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EXTENDED ABSTRACT

Evaluation of ground relaxation parametrization over complex terrain and experimental validation for pollutant dispersion: application to the CERN Meyrin site

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Motivation and Objectives

Accurately modelling accidental pollutant dispersion over complex terrain is essential for industrial risk assessment and emergency response planning, particularly near sensitive or populated sites. Computational Fluid Dynamics (CFD) has become a key tool in this context, offering high-resolution flow and dispersion predictions. However, the reliability of these predictions depends heavily on boundary conditions and terrain representations, especially when complex topographies are involved (Lateb et al., 2016).

With the increasing availability of high-resolution digital elevation models and geospatial datasets (Yu et al., 2025), CFD models now have access to detailed topographic inputs, including both terrain and buildings. While this enables more accurate representations of real-world environments, it also introduces challenges in terms of mesh size, boundary condition definition, and overall computational cost. Capturing all geometric detail across large domains is often infeasible, forcing trade-offs between fidelity and efficiency.

One of the most critical components of CFD setup in complex terrain is the treatment of boundary inflow and the upstream development of the atmospheric boundary layer (ABL) (Tominaga et al., 2016). The far-field wind may be known, but its evolution over heterogeneous terrain toward the area of interest is uncertain; inconsistent treatment, especially near lateral boundaries, can induce streamwise gradients and horizontal inhomogeneities that degrade physical reliability (Tominaga et al., 2016). To mitigate this, computational domains often include transition regions where the flow develops over simplified terrain before reaching the core area. We refer to these as terrain-relaxation zones: buffer regions that gradually blend real topography into an idealized surface. Buildings and terrain are explicitly resolved in the central region, while upstream and downstream zones represent them implicitly via roughness parameters, notably the aerodynamic roughness length (z_0). Figure 1 illustrates this conceptual structure, highlighting the succession of relaxation zones, roughness parameters, and the central zone where buildings and terrain are fully modelled. In current practice, the extent and formulation of relaxation zones are typically determined ad-hoc by modeller experience or constraints, leading to non-reproducible setups and sub-optimal domain sizes that can distort the incident wind field.

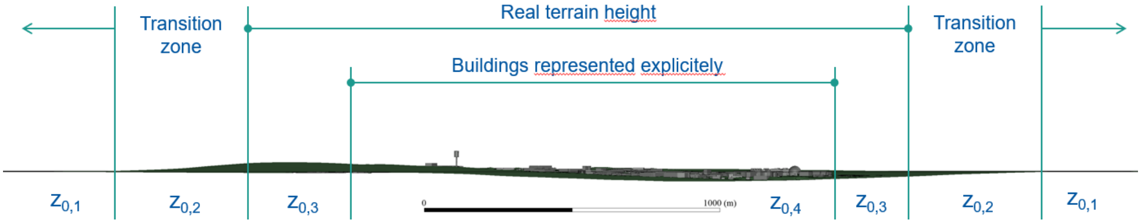

Figure 1. Cross section of the CERN Meyrin CFD domain partitioning with terrain-relaxation zones. Upstream and downstream transition zones ($z_{0,1}$ and $z_{0,2}$) gradually blend an idealized surface into the real topography. The central region contains the fully resolved terrain height ($z_{0,3}$ and $z_{0,4}$) and explicitly modelled buildings ($z_{0,4}$).

The objective of this study is to define a systematic methodology for parametrizing terrain-relaxation zones in steady-state CFD simulations of atmospheric flow and pollutant dispersion over complex terrain. We focus on domains using the Reynolds-Averaged Navier–Stokes (RANS) equations with a standard k–ε turbulence model (Launder and Spalding, 1974) and wall-function approaches compatible with z_0 formulations. Our goal is to provide practical recommendations for domain extent, relaxation offset, and relaxation length that ensure consistent flow development while minimizing unnecessary domain growth and computational cost.

This methodology is intended to support robust, reproducible CFD setups in environmental risk modelling, with direct applicability to industrial safety scenarios involving accidental airborne releases around complex terrain. We present the structured parametrization and its validation using wind-tunnel experiments, progressively testing the influence of relaxation parameters, surface roughness, and domain design on flow and concentration fields, from idealized configurations to realistic large-scale applications.

Methodology

In the first phase, a two-dimensional parametric analysis uses idealized sinusoidal terrain profiles. Steady RANS simulations (k–ε turbulence model with wall-function) evaluate the effects of relaxation-zone offset and length. Flow development is examined via velocity-profile deviation, separation behaviour and streamwise homogeneity to identify parameter ranges that limit boundary artefacts while containing domain size. The terrain relaxation is implemented using a radial cosine blending function centred at (x_c, y_c) and varying from 1 (fully modelled terrain) to 0 (fully relaxed/flat surface) across the relaxation area. The relaxed height is obtained by linearly blending original terrain and a baseline using this weight and two defined radii, producing a continuous transition that avoids geometric or roughness discontinuities.

