SPECIAL 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	2023
Project Title:	A large ensemble of climate projections at high resolution
Computer Project Account:	spsebelu
Principal Investigator(s):	Danijel Belušić
Affiliation:	Swedish Meteorological and Hydrological Institute
Name of ECMWF scientist(s) collaborating to the project (if applicable)	n/a
Start date of the project:	1 January 2021
Expected end date:	31 December 2023

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)	60 000 000	60 812 375	60 000 000	2 035 017
Data storage capacity	(Gbytes)	70 000	-	105 000	-

Summary of project objectives (10 lines max)

The project develops and utilises an on-demand climate downscaling procedure for high-impact weather events using a high-resolution regional climate model (convection permitting regional climate model - CPRCM). The procedure consists of two main steps:

1. detecting potential high-impact events of interest in a parent simulation, typically a global climate model (GCM),
2. using an automated downscaling procedure for extreme events, which includes re-running the parent model to save model levels and running the CPRCM for a large number (hundreds) of detected events.

The goal is to provide a sufficient number of simulations for a robust statistical analysis of extreme events.

Summary of problems encountered (10 lines max)

There were no significant problems encountered in the previous year.

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

The extensive simulations for this year will be started in autumn and include a large number of simulated events in the present and future climate using km-scale simulations with a CPRCM.

List of publications/reports from the project with complete references

The event-based downscaling is based on high-impact event detection from GCMs, which is in turn related to the circulation type classification of GCM ensembles. The following three papers address the circulation type classification methodology and its application to the SMHI Large Ensemble performed with EC-Earth:

1. Hansen, F., Belušić, D., 2021: Tailoring circulation type classification outcomes. Int. J. Clim., 41, 6145–6161, doi: 10.1002/joc.7171.
2. Hansen, F., Belušić, D., Wyser, K., Koenigk, T., 2023: Future changes of circulation types and their effects on surface air temperature and precipitation in the SMHI large ensemble. Clim. Dyn., doi: 10.1007/s00382-023-06704-y.
3. Hansen, F., Belušić, D., Wyser, K., 2023: Relationship between Circulation Types and Extreme Precipitation over Scandinavia is stable under Climate Change. Geophys. Res. Lett., submitted.

The added value of the convection permitting model HCLIM, which is used in this project, over a Fenno-Scandinavian domain for the present and future climate has been addressed in the following papers:

1. Médus, E., Thomassen, E. D., Belušić, D., Lind, P., Berg, P., Christensen, J. H., Christensen, O. B., Dobler, A., Kjellström, E., Olsson, J., Yang, W., 2022: Characteristics of precipitation extremes over the Nordic region: added value of convection-permitting modeling. Nat. Hazards Earth Syst. Sci., 22, 693–711, doi: 10.5194/nhess-22-693-2022.
2. Lind, P., Belušić, D., Médus, E., et al., 2023: Climate change information over Fenno-Scandinavia produced with a convection-permitting climate model. Clim. Dyn., 61, 519–541, doi: 10.1007/s00382-022-06589-3.

The applicability of an additional downscaling step for urban areas aiming at a 100-m horizontal resolution using an offline land-surface model, which will be employed in the on-demand climate downscaling of heat-wave events in this project, was published in the following paper:

1. Wang, F., Belušić, D., Amorim, J. H., Ribeiro, I., 2023: Assessing the impacts of physiography refinement on Stockholm summer urban temperature simulated with an offline land surface model, Urban Clim., 49, 101531, doi: 10.1016/j.uclim.2023.101531.

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.

The work was performed in two parallel tasks. Task 1 was focused on evaluating the CPM performance over different domains, including different regions and different sizes of domains over the same region. The former is to test the applicability of the CPM for simulations in different regional climates, and for this purpose the work has been extended to domains covering different regions in Europe and Africa (Fig. 1). The latter is to estimate the optimal domain size for capturing atmospheric phenomena of interest. For example, reproducing MCS's in the Sahel might require the CPM domain extending very far to the east or south (Fig. 1, right panels).

