SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	Arctic regional climate modelling with HCLIM
Computer Project Account:	spnoland
Start Year - End Year :	2021 - 2022
Principal Investigator(s)	Oskar Landgren
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Other Researchers (Name/Affiliation):	

The following should cover the entire project duration.

Summary of project objectives

(10 lines max)

- Applying the regional climate model HARMONIE-Climate (HCLIM, Belušić et al. 2020) in its latest version (cy43) over the pan-Arctic domain.
- Producing a downscaled pan-Arctic simulation based on ERA5 which can be used for HCLIM model evaluation as well as baseline for Arctic CORDEX simulations.
- Starting production of simulations for Arctic CORDEX intercomparisons.

Summary of problems encountered

(If you encountered any problems of a more technical nature, please describe them here.)

It took longer to get the latest version of HCLIM (cy43) ready than foreseen (not just for the Arctic as in this project), so we were not able to use many computational resources for the first nine months of the project.
A bug in the sea ice scheme was identified and corrected, which forced a rerun that delayed new simulation results by a few months.
Other deviations compared to the original plan can however be explained by our wish to conform to criteria set by the EU H2020 PolarRES project. This enables the simulations to be part of more intercomparisons and benefit a wider community.

Experience with the Special Project framework

(Please let us know about your experience with administrative aspects like the application procedure, progress reporting etc.)

The special project framework works well.

Summary of results

(This section should comprise up to 10 pages, reflecting the complexity and duration of the project, and can be replaced by a short summary plus an existing scientific report on the project.)

Compared to the date of the project application, the focus of the special project has shifted slightly to better align with the EU project PolarRES, where modelling groups of the Polar CORDEX have agreed on a joint modelling protocol for production of downscaled simulations for the Arctic and Antarctic.
Most importantly, we have increased the horizontal resolution from our proposed 24 km to the finer 11 km. More emphasis has also been put on implementing spectral nudging (von Storch et al. 2000) as this is important to avoid having the regional model develop an internal polar circulation that is no longer representative of that of the global model (see e.g. Berg et al. 2013).
Furthermore, the decision of which global models to downscale in that project is based on a linear regression “storyline” framework similar to Zappa et al. 2017. For the Arctic, NorESM2-MM (Seland et al. 2020) and CNRM-ESM2-1 have been selected. As the final decision on selection was made later than foreseen, we have only downscaled NorESM2-MM and not yet CNRM-ESM2-1.

Model evaluation

We have focused on evaluation against the Copernicus Arctic Regional Reanalysis (CARRA, Schyberg et al. 2020). This is a state-of-the-art high-resolution (2.5 km) reanalysis for two subdomains of Arctic. The pan-Arctic 11 km HCLIM reference simulation (downscaled from ERA5) was interpolated to the 2.5 km CARRA-East grid and results for 2-metre temperature and precipitation are shown in Figure 1.

