EMI R&D PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	2026
Project Title:	NorCP 2nd Phase: A suite of 'convection-permitting' regional climate model simulations over the Nordic region
Computer Project Account:	spselind
Principal Investigator(s):	Petter Lind
Affiliation:	Swedish Meteorological and Hydrological Institute
Name of ECMWF scientist(s) collaborating to the project (if applicable)	Fuxing Wang, Yi-Chi Wang, Aitor Aldama Campino
Start date of the project:	01/01/2025
Expected end date:	31/12/2027

Computer resources allocated/used for the current year and the previous one
(if applicable)
Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	150M	62M (41%)	100M	18,6M (19%)
Data storage capacity	(Gbytes)	75000	5000	100000	<10000

Summary of project objectives (10 lines max)

The project is a continuation and expansion of the first phase of the Nordic Convection-Permitting Climate Projections (NorCP) project (Lind et al., 2020). In this second phase, a new version (cycle 46) of the HARMONIE-Climate (HCLIM) convection-permitting regional climate model (CPRCM) will be applied in a suite of simulations at km-scale over the Nordic region. The objectives involve: i) run HCLIM46 forced by ERA5 reanalysis over a time period covering the last ~40 years; ii) perform a set of HCLIM46 simulations forced by several GCMs from the CMIP6 and forthcoming CMIP7 ensembles, covering both pre-industrial (for attribution studies), present and future time periods. The high-resolution climate data will be used in impact modeling, climate adaptation studies and also support the development of AI/ML methodologies and tools. In addition, benchmark simulations will be performed with a coupled atmosphere-ocean version of HCLIM.

Summary of problems encountered (10 lines max)

The development and evaluation of the new version of HCLIM, cycle 46, has taken longer time than anticipated, due to unforeseen technical problems running the model code, developments of model physics components and configurations not being ready and tested in time, and issues related to model performance. A major effort in the recent 6-12 months have led to significant improvements in the HCLIM cycle 46 version, and we have recently finished the work to define the operational model configuration to be used in NorCP 2.0.

Another issue is the delays experienced in finalizing the new versions, and completing the new simulations, of the GCMs planned to provide forcing conditions to HCLIM46. However, this is a minor issue since we will start with the ERA5 driven evaluation simulations, while GCM forced runs will start in the fall or winter of 2026.

Summary of plans for the continuation of the project (10 lines max)

The main priority recently has been to complete the evaluation and finalize the operational configuration of HCLIM cycle 46. With the model ready, final short test simulations will be done in the immediate future to finalise the experiment setups, and by late July or August, the evaluation simulation, forced by ERA5, will be initialized. With this simulation we expect to heavily increase the use of the SBUs and storage allocated for the current year. GCM driven simulations for a historical period are currently planned for the third and fourth quarters of 2026, with past/future scenario simulations following in the first and second quarter of 2027.

List of publications/reports from the project with complete references

n/a

Summary of results

If submitted **during the first project year**, please summarise the results achieved during the period from the project start to June of the current year. A few paragraphs might be sufficient. If submitted **during the second project year**, this summary should be more detailed and cover the period from the project start. The length, at most 8 pages, should reflect the complexity of the project. Alternatively, it could be replaced by a short summary plus an existing scientific report on the project attached to this document. If submitted **during the third project year**, please summarise the results achieved during the period from July of the previous year to June of the current year. A few paragraphs might be sufficient.

A major part of the work since the beginning of the project in 2025 has been dedicated to developing and finding a suitable configuration of the most recent version of HCLIM, cycle 46 (HCLIM46). Compared to the previous operational HCLIM version, cycle 43 (HCLIM43), HCLIM46 includes several important new features, such as support for dual precision (single plus double precision), a new dry soil layer parameterization, and an increased number of patches in the SURFEX land surface model (from 2 to 3), among other updates. Members of the NorCP 2.0 project have been integral in conducting a large number of tests to adapt HCLIM46 (using both ALADIN and AROME physics configurations) for deployment on ECMWF computing infrastructure over the Fenno-Scandinavia domain (Fig. 1). These tests include assessments of processor compatibility, testing of dual precision (which will enhance the computational efficiency during runtime), regular debugging procedures, and most importantly investigating the impacts and potential biases introduced by the numerous model updates.

