University of Warsaw Lagrangian Cloud Model - a modern LES with Lagrangian microphysics

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Introduction

Two libraries have been developed in the Microphysics of Clouds group at the University of Warsaw: libmpdata++ for atmospheric fluid dynamics and libcloudph++ for cloud microphysics. Now we use them in our Large Eddy Simulations code with sophisticated model of cloud microphysics.

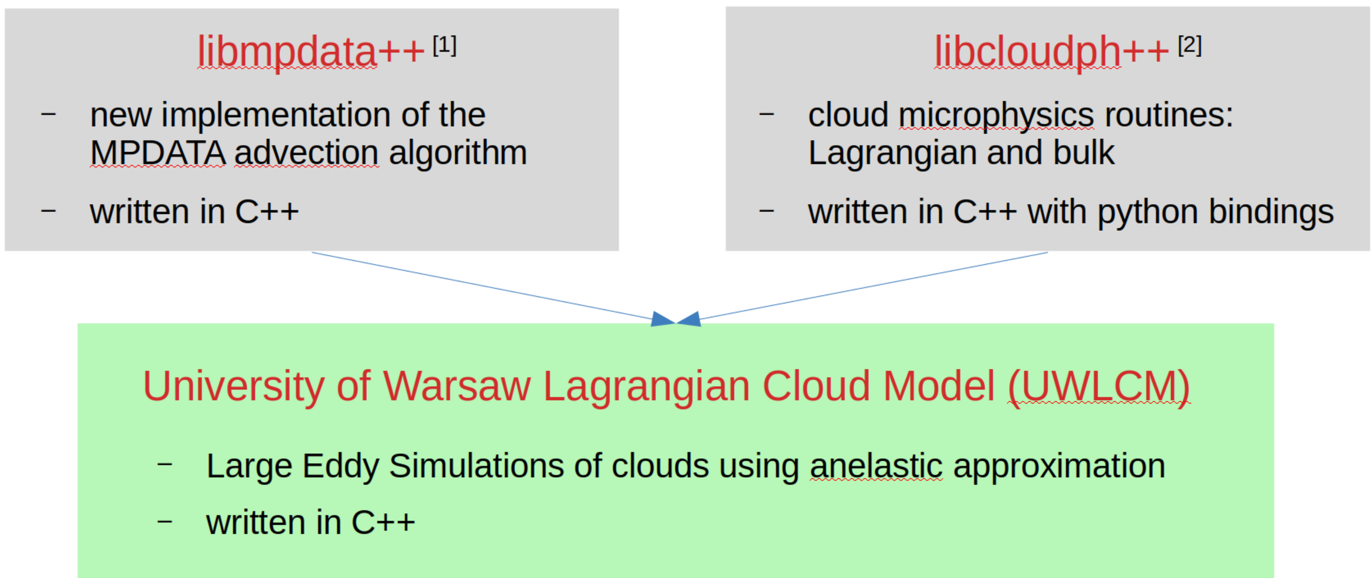

Figure 1: Software developed by our group

Key assumptions:

- Use object-oriented programming techniques to simplify code development and increase code reusability.
- Make use of modern hybrid CPU/GPU supercomputers.
- Make use of external, well-developed libraries (blitz++, thrust, boost, HDF5).
- Lagrangian particle-based microphysics + bulk microphysics for reference.
- Open-source code with a repository on github (github.com/igfuw).
- Automated tests ran on every proposed code update.

[1] A. Jaruga et al. *Geoscientific Model Development* 2015, vol. 8, pp. 1005-1032

[2] S. Arabas et al. *Geoscientific Model Development* 2015, vol. 8, pp. 1677-1707

Modern code structure

- Separation of concerns: model built from modules serving specific tasks, each ready to be reused and developed independently.
- Many models in one source code: easy change of dimensionality, microphysics, setup, numerical precision, number of threads, number of nodes, etc.