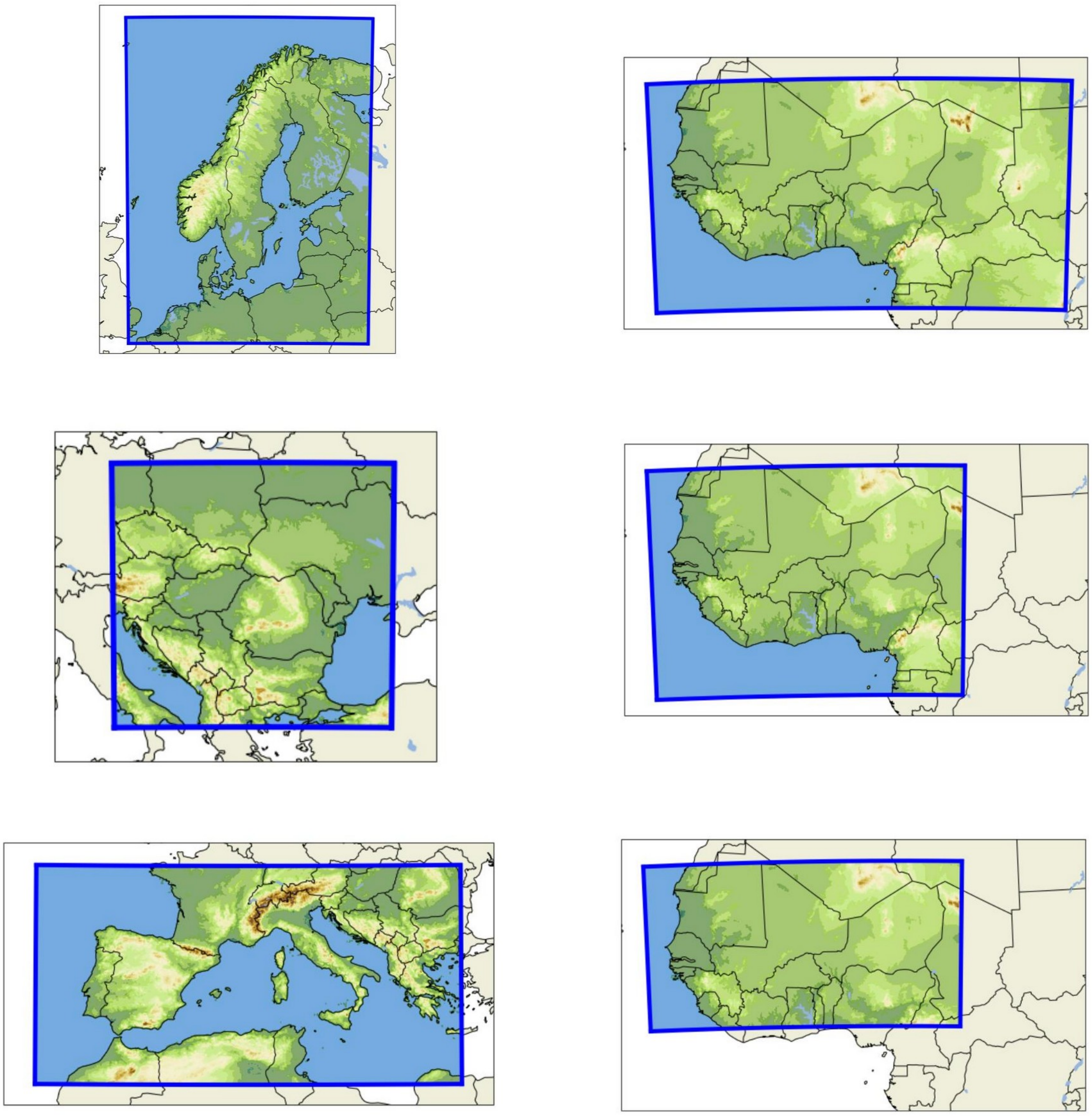

Figure 1. Domains used in Task 1.