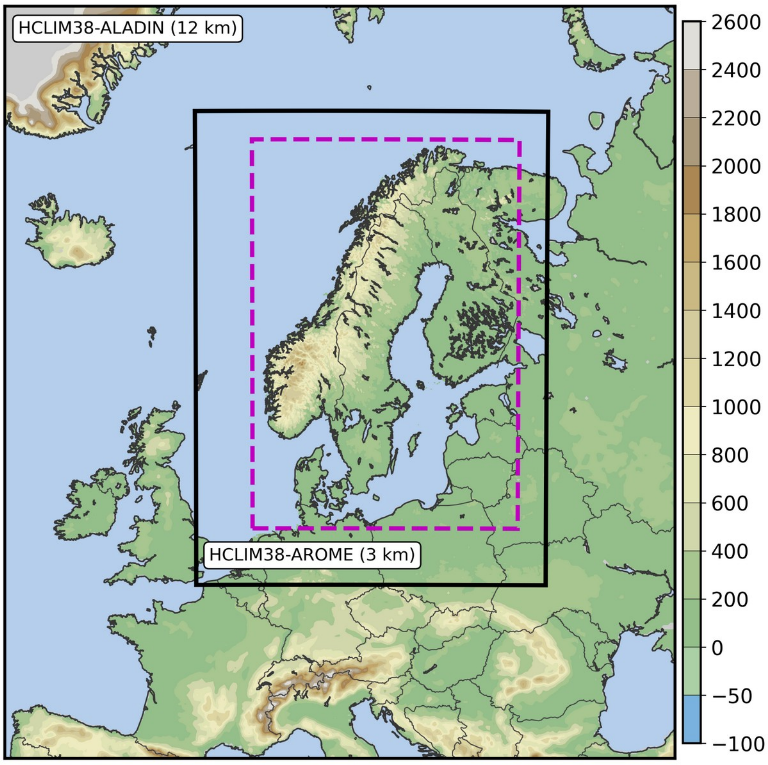

Fig. 1 Domains used for HCLIM in NorCP 1.0. Similar domains will be used in NorCP 2.0, although with some modifications; the domain for HCLIM46-ALADIN will cover the whole of Europe and extend further west over the North Atlantic. The Fenno-Scandinavia domain for HCLIM46-AROME will be slightly expanded in the east-west direction.

Several multi-year simulations using HCLIM46 have been conducted on ECMWF systems to evaluate systematic biases. These simulations included runs with the default configuration, as well as experiments incorporating new features such as a dry soil layer, multi-patch surface representation by differentiating the vegetation patch into low and high vegetation (2 to 3 patches), and an updated solar constant based on values used in the sixth phase of the Coupled Model Intercomparison Project (CMIP6). Additional sensitivity experiments have been carried out with shallow convection deactivated when the grid-point vertical velocity was considered sufficiently strong to support deep convection.

The performance of the simulations with AROME physics with 3 km horizontal resolution for the Scandinavian domain has been assessed through extensive analysis and comparison against various observational and reanalysis datasets. The evaluation indicates that HCLIM46 produces annual and seasonal averages of precipitation and temperature that are broadly similar to those from HCLIM43. For instance, Figures 2 and 3 illustrate the seasonal and regional differences between HCLIM46, HCLIM43, and observational datasets, highlighting biases in precipitation and temperature; in particular wetter conditions in HCLIM, e.g. a clear overestimation of precipitation over the Scandinavian mountains (however, the amounts of precipitation in complex terrain are usually underestimated in observations). Also, persistent cold biases in daily mean temperature across large areas of Scandinavia.

