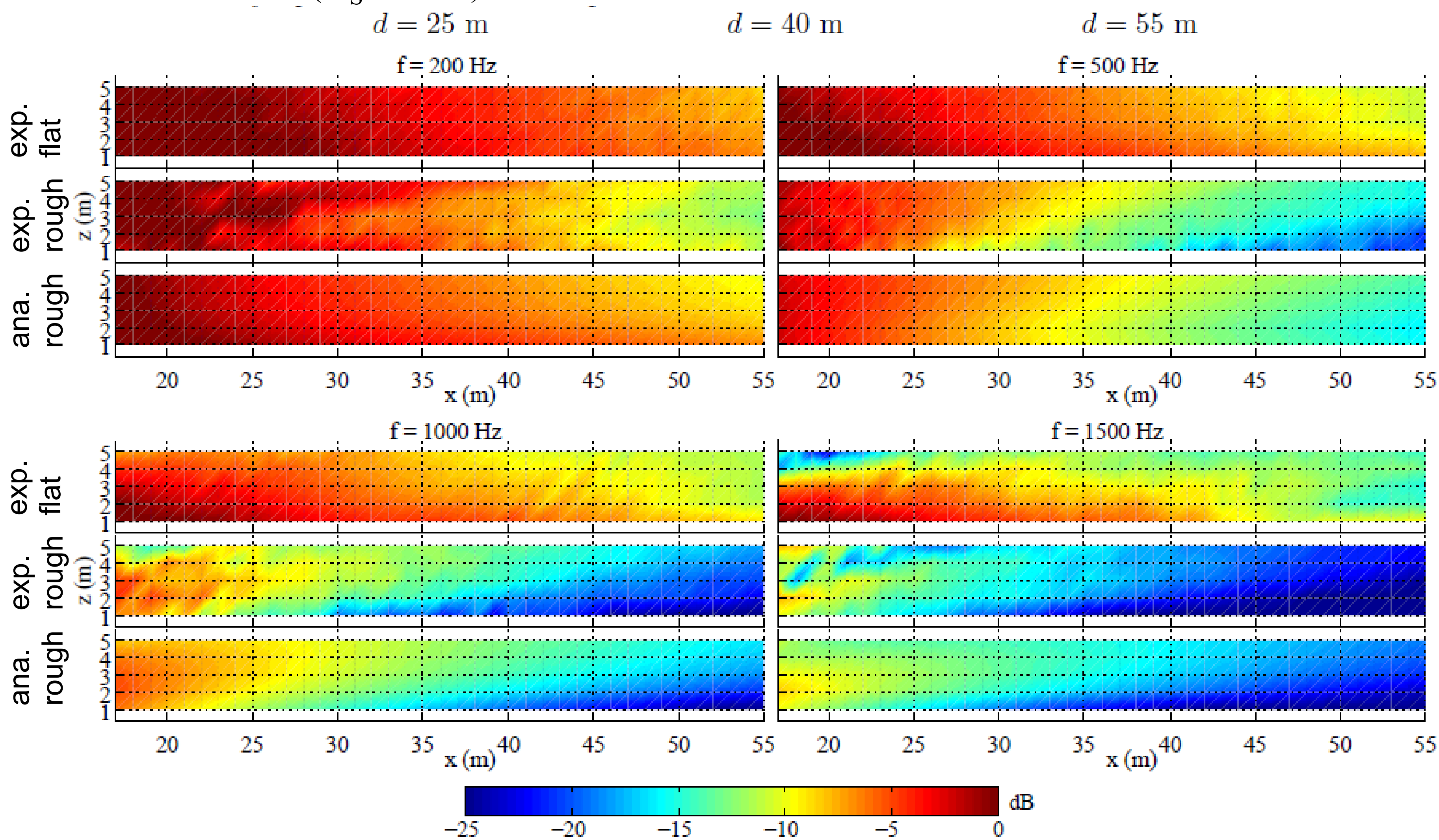
En savoir + : mémoire de thèse O. Faure
https://tel.archives-ouvertes.fr/tel-01132517

IV. Results in frequency-domain

IV.1 – Reflective surfaces

• Low source (H_S=0.2 m)

