SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	Polar Regions in the Earth System: Role of local-regional scale polar processes in the changing polar and global climate system (PolarRES)
Computer Project Account:	spdkoles
Start Year - End Year :	2022.03.15 - 2024.12.15
Principal Investigator(s)	Martin Olesen, Climate scientist, PhD
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Other Researchers (Name/Affiliation):	José Abraham Torres Alavez Danish Meteorological Institute

Summary of project objectives

The regional climate model Harmonie Climate (HCLIM) was successfully prepared for polar downscaling experiments. HCLIM was configured and used to dynamically downscale the ERA5 reanalysis dataset for both the Arctic regions. Similar downscaling experiments were conducted in the Antarctic, following the same methodology (but different physics schemes) as in the Arctic, to ensure a comprehensive analysis of both polar areas.

These efforts have improved our understanding of key local to regional scale physical processes governing atmosphere-ocean-ice interactions in both polar regions, and have clarified their influence on projected changes in global circulation.

Summary of problems encountered

The project started in March 2022. Initially, HCLIM cycle 38 was configured with various test boundaries, employing different spatial resolutions and time steps. This phase encountered some instability issues, which have since been resolved.

Now, the system was upgraded to HCLIM cycle 43. This transition introduced both minor and major challenges, particularly in generating boundaries and in handling boundary data from MARS within the Prefetch_boundaries job. All identified issues have now been addressed.

Additionally, it was observed that ice shelves in Antarctica were not accurately represented in HCLIM cycle 43. This issue has been largely rectified. Further analysis revealed temperature biases, potentially attributable to excessive incoming solar radiation.

Finally, the relocation to Bologna needed adaptations to several operational routines.

Experience with the Special Project framework

The experience with the special project framework was overall very good.

Summary of results

With Harmonie climate cycle 43, various spatial resolutions, domains, and time steps have been tested to optimize the downscaling performance for the entire Greenland region, as well as for the pan-Arctic and Antarctic domains.

Previously, ERA5 reanalysis data were downscaled using the regional climate model HIRHAM5 up to 2023. HIRHAM5, a hydrostatic regional climate model, has been co-developed and utilized at DMI for many decades. To evaluate the performance of HCLIM, ERA5 data for 2019 were downscaled and the results were compared with the corresponding HIRHAM5 experiment.

It is well-documented that HIRHAM5 tends to produce excessive precipitation over certain areas of Greenland. For example, annual precipitation downscaled with HIRHAM5 from ERA5 exceeds 25 meters in some mountainous regions along Greenland's southeast coast—values that have never been observed in these areas and are considered unrealistic.

In contrast, HCLIM cycle 43 produces a more realistic simulation of precipitation for the south-east coast when downscaling ERA5 for 2019. This demonstrates that HCLIM cycle 43 improves the quality of reanalysis downscaling experiments. Furthermore, it enhances the reliability of future experiments in which global circulation models (GCMs) will be downscaled for various SSP scenarios. A comparison of HIRHAM5 and HCLIM results is presented in Figure 1.