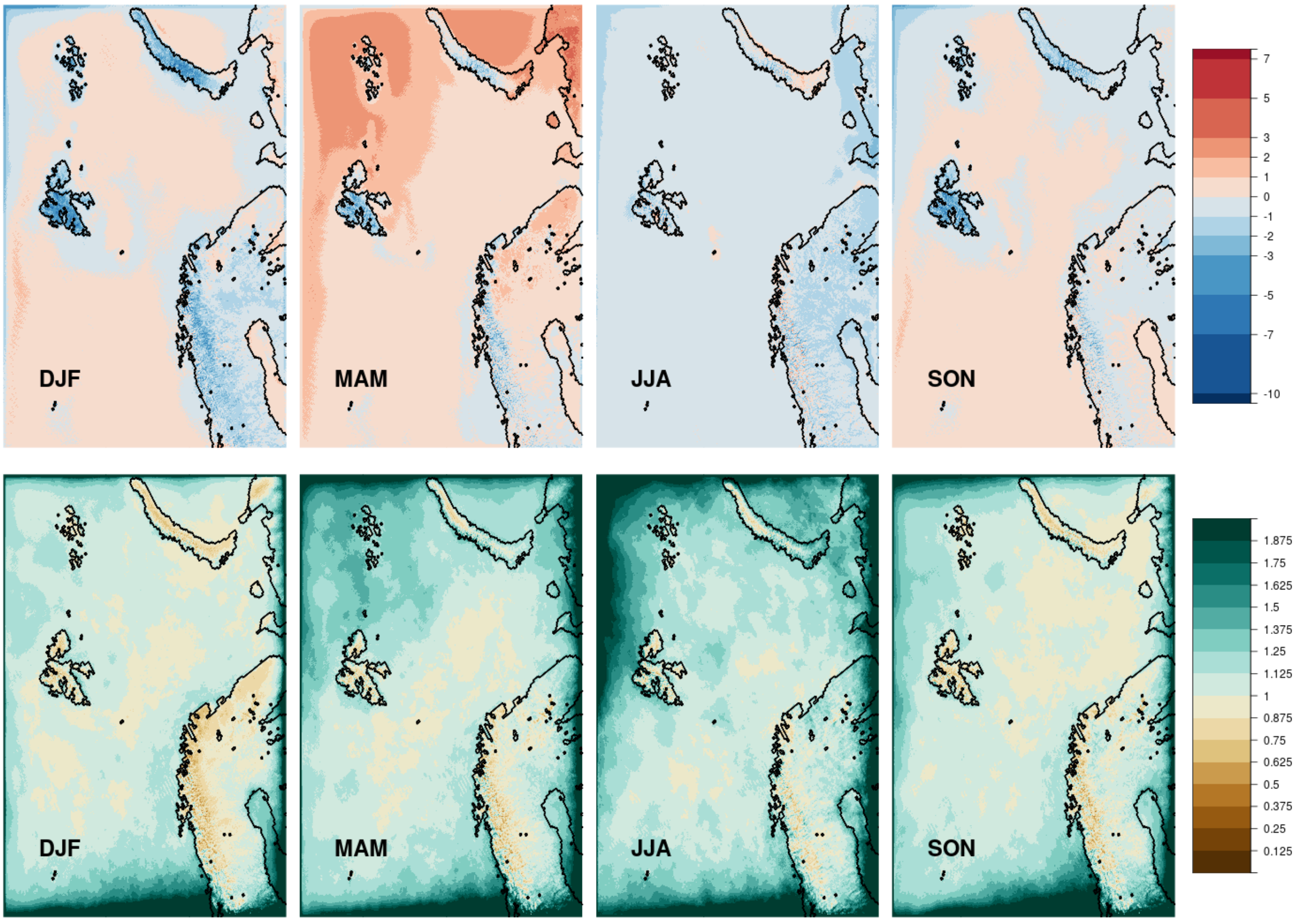

Fig. 1: Seasonal bias in 2-metre temperature (top, in Kelvin) and relative precipitation (bottom), calculated as HCLIM43-ALADIN minus (for precipitation divided by) CARRA for years 2000-2010.

HCLIM manages to reproduce the precipitation climatology of CARRA quite well, but comparison is not very useful close to the edge of the CARRA-East domain, since the CARRA dataset likely suffers from spatial spin-up of precipitation. Since the pan-Arctic domain is much larger, HCLIM does not suffer from this problem in this area. It is particularly interesting to note the area just north of Svalbard in the summer, which has more precipitation than other seasons due to influx of moister air. Other differences such as the dry bias over the Scandinavian mountains can be explained by the coarser resolution of HCLIM (11 km) vs CARRA (2.5 km).
The temperature biases are within 1 K for most areas and seasons, with the exception of sea ice covered areas in the spring, which is the subject of further investigation.

The HCLIM model uses the Simple Ice scheme (SICE, Batrak et al. 2018) as part of the SURFEX land model which in turn is directly coupled to the HCLIM43-ALADIN atmospheric physics code. SICE implements thermodynamically evolving prognostic sea ice thickness as well as snow on top of the sea ice via the 12-layer ISBA-ES snow scheme (Boone 2002). To evaluate the sea ice scheme, we compare the volume against the PIOMAS sea ice volume reanalysis (Schweiger et al. 2011). In our first comparisons, it was clear that we had a strong negative bias of sea ice thickness (not shown here). This was investigated further, an error was corrected and multiple reruns were made to test sensitivity to different values of ocean heat flux as well as different snow albedo scheme over sea ice. These sensitivity tests were run at a coarser 24 km horizontal resolution instead of 11 km. Fig. 2 shows the total Arctic sea ice volume for the different sensitivity experiments.

