



forum **acusticum** 2023

Transmission Line matrix method for sound propagation modelling in forests: comparison with in-situ measurements

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10th Convention of the European Acoustics Association

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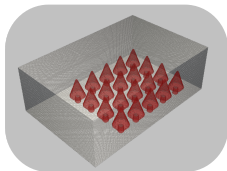
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- Introduction & context
- *Transmission Line Matrix* (TLM) numerical model
- Geometric modeling from a forest survey
- Experimental campaign from MNHN [Hauptert et al., 2023]
- Simulation setup
- Results of the comparison with the “Nouragues” forest experiment
- Conclusion & perspectives

- Biodiversity crisis: [Rigal et al., 2023]
 - -25% birds population overall (1996-2016)
 - -60% in farmlands
 - -18% in forests
- European directive [2002/49/EC]:
protection of quiet areas
- Acoustic propagation in forest environments
 - Multi-scale
 - Multiple scatterers
 - Impedance boundary conditions
- Various sources



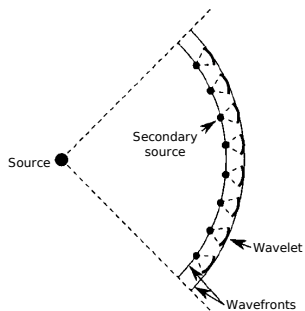
History

Transmission Line Matrix model (TLM)

Introduced to model high-frequency magnetic fields
[Johns and Beurle, 1971].

- Time-domain method (3D, complex geometries, impedance boundary conditions)
- Validated and/or studied for
 - Room acoustics [Guillaume, 2009]
 - Propagation in urban areas [Guillaume et al., 2008]
 - Propagation through parallel cylinder(s) above a horizontal plane [Chobeau et al., 2017]
- Python/OpenCL parallelized on GPUs [Guillaume and Fortin, 2014]

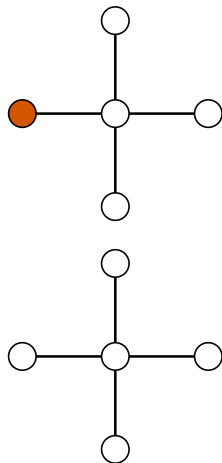
Basis



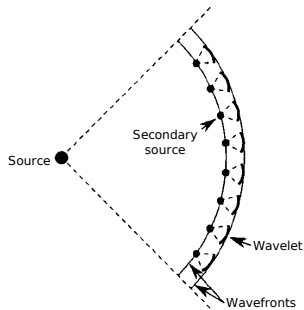
Huygens-Fresnel principle

[Guillaume, 2009, Chobbeau, 2014].

⊕ detailed: [Goestchel et al., 2022]



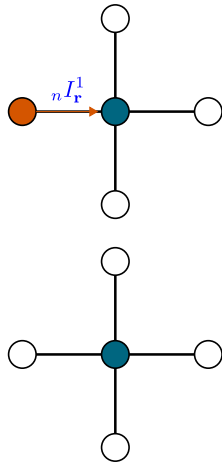
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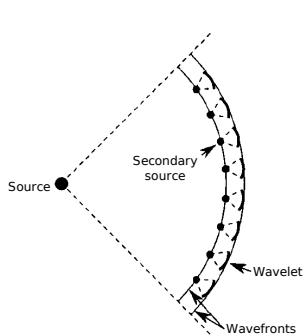
Huygens-Fresnel principle

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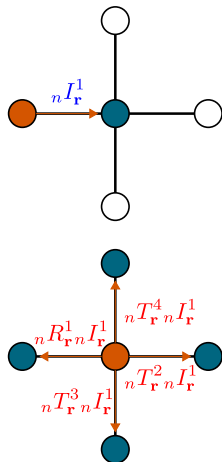
Basis



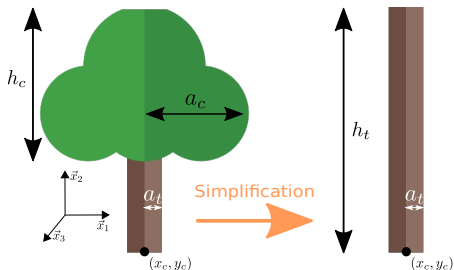
Huygens-Fresnel principle

[Guillaume, 2009, Chobea, 2014].

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Trees description



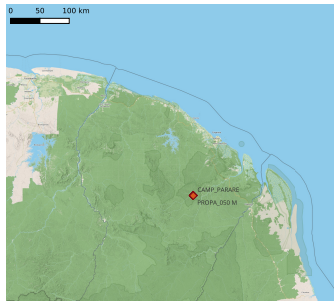
Simplification of tree descriptive parameters.