Task 2 was focused on the spin-up of soil moisture and temperature. Climate models with sufficiently realistic land-surface schemes have long memory in deeper soil layers and hence require long spin-up time to reach equilibrium. The proper spin-up is needed to ensure consistent surface fluxes and consequently the reproduction of events of interest (Fig. 2).

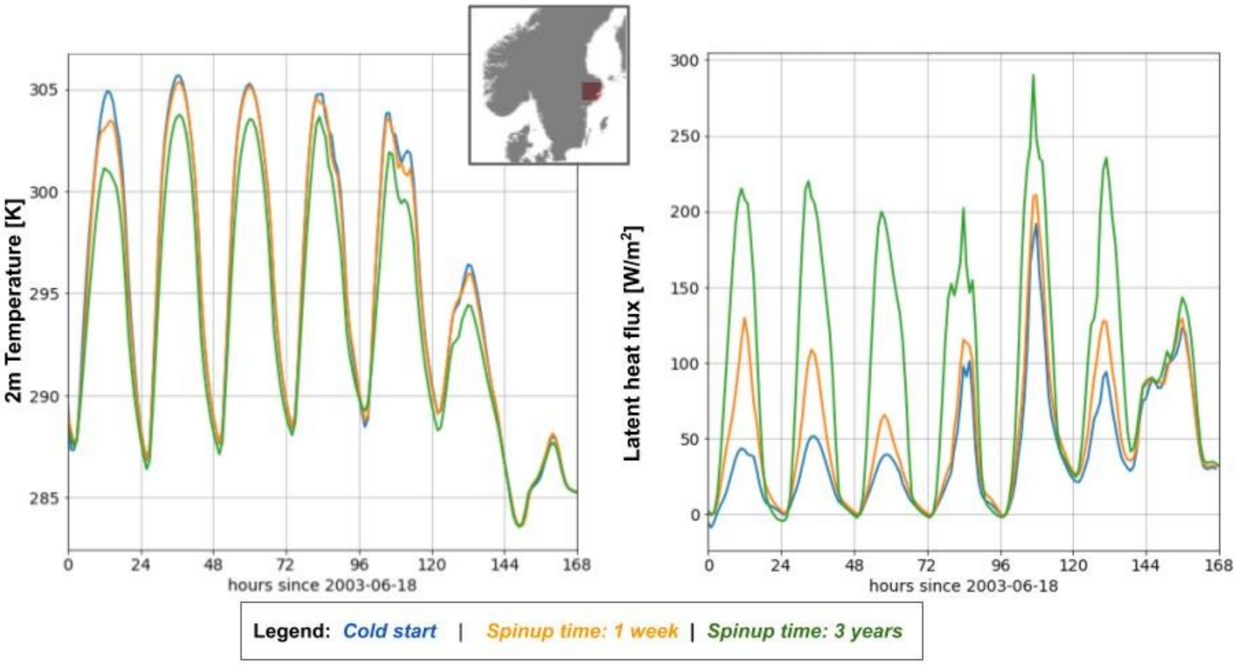

Figure 2. An example of the effects of spin-up time on the 2-m temperature (left) and surface latent heat flux (right) for a week-long event in summer in south-east Sweden (inset).

We estimated the spin-up needed in different regions using different initializations, and in extreme climates (deserts or glaciers) the spin-up can take over a decade, while in more temperate climates it usually takes a few years. However, given the current approach of downscaling individual events, which are typically of short duration (e.g. 1 week), long spin-up defies the purpose. So several different approaches were tested with the goal of speeding up the spin-up, while still reaching the soil equilibrium. After many tests, the hybrid approach was chosen (Fig. 3) that uses long (several years or decades) simulations with the offline land-surface model (SURFEX) prior to the event, while the fully coupled simulations are used only comparatively very shortly before the event onset (e.g. a few days or weeks).

