**3-y Ph.D. position**

Location: **CNRM** UMR3589, Météo-France, Toulouse (France)

Topic: **Decameter-scale circulations and turbulence in convective clouds**

Supervisors: Dr Didier Ricard (CNRM), Dr Christine Lac (CNRM)

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Doctoral School S2UDE (ED173 "Geosciences, Astrophysics, Space and Environmental Sciences")

Convective clouds are associated with high vertical velocity and intense turbulent circulations. Recent studies (Verrelle et al, 2015, 2017; Strauss et al, 2019) have shown that Cloud Resolving Models (CRM) tend to underestimate turbulence in clouds and overestimate vertical velocity. A Large Eddy Simulation (LES) with a resolution of 5 meters allowed to study in more detail the typical structures associated with a congestus cumulus (Strauss et al, 2021): an ascending core with positive buoyancy, large eddies at the top forming a toroidal circulation and a subsiding shell surrounding the cloud. This LES was also used to characterize the turbulence within the cloud, which is on a finer scale at the edges than inside the cloud. At this fine resolution, the dynamic production of subgrid turbulence due to wind shear dominates the thermal production, linked to buoyancy. The edges are characterized by an increased presence of downdrafts and exhibit an inversion of buoyancy due in part to the cooling effects related to the evaporation of cloud droplets. Although downdrafts exist at the top of the cloud, they are few in number and not very penetrating. Lateral entrainment dominates the cloud-top entrainment.

As part of this thesis, the study of physical processes at the cloud interface will be continued and the previous results obtained for a particular cloud will be generalized with different sensitivity tests: on the maturity of the convective clouds considered; on wind shear, in order to measure its impact on the asymmetry between the upstream and downstream parts of the cloud or on instabilities; on the humidity of the environment; and on the presence of mixed-phase hydrometeors. For that, we propose to perform very fine resolution (decametric) simulations with the Meso-NH model (Lac et al, 2018) to characterize the circulations within convective clouds (from cumulus to cumulonimbus), as well as the associated turbulent structures.

It will also be investigated whether the introduction of radiative cooling, by activating the radiation scheme, enhances the cloud-top entrainment. Taking into account a so-called 2 moment microphysical scheme, which prognostically describes the concentration of hydrometeors in addition to their mass, will allow to analyze the notion of homogeneous/heterogeneous mixture at the edges of clouds, and to introduce a direct interaction between turbulence and microphysics, in particular through the droplet activation process. The Meso-NH model will thus use sophisticated parameterizations such as the 3D turbulence scheme CBR (Cuxart et al., 2000), the microphysics scheme LIMA (Vié et al., 2016), or the radiation scheme ecRad (Hogan and Bozzo, 2016).

Another objective will be to extract and identify the coherent structures within the simulated clouds (number, size, shape…). Indeed, there may exist within turbulent flows coherent eddies which have a lifetime much longer than their turnover time, such as those of the toroidal circulation. These coherent structures indicate non-local turbulence. Characteristics on turbulent structures obtained using wavelet multi-resolution analysis will provide useful indications for the parameterization of non-local turbulence in clouds. In particular, the characteristic size of these structures will have to be compared to the mixing length used in the CBR turbulence scheme, which may provide some improvement in the formulation of this length. The best way to visualize fine-scale flows and coherent structures within simulated clouds will be to use a 3D visualization tool adapted to large volumes of data (such as Paraview).

Part of these simulations will be performed in an idealized framework (initialization from vertical profiles of temperature, wind and humidity), but we also plan to simulate real cases observed during measurement campaigns for which we have airborne radar data of wind, reflectivities and turbulent dissipation (such as the recent DACCIWA campaign in the Cape Verde Islands) in order to compare the observed and simulated turbulence structures.

A better understanding of the turbulent characteristics of convective clouds, in connection with radiation and microphysics schemes, should ultimately improve the parameterization of numerical weather prediction models.

Nature of the expected work and desired skills

This work will require the realization of LES at high resolution (50-10 m) on large grids with the research Meso-NH model. This work will require LES on large grids with the Meso-NH model. Existing diagnostics or those to be coded in Python will be used on these large volumes of numerical data in order to characterize the eddies and analyze the physical processes that drive them.

Profile of the candidates:

- a Master of Science degree or an equivalent qualification in atmospheric physics, oceanography, environmental physics or climate before starting the Ph. D. project
- knowledge of atmospheric physics
- good written and oral English skills to present scientific results
- good programming and data processing skills (Fortran, Shell, Python or similar)
- experience in numerical modelling

About the CNRM:

The French Centre National de Recherches Météorologiques (CNRM, www.cnrm-game-meteo.fr) is a joint research unit (UMR 3589) affiliated to Météo-France and the CNRS. It brings together 80 researchers and 150 engineers, technicians and administrative staff. Each year, the CNRM welcomes between 15 and 20 new doctoral candidates.

Applications:

Candidates should send a letter of motivation, with a CV, a copy of their diplomas with the corresponding transcript of marks, a summary of the subject of their Master thesis, as well as the names of two references including their email address and telephone number. Given the very tight schedule, candidates are encouraged to express their intention to apply as soon as possible.

Deadline: as soon as possible, applications being processed on an ongoing basis.

References :

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Strauss, C, Ricard, D, Lac, C, and, A. Verrelle, 2019. Evaluation of turbulence parametrizations in convective clouds and their environment based on a large-eddy simulation. *Q J R Meteorol Soc.*, 1– 23.

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Vié, B., J.-P. Pinty, S. Berthet, and M. Leriche, 2016. LIMA (v1.0): a quasi two-moment microphysical scheme driven by a multimodal population of cloud condensation and ice freezing nuclei, Geosci. Model Dev., 9, 567-586.