Project: **1461**

Project title: **Glacier Space**

Principal investigator: **Tobias Sauter**

Report period: **2025-11-01 to 2026-10-31**

The *Glacier Space* project investigates glacier–atmosphere interactions and the role of small-scale atmospheric processes in alpine environments. To address the project's scientific questions, the ICON-LES model was applied in limited area mode (LAM) at very high spatial resolutions. This report summarizes the activities, computational needs, and results obtained within the project. After completing ICON initialization (Phase 1) and validation (Phase 2) in 2025, as detailed in the corresponding project report, we expanded our portfolio of experiments and conducted various analyses.

Phase 3 and 4 (cont'd): Sensitivity Studies

The validation experiments serve as a baseline for the sensitivity studies. The main goal is to quantify the additional atmospheric warming over the remaining ice caused by reduced overall ice extent (*manuscript in preparation*).

Using outputs from the Open Global Glacier Model (OGGM), we simulated glacier outlines for different future years (Fig. 1) and forced ICON with adjusted external parameters. Former glacierized areas have been assigned land use types, soil types, and albedo values that align with current glacier forefield values. All ICON experiments use the same initial and lateral boundary conditions as the baseline experiment.

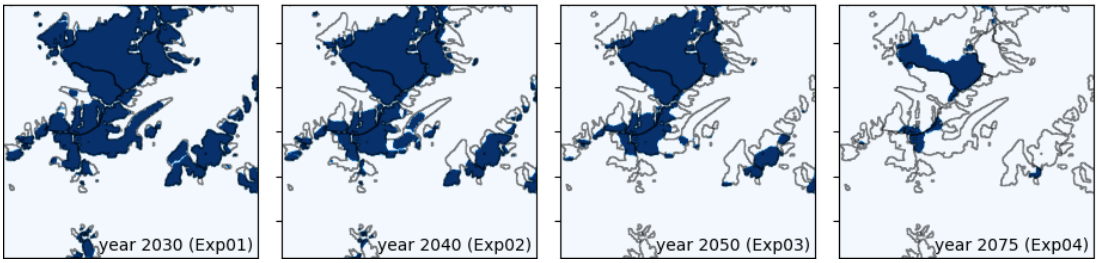


Fig 1. *Projected glacier extents from OGGM simulations for the years 2030, 2040, 2050, and 2075. The original RGI v7.0 extents are shown as black outlines.*

Furthermore, a study was conducted that applied a complex network analysis of near-surface air temperature over our domain (*manuscript in preparation*). The analysis characterizes how temperature synchronization patterns reorganize under progressive deglaciation. Four ice cover configurations were examined: the current glacier extent and projected future extents for 2040, 2050 and 2075, as well as a fully ice-free simulation.

The results reveal a systematic reorganization of the temperature network. As the glacier retreats, the formerly glacierized valley floor acquires stronger, more internally cohesive temperature synchronization driven by terrain rather than ice (Fig. 2). Conversely, ice-covered ridges lose connectivity as individual ice caps fragment and decouple. These findings demonstrate that glacier loss not only warms the local environment, but also alters the spatial structure of the alpine microclimate.

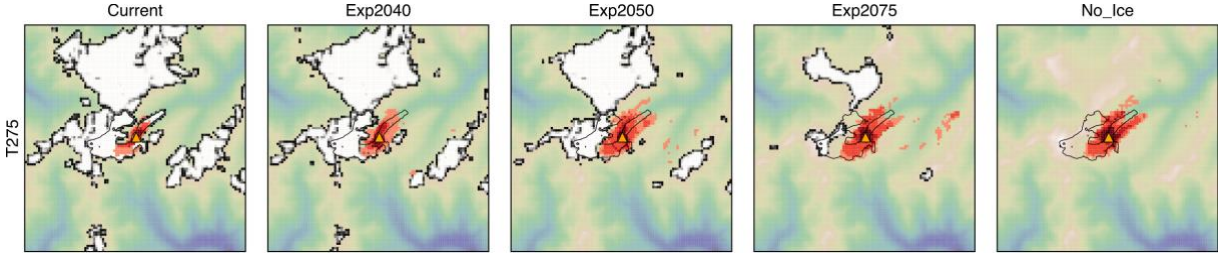


Fig 2. *The network neighborhood (connected pixels) of station T275 is highlighted in red. Darker shades of red indicate pixels that are more frequently connected to the station across the analyzed time windows.*

To further extend the range of meteorological conditions, we plan to perform additional simulations using the same glacier outlines, but for the period of HEFEX III campaign (Table 1).