SPL relative to free field at 1m

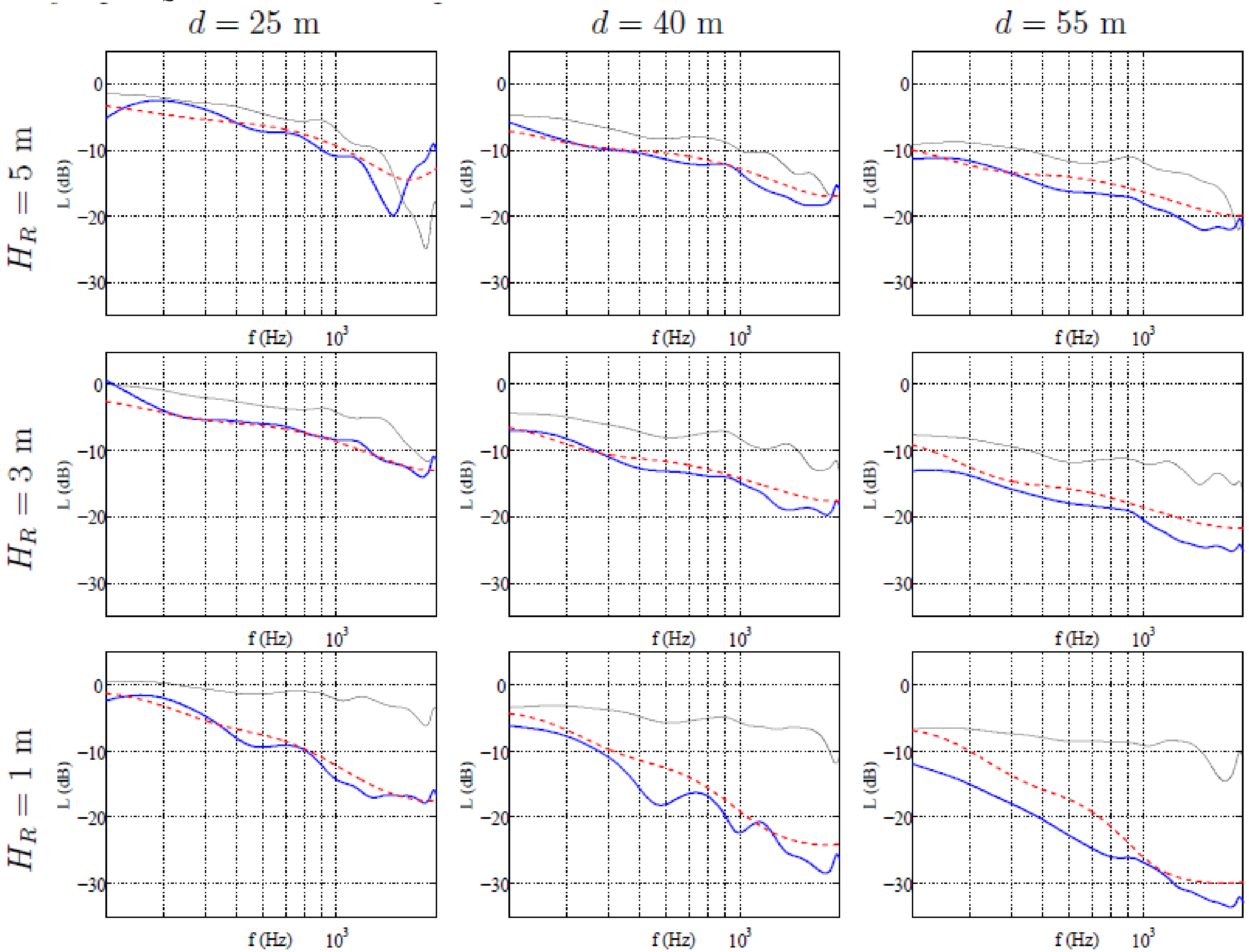


IV. Results in frequency-domain

IV.1 – Reflective surfaces

- Low source (H_S=0.2 m)