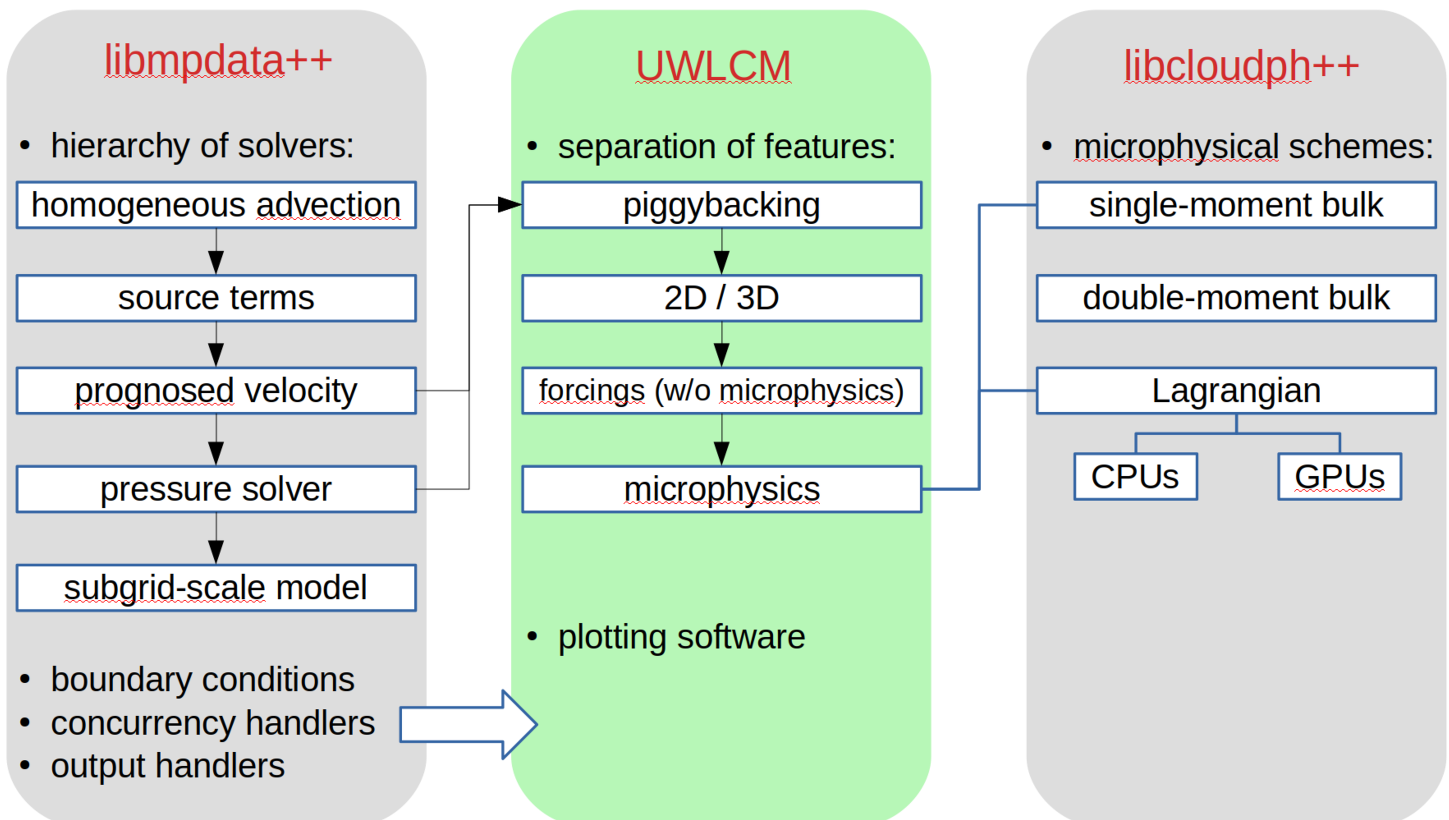

Figure 2: Structure of the UWLCM code. Black arrows denote inheritance.

