Geophysical Laboratory: Introduction to Numerical Modeling of Clouds

Introduction

In this exercise, students will learn to run and analyze numerical simulations of clouds. Simulations will be performed using the University of Warsaw Lagrangian Cloud Model (UWLCM), an advanced model developed at the Institute of Geophysics (IGF). Data analysis will utilize the Xarray Python package. Both the simulations and the analysis will be conducted within a Jupyter Notebook, running on a supercomputing cluster. A basic understanding of the Python programming language is the only prerequisite for participation in this laboratory.

University of Warsaw Lagrangian Cloud Model (UWLCM)

The UWLCM is a sophisticated tool for simulating cloud formation and dynamics. It employs the Large Eddy Simulation (LES) approach to model turbulence. The cloud microphysics are represented using a Lagrangian particle-based method, specifically the Super-Droplet Method (SDM). In SDM, computational particles (super-droplets, SDs) represent real cloud droplets, with each super-droplet corresponding to a large number of identical real droplets.

Access to the Computing Cluster

The work will be carried out on the Cyfronet Athena cluster. Students must register for an account at the PLGrid Portal: https://portal.plgrid.pl/. Once registered, they will be added to the PLGrid team "plgguwicmw" and granted access to the computing resources. Next, users need to apply in the portal for two services: access to Athena and to Jupyter. The Jupyter Notebook environment is available at https://jupyter.plgrid.pl/.

Job Configuration:

- Cluster: Athena
- Partition: plgrid-gpu-a100
- Number of CPU cores: 16
- Number of GPUs: 1
- Job memory limit: 128 GB

Please ensure to terminate the job allocation once your work is completed (in Jupyter, go to File->Hub Control Panel, then Stop Server).

Data Analysis

The output from UWLCM simulations is stored in HDF5 files. While students are free to use any tool for data analysis, we recommend utilizing the **xrUWLCM** Python package. This package facilitates the loading of UWLCM output as XArray DataSets, which can be efficiently analyzed within a Jupyter Notebook.

Task Description

The goal of this exercise is to investigate how aerosol concentration affects cloud properties. This will be achieved by simulating a rising thermal—a simplified model of a cloud. Initially, a bubble of supersaturated air exists within a subsaturated environment. The bubble rises due to positive buoyancy, causing cloud formation, which later dissipates as it mixes with dry air. Default aerosol concentration is $100/cm^3$. Aerosol concentration can be changed by setting the parameter "case_n_stp_multiplier". Students will need to assess the convergence of simulation results with respect to various parameters, including time step length, resolution, and the number of super-droplets.

A sample Jupyter Notebook, which serves as a useful starting point for this exercise, can be found on Athena at:
`/net/pr2/projects/plgrid/plgguwicmw/geolab/code/UWLCM_geolab.ipynb`

The **xrUWLCM** package is available on Athena at:
`/net/pr2/projects/plgrid/plgguwicmw/geolab/code/xrUWLCM`
Please ensure that the **xrUWLCM** folder is located within the same directory as the Jupyter Notebook.

Before using the UWLCM_geolab.ipynb notebook it is necessary to install some Python modules. This can be done by running the following commands on Athena (e.g. through terminal opened via jupyter.plgrid.pl):

```
$ module load GCCcore/13.2.0 Python/3.11.5
$ pip install matplotlib numpy xarray xhistogram h5netcdf netcdf4
```

Additional Resources

- [Jupyter Notebook Tutorial]
- [XArray Documentation]
- Athena Cluster Documentation
- UWLCM Source Code on GitHub
- xrUWLCM Source Code on GitHub
- [Super-Droplet Method (SDM) Paper]
- [UWLCM Model Paper]