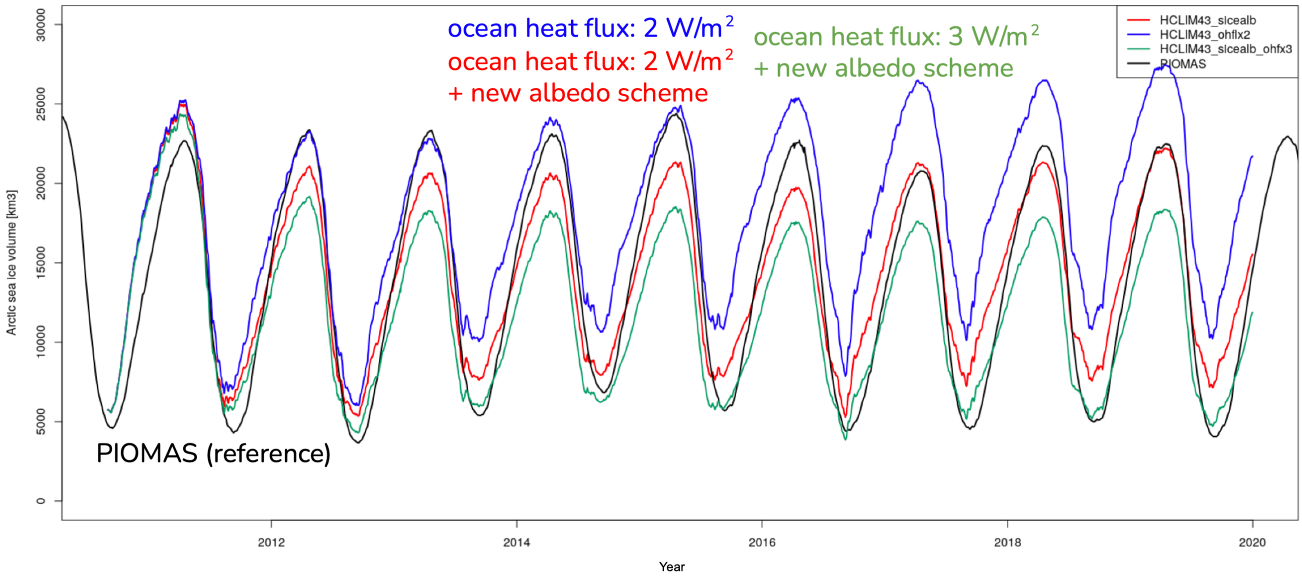

Fig. 2: Total Arctic sea ice volume (on the y axis, in km^3) for years 2010-2020 (on the x axis) for various different HCLIM sensitivity experiments, shown in red, blue and green, compared against PIOMAS in black.

While no setup manages to perfectly fit both the peaks and the valleys, the new albedo scheme in combination with 2 W/m2 ocean heat flux gives a better fit for the annual maximum values in the latter period.

Multiple experiments were also carried out to assess the impact of varying the spectral nudging coefficients by analysing the difference before and after downscaling. An example is shown in Fig. 3.

