PhD offer - Laboratoire de recherche en Hydrodynamique Énergétique et Environnement Atmosphérique :

Title of PhD research project

Multiscale modelling of the influence of trees on urban microclimate and pollutant dispersion: from local to neighbourhood scale.

General context

In a context of global warming and urban population growth, preventing the health risks associated with heat waves and high exposure to anthropogenic pollutants is a major challenge. The introduction of trees in cities is often advocated as a means of regulating the urban heat island and improving thermal comfort. However, studies have shown the aerodynamic influence of trees which, in certain configurations, can reduce ventilation and the dispersion of pollutants emitted into the streets. The way in which trees, by modifying microclimatic variables, in turn modify the thermal stability of the atmosphere, the structure of the urban boundary layer and, consequently, the exchanges of mass, momentum and heat at the top of the canopy and in the street is poorly understood.

Cities adaptation strategies to regulate the urban microclimate and improve outdoor air quality must be based on a detailed understanding of the dynamic (wind and turbulence) and thermal interactions between the urban canopy and the atmospheric boundary layer. Numerical modelling of atmospheric flow in urban environments can be a suitable tool for this purpose, but still represents a major scientific challenge due to the multi-scale nature of interactions between large-scale turbulent movements, characteristic of the atmospheric boundary layer, and flows within the urban canopy, which are specific to each built environment. Moreover, the thermo-radiative behaviour of urban surfaces modifies not only the flow in streets and around buildings, but also the thermal stability of the lower atmosphere, its structure and turbulent transfer processes with the urban canopy. It is therefore particularly important to take these multi-scale and multi-physical processes into account in numerical modelling of urban microclimate and pollutant dispersion.

For a several years, the Dynamics of the Urban and Coastal Atmosphere (DAUC) team of the LHEEA has been developing an atmospheric boundary layer model adapted to the study of different scales (city, neighbourhoods, streets) and enabling the simulation of multi-scale unsteady exchanges governing transfer processes between the urban canopy and the atmosphere. For the city and atmospheric boundary layer scale, a drag-porosity approach has been developed to represent, at low computational cost, the influence of neighbourhood morphology on atmospheric boundary layer flow (Maché, 2012; Tavares et al. 2015; Bucquet et al., 2023). For the neighbourhood and roughness sublayer scales, an IBM (Immersed Boundary Method) approach has been implemented to simulate flows around buildings in greater detail. The joint use of the drag-porosity approach on extended domains and the IBM approach at the neighbourhood scale makes it possible to account for the multi-scale dynamic interactions that govern exchanges between the urban canopy and the atmosphere. This coupled approach has been successfully tested in the configuration of a cube canopy (without trees), under neutral atmospheric conditions (Bucquet, 2023). In line with previous work, we now plan to extend the capabilities of the atmospheric model by taking into account multi-process interactions (radiation, heat and moisture transfer, turbulence, etc.) between the atmosphere, trees and the built environment.

The doctoral research project is part of the ANR project CITRY (2024-2027) (Contribution of trees to urban microclimate and pollutant dispersion from local to city scale), which aims to assess the multi-scale influence of urban trees on microclimate and pollutant dispersion, from the street to the entire city and taking into account variations in atmospheric thermal stability. The doctoral research project proposed at LHEEA (Nantes, France) focuses on scales ranging from the street to the neighbourhood, while another doctoral thesis at UMR ISPA of INRAE (Bordeaux, France) will study scales ranging from the city to the neighbourhood. A strong interaction between these two theses is expected to ultimately cover the continuum of scales from street to city.

Description of the PhD project

The aim of the thesis is to study the impact of trees on urban micro-meteorology and the dispersion of particulate pollutants, from the neighbourhood to the street scale and under different conditions of atmospheric stability. To achieve this objective, several stages are envisaged.

First of all, a literature review will be carried out in order to (1) establish the state of the art of research on "trees in the city", (2) understand the physics of the urban boundary layer and of multi-scale and multi-process interactions, and (3) identify relevant thermo-radiative transfer models to account for heat exchanges between built surfaces and the atmosphere, and for the influence of trees on these exchanges at the local scale.