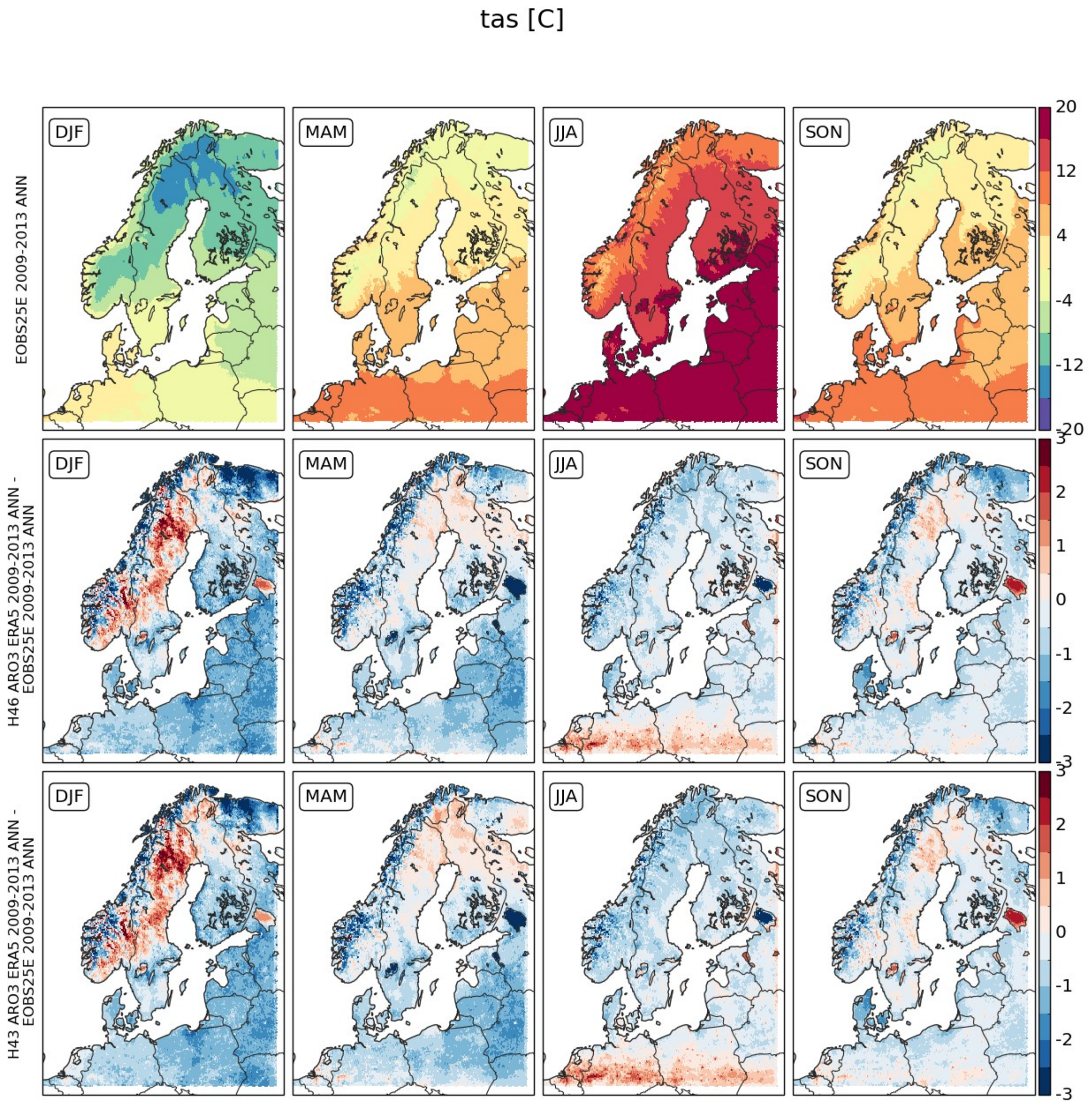

Fig. 2 Seasonal mean near-surface temperature (℃) averaged over 2009–2013 (2008 for spin-up) in HCLIM and observations. The top row shows EOBS precipitation for each season: DJF (winter), MAM (spring), JJA (summer), and SON (autumn). The remaining rows show the differences with respect to EOBS for HCLIM46 AROME3 (2nd row) and HCLIM43 AROME3 (3rd row). Reddish colors indicate higher temperatures than EOBS, while blue colors indicate lower temperatures.