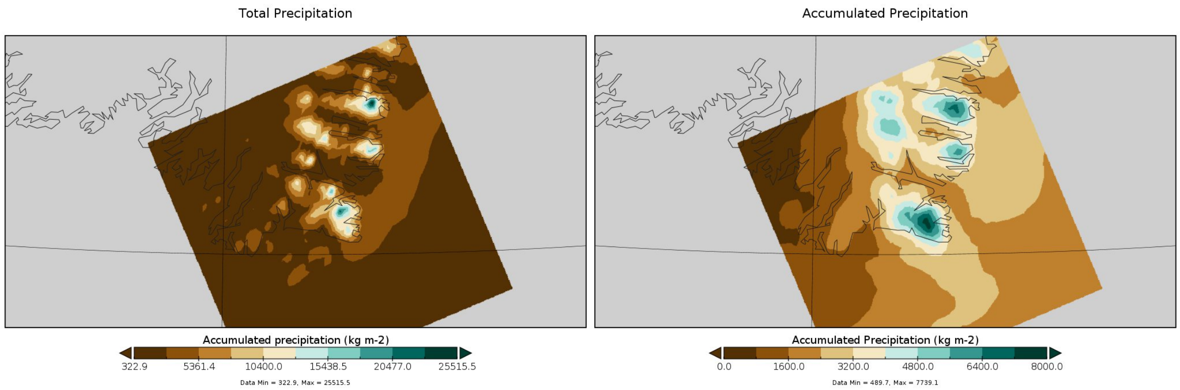

Figure 1. Accumulated precipitation (mm/year) for 2019 simulated with HIRHAM5 (left) and HCLIM (right) forced with ERA5 on the boundaries.

HCLIM-AROME is the Convection-Permitting Regional Climate Model (CP-RCM) of HCLIM. AROME is a non-hydrostatic physics scheme with a semi-Lagrangian advection scheme and semi-implicit time discretisation. Although deep convection is no longer parameterised, sub-grid shallow convection is still parameter-rich or parameter-saturated using the EDMFm scheme, which is based on the eddy diffusivity of the mass-flux framework (de Rooy and Siebesma, 2008; Bengtsson et al., 2017). Turbulence is parameterised using the prognostic predictive equation for turbulent kinetic energy (TKE), combined with a diagnostic length scale (Lenderink and Holtslag, 2004; Bengtsson et al., 2017).

Various simulation components, including nudging and different physics schemes (AROME and ALADIN), have been tested to assess the impact of permitting convection in regions characterized by steep topography. Figure 2 presents the differences between hydrostatic and non-hydrostatic downscaling experiments. The results indicate that the non-hydrostatic AROME physics configuration produces substantially more precipitation at higher elevations compared to the hydrostatic simulation, while simultaneously generating less precipitation in the fjord regions. These findings demonstrate that, for mountainous areas and at relatively high spatial resolutions (down to 2 km), the simulated precipitation patterns are highly sensitive to whether convection is explicitly represented in the model physics

