# SPECIAL PROJECT PROGRESS REPORT

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

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|---|---|
| **Reporting year** | 2022 |
| **Project Title:** | Arctic regional climate modelling with HCLIM |
| **Computer Project Account:** | spnoland |
| **Principal Investigator(s):** | Oskar Landgren |
| **Affiliation:** | Norwegian Meteorological Institute |
| **Name of ECMWF scientist(s) collaborating to the project** (if applicable) | - |
| **Start date of the project:** | Jan 4, 2021 |
| **Expected end date:** | Dec 31, 2022 |

## 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) | 35 000 000 | 6 440 653 | 35 000 000 | 8 410 372 |
| **Data storage capacity** | (Gbytes) | 20 000 | 0 * | 30 000 | 0 * |

** Note regarding disk space: We did not need to use project storage as there was enough user quota on ectmp, and long-term storage is on MET Norway's own post-processing infrastructure. There may still be a need to use project quota before the end of the year.*

## Summary of project objectives (10 lines max)

We will produce the first Pan-Arctic HCLIM simulation downscaling of ERA5, as well as downscaled climate projections from CMIP6. This will form the basis for the HCLIM collaboration's contribution to the regional climate model ensemble Arctic CORDEX. There are three purposes:
1. Downscaled global climate simulations will provide climate change projections for the pan-Arctic competitive with current state-of-the-art regional climate simulations. This will be useful in climate change assessments as well as for impact modelling.

2. Downscaled ERA5 will constitute a baseline for assessment of biases in the downscaled climate scenario as well as serve as an evaluation of the performance of HCLIM in the Arctic.

3. Downscaled ERA5 can complement Arctic reanalysis datasets (e.g. CARRA, ASRv2).

## Summary of problems encountered (10 lines max)

Simulations began much later last year than anticipated, as we waited for a better consensus within the HCLIM consortium regarding default HCLIM-ALADIN configuration.

This year there were occasional issues with retrieval of ERA5 data from MARS but in practice it only meant slightly more manual work making sure that failed jobs were resubmitted.

An error in the HARMONIE system lead to orography from GMTED2010 not being read properly at 150-180E. The error was found and corrected.

Boundary data from CMIP6 models stored on regular longitude-latitude grid did not prove compatible with polar domains. A fix has been implemented in the current HCLIM setup.

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

In order to make the simulations more useful in other projects, we have decided to not run simulations on 24 km resolution but instead focus on 12 km. Of particular relevance is the EU H2020 PolarRES project, where HCLIM and other regional climate models will be used to downscale various CMIP6 models to ~12 km over the Arctic and Antarctic.

We have completed 33 years (1990-2022) downscaling ERA5 to 12 km.
As of today (2022-06-30) we have completed 7 years (1981-1987) of downscaling of NorESM2-MM to 12 km.
For the remaining half year until special project end we will continue the downscaling of NorESM2-MM with the SSP5-8.5 scenario to 12 km.

## List of publications/reports from the project with complete references

None yet, but a manuscript about the simulation description and evaluation is under preparation.

## 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 first Pan-Arctic simulations using the HARMONIE Climate (HCLIM, Belušić et al. 2020) model system has been carried out. The domain used is shown in Fig. 1. Compared to cycle 38 used in Belušić et al. 2020, the simulations in this special project uses a newer cycle 43 of the HARMONIE system. HARMONIE-ALADIN is used as the atmospheric physics. (Other options are ALARO-0 for "gray-zone" resolutions of 5-15 km, and HARMONIE-AROME for convection-permitting simulations at single kilometre resolution or finer.) The land surface model is SURFEX with 12-layer snow scheme ISBA-ES (explicit snow, Boone 2002). The sea ice scheme SICE (Simple Ice, Batrak et al. 2018) was used allowing for snow on the sea ice and prognostic (thermodynamic) sea ice thickness, while sea ice concentration was read from the boundary model. The model time step is 300 seconds and most fields are output every hour. Files are transferred from ECFS at ECMWF to the Lustre file system at MET Norway's post-processing infrastructure, which may also be used for final dissemination using the THREDDS service until the ESGF data nodes are ready for 12 km Arctic CORDEX data (currently only 0.44 and 0.22 degrees).

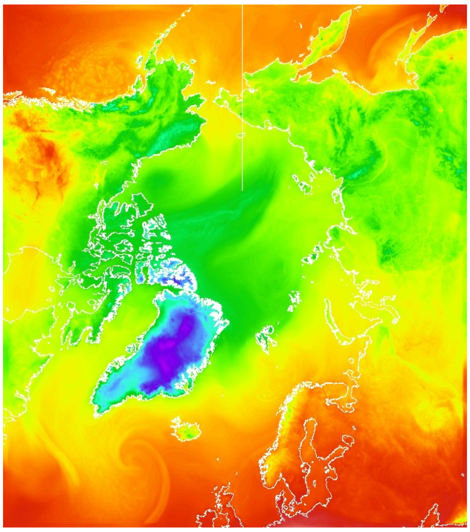

Fig. 1: The Pan-Arctic domain used in these experiments (colours show 2-metre temperature for a sample time, but land borders are shown in white). The 12 km grid shown consist of 629×709 grid points (plus 11 points extension zone each in x and y direction), and 65 vertical levels.

