Demystifying fog microphysics

Large-eddy simulation of radiation fog with bulk microphysics and particled based microphysics

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Kurzgefasst

- The parallelized large-eddy simulation model PALM
- High-resolution large-eddy simulation of nocturnal radiation fog
- First time simulate radiation fog with a Lagrangian cloud model
- 10,000 processor cores or more required

Abbildung 1: *The PALM logo.*

Fog as a meteorological phenomenon can have a strong impact on the economy but also on personal safety by reducing the visibility in the atmospheric boundary layer [2]. Total economic losses associated with fog on aviation, marine and land transportation are comparable to those of winter storms [3]. Despite the fact that there is abundant literature on fog research, our knowledge about the physical processes that lead to fog formation and its microstructure remains partial. This is due to the fact that many complex processes like radiative cooling of the underlying surface, turbulent mixing and the microphysics of fog interact non-linearly with each other. Often, so-called Kelvin-Helmholtz instabilities develop at the fog top, leading to enhanced vertical mixing of the fog. Moreover, surface heterogeneity regarding vegetation and soil characteristics can further complicate the predictability of fog and induce local circulations that play an important role for the patchiness often observed in fog layers. As a direct consequence, the fog forecasting capability of today's numerical weather prediction models is still poor.

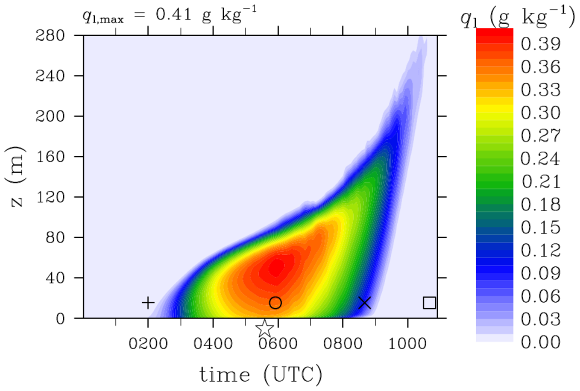

***Abbildung 2:** Height-time cross section of the horizontally-averaged liquid water content specific humidity q_l. Time marks related to the fog life cycle, formation, maximum liquid water content within the cloud, lifting, and dissipation, are marked by plus signs, circles, crosses, and squares, respectively. Additionally, the time of sunrise is marked by a star symbol. The model domain was approx. 1 km × 1 km × 0.5 km ($x \times y \times z$) with a grid spacing of 1 m.*

In this project, high-resolution large-eddy simulation (LES) is used to investigate the effect of turbulence on nocturnal radiation fogs. Fig. 2 shows the temporal development of radiation fog. The results of previous simulations of this project are in good agreement with observational data from the super-sites at Cabauw (The Netherlands)[4] . For the realization and execution of the project, the LES model PALM is used, which has been developed at the Institute of Meteorology and Climatology at Leibniz Universität Hannover. The model code is based on Fortran 95, with some 2003 extensions. Parallelization is achieved using MPI. The model is designed to run on massively parallel computer architectures and has shown excellent performance and scalability on up to 20,000 processor cores and more. A detailed description of the model in its current version 4.0 can be found in [1]. In this project, PALM (see also Fig. 1 is and will be used at very high resolution ≤ 1 m with both an Eulerian bulk cloud physics scheme and an embedded Lagrangian cloud model (LCM) that allows for explicitly resolving aerosols and fog droplets.

In the last year, the HLRN-computing resources allowed us to gain a even more detailed understanding of the microphysics of fog using the sophisticated LCM, which are published in a recent paper [6]. While comparing the LCM-results against the improved bulk cloud model (BCM) we found some major differences which could also be quantified. In this way, we could show the importance of a proper representation of microphysical processes for the development of radiation fogs in numerical models. Furthermore, we were able to investigate the evolution of droplet size distributions in fogs while taking advantage of the explicit resolving character of the LCM. These were contrasted with the assumed size distributions of bulk models in order to assess their shortcomings. Those findings can be summarized as follows:

For the overall development of the radiation fog we made five major observations with significant differences among the models and aerosol environments. First, the onset of fog in BCMs is delayed by up to 70 minutes compared to the LCM simulations for the case studied. Second, BCMs tend to overestimate the liquid water path as the LCM suggests much lower values for both aerosol environments. Third, the amount of liquid water (in relative terms to the overall LWP), which is sedimented during the fog, is significantly higher using the LCM than the BCM. Fourth, a higher aerosol loading leads to higher fog droplet concentrations and a more dense fog layer with a higher overall LWP. Fifth, the temporal evolution of the overall number of fog droplets within the fog layer differs notably. For the LCM simulations (both aerosol environments) the number of medium sized fog droplets is lower than for the BCM simulations, while we observe the opposite for small droplets and swollen aerosols.

All these observations can be linked to microphysical processes and how they are represented within the models. As BCMs are not capable to simulate the gradual transition from aerosols to fog droplets, they fail to resolve the swelling of aerosols, which consequently results in a delayed production of liquid water and reduction in visibility. Also our LCM results suggest that the number of actual fog droplets is lower than predicted by the BCM as many aerosols have swollen in size but not activated due to low supersaturations. Moreover, as the spectral shape and the width of the fog distribution must be prescribed and assumed to be constant (in space and time) in the BCM, such models are incapable of representing different microphysical stages of the fog associated with various spectral shapes. In contrast, our LCM simulations suggest that the droplet size distributions develops during the life cycle (gamma shaped, bi-modal and platykurtic). This in turn also influences the process of fog droplet sedimentation, which is quite differently represented in the schemes. The LCM resolves the settling velocity of each superdroplet individually, whereas the BCM calculates a sedimentation flux based on the parameterized distribution. These differences of the model formulation cause, besides different results of the sedimentation fluxes, that the removal of aerosol due to wet deposition is considered in the LCM but excluded in the BCM by design. However, this process potentially interacts in turn with the development of the fog layer as it changes the underlying aerosol conditions.

WWW

`http://www.muk.uni-hannover.de/maronga.html?&L=1` or `https://www.muk.uni-hannover.de/215.html?&no_cache=1&tx_tkinstpersonen_pi1[alias]=schwenkel`

Weitere Informationen

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Förderung

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