Laboratoire de Mécanique des Fluides de Lille
Kampé de Fériet

PhD proposal

Numerical modeling of the turbulence in a stable boundary layer with a low-level-jet under thermal and orographic forcing

Supervisor : Benjamin Luce (Assistant Professor)
Location : Build. M6, Av. Paul Langevin, Cité Scientifique, 59655 Villeneuve d'Ascq

Duration : 3 year, starting around October, 2024

Contact : benjamin.luce@univ-lille.fr

Requirements :

- Knowledge of fluid mechanics and/or numerical simulations (theory) at Master level.
- Basic knowledge of a programming language (C++ and/or python are best but not mandatory).
- Knowledge of atmospheric boundary layer not required.

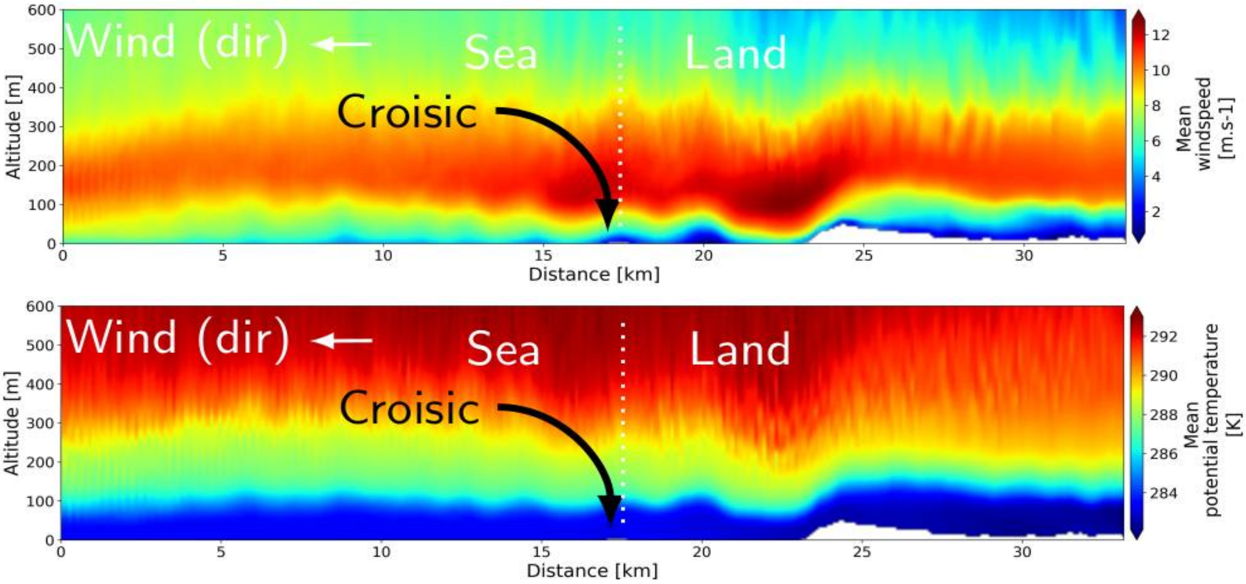

Figure 1: Vertical cut of a low-level-jet on the french Atlantic coast. The red region on the top picture (mean windspeed) clearly show the jet and the influence of the hill.

Low-level jets (see Fig. 1) are atmospheric structures appearing mostly during the night in a stable atmospheric boundary layer. The jet is best described as a pronounced wind speed less than a km over the surface, a sharp change to the classical logarithm profile expected from boundary layer, developing during sunset in cloud-free conditions. The wind speed often reaches a peak in the early morning before decaying after dawn with the onset of convective mixing.
There has been numerous observations over the Great Plains in the USA and several theoretical models have been developed as early as 1957 (see [1] and references herein. For an easier conceptual approach, see [2]).
Nowadays, several realistic approaches have been made to simulate low-level jets over specific areas, supported by improved on-site measurement methods. **This spark of interest results from offshore wind-farm.** Low-level jets were seen to developed over land-sea interface, with thus a **potential resource for wind energy**. If these studies offer great insight on the local behavior of a jet, they, unfortunately, cannot grant a deep understanding of a more general view of this kind of specific structure. For example, what are the difference between a land jet and a land-sea jet? A recent direct numerical simulation by [3] had shown noticeable differences between a jet over a

plane surface and a slow-slope. What happens with the thermal difference between land and sea, which is known to sharply change the turbulence in boundary layer [4]? What about the roughness change [5]? What happens when gravitational waves are added [6], [7]? These questions remain with little to no answer. Even with a simple jet over a plan, the turbulence behavior over such a stratified boundary layer is still an open question.

