Mixed-Phase Processes in a Cloud Chamber Modeled with the UWLCM

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UWLCM

The University of Warsaw Lagrangian Cloud Model (UWLCM) is a large-eddy simulation tool for cloud modeling with an Eulerian dynamical core and Lagrangian particle-based microphysics, developed by the cloud modeling group at the University of Warsaw, described by Dziekan et al. (2019).

A new implementation of ice processes to UWLCM is applied for simulations of mixed-phase clouds. Super-Droplet method is used - a large number of real droplets and ice particles is represented by a smaller number of super-droplets and ice super-particles.

Particles are assumed to grow by condensation/deposition only. The ice nucleation is not resolved. Instead, the injection of ice particles (that are assumed to be spherical) is considered.

Simulation setup

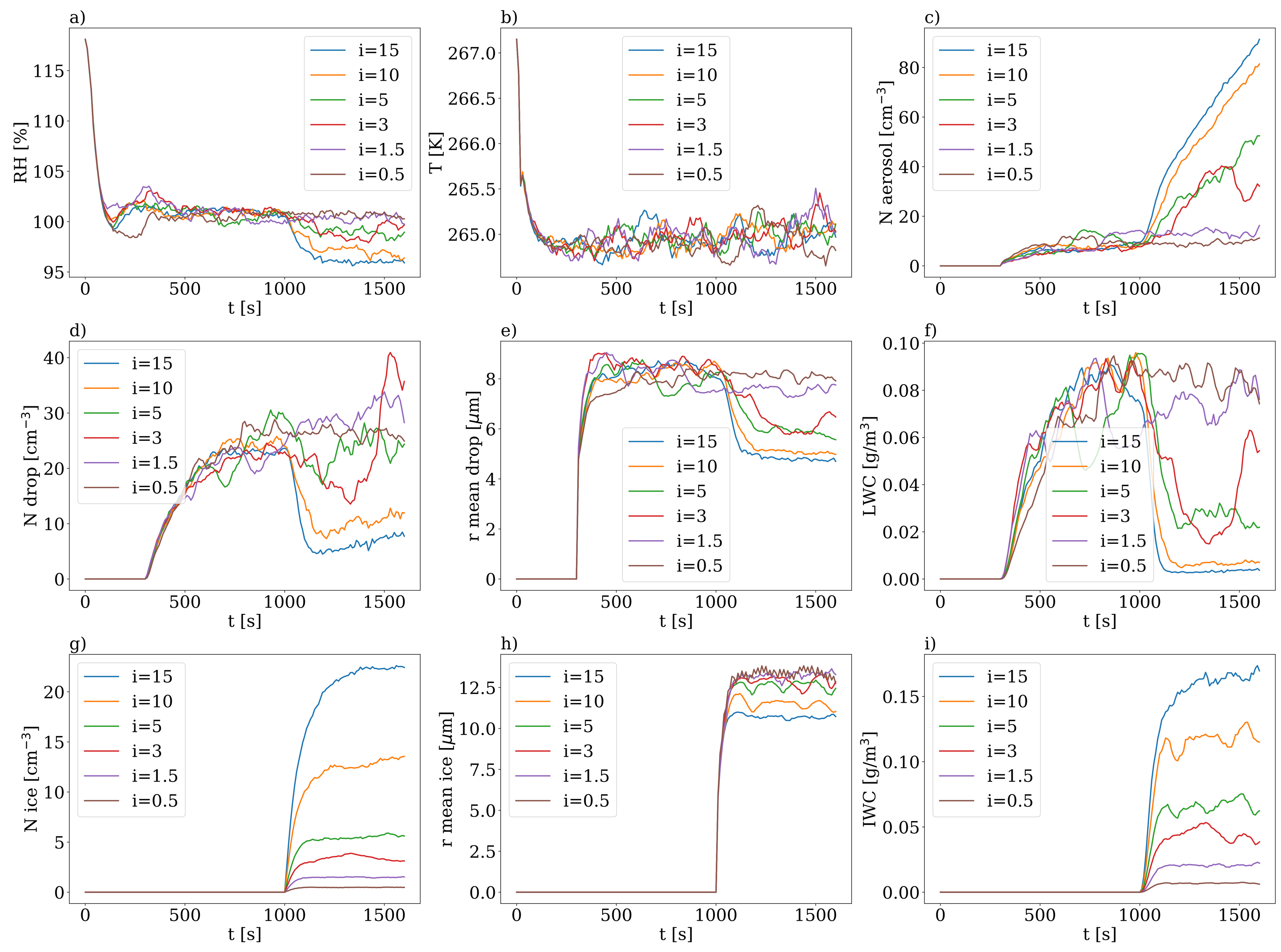
The simulation setup is based on experiments performed in the Pi Chamber (Chang et al., 2016). The chamber is represented in the simulation as a cuboid, with size 2 x 2 x 1 m. It is divided into $\sim$ 130 000 cubic grid boxes with edges 3.125 cm. The time step of the model is 0.02 s.

