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 …….June 2020- June 2021……..……

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	5248222.03	950000000	488.83
Data storage capacity	(Gbytes)	16000		16000	

Summary of project objectives (10 lines max)

This project aims to set-up the HARMONIE climate model (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)

In spite of delays largely related to the home-working necessitated by the Coronavirus pandemic and personnel changes at DMI, the project has started and is on course to meet the objectives. We have used the opportunity of this special project to train several colleagues in the use and running of HCLIM and as this has been necessarily slower remotely, this has further delayed the start of the intended simulations. Assistance from the HCLIM community and NWP colleagues within the HARMONIE (ACCORD) consortium has been essential in getting the model set up and running. For example, numerical instabilities resulted in strange artefacts within output variables, related to time step issues at high resolution, but these were solved with the assistance of colleagues within the NWP community.

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

Although there has been a late start to this project we plan to continue along the lines laid out in our initial application. Personnel changes at DMI have been reflected in the composition of the project. Rasmus Anker Pedersen is still available for consultation within this project but his role in the day-to-day running of HCLIM has been replaced by Fredrik Boberg and Martin Olesen with assistance on a technical level from Ole Bøssing Christensen. In addition, we are in the process of recruiting a new PhD student together with Aarhus University collaborators who will work on the output produced in this project for surface mass balance modelling of the Greenland ice sheet. While our project is therefore somewhat delayed and we have not yet made maximal use of resources we expect to do so over the remainder of the special project. The project itself has become more important due to our involvement in the recently awarded PolarRES grant – a project funded under the EU Horizon 2020 polar climate call where we and our collaborators at NetNorway and the Finnish Meteorological Institute will run the version of HCLIM developed for the polar regions. In addition, the recently started Danish National Centre for Climate Research (NCKF) also has a number of projects where the output of these planned simulations will be used for the provision of climate services in Greenland. We are therefore keen to recoup lost time in 2021 and 2022 as far as possible.

List of publications/reports from the project with complete references

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:

Most of the resources used in the first 18 months of this project have been used for training colleagues and testing purposes, in particular testing the surface scheme of the model over the Greenland ice sheet in different configurations. We have also focused resources on the set-up of the model at kilometre scale resolution. A number of issues relating to both the expected output and different options that can be implemented within the model required running and re-running a single test year for the whole Greenland domain at 5km to optimise for surface mass balance calculations.

The outcomes of different experiments examining the different HCLIM options and assessing optimal set-ups are being documented in a report that will be published on the DMI website when simulations have been finished. Preliminary analysis of this data was carried out within a student project and was also presented at the EGU 2021 Spring meeting. This work is ideal for an MSc student project and we are offering this as a supervised project this year to document the model thoroughly. 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. We have also opted to set-up a new test-domain over the Qaanaaq region of North West Greenland for very high resolution simulations (see Figure 1). The 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 means that we can use it as a test site for the kilometre scale model in Greenland. A good deal of the work done this year within our special project has been dedicated to fine-tuning the kilometre scale HCLIM set-up.

The Qaanaaq region is important climatically, socially, culturally and economically due to its location close to the north water polynya where traditional harvesting techniques are still practiced (e.g. Ribeiro et al., 2021) under the auspices of a cross-border (Greenland – Canada) Inuit-led management organisation. 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). The new PhD student who will be employed on analysing the data in this project will focus in particular on ice albedo and precipitation (see figures 1b and 1d) .