Hybrid computing architecture

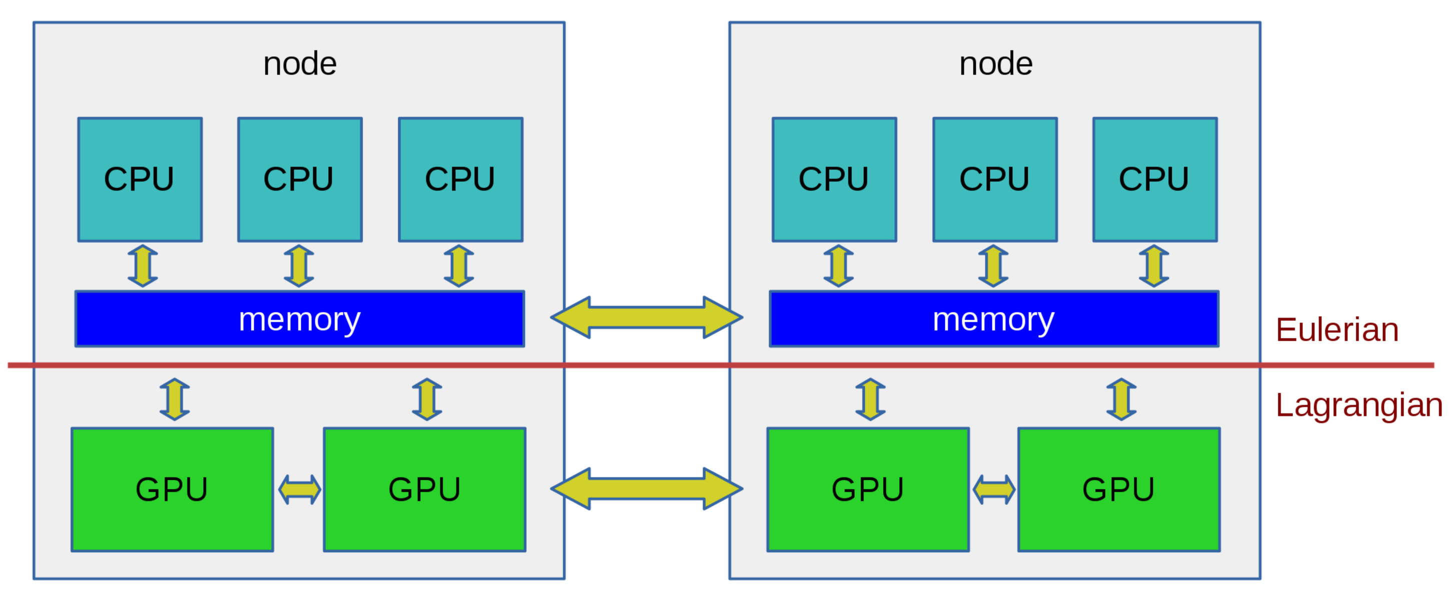

Figure 3: Schematic structure of hybrid HPC nodes. Yellow arrows denote data transfers.

- Simultaneous computing of Eulerian fields on CPUs and Lagrangian microphysics on GPUs.
- Microphysics can also be calculated using CPUs.
- Hybrid MPI/OpenMP parallelization.

Model validation - DYCOMS stratocumulus

- Test UWLCM against 14 models from Ackerman et al. 2009[3]
- Other models use bin or bulk, we use Lagrangian microphysics
- Other models use subgrid-scale schemes, we use implicit LES