Forcing a temperature difference between the top and the bottom results in the formation of Rayleigh-Bénard convection and isobaric mixing of the air. The mixed air is supersaturated.

Supercooled liquid droplets are formed by the injection of NaCl particles with the dry radius 62.5 nm, at a rate 11 cm^{-3} /min.

Ice particles with the radius 2 μm are injected to form a mixed-phase cloud. Different rates of ice injection are considered.

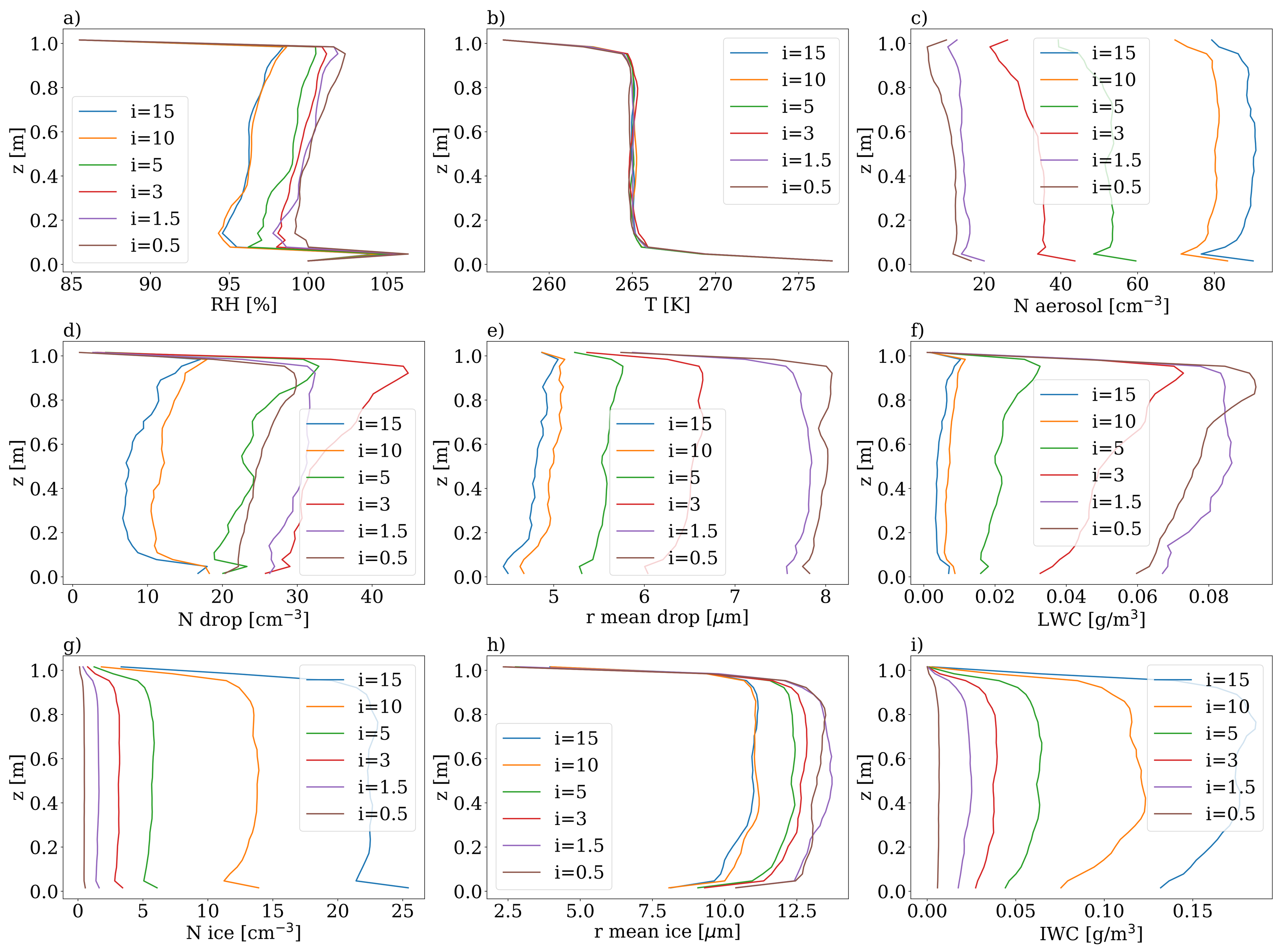
Time Series



Time series of the average (a) relative humidity, (b) temperature, (c) aerosol concentration, (d) cloud droplet concentration, (e) mean