Parameter	Formalism
Trunks center coordinates	x_c, y_c
Tree height	h_t
Trunks radius	a_t
Canopy radius (approx.)	a_c
Canopy height	h_c
Tree species	"species"

Geometric parameters' description. Canceled parameters are the ones not considered in the TLM simulations.

Dataset from in-situ survey: CNRS “Nouragues” research station

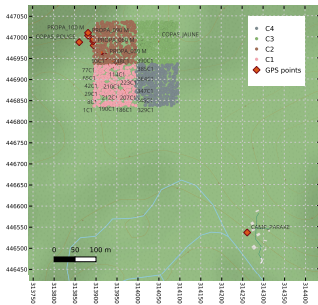
- Tree localization provided by Evolution and Biological Diversity laboratory (EDB), Toulouse III University.
 - Part of the COPAS project in French Guiana
 - 1851 trees with radii $a_t \in [0.016 - 1.43]$ meters



Tree inventories of Nouragues nature reserve, French Guiana.

Dataset from in-situ survey: CNRS “Nouragues” research station

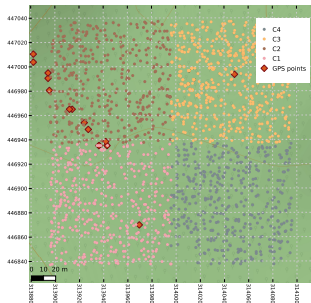
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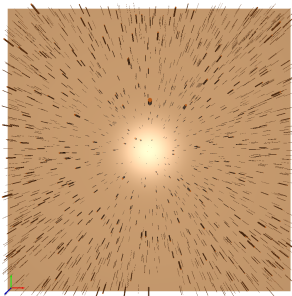
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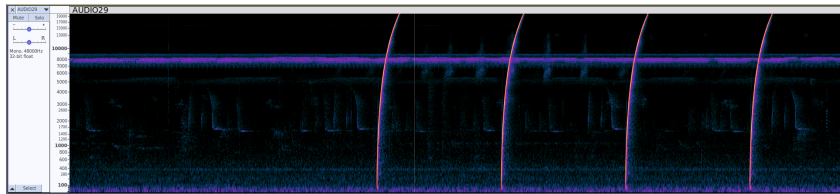
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Tree inventories of Nouragues nature reserve, French Guiana.

French National Museum of Natural History Campaign

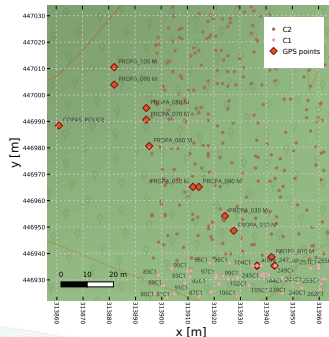
- Recordings provided by the *Institut de Systématique, Evolution, Biodiversité* (ISYEB)
- Described in detail in [Hauptert et al., 2023]
- In brief:
 - 1 source, 1 microphone (Svantek sonometer)
 - 10 source-receiver distances (1-100m)
 - 3 sequences, 4 repetitions at each distance



Spectrogram of the experimental measurements at 1 m, ≈ 35 s display.

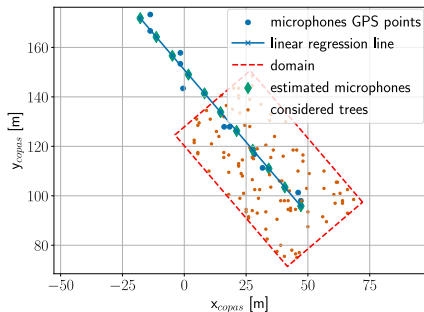
Geometric reproduction process

- GPS points accuracy is questionable
- Approximations made:
 - axis of the coordinates of the trees, one tree as reference
 - regression line between GPS points to place the microphones