PhD Thesis (3 years) :
The PhD student will investigate the physics of low-level jets through direct numerical simulations on ideal cases. Several conditions will have to be changed, such as the Rayleigh and Reynold numbers (for the flow conditions) as well as introducing topography effects to see the impact of internal waves on the low-level jet structure. The use of a LES framework within microHH is expected for reaching realistic atmospheric conditions. Several cases could be developed. It is expected for the turbulence modeling in stably stratified flows to be insufficient with only a TKE model, thus the PhD will turn toward incorporating a total turbulent energy model based on the work of [8] within the microHH code.
Then, should the comparison between DNS and LES offers a satisfying agreement over turbulent features, the work will go over more complex simulations with a state-of-the-art atmospheric code (WRF), using comparisons with meteorological databases to check on the correctness of the numerical model.

Location and context:
The PhD will take place at LMFL (Lille Fluid Mechanics Laboratory) on the Lille University campus of Villeneuve d'Ascq. The LMFL is a CNRS research laboratory with 15 faculties and about 30 PhD students and post-docs from 5 institutions (see https://lmfl.cnrs.fr for more details)

Bibliography :

[1] A. Shapiro, E. Fedorovich, et S. Rahimi, « A Unified Theory for the Great Plains Nocturnal Low-Level Jet », *Journal of the Atmospheric Sciences*, vol. 73, nº 8, p. 3037-3057, août 2016, doi: 10.1175/JAS-D-15-0307.1.

[2] B. J. H. V. de Wiel, A. F. Moene, G. J. Steeneveld, P. Baas, F. C. Bosveld, et A. a. M. Holtslag, « A Conceptual View on Inertial Oscillations and Nocturnal Low-Level Jets », *Journal of the Atmospheric Sciences*, vol. 67, nº 8, p. 2679-2689, août 2010, doi: 10.1175/2010JAS3289.1.

[3] E. Fedorovich, J. A. Gibbs, et A. Shapiro, « Numerical Study of Nocturnal Low-Level Jets over Gently Sloping Terrain », *Journal of the Atmospheric Sciences*, vol. 74, nº 9, p. 2813-2834, sept. 2017, doi: 10.1175/JAS-D-17-0013.1.

[4] D. V. Mironov et P. P. Sullivan, « Turbulence Structure and Mixing in Strongly Stable Boundary-Layer Flows over Thermally Heterogeneous Surfaces », *Boundary-Layer Meteorol*, vol. 187, nº 1, p. 371-393, mai 2023, doi: 10.1007/s10546-022-00766-x.

[5] M. Kadivar, D. Tormey, et G. McGranaghan, « A review on turbulent flow over rough surfaces: Fundamentals and theories », *International Journal of Thermofluids*, vol. 10, p. 100077, mai 2021, doi: 10.1016/j.ijft.2021.100077.

[6] J. Sun *et al.*, « Review of wave-turbulence interactions in the stable atmospheric boundary layer », *Reviews of Geophysics*, vol. 53, nº 3, p. 956-993, 2015, doi: 10.1002/2015RG000487.

[7] S. Roy, A. Sentchev, F. G. Schmitt, P. Augustin, et M. Fourmentin, « Impact of the Nocturnal Low-Level Jet and Orographic Waves on Turbulent Motions and Energy Fluxes in the Lower Atmospheric Boundary Layer », *Boundary-Layer Meteorol*, vol. 180, nº 3, p. 527-542, sept. 2021, doi: 10.1007/s10546-021-00629-x.

[8] S. S. Zilitinkevich *et al.*, « Turbulence energetics in stably stratified geophysical flows: Strong and weak mixing regimes », *Quarterly Journal of the Royal Meteorological Society*, vol. 134, nº 633, p. 793-799, 2008, doi: 10.1002/qj.264.