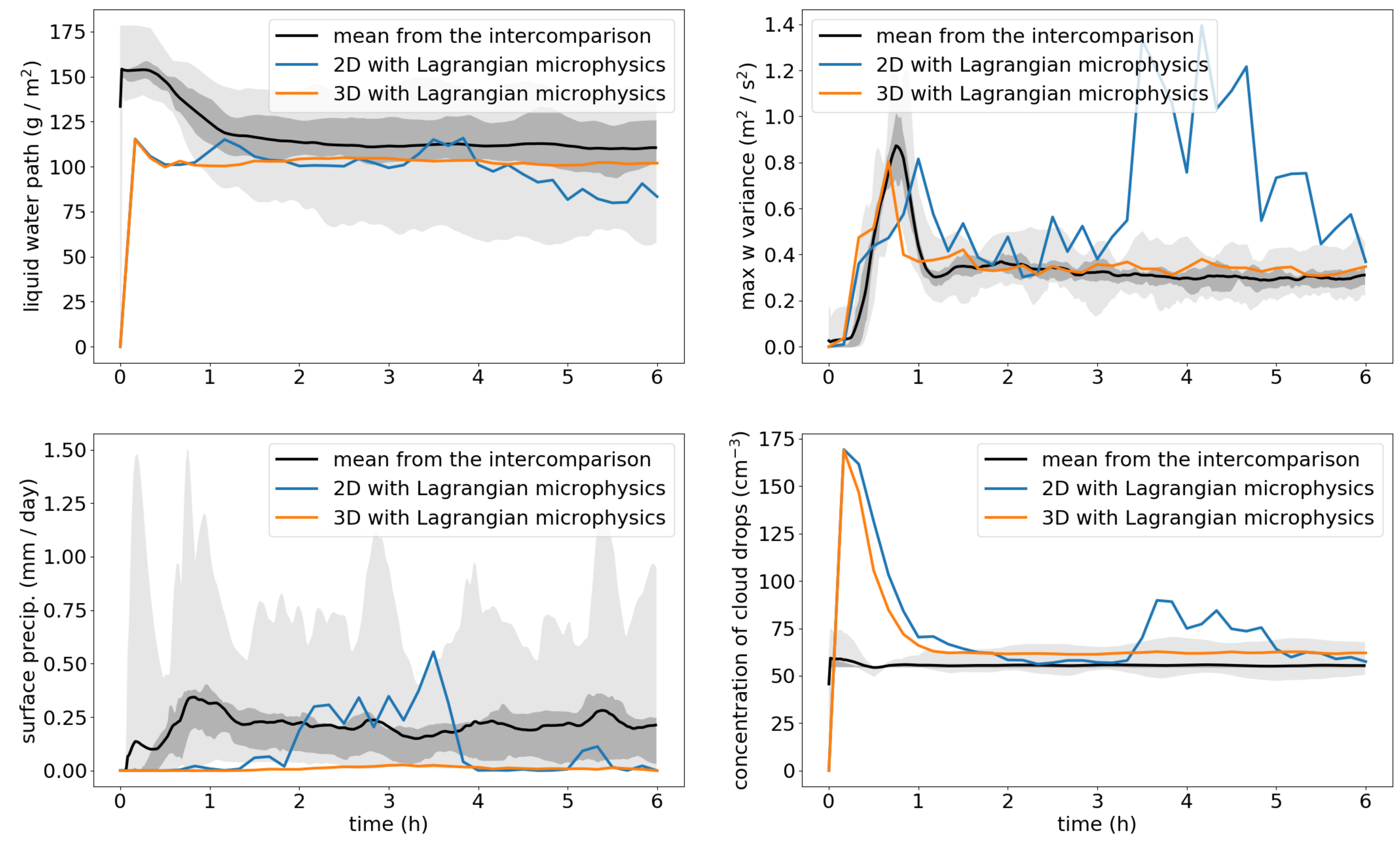

Figure 4: Time series from 2D/3D UWLCM with Lagrangian microphysics and from the DYCOMS RF02 intercomparison. Dark (light) shaded region depicts middle two quartiles (whole range) of the ensemble of simulations from the intercomparison. Only selected time series that differ most are shown.