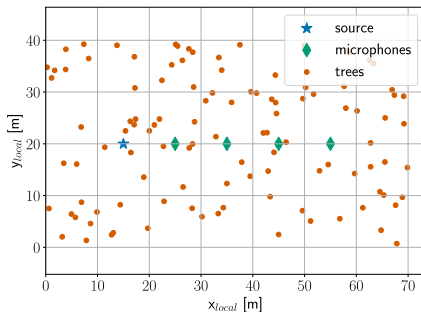
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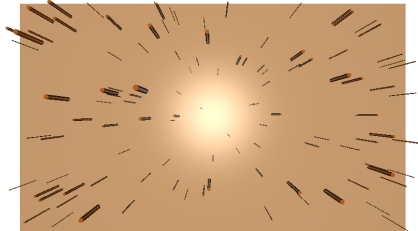
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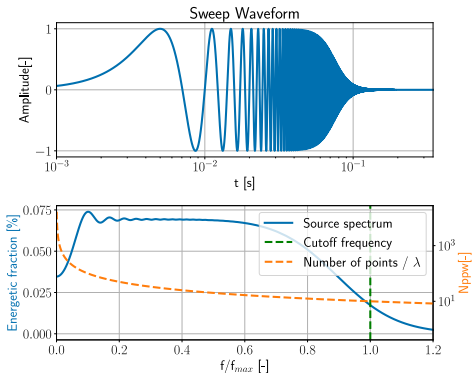
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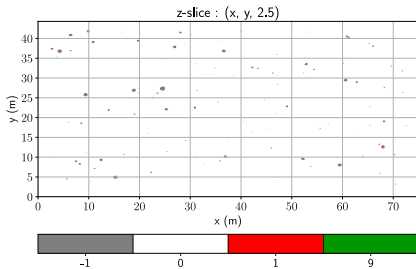
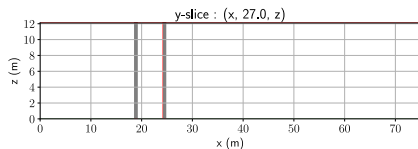
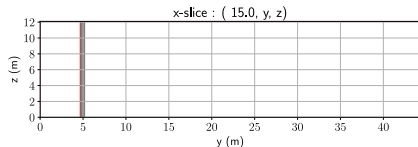
Sound source

- Experimental sound source: JBL Xtreme 2 loudspeaker
- Numerical sound source: monopolar point source with time-domain support



Filtered Sweep ($f_{max} = 1500$ Hz).

Computational domain



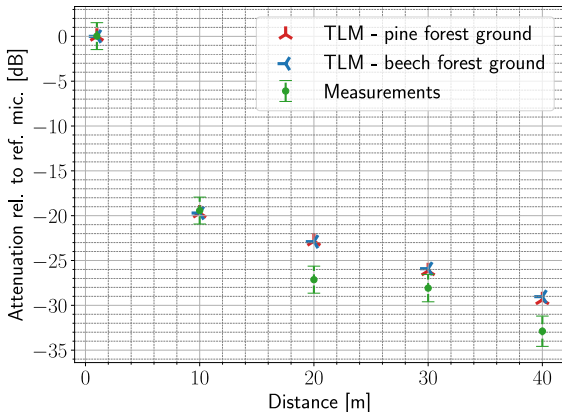
$\Delta \ell$ (m)	Δt (s)	$N_x \times N_y \times N_z$	Memory (GB)	t_{comp} (h)	$r_{\text{max}}/\lambda_{\text{min}}$
2.29e-02	3.90 e-05	3265 × 1931 × 527	6.65 Gb	97.25	174

Configuration for the 3D simulation setup with $f_{\text{max}} = 1500$ Hz, $N_{\text{ppw}} = 10$ and the source-receiver distance $r_{\text{max}} = 40$ m.

Time-domain simulation

- Low frequency simulation, Windowed Chirp source $f = 400$ Hz, view from above.

Comparison of the attenuation relative to a reference microphone



Results Comparison for a simulation with $f_{\max} = 1500$ Hz.

- Encouraging comparison between time-domain method and experimental results
 - Frequency analysis needed for the comparison
 - High-frequency limitation due to computational burden
-
- Effective wavenumber method [Ostashev et al., 2017] adaptation to time-domain methods for foliage modeling
 - Dedicated experimental campaign for more comprehensive comparisons
 - Calculation of detection spaces for bioacoustic [Guibard et al., 2022]



Attenborough, K., Bashir, I., and Taherzadeh, S. (2011).

Outdoor ground impedance models.

The Journal of the Acoustical Society of America, 129(5):2806–2819.



Chobeau, P. (2014).

Modeling of Sound Propagation in Forests Using the Transmission Line Matrix Method: Study of Multiple Scattering and Ground Effects Related to Forests.

PhD thesis.



Chobeau, P., Guillaume, G., Picaut, J., Ecotière, D., and Dutilleul, G. (2017).

A Transmission Line Matrix model for sound propagation in arrays of cylinders normal to an impedance plane.

Journal of Sound and Vibration, 389:454–467.



Goestchel, Q., Guillaume, G., Ecotière, D., and Gauvreau, B. (2022).

Analysis of the numerical properties of the transmission line matrix model for outdoor sound propagation.

Journal of Sound and Vibration, 531:116974.



Guibard, A., Sèbe, F., Dragna, D., and Ollivier, S. (2022).

Influence of meteorological conditions and topography on the active space of mountain birds assessed by a wave-based sound propagation model.