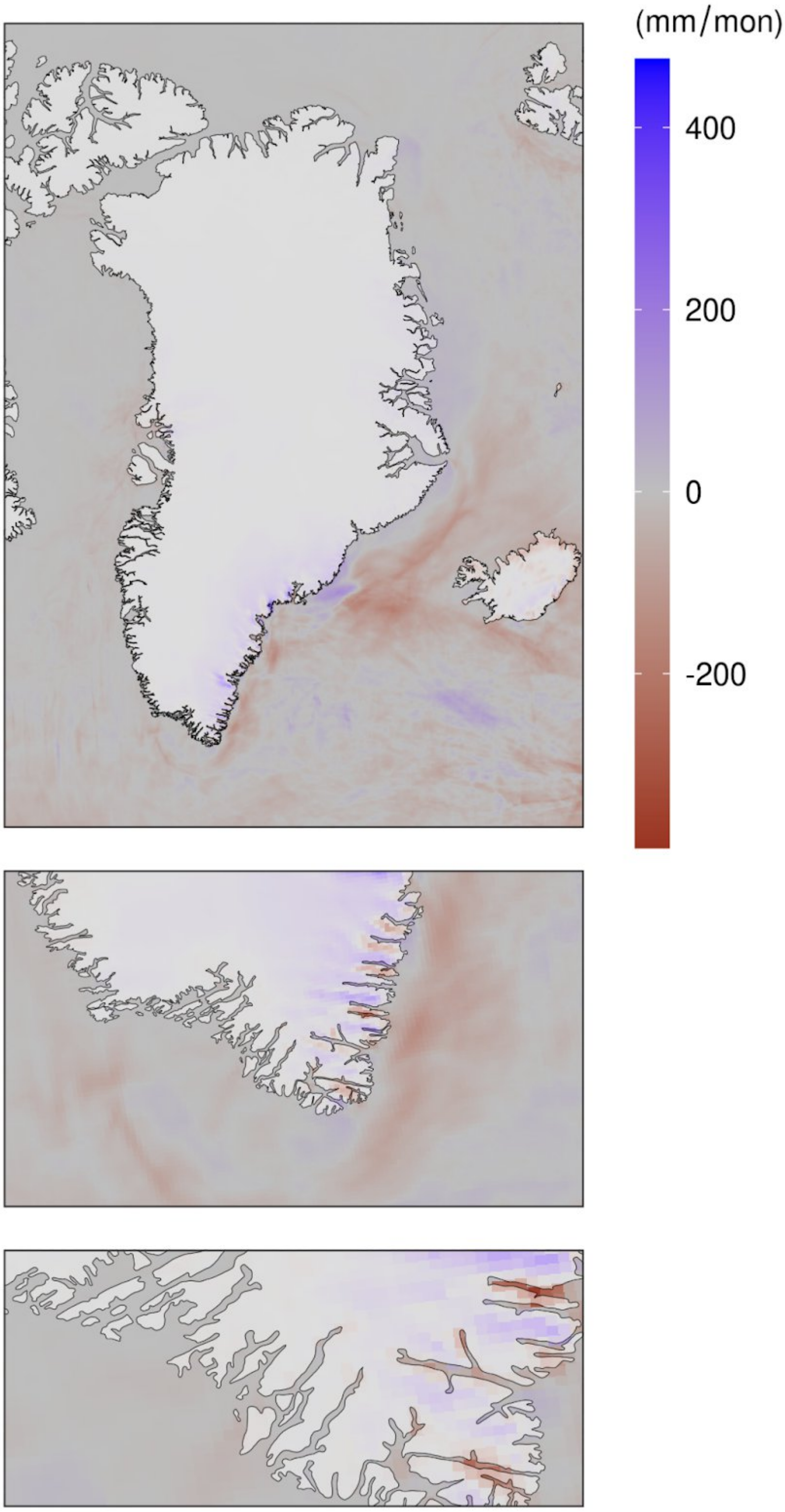

Figure 2. The difference between downscaling with non-hydrostatic (arome physics) and hydrostatic (aladin physics) for precipitation for December 2012. Era5 downscaled over Greenland (top), southern tip of Greenland (middle) and zoom of southern top (bottom) with HCLIM c43.

For corresponding Antartic simulatoins we used cycle 43 of the HCLIM modelling system (Belusic eta al 2020) to conduct as high-resolution simulations as possible. This setup is based on the ALADIN-HIRLAM numerical weather prediction system and uses the two different atmospheric physics packages: AROME and ALADIN.

ALADIN is a bi-spectral, hydrostatic, limited-area regional climate model (RCM) with a semi-Lagrangian advection scheme and a semi-implicit time discretisation. This model uses a deep convection scheme based on moisture convergence closure (Bougeault, 1985). The boundary layer parameterisation is based on the prognostic equation of turbulent kinetic energy (TKE; Cuxart et al., 2000), and the convective mass flux scheme of Bechtold et al. (2001) is used for shallow convection.

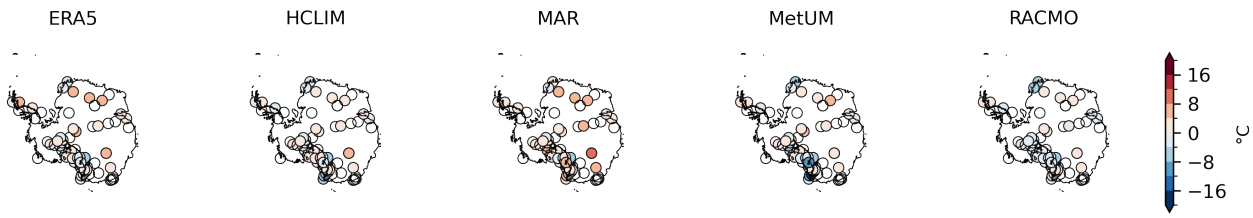

Figure 3. The 2m temperature winter bias (JJA) is shown for different regional models, including HCLIM and ERA5 reanalysis, for the period 2000–2020. This bias was calculated using the stations available in ANTAWS.