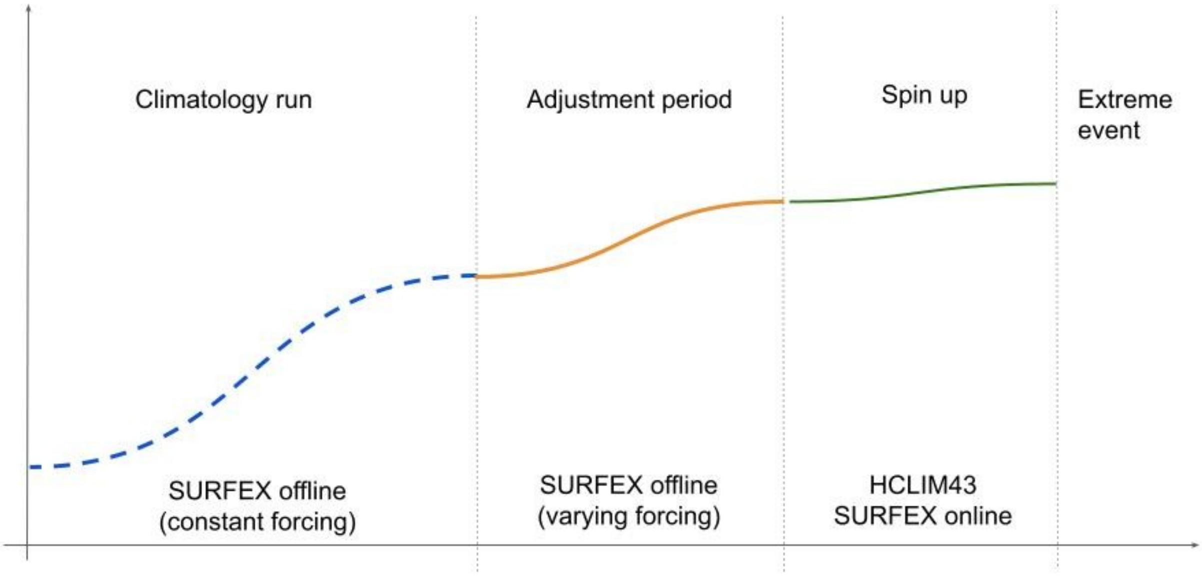

Figure 3. A schematic of the hybrid procedure for fast soil spin-up used before event downscaling.

Finally, the first batch of downscaled events in the present and future climate are related to heat waves in Swedish urban areas (Fig. 4).

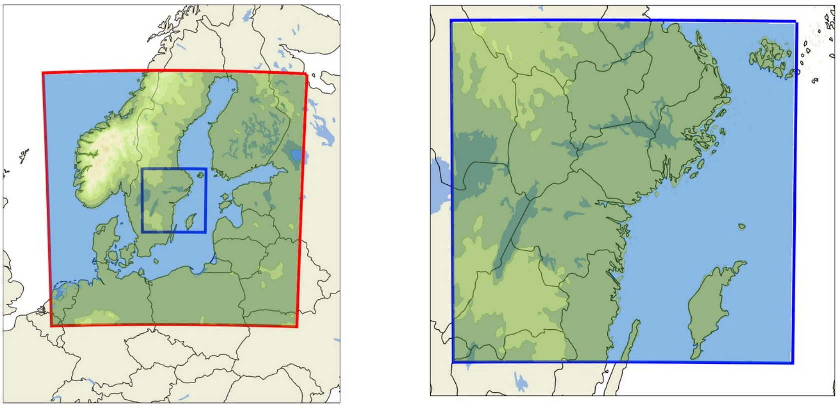

Figure 4. Domains used for downscaling of heat-wave events over Swedish urban areas. Left: the 12-km regional climate model domain with the 3-km CPM domain indicated; Right: the 3-km CPM domain.

The selected events from the present climate are projected to the future using the pseudo global warming (PGW) approach, where the future climate change signal ("delta") is calculated from global climate models and is added to the historical event data obtained from the reanalysis (ERA5). This is done for two specific warming levels (2 and 3 degrees global warming compared to the pre-industrial climate). Figure 5 shows the warmest days during three heat-wave events in the historical period and for the two specific warming levels.

