SPECIAL PROJECT PROGRESS REPORT

Reporting year	………June 2021- June 2022………………………..……
Project Title:	Greenland climate modelling: assessing and developing HCLIM
Computer Project Account:	SPDKMOTT………………………………………..……
Principal Investigator(s):	Dr Ruth Mottram (PI), Rasmus Anker Pedersen, Ole Bøssing Christensen, Fredrik Boberg, Martin Olesen
Affiliation:	Danish Meteorological Institute
Name of ECMWF scientist(s) collaborating to the project (if applicable)	……………………………………………………..…… ……………………………………………………..……
Start date of the project:	February 2020 ………………………………….……
Expected end date:	December 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)	950000000	7642000	950000000	7830
Data storage capacity	(Gbytes)	16000		16000	

Summary of project objectives (10 lines max)

This project aims to set-up the HARMONIE climate model (HCLIM) (Belusic et al., 2020) for Greenland with the aim of downscaling climate projections and ERA-5 reanalysis. The ultimate aim is to run high-resolution, kilometre-scale climate simulations that can serve as a reference for climate and ice sheet surface mass balance studies and provide future projections. The project focuses on Greenland ice sheet surface mass budget, a key variable in assessing the ice sheet's contribution to sea level rise. Key objectives include:

- Assess the performance of the model at different resolutions (12km, 5km, 2.5km) and using different physical schemes against observational data and CARRA reanalysis
- Testing output to ensure it can be used offline to run the SMB model (see polarportal.dk) for providing a near real-time monitoring of the ice sheet
- Implement an SMB scheme internally within the model to account for snowpack processes
- Downscale a 10 year period of ERA-5 and GCM output for projections.

Summary of problems encountered (10 lines max)

Illness (notably a COVID19 wave in Copenhagen in the first half of 2022) affecting several staff, in combination with fieldwork commitments has led to slow progress in the first half of 2022, but significant progress was made in training personnel to run and develop the model in 2021. It is anticipated however that the target of a working Greenland set-up including surface mass budget calculation will be met by the end of this year. Our NWP HARMONIE colleagues have also assisted with grid optimization and other questions allowing us to run the model at very high resolution and some process studies have begun.

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

Some highlights:

- A new PhD student. Mathias Larsen, together with Aarhus University collaborators was recruited and started in December 2021 with an adaptation of the Copernicus Arctic Reanalysis (CARRA) dataset for surface mass balance modelling of the Greenland ice sheet (Langen et al., 2018).
- Two subdomains in NW Greenland (Qaanaaq region) and southern Greenland have been set-up, these will be used further in a study of piteraq (extreme katabatic) winds and impacts on local communities as well as in local studies aimed at clarifying surface mass balance processes on the ice sheet.
- The 3km pan-Greenland model is now running and will downscale the 1980 – 1990 pre-CARRA period over the rest of this year.

List of publications/reports from the project with complete references

From previous years

Mottram, R., Landgren, O., Anker Pedersen, R., Pagh Nielsen, K., Bøssing Christensen, O., Olesen, M., Boberg, F., Hansen, N., Amstrup, B., and Yang, X.: Physics, Resolution and Data Assimilation: Making sense of Greenland climate and ice sheet Surface Mass Balance with HARMONIE Climate, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-16100, https://doi.org/10.5194/egusphere-egu21-16100, 2021

Summary of results:

In the first 18 months of this project we focused on training colleagues and testing different configurations of the model over Greenland. This report covers the subsequent period from June 2021 to June 2022 where we extended this work to explore further the best configurations at kilometre scale resolution as well as setting up domains covering the larger areas we plan to run for climate projections over Greenland. We have focused on the cycle 38 version covering the large domain of Greenland, Iceland and Svalbard at 5km and for a small domain over southern Greenland at 2.5km. HCLIM cycle 43 which as of today is the newest version has been set up to downscale ERA5 for the large domain at 5 km for 2019 as a test year.

