Project: **1143**
Project title: **FORCES**
Principal investigator: **Johannes Quaas**
Report period: **2023-11-01 to 2024-10-31**

The work within CleanCloud – a project that started in the report period – followed a somewhat different trajectory compared to what was requested in last year's DKRZ project 1143 proposal. We did not perform perturbed-parameter ensembles in its original sense, but instead performed tailored sensivitity studies with the ICON model.

(a) Perturbed aerosol and aerosol-cloud interactions

In the reporting period, the process-level significance of aerosol-cloud interaction has been investigated using the ICON-LES simulation (Dipankar et al., 2015; Heinze et al., 2017). A joint probability histogram analysis was used to investigate the cloud adjustment (as done earlier also by Dipu et al., 2022). The effect of increased aerosol loading on the cloud adjustment was investigated using the ICON-LES simulations with perturbed cloud condensation nuclei (CCN) concentrations. Figure 1 illustrates the comparison between cloud droplet numbers and number concentration (Nd) and liquid water path (LWP) and their distribution in the reference (2013 CCN) and perturbed (1985 CCN) simulation. Further, investigated the microphysical properties of fog with satellite observations and compared with in-situ measurements (Neuberger et al., 2024). Satellite observations of fog provided a spatial context and agreed well with in-situ droplet size measurements.

(b) Aircraft perturbations and cirrus

The goal of these simulations was to study contrail development under various weather conditions and compare them with the observational study by Marjani et al. (2022). We used the ICON Large Eddy Model (ICON-LEM) with a horizontal resolution of 156 meters and 160 vertical layers to focus on contrail interaction with existing cirrus clouds. The study covers the midlatitude Pacific Ocean, simulating the same 26-day synoptic conditions analyzed by Marjani et al. (2022), using both control and perturbation setups. This work involved two phases. First, we ran ICON-NWP at kilometer-scale resolution, using ECMWF IFS data as initial conditions. Three nested domains refined the spatial resolution from 5 km to 1.25 km. This prepared the ground for high-resolution ICON-LEM simulations at 156 m, reducing discrepancies and minimizing spin-up time. In the second phase, ICON-LEM was initialized from the finest 1.25 km nest and configured with a two-second time step and hourly boundary updates. Simulations started at least four hours before contrail implementation and continued for four hours after, with both control and perturbation runs (Fig. 2).

(c) Vegetation perturbation and clouds

We explored the impact of vegetation on clouds using high-resolution simulations with ICON at a river delta in Madagascar (NWP physics at a 600m resolution). The goal was to investigate the effect of vegetation on cloud formation (Fig. 3). The analysis of the simulation results is part of an on-going Master's thesis.

References

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Dipu, S, et al. 2022. Exploring Satellite-Derived Relationships between Cloud Droplet Number Concentration and Liquid Water Path Using a Large-Domain Large-Eddy Simulation. Tellus B: Chemical and Physical Meteorology, 74(2022): 176–188. DOI: https://doi.org/10.16993/tellusb.27

Heinze, R., et al., Large-eddy simulations over Germany using ICON: A comprehensive evaluation, Quart. J. Roy. Meteorol. Soc., 143, 69-100, doi:10.1002/qj.2947, 2017.

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Neuberger, A., et al., From molecules to droplets: The Fog and Aerosol InteRAction Research Italy (FAIRARI) 2021/22 campaign, Bulletin of the American Meteorological Society, 2024.

(a (b)