In a second phase, the IBM version of the atmospheric boundary layer model will be adapted to meet the targeted objectives. In particular, this will involve (1) implementing a thermo-radiative transfer model between atmosphere, trees and artificial surfaces, (2) integrating a simplified functioning model for trees, represented by a porous zone, to simulate evapotranspiration process, (3) adapting the particle dispersion model to the IBM approach. Each of these developments will be evaluated in simplified urban configurations or with reference to real-site measurements already carried out in the city of Nantes (Rodrigues, 2015; Connan et al., 2015).

The third phase of the thesis project will consist in setting up and carrying out numerical simulations for different meteorological situations and thermal stability conditions observed during the experimental campaign planned at the start of the CITRY project. Thanks to the coupling between the neighbourhood and local scales, these simulations will enable us to assess the model developed for the local scale in realistic situations, to analyse the exchange processes at the top of the urban canopy, to understand the role of urban trees on the variability of micro-meteorological fields and ventilation in the street, and finally to investigate different scenarios of urban vegetation.

References

Bucquet Q. (2023) Vers une approche intégrée de modélisation multi-échelles de l'écoulement atmosphérique en milieu urbain, Thèse de doctorat de l'Ecole Centrale de Nantes.

Bucquet Q., Calmet I., Perret L., Maché M. (2023) Large-eddy simulation of the urban boundary layer using drag-porosity modelling, Journal of Wind Engineering & Industrial Aerodynamics **238**, 105432.

Connan O., Laguionie P., Maro D., Hébert D., Mestayer P.G., Rodriguez F., Rodrigues V., Rosant J-M. (2015) Vertical and horizontal concentration profiles from a tracer experiment in a heterogeneous urban area, Atmospheric Research 154:126-137.

Maché M. (2012) Représentation multi-échelle des transferts entre couche de canopée urbaine et atmosphère à l'échelle de la ville, Thèse de doctorat de l'Ecole Centrale de Nantes.

Rodrigues V. (2015) Evaluation des zones de footprint en site hétérogène par simulation des grandes échelles des écoulements turbulents et de la dispersion des traceurs passifs dans et au-dessus de la canopée urbaine, Thèse de doctorat de l'Ecole Centrale de Nantes.

Tavares R., Calmet I., Dupont S. (2015) Modelling the impact of green infrastructures on local microclimate within an idealized homogeneous urban canopy, 9th International Conference on Urban Climate/12th Symposium on the Urban Environment, 20-24 July 2015, Toulouse (France).

Keywords : Urban boundary layer ; Urban canopy; Urban vegetation ; Large-eddy simulations ; Immersed Boundary Method ; Pollutant dispersion ; Energy transfers.

Candidate profile

- Master's degree or Engineering degree in one of the following fields: Fluid Mechanics, Atmospheric Sciences, Applied Mathematics.
- Expected knowledge in several of the following fields: Theoretical fluid mechanics, Numerical fluid mechanics, Atmospheric sciences, Turbulence, Energy transfers, Numerical analysis, Programming.
- Excellent writing skills; written and oral fluency in English.
- Personal qualities: rigorous and organized; initiative and creativity; motivation for research; ability for collaborative work and scientific mediation activities.

Supervision and working conditions

The doctoral research project will be carried out under the supervision of Isabelle Calmet (Professor at Ecole Centrale de Nantes) in collaboration with Sylvain Dupont (Research Director at INRAE). It will take place at Ecole Centrale de Nantes (France), in the team « Dynamique de l'Atmosphère Urbaine et Côtière » (DAUC) of the « Laboratoire de recherche en Hydrodynamique, Énergétique et Environnement Atmosphérique » (LHEEA).

Funding for the doctoral thesis has already been fully obtained for a 3-year period, with a target start date of autumn 2024.

Information and application

All interested students in their final year of a Master or Engineering program, or graduates, are invited to send their CV (with contact details of reference teachers), a letter of motivation, and available transcripts (L3, M1 and M2 levels) to Isabelle Calmet by **May 15, 2024 at the latest**.

Email address to apply : isabelle.calmet(at)ec-nantes.fr
Subject : PhD application - LHEEA - ANR CITRY