In the second phase, the methodology extends to fully three-dimensional domains with idealized terrain. These simulations test the robustness of the proposed parametrization strategy under complex flow conditions, and evaluate potential asymmetries, recirculation patterns, or turbulence amplification. This stage also includes preliminary coupling with the SLAM (Safety Lagrangian Atmospheric Model) model (Vendel et al., 2011), developed by the LMFA (Laboratoire de Mécanique des Fluides et d'Acoustique), to explore how upstream boundary treatment impacts concentration predictions.

The third stage of the study applies the methodology to a real case: the CERN Meyrin site. Topographic data are used to construct the domain, and the terrain-relaxation approach derived from the idealized cases is implemented. RANS simulations generate wind fields, which serve as input for SLAM to simulate accidental release scenarios.

A wind-tunnel experimental campaign has been conducted at École Centrale de Lyon, and a comparison with numerical results is done. The main objective of this experimental campaign is to serve as a baseline for the validation of numerical simulations.

An additional sensitivity analysis quantifies the impact of upstream surface roughness definitions on flow development. A subset of the 2D and 3D test cases is revisited using a range of roughness values (e.g. from 0.001 to 1 m), representing different land-use types classified according to CORINE Land Cover data (Feranec et al., 2016). The analysis assesses the influence of abrupt vs. gradual roughness transitions and evaluates whether simplified roughness assumptions significantly affect the conclusions of the previous tests. A longer-term objective is to automate the definition of roughness fields from land-cover maps using user-defined functions.

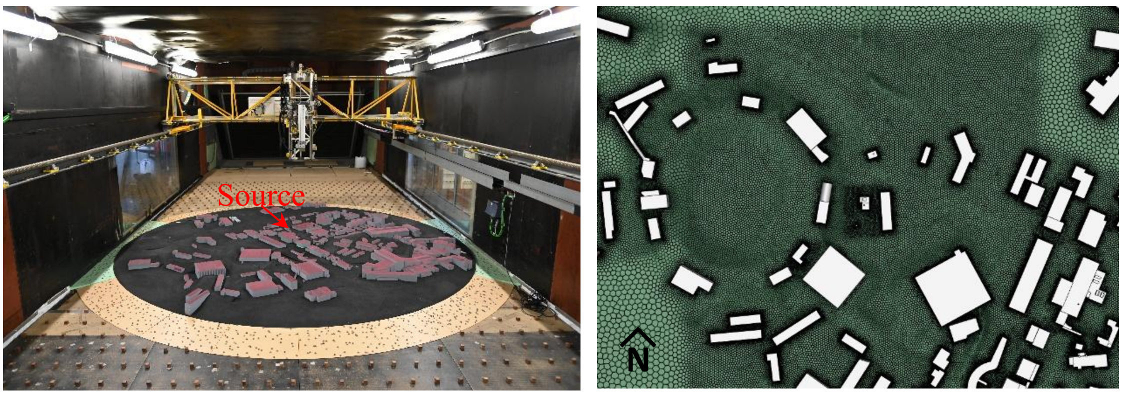

Figure 2. (a) Wind-tunnel CERN Meyrin mock up in the wind tunnel in Lyon, with the source placed in the center and, (b) numerical model of the same area in Ansys Fluent

Wind tunnel experiments

The experimental facility at École Centrale de Lyon is a recirculating wind tunnel with a test section of 14.0 m (length) x 3.8 m (width) x 2.0 m (height). A portion of the CERN Meyrin site was reproduced at a scale of 1:250 (Figure 2a), using a mock-up constructed and provided by Universität Hamburg. The upstream flow corresponds to a neutral surface boundary layer, characterised by a boundary-layer height of 0.8 m, a free-stream velocity of 5 m·s^{-1} and a friction velocity u* of 0.185 m·s^{-1}, following the configuration of Nironi (2013). Two source locations representative of CERN scenarios (ISOLDE and PS) were considered. Ethane was used as the released species, as with a density close to that of air behaves as a passive tracer; source momentum and buoyancy effects were negligible compared to the free flow. Concentration measurements were acquired with a flame ionisation detector (FID). Several hundred sampling points were taken per configuration at multiple downwind locations for each source. Measurements were performed for two wind directions (67° and 239°) to probe differing flow conditions.

Numerical results and comparisons

Eulerian RANS CFD simulations were performed using Ansys Fluent, using a k–ε turbulence model. The numerical domain (Figure 2b) represents a 5000 m x 5000 m x 450 m area. The mesh consists of around seven million of poly hexahedral elements, with grid minimum size of 0.3 meters on the source and one meter on the built area. Steady upstream meteorological profiles and source characteristics match the wind-tunnel configurations. Particle dispersion is computed with the Lagrangian SLAM model.

Buildings are explicitly modelled in an inner area of roughly 1000 m x 1500 m, with fully resolved terrain in a 1600 m radius of the release points and a transition zone of 1000 m.