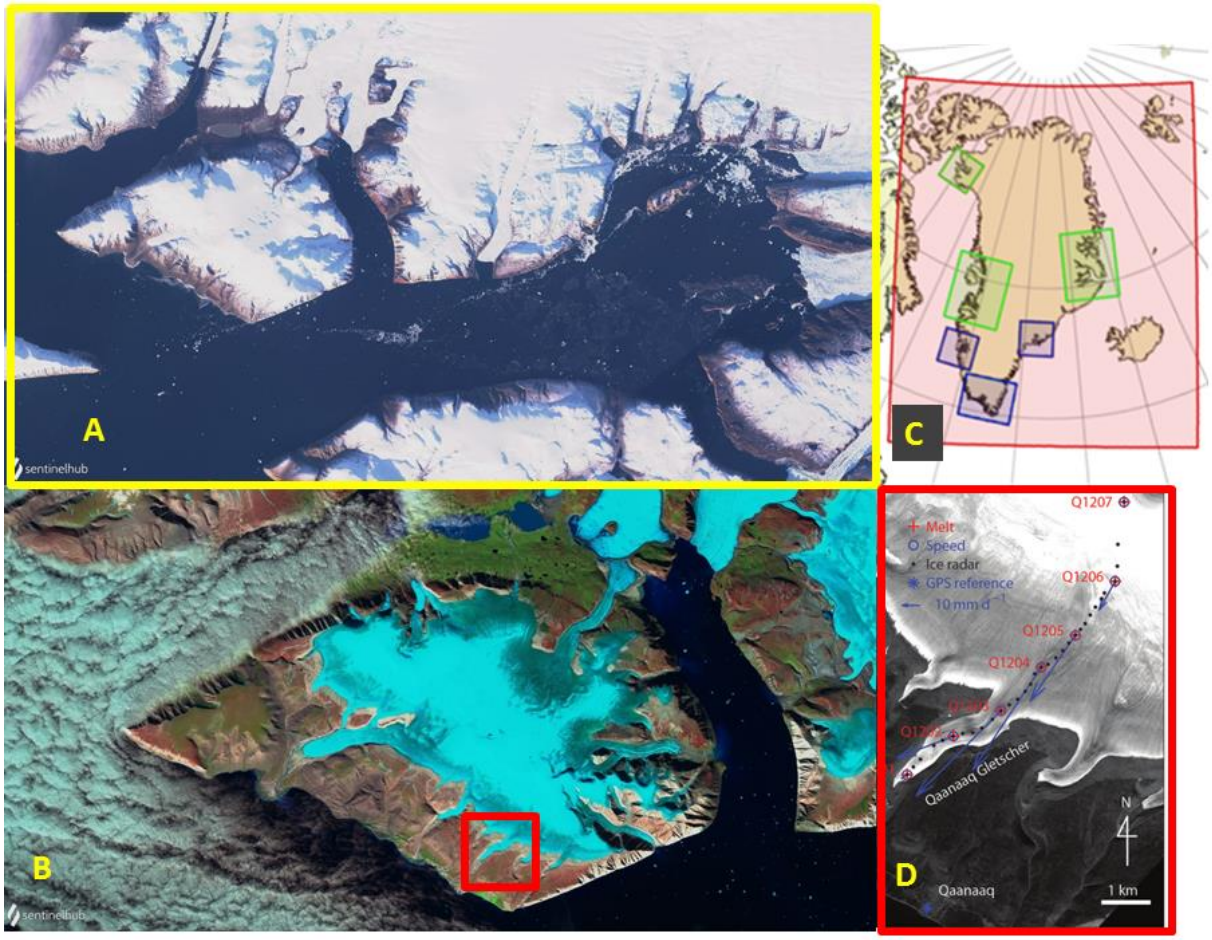

Figure 1 a) Inglefield Bredning fjord and the Qaanaaq ice cap in North West Greenland from Sentinel-2 processed on Sentinel hub. The region has many outlet glaciers from the ice sheet flowing into the fjord where thick seasonal sea ice builds up from around November until June each year. (b) The Greenland 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. (c). The Qaanaaq ice cap in July 2019 from Sentinel-2 satellite imagery processed on Sentinel Hub in the infra-red range. The blue is bare glacier ice and snow and the dark bands indicate areas where surface dust is melting out and biological activity is also likely active and contributing to surface darkening and enhanced melt. The red box indicates the outlet glacier from the ice cap shown in (d) from Tsutaki et al., 2019, where the University of Hokkaido have established a line of observation stakes for measuring ice mass balance.

As Figure 1b shows, glaciers in the region exhibit substantial variation in ice surface albedo, related to dust and the growth of surface biology, particularly algae, on the surface of the glaciers. Data collected by the PI, Ruth Mottram, on the local ice cap in June 2021 and processed under the European Research Council Synergy Project DeepPurple will be included in this project in order to better use the spectral albedo scheme within HCLIM to better simulate ice sheet melt rates. A further focus identified from analysis of initial output together with CARRA data is the optimisation of precipitation in the model. Initial analysis by BSc student Lene Bonde from the University of Copenhagen indicated much improved snowfall in Greenland in CARRA and the HCLIM model when compared to PROMICE data sets and earlier regional climate simulations with HIRHAM5.

As precipitation is key for accurately determining ice sheet surface mass balance (Fettweis et al., 2020; Hermann et al., 2018), these initial indications are a focus for future work and we have therefore also spent some time working on evaluating the precipitation output to better understand how this can be evaluated and used for improved SMB modelling. Observations by the University of Hokkaido since 2012 (Tsutaki et al., 2017) supplemented by DMI field activities in June this year and planned for subsequent years (see Figure 1d) can supply a unique dataset of observations for evaluating accumulation of snowfall and snowpack properties for fine scale process studies in this region.

We expect at least 3 publications as well as simulations useful for climate processes and climate services applications in Greenland will result from our results so far with applications from this project to the PolarRES project that will start 1st September.

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.

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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