Project:	**1376**
Project title:	**IFCES2: Cloud Microphysics Application Case**
Project lead:	**Dr. Fabian Senf (TROPOS)**
Allocation period:	**1.7.2025 - 30.6.2026**

Overview

The compute project bb1376 was started to support the BMBF-funded IFCES2 initiative (project end: 31 Dec 2025), which aims to develop and implement novel algorithms to improve the parallelizability and scalability of ICON and its associated components. The key technical outcome of these efforts is a sophisticated cloud microphysics scheme that runs in concurrent coupling with the ICON atmosphere model. Moreover, a unique high-resolution dataset for the evolution of a tropical storm over the Atlantic Ocean was created for which highly efficient modeling workflows have been developed.

Resource Utilization

At the time this report was written, approximately 58.2% of the granted computing resources were being used by project members, while 18.3% expired unused and 24.6% still remain for compute work until the end of the allocation period. In total, 13 project members from four different institutions contributed to cross-institutional collaboration, 11 of whom are early career scientists. The largest amount of resources were used to set up and produce ICON - LAM + LES mode simulations. To address the challenges posed by the significant budget cuts (60%), a twin project was proposed and implemented at the JSC. The required simulations were distributed across the HPC platforms, but the resulting data was transferred to the DKRZ. For this purpose, ARCH (over 210 TB) and WORK (up to 170 TB) were utilized very effectively.

Scientific Results

An important amount of work went into scaling, profiling, calibration, and optimization of the concurrent and flexible infrastructure ICON-ConTra, including LOBSTR data structures. Two test cases were primarily investigated: a small setup in the Swiss Alps and a simulation of a hurricane over the Atlantic Ocean. For both cases, the scaling and performance of the new infrastructure were tested on the HPC platform Levante to improve efficiency and flexibility. Similar analyses were carried out in Jülich (JUWELS system) and Dresden (Barnard system) to ensure the portability and performance of the infrastructure across different HPC platforms. The concurrent execution capability of the infrastructure is achieved by distributing processes into separate MPI groups, enabling the atmospheric transport of specific constituents to be computed simultaneously with the atmospheric dynamics. Since this partitioning is static in nature, extensive calibration and optimization work was performed to achieve an optimal distribution of processes. For the spectral cloud microphysics, an optimum was found at a partitioning ratio of 7 to 1 (ConTra to atmo). Furthermore, work was carried out to improve halo communication and to reduce latency in the communication of small MPI messages. Another highlight achieved within the IFCES2 project with the support of compute project bb1376 concerns the new flexible data structures and their capacity for load balancing. Since model components such as cloud microphysics perform their computations in a spatially heterogeneous manner, significant load imbalances can arise. Through extensive testing, the LOBSTR data structure was optimized such that dynamic load redistribution reduces load imbalance and lowers the overall load to 70% (see Fig. 1). All of these exciting technical developments contributed to the successful completion of the IFCES2 project at the end of January 2026.

Outstanding efficiency gains were achieved through the development of a hurricane-centric setup and workflow. In this approach, the ICON simulation is implemented such that the focus remains on the center of the hurricane, reducing the required horizontal extent of the model domain and thereby decreasing the number of grid points and associated computational costs. The method is available as open-source software in Senf (2026). A detailed scientific description including illustrative figures is currently in review in Senf and Cremer (2026), where the advantages and limitations of the method are discussed. As a result, high-resolution hurricane simulation data with grid spacings down to 300 m are now available in four methodological variants (narrow and medium vs. 12h-reinit and 24h-reinit), which are to be further analyzed intensively in the next allocation period. Furthermore, simulations of the sensitivity of Hurricane Paulette to aerosol perturbations were carried out to support activities within the EU project CleanCloud. The Synsat tool (Senf, 2025) was applied to all simulation data to enable a consistent comparison with satellite observations.

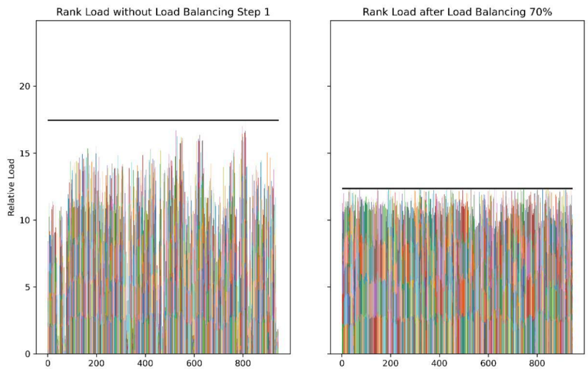

Figure 1: Distribution of relative load across more than 900 MPI ranks (x-axis) (a) before and (b) after the application of load balancing. Bars indicate the relative load per process.

References

Senf, F., 2025: Synsatipy: v1.1.0 - mtg-fci support, hamlite data interfacing and fixed mask handling. Zenodo, URL https://doi.org/10.5281/zenodo.17607882, doi:10.5281/zenodo.17607882.

Senf, F., 2026: Hurricane centric toolset version v2026.01 - common initialization and perturbation experiment capabilities. Zenodo, URL https://doi.org/10.5281/zenodo.18271898, doi:10.5281/zenodo.18271898.

Senf, F., and R. Cremer, 2026: Advancing the capabilities for efficient hurricane-centric simulations with the atmospheric model icon. *EGUsphere*, **2026**, 1–26, doi:10.5194/egusphere-2026-1412, URL https://egusphere.copernicus.org/preprints/2026/egusphere-2026-1412/.