South Greenland:

Southern Greenland is an extremely challenging region to model with conventional regional climate models owing to the rugged terrain and adjacent North Atlantic Ocean where frequent cyclones carry a lot of snow but the position relatively far south also leads to advection of warmer air masses that can lead to large amunts of melt over the ice sheet in summer. High katabatic winds and the south Greenland tip jet often given dangerous weather conditions to local communities where fishing and hunting are still important subsistence activities. It is therefore an ideal location to run very high resolution climate models where both physics and resolution give a significant advantage in process studies and climatological analyses.
Here we present initial results from HCLIMcy38 using a set-up at 2.5km, the same resolution and domain used at DMI for NWP. These experiments are also now being repeated with HCLIMcy43 to assess if there are significant differences and to allow the use of updated suface schemes included in cycle 43.

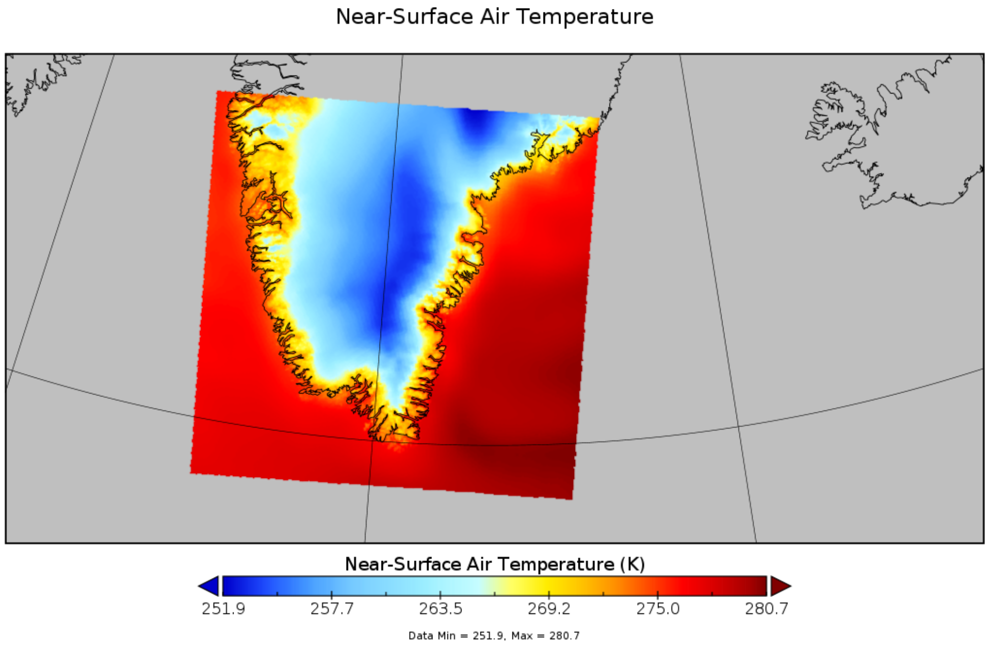

Figure 1. Near surface temperature for the southern Greenland domain from Olesen et al., 2021. The zoom into the tip of south Greenland shows the remarkable effect that the high resolution has on defining the 2m air temperatures without requiring interpolation or smoothing.

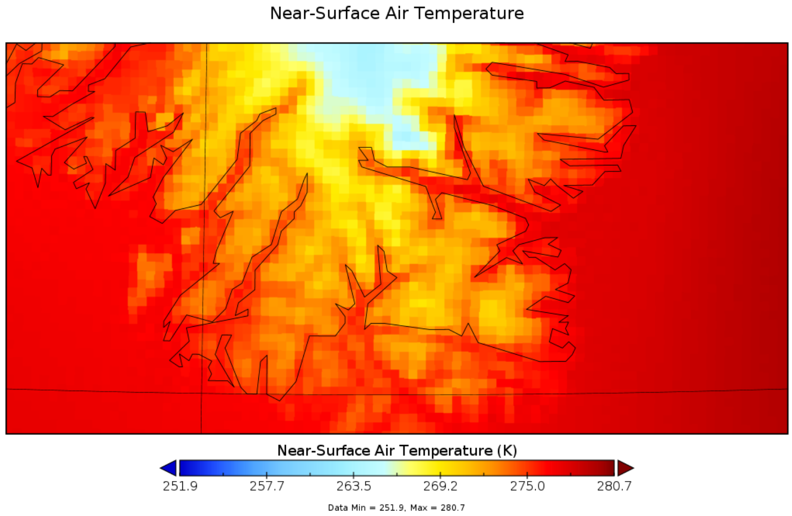

Figure 2. 2m temperature in high resolution over south Greenland (from Olesen et al., 2021).