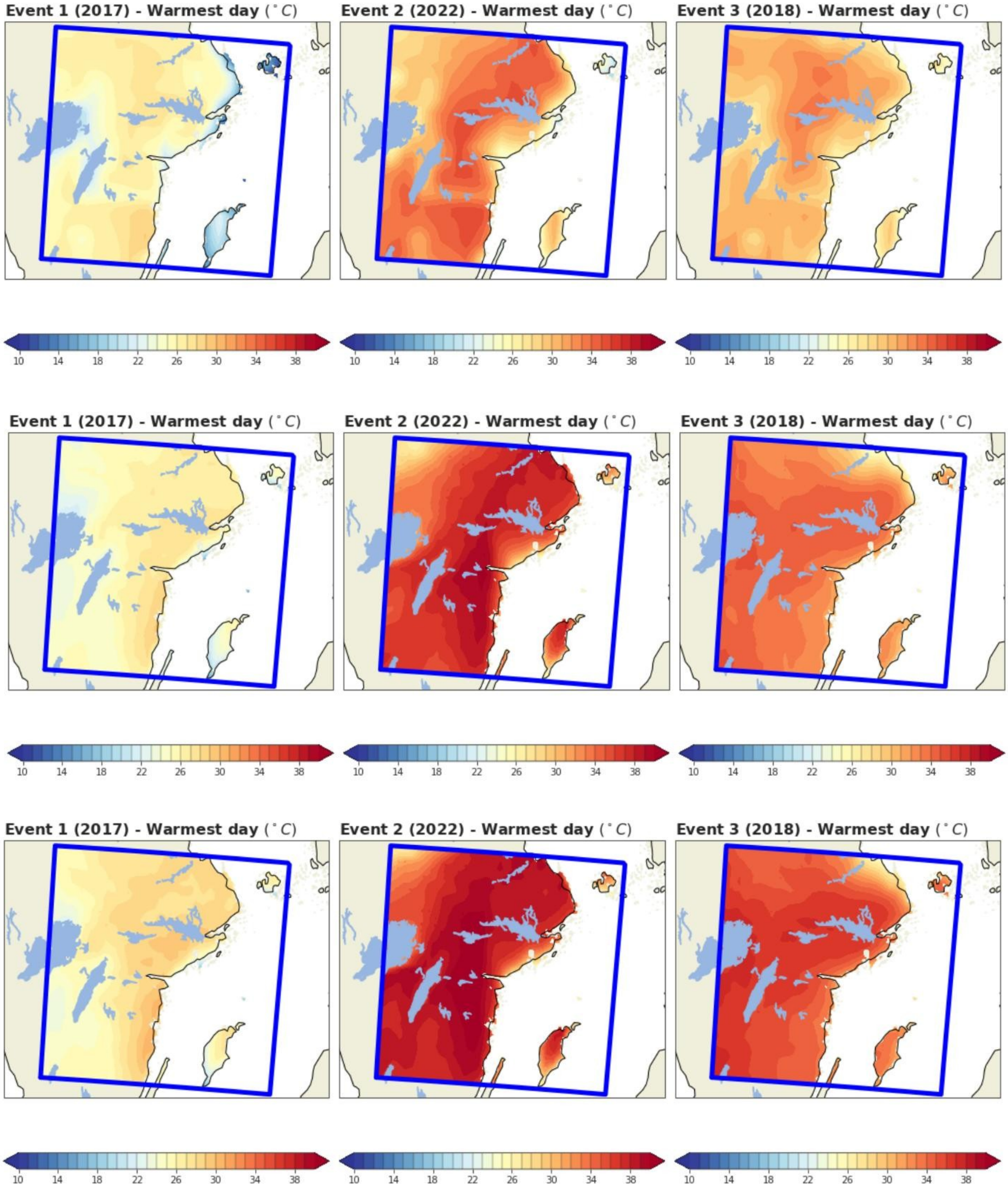

Figure 5. The warmest day for three heat-wave events in the historical climate (top), and the same events at specific warming levels of 2 K (centre) and 3 K (bottom) compared to the pre-industrial climate.