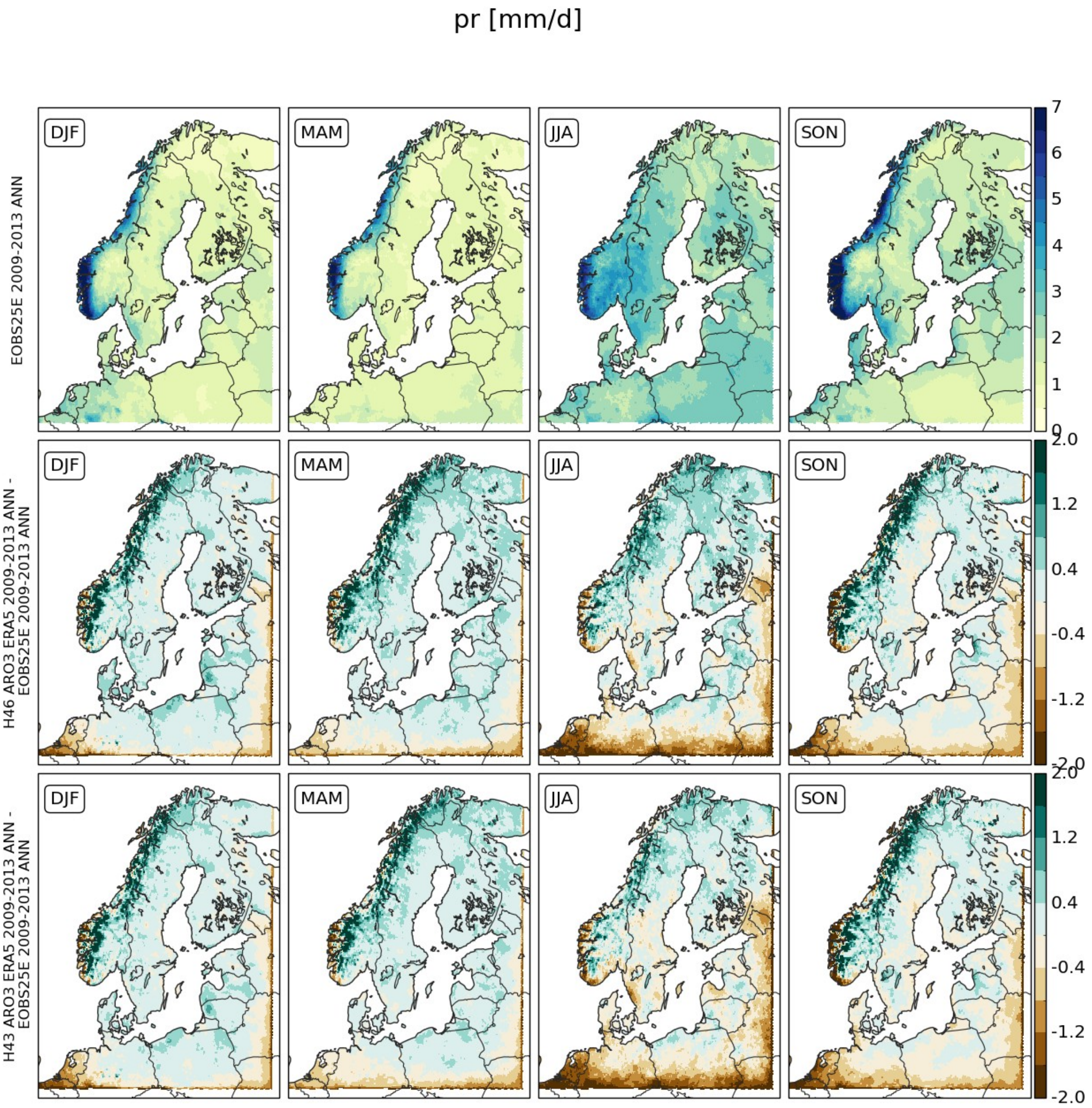

Fig. 3 Seasonal mean of precipitation (mm/day) averaged over 2009–2013 (2008 for spin-up) in HCLIM and observations. The top row shows EOBS precipitation for each season: DJF (winter), MAM (spring), JJA (summer), and SON (autumn). The remaining rows show the differences with respect to EOBS for HCLIM46 AROME3 (2nd row) and HCLIM43 AROME3 (3rd row). Positive values (green) indicate higher precipitation than EOBS, while negative values (brown) indicate lower precipitation.

However, further analyses to understand these biases, especially those associated with the near-surface temperature, have pointed to the land surface-atmosphere interaction and soil processes. Simulations over different parts of Europe have shown strong warm biases in HCLIM compared to observations, which is the result of too strong and quick loss of soil moisture, causing dry conditions and excessive sensible heat fluxes and too high near-surface temperatures (see example of heatwave event in Po Valley in Fig. 4).