The Journal of the Acoustical Society of America, 151(6):3703–3718.



Guillaume, G. (2009).

Application de La Méthode TLM à La Modélisation de La Propagation Acoustique En Milieu Urbain.

PhD thesis.



Guillaume, G. and Fortin, N. (2014).

Optimized transmission line matrix model implementation for graphics processing units computing in built-up environment.
Journal of Building Performance Simulation, 7(6):445–456.



Guillaume, G., Picaut, J., and Dutilleul, G. (2008).

Use of the transmission line matrix method for the sound propagation modeling in urban area.
The Journal of the Acoustical Society of America, 123(5):3924–3924.



Hauptert, S., Sèbe, F., and Sueur, J. (2023).

Physics-based model to predict the acoustic detection distance of terrestrial autonomous recording units over the diel cycle and across seasons: Insights from an Alpine and a Neotropical forest.
Methods in Ecology and Evolution, 14(2):614–630.



Johns, P. and Beurle, R. (1971).

Numerical solution of 2-dimensional scattering problems using a transmission-line matrix.
Proceedings of the Institution of Electrical Engineers, 118(9):1203–1203.



Ostashev, V. E., Wilson, D. K., and Muhlestein, M. B. (2017).

Effective wavenumbers for sound scattering by trunks, branches, and the canopy in a forest.
The Journal of the Acoustical Society of America, 142(2):EL177–EL183.



Rigal, S., Dakos, V., Alonso, H., Auniš, A., Benkő, Z., Brotons, L., Chodkiewicz, T., Chylarecki, P., de Carli, E., del Moral, J. C., Domša, C., Escandell, V., Fontaine, B., Foppen, R., Gregory, R., Harris, S., Herrando, S., Husby, M., Ieronymidou, C., Jiguet, F., Kennedy, J., Klvaňová, A., Kmecl, P., Kuczyński, L., Kurlavičius, P., Kålås, J. A., Lehikoinen, A., Lindström, Å., Lorrillière, R., Moshgij, C., Nellis, R., Noble, D., Eskildsen, D. P., Paquet, J.-Y., Pélissié, M., Pladevall, C., Portolou, D., Reif, J., Schmid, H., Seaman, B., Szabo, Z. D., Szép, T., Florenzano, G. T., Teufelbauer, N., Trautmann, S., van Turnhout, C., Vermouzek, Z., Vikstrøm, T., Voříšek, P., Weiserbs, A., and Devictor, V. (2023).
Farmland practices are driving bird population decline across Europe.
Proceedings of the National Academy of Sciences, 120(21):e2216573120.

Thank you for listening!

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Unité Mixte de Recherche en Acoustique Environnementale (UMRAE) is a joint research unit in environmental acoustics between Gustave Eiffel University & CEREMA.



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Appendix

10th Convention of the European Acoustics Association

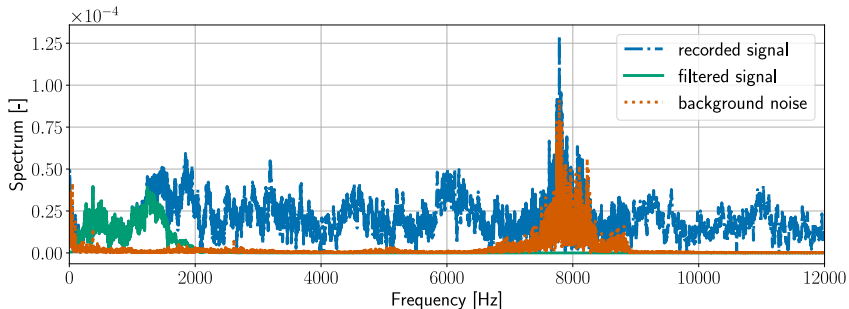
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Time-domain simulation

- Low frequency simulation, Gaussian pulse source $f = 400$ Hz, view from above.

Pre-processing of experimental & simulation data



Spectrums of recorded sweep signals at 10 m from the source before filtering (blue dash-dotted) and after filtering (green). Ambient noise (orange dotted).

Impedance characteristics

Ground parameter	σ_0 [kPa.s.m ⁻²]	Ω [-]
#10, table VII [Attenborough et al., 2011] pine forest	102.5	0.58
34, table VIII [Attenborough et al., 2011] beech forest	22.5	0.50

Bark parameter	σ_0 [kPa.s.m ⁻²]	Ω [-]
Oak bark measurements	50.00×10^3	0.5
Test value (more absorbing)	10.00×10^3	0.5

Parameters for “slit-pore” (semi-infinite) model: (left) Ground parameters, (right) Bark parameters.