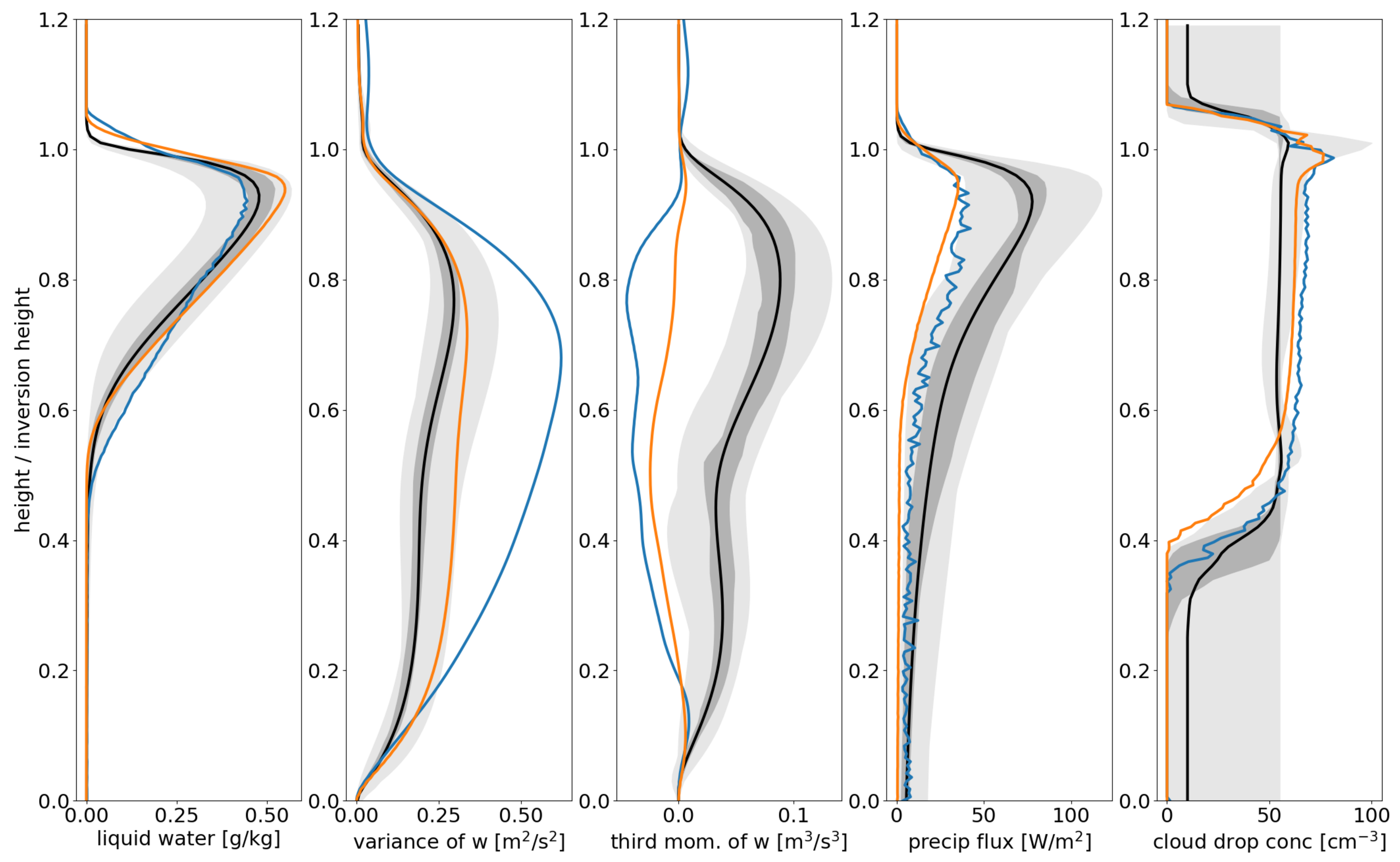

Figure 5: As in Fig.4, but for averaged vertical profiles.

[3] AS Ackerman et al. *Monthly Weather Review* 2009, vol. 137.3, pp. 1083-1110

Model application - multimodal size specta

- Broadening of size spectra due to different droplet trajectories.
- Based on Lasher-Trapp et al. 2005[4], which required LES with bulk microphysics, backtracking of parcel trajectories and parcel simulations with bin microphysics.
- Shows the same effect in a single LES run with Lagrangian microphysics.