There are few observations in this region but we compare the new simulation with one run by the old regional climate model HIRHAM5 for the same year and with the same boundaries. As we are moving from an old hydrostatic model to a non-hydrostatic set-up, this comparison is essential to understand differences in local and regional climate projections. In this case both models are downscaling ERA-5 for the year 2019. We chose this year as an unusually dry winter followed by a warm summer led to very high losses of ice from the Greenland ice sheet but different models estimate different amounts of ice loss. This is therefore an excellent case study to examine the strengths and weaknesses of the different set-ups. A paper is in preparation on the implications of different modeled climate on SMB of the Greenland ice sheet during this period which serves also as a model evaluation of the HCLIMcy43 model in Greenland (Olesen et al., in prep.).

Figure 3 compares total precipitation in 2019 from HCLIMcy43 with HIRHAM5. Note the different colour scales. Although we have few observations in this region, we consider that the values in HCLIMcy43 are more realistic than in HIRHAM5, especially over the steep mountains. We are still working on optimizing the precipitation scheme using the different options in the HCLIM system.

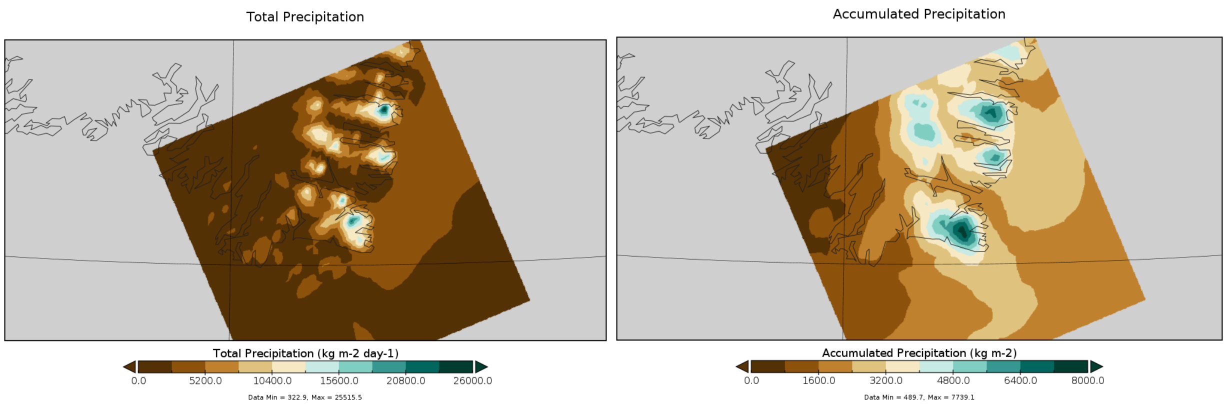

Figure 3. Comparison of precipitation over south-east Greenland in 2019 in HIRHAM5 (left) with HCLIMcy43 (right) (from Olesen et al., 2021)

North-West Greenland

The sub-domain in North-West Greenland covers Inglefield Bredning and includes glacier, land, ocean, sea and sea ice terrain. It has been set-up partly for local studies into ice sheet surface mass balance and dynamical modelling with the PISM ice sheet model and partly to examine the impacts of the S-ICE sea ice model that is included in the HCLIM model system. This region includes the North Water Polynya, an area of open water that is a rich and important hotspot of biodiversity in the Arctic (see Figure 4, Ribeiro et al., 2021).