Phase 4 (cont'd): HEFEX III field campaign integration

In August 2025, a large-scale field campaign was conducted in the Ötztal Alps in Austria. The campaign aimed to collect atmospheric measurements of the atmospheric boundary layer (10m tower) and the valley atmosphere (two Doppler lidar systems). High-resolution ICON-LES simulations were performed during the same time period to validate the model outputs under different atmospheric conditions using this unique observational dataset (Fig 3).

Validation of the performance of the ICON-LES model based on the HEFEX II (2023) and HEFEX III (2025) field campaigns has been submitted to the EGU GMD journal for publication and is *currently under review* (DOI: 10.5194/egusphere-2026-3922). The reviewers requested a partial rerun of the simulation with a different configuration.

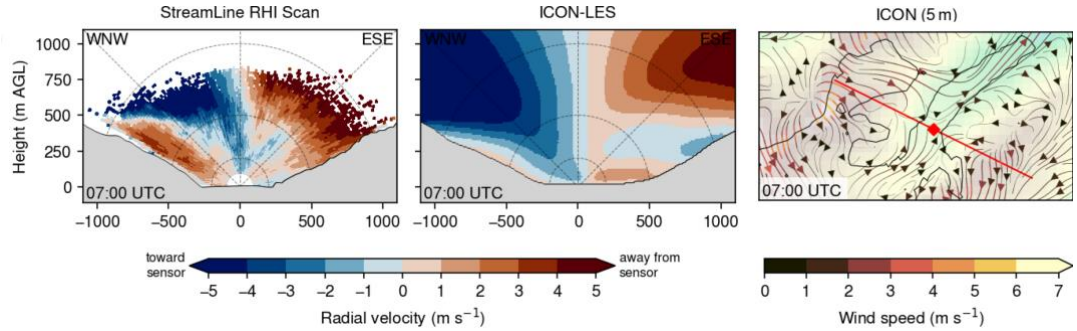


Fig 3. *Comparison of observed and simulated radial velocity fields during a case study on 10 August 2025. The tiles represent a 30 min averaged time period of radial velocity (1st and 2nd column) and horizontal wind field (3rd column). The lidar scan axis is added for reference. Positive and negative radial velocities indicate movement away from and toward the lidar, respectively. Time stamps denote the end of the averaging interval.*

Overview of simulations

Table 1. *Overview of completed (green), running (blue) and planned simulations (red).*

Campaign	Reference	Y2030	Y2040	Y2050	Y2075	Y2100	NO_ICE
HEFEX II	completed	rerun	completed	completed	completed	50%	completed
HEFEX III	completed	rerun	10%	0%	0%	0%	completed

Technical usage summary

The computational resources of the DKRZ HPC system *Levante* were essential for carrying out this project. As of 13 October 2026, the usage statistics are:

- **CPU node hours consumed (2026 only):** ~25’800 / 33’000
- **Disk storage consumed:** ~116 / 150 TiB

These figures reflect both the high-resolution, long-duration simulation runs and the large volume of model output (including high-frequency data).

Conclusion

The DKRZ HPC system *Levante* has been central to the progress of the *Glacier Space* project. Its resources enabled:

- Rigorous validation of simulations against unique high-mountain observational datasets.
- Scenario experiments exploring the future state of alpine glacier–atmosphere interactions.
- Quantification of additional warming caused by ice loss, which acts as positive feedback on future glacier melt.

Without Levante’s computational power and data management capabilities, the project's objectives could not have been achieved.