Project:	**1376**
Project title:	**IFCES2: Cloud Microphysics Application Case**
Project lead:	**Dr. Fabian Senf (TROPOS)**
Allocation period:	**1.7.2024 - 30.6.2025**

Overview

The compute project bb1376 is part of the BMBF-funded IFCES2 initiative, which focuses on developing and implementing new algorithms to enhance parallelizability and scalability within ICON and add-ons. These advancements are a complex cloud microphysical scheme that is concurrently coupled with the ICON atmosphere model. The "cloud microphysics" application serves as a representative example of the increasing complexity and flexibility required from future Earth System Models (ESMs). Within IFCES2, the scientific objective addressed here is the creation of a unique scientific dataset capturing the development of a tropical storm over the Atlantic Ocean. To achieve this, in the first stage reference simulations of the tropical storm "Paulette" (September 2020) were conducted using bulk microphysics with different parameter setups and subsequently evaluated against observational data, especially satellite measurements. On the second stage the horizontal resolution of the simulation was increased to $\sim$250 m, still using bulk microphyics. To this end, methods were developed for the high-resolution simulations that enable ICON simulations to be centered around the hurricane, thereby significantly increasing the efficiency of the application.

Resource Utilization

At the time this report was written, approximately 69% of the granted computing resources were being used by project members, while 7.8% expired unused and 23.2% still remain for compute work until the end of the allocation period. In total, 15 project members from four different institutions contributed to cross-institutional collaboration, 13 of whom are early career scientists. The largest amount of resources were used to set up and produce ICON - LAM + LES mode simulations.

Scientific Results

During the last allocation period the sensitivity simulations with ICON-NWP v2.6.6 were further analyzed and additional simulations changing the ice formation were performed. Simulated cloud characteristics were constrained by observational products from CERES and CMSAF. The scientific results were well received at ICCARUS (March 2025, Poster) and EGU (April 2025, Talk).

Most of the resources were used to design, implement and improve a hurricane-centric ICON setup to be able for the first time ever to produce hurricane simulations with a resolution of $\sim$ 250 m. To achieve this, the hurricane was tracked in reference simulations (mesh size 2.5 km) using the tracking tool *tobac* (Heikenfeld et al., 2019; Sokolowsky et al., 2024). Segments were defined along the track in which the hurricane remained for 36 hours. Flexible ICON grids were generated for these segments in order to perform spatial refinements only around the hurricane. After 24 hours of integration time,

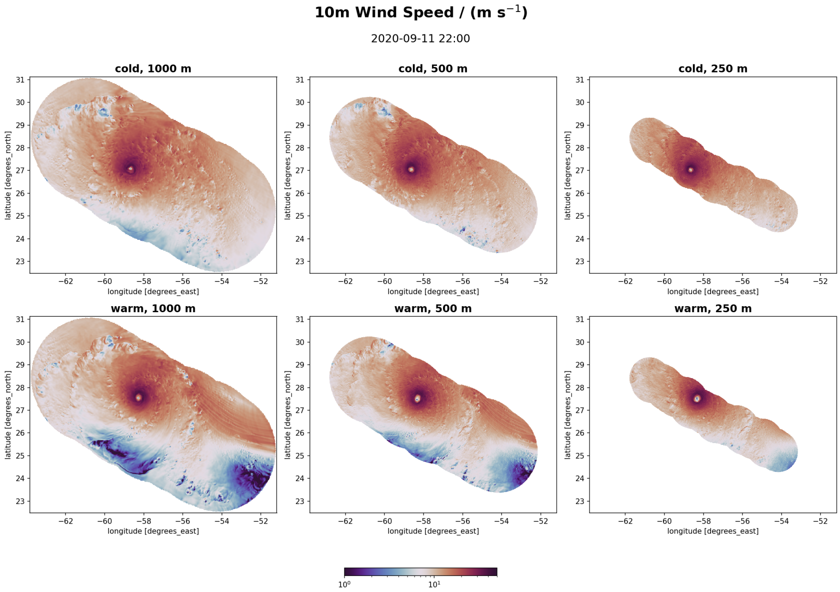

Figure 1: Overview of the 10m wind speed for performed LEM simulations in cold (upper row) and warm (lower row) start for 3 different horizontal resolution setups (1000m, 500m and 250m).

the integration domain was shifted to the next segment and reinitialized. For initialization, either the reference simulation (cold start) was used or a hybrid IC state was generated from the previous segment and the reference (warm start). In Fig. 1 the 10m wind speed for the cold start (upper row) and warm start (lower row) can be seen for the three chosen nests (1000m, 500m and 250m) and two-moment cloud microphysics. Figure 1 shows a significant difference in the dynamical structure of the tropical storm between cold and warm start setup. While in the cold start the center of the hurricane is better caught by the simulation area, a more defined and heterogeneous wind structure of the storm is displayed in the warm start setup, which resembles the satellite observations closer. Additionally, in both setups it is clear that the area chosen for the 250m simulation is too small to catch the whole storm, a bigger area with this high resolution would be more appropriate, but comes with a higher computational and storage demand.

Scientific analysis of the different setups is currently ongoing. Computationally, we are tackling the challenge of keeping the simulations efficient while ensuring that the hurricane does not come too close to the domain boundaries. The comparison and analysis between model and satellite date is also continued and the project bb1376 supported the continued development and testing of the SynSatPy package with its release of v1.0.0 in April 2025 (Senf, 2025).

References

Heikenfeld, M., P. J. Marinescu, M. Christensen, D. Watson-Parris, F. Senf, S. C. van den Heever, and P. Stier, 2019: tobac 1.2: towards a flexible framework for tracking and analysis of clouds in diverse datasets. *Geosci. Model Dev.*, **12 (11)**, 4551–4570, doi:10.5194/gmd-12-4551-2019, URL https://www.geosci-model-dev.net/12/4551/2019/.

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Sokolowsky, G. A., and Coauthors, 2024: *tobac* v1.5: introducing fast 3d tracking, splits and mergers, and other enhancements for identifying and analysing meteorological phenomena. *Geoscientific Model Development*, **17 (13)**, 5309–5330, doi:10.5194/gmd-17-5309-2024, URL https://gmd.copernicus.org/articles/17/5309/2024/.