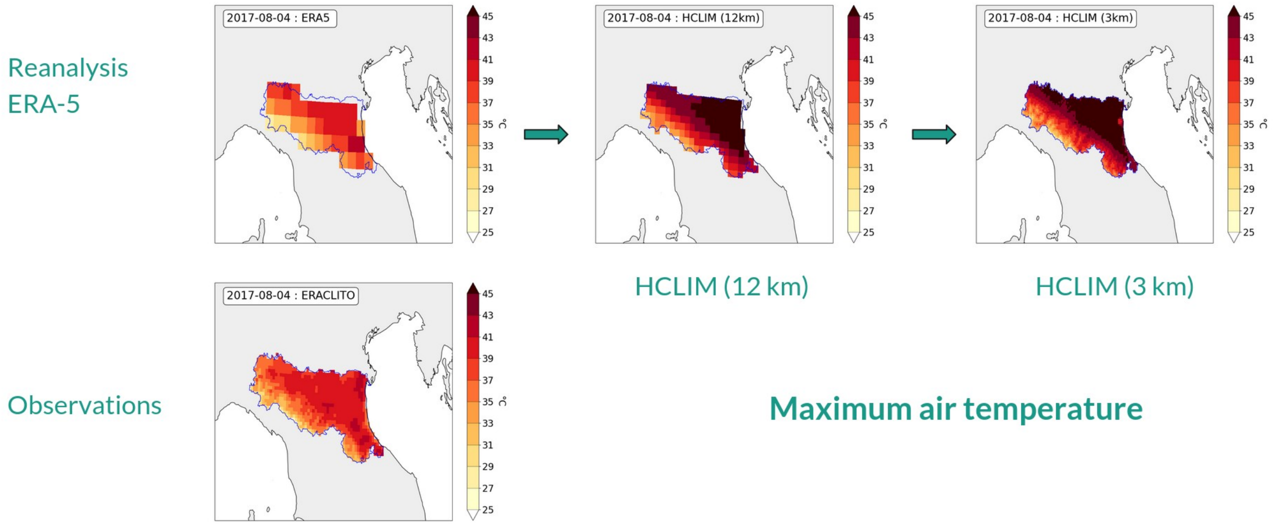

Fig. 4 Daily maximum near-surface temperature on 4 Aug 2017 in the Po Valley as simulated in HCLIM at 12 and 3 km resolution (forced by ERA5) and in ERA5 reanalysis and observations. Note that the temperature is significantly higher in HCLIM compared to observations.

Therefore, a major effort was undertaken to investigate, modify and tune the parameterizations of soil processes and parameters such as root fraction, soil water conductivity, surface runoff magnitudes et cetera. The incrementally introduced modifications were tested in numerous sensitivity simulations and have led to significant improvements in the representation of soil moisture, with strong implications on surface energy fluxes. As seen in Figure 5, changes in root fraction, soil water conductivity and percolation, and in the field capacity and wilting point, incrementally reduced the bias (compared to the RACMO climate model which has shown better performance than HCLIM) of surface turbulent fluxes through reducing the sensible heat flux and increasing the latent heat flux. Hence, in this situation, with a very warm period over central France in 2018, and where the HCLIM46 default version has shown a relatively strong warm bias, the temperature was lowered with these soil modifications and thus in better agreement with observations (Fig. 6).

In addition, it was noted that the surface albedo was lower compared to in-situ observations and compared to other state-of-the-art regional climate models and thus the value for the albedo was increased over low vegetation patches in HCLIM. The results showed further improvements in the near-surface temperature. For example, the remaining warm biases over the Iberian Peninsula and south-east Europe after the soil modifications were reduced with the changes to the albedo (not shown).

Even though the recent development work has taken up a lot of time in the past year and therefore delayed the start of the project simulations significantly, the latest developments of HCLIM cycle 46 have led to improvements in its performance in representing the climate over Europe, which the project benefits highly from. A more comprehensive summary of results can be found in the HCLIM community GitHub repository: https://github.com/Hirlam/HCLIM/wiki/Evaluation. We are finally now entering the phase of the NorCP 2.0 project where we will start the operational simulations in the near term. Final tests are currently being performed on ATOS to optimize the experiment configurations, for example defining the full output and making sure that everything runs efficiently on the system.