Figures

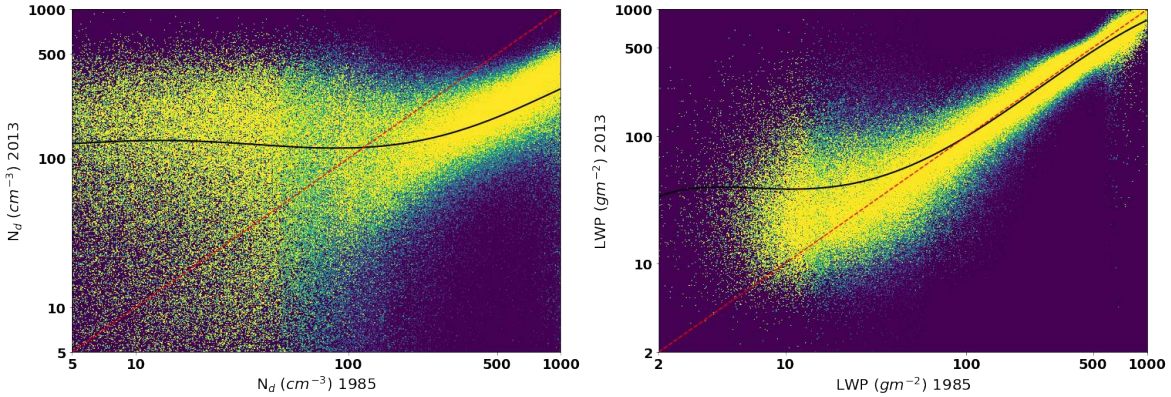

Fig. 1. Comparison of cloud droplet number (Nd) and liquid water path (LWP) with two simulations. (a) Nd2013-Nd1985, (b) LWP2013-LWP1985 joint histogram for reference (2013, CCN) and the perturbed (1985, CCN) simulation.

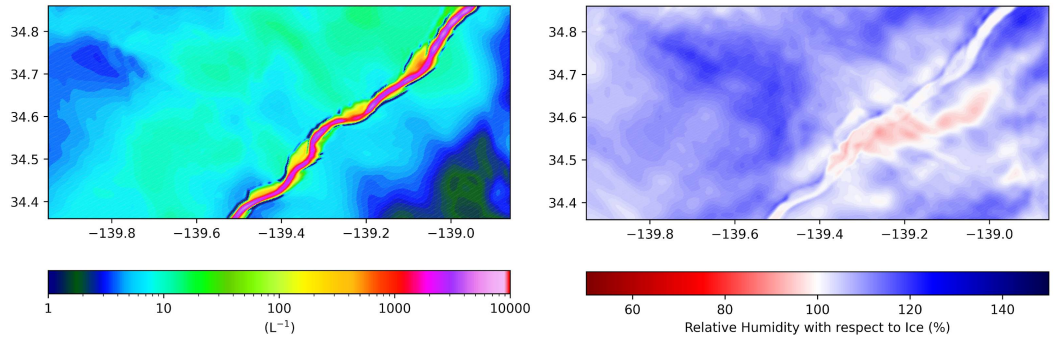

Fig. 2. Map of contrail evolution in cloudy weather conditions after 70 minutes. Left: Ice Crystal Number Concentration (ICNC); Right: Relative Humidity with respect to ice.

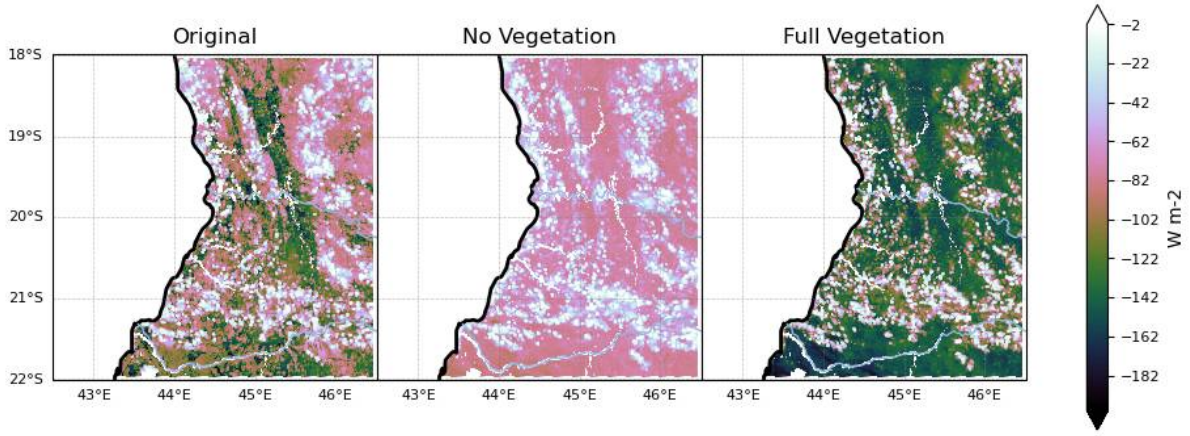

Fig. 3. Solar reflected flux in the control simulation (right), a perturbed simulation without vegetation (middle) and one with increased vegetation (right).