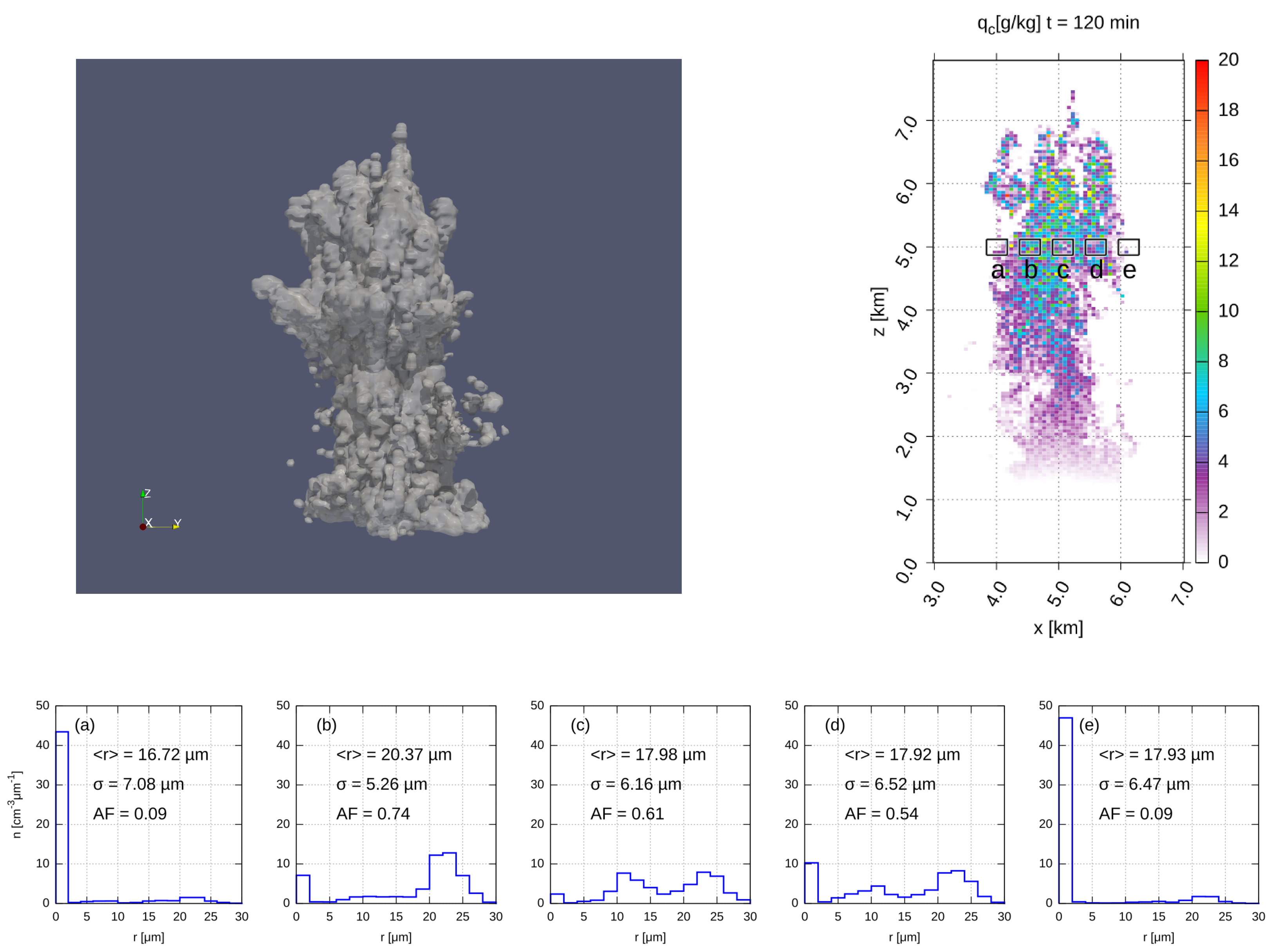

Figure 6: Spectra of droplet sizes at five locations within the cloud.

[4] SG Lasher-Trapp et al. *Q. J. R. Meteorol. Soc.* 2005, vol. 131, pp. 195–220

work financed by NATIONAL SCIENCE CENTRE POLAND