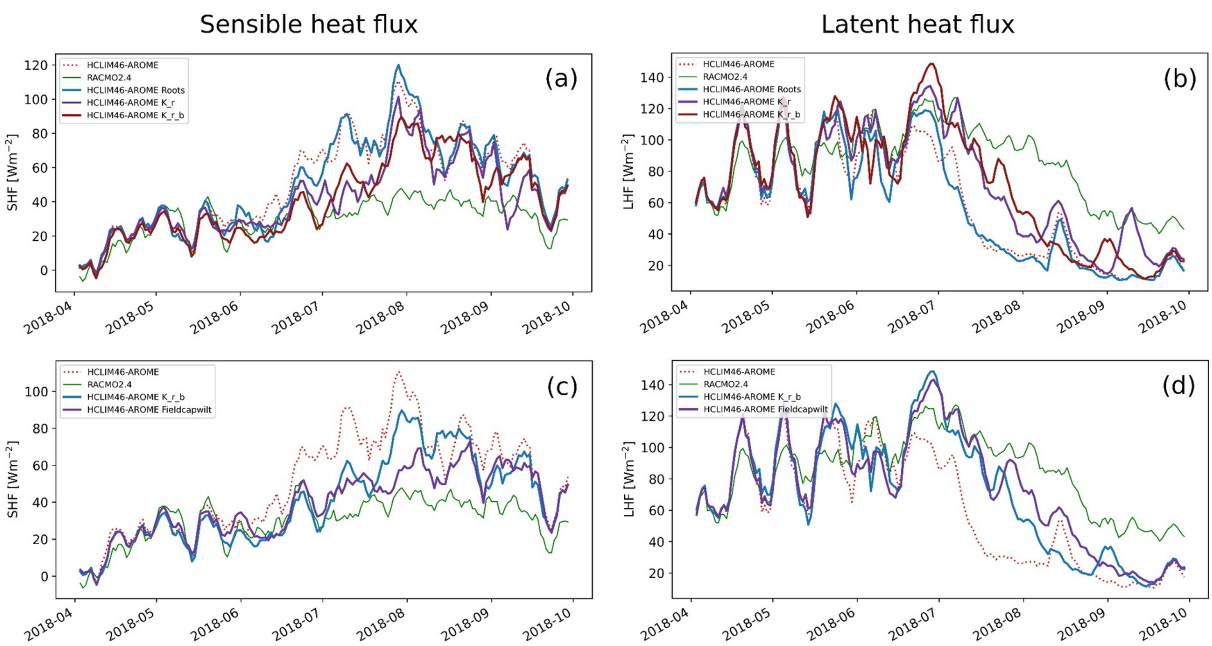

Fig. 5 Sensible (a, c) and latent (b, d) surface heat fluxes over central France April-September 2018, in RACMO regional climate model (green line), HCLIM46 default version (red dotted line) and HCLIM46 with modifications to soil parameterizations: "Roots" – changed root fractions (light blue line in panel (a) and (b)); "K_r" – changed hydraulic conductivity (dark purple in (a) and (b)); "K_r_b" – changed hydraulic conductivity *and* percolation in non-saturated conditions (red line in (a) and (b)). In (c) and (d) "K_r_b" is the light blue line while changes in field capacity and wilting point ("Fieldcapwilt") is represented by the dark purple line.