cloud droplet radius, (f) LWC, (g) ice particles concentration, (h) mean ice radius and (i) IWC in simulations with different ice injection rates i, in cm^{-3} /min.

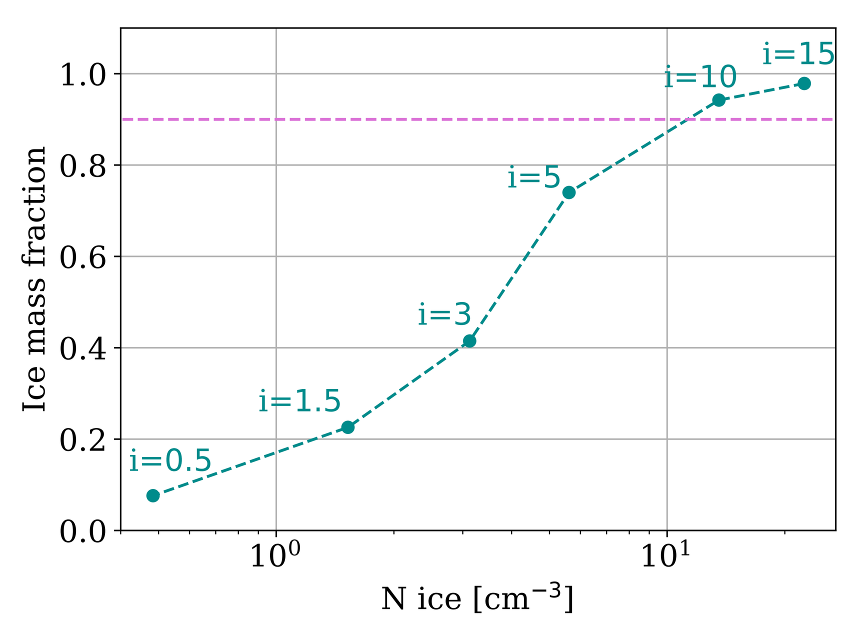
In the first 300 s of simulations, Rayleigh-Bénard convection develops and no particles are present. Between 300 – 1000 s, CCN are injected and a steady-state supercooled liquid cloud is formed. After 1000 s, ice particles are injected together with CCN. A new steady state is established. **In simulations with large ice injection rates, the mass of liquid water is reduced due to the Wegener-Bergeron-Findeisen process.**