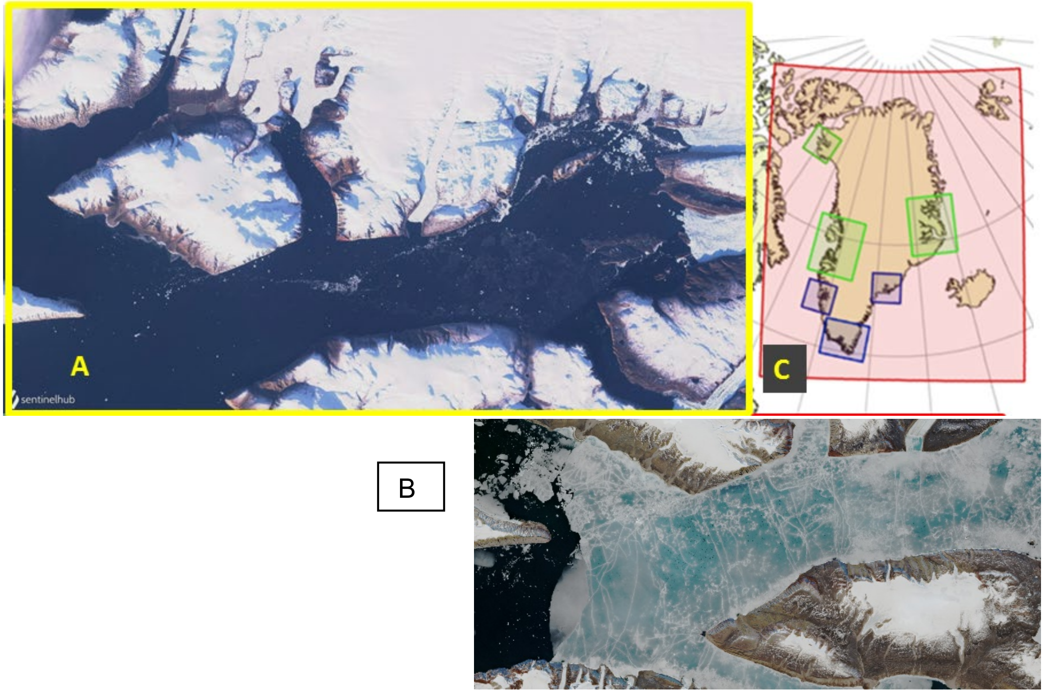

Figure 4 a) Inglefield Bredning fjord and the Qaanaaq ice cap in North West Greenland from Sentinel-2 processed on Sentinel hub. The region has many outlet glaciers from the ice sheet flowing into the fjord where thick seasonal sea ice (b) that builds up from around November until June each year. (c) The Greenland model domain used in this project coincides with that used for numerical weather prediction at DMI, the green and blue hatched boxes indicate the regions where very high resolution (750m) operational weather forecasts are made for extreme weather warnings. The high resolution Qaanaaq domain also used in this project for kilometre scale simulations in process studies is top left.

PhD student at DMI, Mathias Larsen, will use model output from this domain to compute ice sheet surface mass budget. The output from the model in this region will also be compared with the Copernicus Arctic Regional ReAnalysis (CARRA), PROMICE AWS data and data collected by the PI Ruth Mottram, on the local ice cap in June 2021 and in March/April 2022 to tune the SMB model that will is being aligned to be run with HCLIM outputs. The focus of this work, which will be carried out over the remainder of 2022 is on both precipitation, which is very differently represented compared to HIRHAM (see figure 3), and on spectral albedo schemes in the model. These two parameters to a large extent control regional and local SMB estimates (Fettweis et al., 2020; Hermann et al., 2018) and are therefore crucial to estimate correctly. Observations by the University of Hokkaido since 2012 (Tsutaki et al., 2017) supplemented by DMI field activities can also supply a unique dataset of observations for evaluating accumulation of snowfall and snowpack properties for fine scale process studies in this region.

From a climate modelling perspective, the wide range of different surface environments encompassing glacier, fjord, open sea, sea ice and tundra poses particular challenges to high resolution models. It is envisaged that this work will benefit from but also contribute to the very high resolution model set-up (750m) used by NWP colleagues at DMI for issuing extreme weather warnings related to hurricane force wind speeds (see figure 1c). This is also an excellent opportunity to use observational data collected by DMI colleagues and other collaborators over sea ice and within the fjord system over the last 10 years particularly in relation to the sea ice model within the HCLIM system.