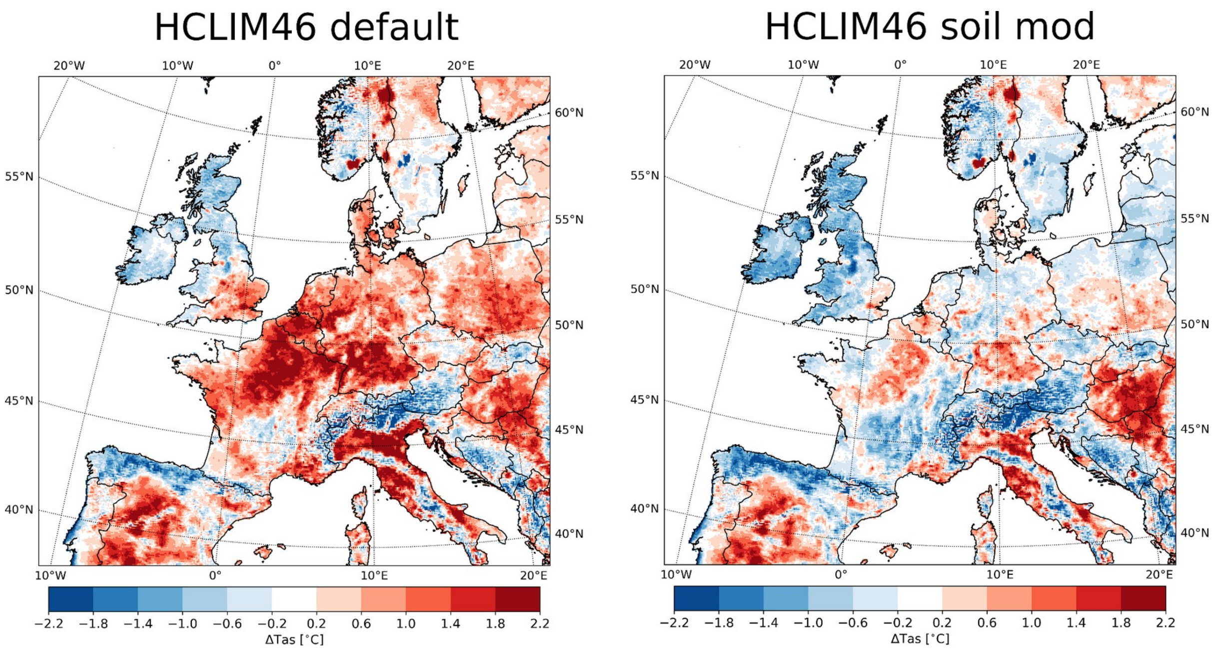

Fig. 6 Difference in June-July-August seasonal average near-surface temperature (℃) with respect to EOBS observations in the default version of HCLIM46 (left panel) and in HCLIM46 with modified soil parameterizations (right panel).

HCLIM46 in CORDEX FPS URB-RCC

An additional important step towards the new operational version of HCLIM46 is SMHI's participation in the CORDEX FPS URB-RCC project, where we are contributing to stage 1 simulations using the HCLIM46 model. The overall plan of stage 1 is to perform ERA5 driven simulations over Paris and several globally distributed satellite cities for historical periods of around 10 years. SMHI is specifically involved in simulations over the cities of Paris and Johannesburg, both at 12.5 km and 3 km resolutions (Table 1). The detailed experiment setups are available from the HCLIM community github repository, https://github.com/HCLIMcom/CORDEX_FPS_URB_RCC, derived in collaboration with KNMI. These long-term simulations have been completed by the end of 2025. The CMOR:ized data were uploaded to the Levante HPC (at DKRZ). Currently, these HCLIM simulation analyses are being evaluated against observational data and benchmarked against other CPM simulations. Figs 7-8 show the preliminary comparison results for daily minimum/maximum near-surface temperature, and precipitation.

Table 1. List of simulations CORDEX FPS URB-RCC stage 1 simulations performed by SMHI

Domain	Period	Downscaling
Paris	2000 - 2009	HCLIM46-ALADIN (12.5 km) to HCLIM46-AROME (3 km)
	2021 - 2023	HCLIM46-ALADIN (12.5 km) to HCLIM46-AROME (3 km)
	2021 - 2023	HCLIM46-AROME (12.5 km) to HCLIM46-AROME (3 km), with two different setups in boundary coupling
Johannesburg	2014 - 2024	HCLIM46-ALADIN (12.5 km) to HCLIM46-AROME (3 km)

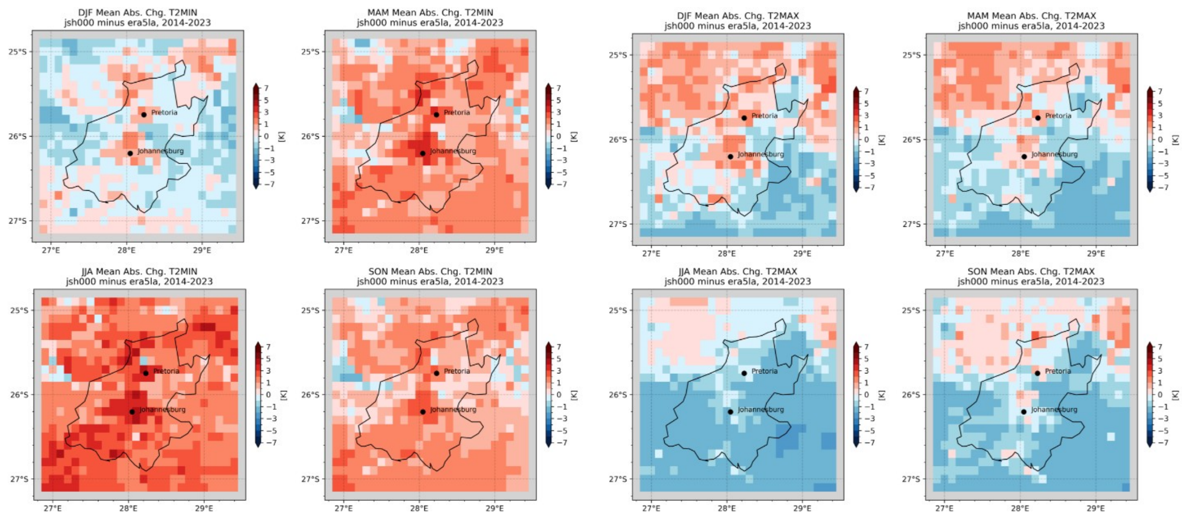

Fig. 7 The comparison of daily minimum (columns 1-2) and daily maximum (columns 3-4) near-surface temperature during 2014- 2023 over Johannesburg domain between HCLIM46-AROME at 3 km resolution (forced by ERA5) and ERA5-Land (0.01°). Source: Torsten Weber (GERICS).