The HCLIM simulations are now being used in various studies investigating changes in precipitation, atmospheric rivers, surface mass balance and extreme events as shown in figure 3 and 4.

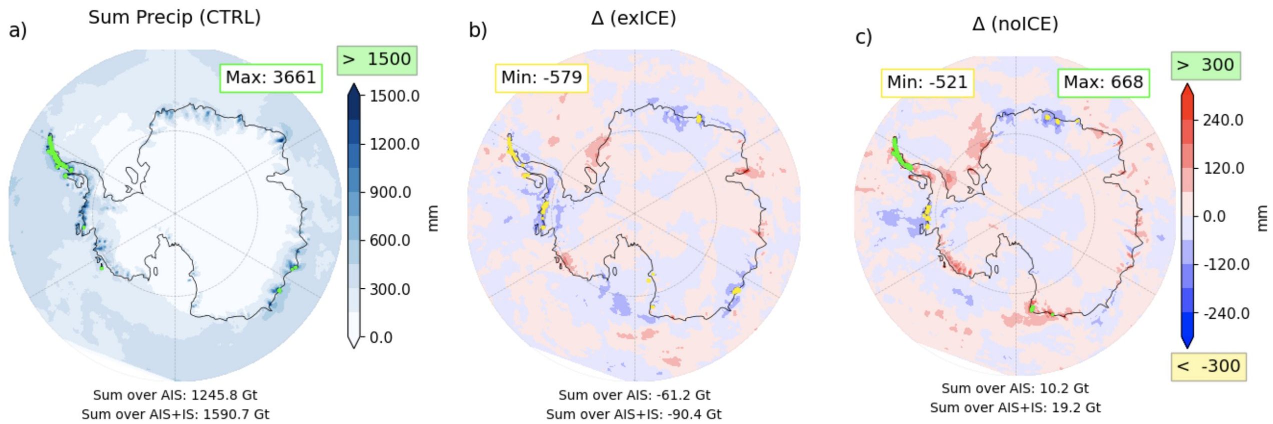

Figure 4. Shows the precipitation in HCLIM simulations driven by ERA5 during January–March 2022, as well as the changes in precipitation when the sea ice concentration around Antarctica is increased to 100% and when the sea ice is completely removed during this period.

These experiments demonstrate that, during a strong atmospheric river bringing precipitation to Antarctica, the observed effect of sea ice loss in recent years can increase precipitation in the eastern part of the continent by up to 1.8 Gt.

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List of publications/reports from the project with complete references

Gilbert, E., Pishniak, D., Torres, J. A., Orr, A., Maclennan, M., Wever, N., and Verro, K.: Extreme precipitation associated with atmospheric rivers over West Antarctic ice shelves: insights from kilometre-scale regional climate modelling, The Cryosphere, 19, 597–618, https://doi.org/10.5194/tc-19-597-2025, 2025.

Kolbe, M., Torres Alavez, J.A., Mottram, R. et al. Model performance and surface impacts of atmospheric river events in Antarctica. Discov Atmos 3, 4 (2025). https://doi.org/10.1007/s44292-025-00026-w

Future plans

Work with the HARMONIE Climate model is an ongoing process, continuously evolving through various development cycles. In the near future, we plan to upgrade from cycle 43, which was used in this study, to cycle 46.

Furthermore, output from the HARMONIE Climate model will be used as input in an offline surface mass balance model. This integration aims to improve the mass budget estimates for both the Greenlandic and Antarctic ice sheets.

Finally, simulations will be conducted for future greenhouse gas concentration scenarios (SSPs). Output from the global circulation model EC-Earth, representing different future scenarios, will be downscaled using HCLIM and subsequently applied in the surface mass balance model.