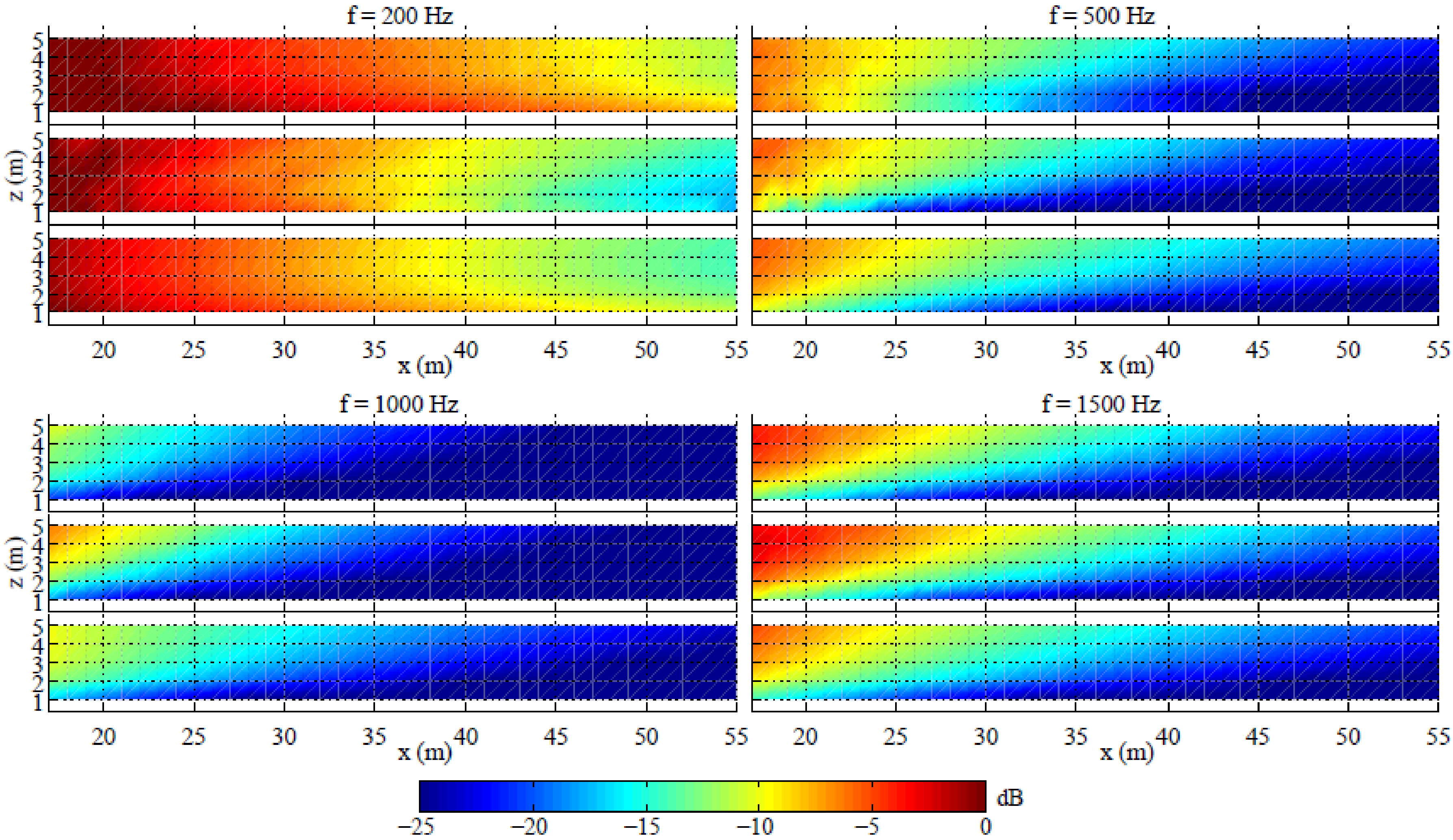
SPL relative to free field at 1m



IV. Results in frequency-domain

IV.2 – Absorbing surfaces

• Low source (H_S=0.2 m)



IV. Results in frequency-domain

IV.2 – Absorbing surfaces

- Low source (H_S=0.2 m)