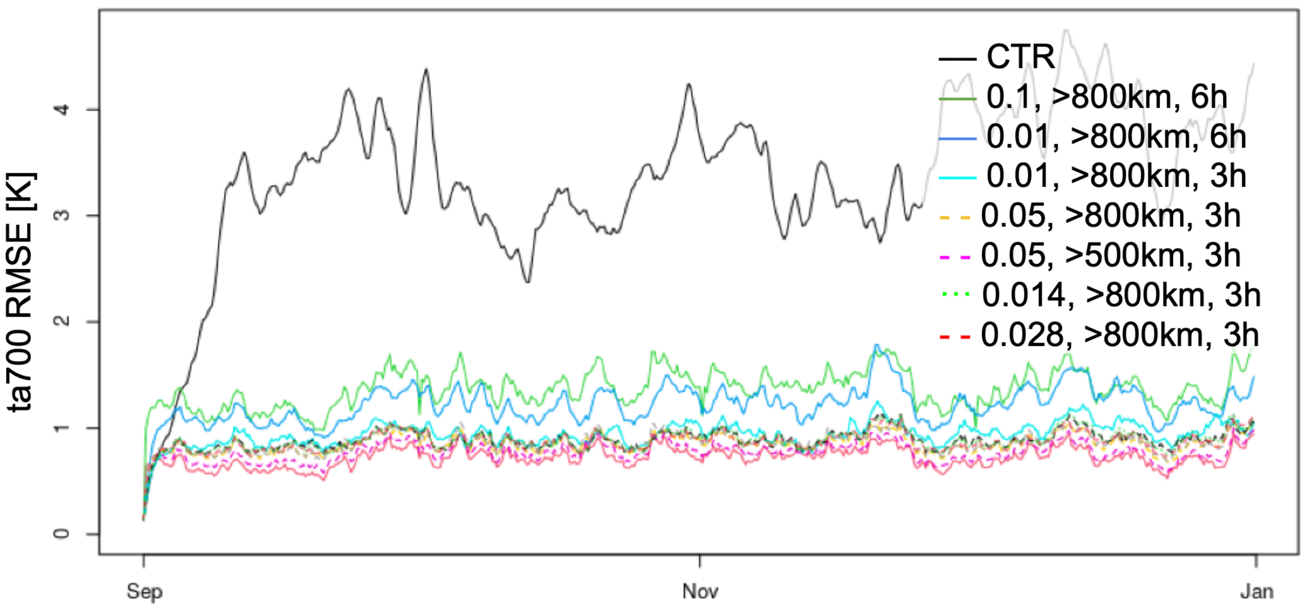

Fig. 3: Root-mean-square error in 700 hPa air temperature for HCLIM minus ERA5. Time (from initialisation on Sep 1) is shown on the x axis. The control run (CTR) is a solid black line while the different spectrally nudged simulations are shown in different colours. The numbers denote the nudging strength, the minimum wavelength and the temporal resolution of the input data (ERA5 fed to HCLIM).

As this HCLIM uses data from ERA5 as boundary data, the increase in RMSE in the control run (CTR) is only due to internal variability developed in the regional model domain by HCLIM running continuously ("climate mode", i.e. without data assimilation or frequent re-initialisation). By turning on spectral nudging the desired effect of forcing the model to keep the large-scale circulation from the boundary dataset (ERA5), and all spectrally nudged runs produce notably smaller RMSE values. Varying the nudging strength has little effect, as does changing the lower wavelength limit from 800 to 500 km. The most important factor when reducing the RMSE is to use higher temporal frequency (3h instead of 6h), which is what has been selected for all future runs whenever the data is available.

We are continuing the evaluation as well as analysis of future projections based on NorESM2-MM (and CNRM-ESM2-1) in an upcoming article.

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.

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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.

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

Schweiger, Axel, Ron Lindsay, Jinlun Zhang, Mike Steele, Harry Stern, and Ron Kwok. "Uncertainty in modeled Arctic sea ice volume." *Journal of Geophysical Research: Oceans*116, no. C8 (2011).

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.

von Storch, Hans, Heike Langenberg, and Frauke Feser. "A spectral nudging technique for dynamical downscaling purposes." *Monthly weather review* 128, no. 10 (2000): 3664-3673.

Zappa, Giuseppe, and Theodore G. Shepherd. "Storylines of atmospheric circulation change for European regional climate impact assessment." *Journal of Climate* 30, no. 16 (2017): 6561-6577.

List of publications/reports from the project with complete references

None published yet, but there are two papers in preparation, plus very likely multiple more that will utilise the simulations once the data is made available via ESGF.

Future plans

(Please let us know of any imminent plans regarding a continuation of this research activity, in particular if they are linked to another/new Special Project.)

The experiments made in this special project have helped lay the foundation for contributions to the Polar CORDEX by the HCLIM community member institutes. Specifically for the Arctic and Antarctic domains, this will include simulations from the Norwegian Meteorological Institute (MET Norway), Danish Meteorological Institute (DMI) and the University of Utrecht, the Netherlands. During the coming year, we will continue to produce downscaled regional climate simulations for future scenario SSP3-7.0 based on the CMIP6 models NorESM2-MM and CNRM-ESM2-1 for the Arctic and CESM2-WACCM and CAMS-CSM1 for the Antarctic, respectively.