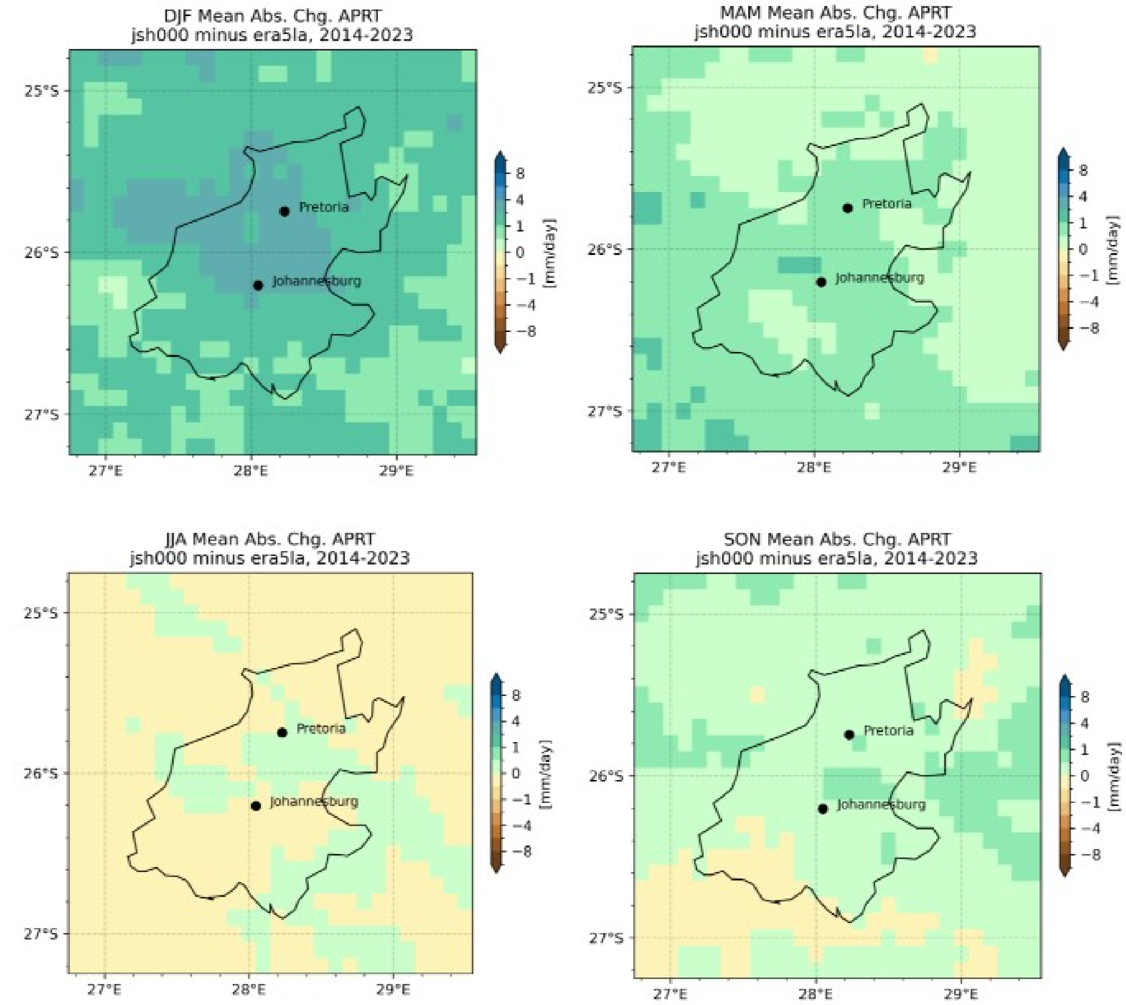

Fig. 8 The comparison of daily mean precipitation during 2014- 2023 over the Johannesburg domain between HCLIM46-AROME at 3 km resolution (forced by ERA5) and ERA5-Land (0.01°). Source: Torsten Weber (GERICS).