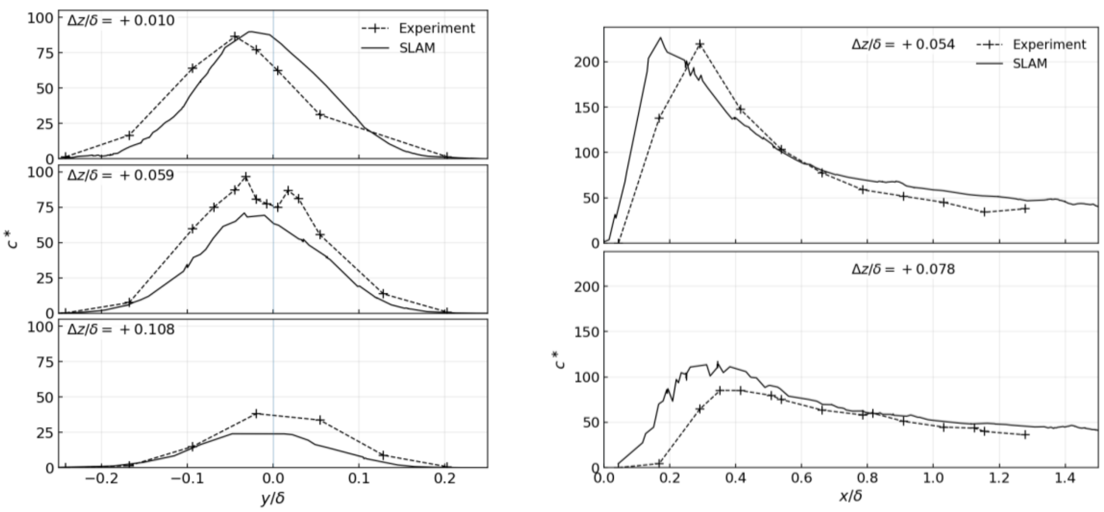

Figure 3. Profiles of adimensionalized concentrations at x/δ=0.65 (left) and y/δ=0 (right), for different heights.

Comparisons of concentration profiles at several downstream locations, in both vertical and transverse sections, show good qualitative agreement between numerical predictions and wind-tunnel measurements. Concentrations at different heights are represented in Figure 3, for a release from ISOLDE and a 67° wind direction, adimensionalized using $c^* = \delta^2\, U_\infty\, C\, Q_{gas}^{-1}$, being δ the BL height. Although the overall agreement between CFD and wind-tunnel results is satisfactory, a lateral asymmetry is seen towards the right of the plume, in particular at higher altitudes. This drift may be attributed to uncertainties related to the experimental campaign, including a slight inflow wind misalignment systematically present in the wind-tunnel, or to numerical factors, notably grid resolution and numerical diffusion or terrain-relaxation zone effects. Further sensitivity tests will be performed in order to investigate these discrepances.

Conclusions and perspectives

A methodology to assess the impact of terrain representation in CFD atmospheric dispersion studies is presented, and preliminary agreement is observed between the wind-tunnel campaign and the initial numerical simulations using a first implementation of terrain relaxation. The influence of the relaxation procedure on flow and concentration fields, the potential for domain-size optimisation, and the effect of more realistic aerodynamic roughness lengths remain under investigation. The planned 2D and 3D simplified scenarios will expand the study framework and inform the development of practical, recommendations for CFD setups in complex terrain. Future work will focus on quantifying discrepancies, extending sensitivity analyses, and automating roughness-field assignment for reproducible model implementations.

References

Feranec, J., Soukup, T., Hazeu, G., & Jaffrain, G. (Eds.). (2016). European Landscape Dynamics: CORINE Land Cover Data (1st ed.). CRC Press. https://doi.org/10.1201/9781315372860

Lateb, M., Meroney, R. N., Yataghene, M., Fellouah, H., Saleh, F., & Boufadel, M. C. (2016). On the use of numerical modelling for near-field pollutant dispersion in urban environments – A review. *Environmental Pollution, 208*(Part A), 271–283. https://doi.org/10.1016/j.envpol.2015.07.039

Launder, B. E., & Spalding, D. B. (1974). The numerical computation of turbulent flows. *Computer Methods in Applied Mechanics and Engineering, 3*(2), 269–289. https://doi.org/10.1016/0045-7825(74)90029-2

Chiara Nironi. Concentration fluctuations of a passive scalar in a turbulent boundary layer. Other. Ecole Centrale de Lyon, 2013. English. ⟨NNT : 2013ECDL0015⟩. ⟨tel-00964852⟩

Tominaga, Y., & Stathopoulos, T. (2016). Ten questions concerning modeling of near-field pollutant dispersion in the built environment. *Building and Environment, 105*, 390–402. https://doi.org/10.1016/j.buildenv.2016.06.027

Vendel, F., Soulhac, L., Méjean, P., Donnat, L., & Duclaux, O. (2011). Validation of the Safety Lagrangian Atmospheric Model (SLAM) against a wind tunnel experiment over an industrial complex area. In *Proceedings of the 14th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes*.

Yu, J., Li, Y., Bai, X. *et al.* A DEM super resolution reconstruction method based on normalizing flow. *Sci Rep* 15, 10681 (2025). https://doi.org/10.1038/s41598-025-94274-w