The initial simulation was using the ERA5 (Hersbach et al. 2020) reanalysis on the boundary, retrieved online in the HARMONIE system from the MARS archive at ECMWF. 3-hourly input data was used. 33 years of this simulation is now complete (1990-2022) and under evaluation. Fig. 2 shows a first evaluation of the precipitation climatology compared against the Copernicus Arctic Regional Reanalysis (CARRA, Schyberg et al. 2020) over the smaller CARRA domain for a period of 12 years. HCLIM43-ALADIN is doing well overall but some key differences can be highlighted: a dry bias in the autumn is apparent over the Norwegian mountains and the Kara sea. Due to the smaller size of the CARRA domain, there is less precipitation close to the boundary in the CARRA simulation than in the Pan-Arctic HCLIM simulation, most strongly visible in the summer season. The wet bias along the southern part of the Norwegian sea in winter is possibly related to differences in circulation and requires further investigation. Other effects are related to the resolution of the topography, where naturally the much finer 2.5 km resolution of CARRA leads to more precipitation over the mountains in Svalbard (winter), Northern Norway and Novaya Zemlya.

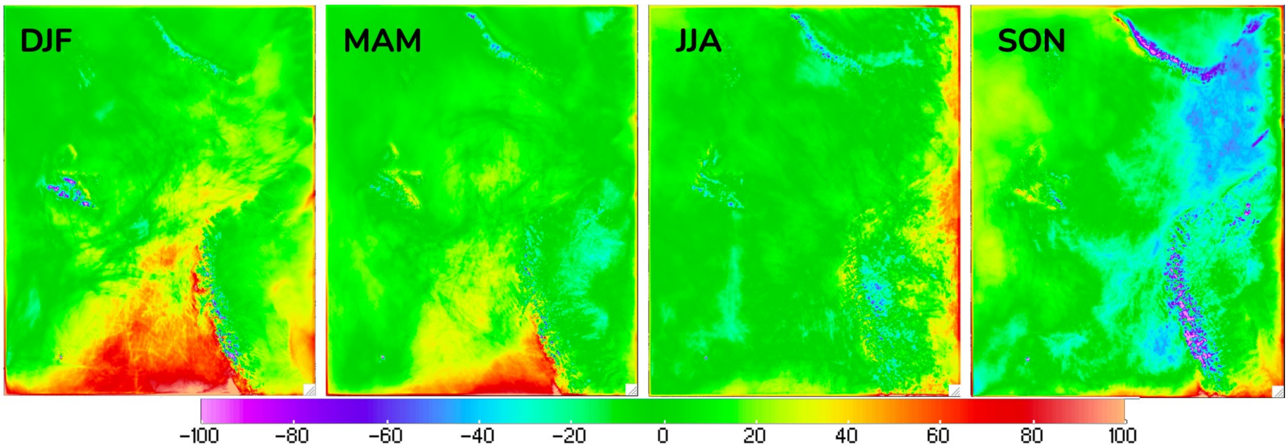


Fig. 2: Bias in precipitation [mm/month] of ERA5 downscaled by HCLIM43-ALADIN to 12 km, versus CARRA at 2.5 km. Values are for HCLIM minus CARRA, using years 1991-2002 for both datasets. The area shown is a subset of the Pan-Arctic HCLIM domain, corresponding to the full CARRA-East domain as described in Schyberg et al. (2020).

We will continue to evaluate the full 33 year period and include additional reference datasets, including from both remote sensing and surface-based observations. Snow on sea ice is expected to give a significant improvement (Batrak et al. 2019) over the Arctic compared to ERA5, and we hope to investigate this further.

The second simulation is using the same setup except that instead of using ERA5 as boundary data we now use data from NorESM2-MM (Seland et al. 2020). This is a coupled Earth System Model from the CMIP6 ensemble with 1.25 × 0.94 degree resolution in the atmosphere, land and ocean. In our setup data is given as input to HCLIM at 6-hourly frequency. The simulation is ongoing, with 7 years completed so far, years 1981-1987. For the future period, starting in year 2015, we will follow the SSP5-8.5 scenario (Kriegler et al. 2017) to investigate climate responses to a strong warming globally, and in particular in the Arctic. A more thorough evaluation will be included in the final report next year.

These first Pan-Arctic HCLIM simulations will be used to compare regional climate change with other regional as well as global models. The model setup used in this project will also serve as a basis for other upcoming simulations, including over the Antarctic, by other HCLIM partners.

## References

Batrak, Yurii, Ekaterina Kourzeneva, and Mariken Homleid. "Implementation of a simple thermodynamic sea ice scheme, SICE version 1.0-38h1, within the ALADIN–HIRLAM numerical weather prediction system version 38h1." *Geoscientific Model Development* 11.8 (2018): 3347-3368.

Batrak, Yurii, and Malte Müller. "On the warm bias in atmospheric reanalyses induced by the missing snow over Arctic sea-ice." *Nature Communications* 10.1 (2019): 1-8.

Belušić, Danijel, et al. "HCLIM38: a flexible regional climate model applicable for different climate zones from coarse to convection-permitting scales." *Geoscientific Model Development* 13.3 (2020): 1311-1333.

Boone, Aaron. "Description du schema de neige ISBA-ES (Explicit Snow)." *Description of the ISBA-ES (Explicit snow scheme), Note de Centre, Meteo-France/CNRM* 70 (2002).

Kriegler, Elmar, et al. "Fossil-fueled development (SSP5): an energy and resource intensive scenario for the 21st century." *Global environmental change* 42 (2017): 297-315.

Hersbach, Hans, et al. "The ERA5 global reanalysis." *Quarterly Journal of the Royal Meteorological Society* 146.730 (2020): 1999-2049.

Schyberg, Harald, et al. "Arctic regional reanalysis on single levels from 1991 to present. Copernicus Climate Change Service (C3S) Climate Data Store (CDS)" (2020) (accessed on 30-Jun-2022), 10.24381/cds.713858f6

Seland, Øyvind, et al. "Overview of the Norwegian Earth System Model (NorESM2) and key climate response of CMIP6 DECK, historical, and scenario simulations." *Geoscientific Model Development* 13.12 (2020): 6165-6200.