Future work

The focus for the final year of this special project is running climate downscaling for Greenland over multiple years using the set-up tested with the new cycle43 version of HCLIM, as well as process studies focused on better SMB modelling and evaluation against observational datasets. We also plan to examine the impact on characterization of extreme winds in the model. Some of this work fits well into a PhD project, other work is ideal for an MSc student project and we are offering two supervised projects this year to work with HCLIM output. We are also currently collaborating with others within the HCLIM consortium on a paper describing the polar region set-up and early results. Currently the learnings from the first test simulations are documented internally on a DMI confluence page.

This special project also connects and contributes to work in the Horizon Europe project PolarRES where pan-Arctic simulations with HCLIMcy43 will be used for high resolution climate projections.

We expect at least 4 publications as well as simulations useful for climate processes and climate services applications in Greenland will result from our results so far. Tentative titles are given below:

Olesen, M. and Mottram, R. The importance of precipitation in extreme mass loss years in Greenland IN preparation

Landgren, O., Olesen, M., Boberg, F., Christensen, O. B., Dobler, A., + others Optimising HCLIMcy43 for Polar regional climate simulations in preparation

Larsen, M., Hansen, N., Langen, P. Mottram, R, Nielsen, K.P., Yang, X., Greenland ice sheet surface mass balance with a next generation regional climate model (in prep)

Boberg, F., Mottram, R., Olesen, M., Christensen, O.B., Landgren, O. Piteraq, Avanaaq, Neqajaq: Resolving extreme Greenlandic winds in a high resolution non-hydrostatic model.

References:

Belusic, D., de Vries, H., Dobler, A., Landgren, O., Lind, P., Lindstedt, D., Pedersen, R.A., Sanchez-Perrino, J.C., Toivonen, E., van Ulft, B., Wang, F., Andrae, U., Batrak, Y., Kjellström, E., Lenderink, G., Nikulin, G., Pietikäinen, J.-P., Rodriguez-Camino, E., Samuelsson, P., van Meijgaard, E., Wu, M., 2019. HCLIM38: A flexible regional climate model applicable for different climate zones from coarse to convection permitting scales. Submitted to Geoscientific Model Development.

Fettweis, X., Hofer, S., Krebs-Kanzow, U., Amory, C., Aoki, T., Berends, C. J., Born, A., Box, J. E., Delhasse, A., Fujita, K., Gierz, P., Goelzer, H., Hanna, E., Hashimoto, A., Huybrechts, P., Kapsch, M.-L., King, M. D., Kittel, C., Lang, C., Langen, P. L., Lenaerts, J. T. M., Liston, G. E., Lohmann, G., Mernild, S. H., Mikolajewicz, U., Modali, K., Mottram, R. H., Niwano, M., Noël, B., Ryan, J. C., Smith, A., Streffing, J., Tedesco, M., van de Berg, W. J., van den Broeke, M., van de Wal, R. S. W., van Kampenhout, L., Wilton, D., Wouters, B., Ziemen, F., and Zolles, T.: GrSMBMIP: intercomparison of the modelled 1980–2012 surface mass balance over the Greenland Ice Sheet, The Cryosphere, 14, 3935–3958, https://doi.org/10.5194/tc-14-3935-2020, 2020.

Hermann, M., Box, J. E., Fausto, R. S., Colgan, W. T., Langen, P. L., Mottram, R., et al. (2018). Application of PROMICE Q-transect in situ accumulation and ablation measurements (2000–2017) to constrain mass balance at the southern tip of the Greenland ice sheet. Journal of Geophysical Research: Earth Surface, 123, 1235– 1256. https://doi.org/10.1029/2017JF004408

Ribeiro, S., Limoges, A., Massé, G. *et al.* Vulnerability of the North Water ecosystem to climate change. *Nat Commun* **12,** 4475 (2021). https://doi.org/10.1038/s41467-021-24742-0

Tsutaki, S., Sugiyama, S., Sakakibara, D., Aoki, T., & Niwano, M. (2017). Surface mass balance, ice velocity and near-surface ice temperature on Qaanaaq Ice Cap, northwestern Greenland, from 2012 to 2016. Annals of Glaciology, 58(75pt2), 181-192. doi:10.1017/aog.2017.7