Vertical Profiles



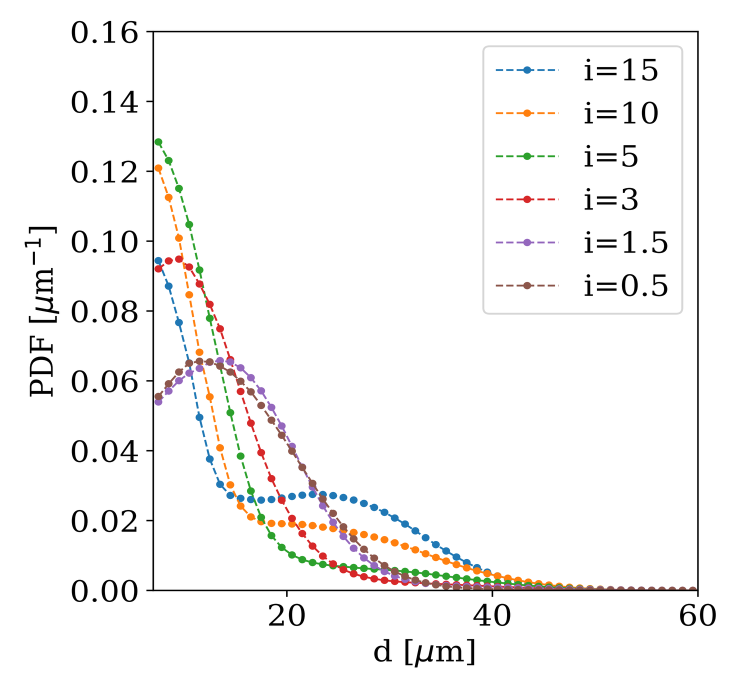
Horizontally-averaged profiles of (a) the relative humidity, (b) the temperature, (c) the aerosol concentration, (d) the cloud droplet concentration, (e) the mean cloud droplet radius, (f) the LWC, (g) the ice concentration, (h) the mean ice radius and (i) the IWC at the end of simulations with different ice injection rates i, in in cm^{-3} /min.

Ice Mass Fraction



Ice mass fraction at the end of the simulation, as a function of the ice concentration at the end of the simulation. Each point corresponds to a simulation with the ice injection rate i in in cm^{-3} /min. The violet dashed line is the cloud glaciation threshold.

Size Distributions



PFDs of particle diameter at the end of the simulation. Colors correspond to simulations with different ice injection rates i, given in in cm^{-3} /min.

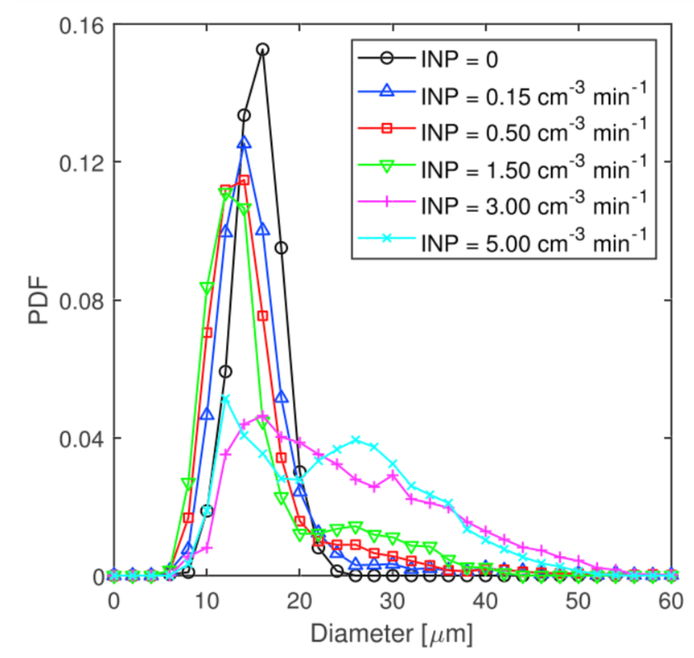


Figure 2 from Desai et al. (2019). PDFs of particle diameter measured in the Pi Chamber. Colors correspond to different INP injection rates.

The probability density functions for particle diameter are in agreement with those measured in the Pi Chamber by Desai et al. (2019). In simulations with large ice injection rates, the distribution has two modes. The smaller mode consists mostly of cloud droplets, while the larger mode consists mostly of ice crystals.

Conclusions

- The simulated mixed-phase clouds are stable. The liquid water is not fully depleted, new cloud droplets form in regions of supersaturation.
- The injection of ice particles and the formation of cloud droplets are balanced by their removal by gravitational settling.
- Cloud properties are controlled by the ice injection rate (in simulations with constant forcing of supersaturation and constant injection of CCN).
- The assessed size distributions are in agreement with those measured in the Pi Chamber.

References

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