REQUEST FOR A SPECIAL PROJECT 2021–2023

MEMBER STATE: …Norway……….…………………………………………...…

Principal Investigator[1]**:** …Oskar Landgren…………………………………….……

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Project Title: …Arctic regional climate modelling with HCLIM……………..……

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If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP** _________________	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2021	
Would you accept support for 1 year only, if necessary?	YES **X**	NO ☐

Computer resources required for 2021-2023: (To make changes to an existing project please submit an amended version of the original form.)		**2021**	**2022**	**2023**
High Performance Computing Facility	(SBU)	35 M	35 M	
Accumulated data storage (total archive volume)[2]	(GB)	20 000	30 000	

Continue overleaf

[1] The Principal Investigator will act as contact person for this Special Project and, in particular, will be asked to register the project, provide annual progress reports of the project's activities, etc.

[2] These figures refer to data archived in ECFS and MARS. If e.g. you archive x GB in year one and y GB in year two and don't delete anything you need to request x + y GB for the second project year etc.

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Extended abstract

The completed form should be submitted/uploaded at https://www.ecmwf.int/en/research/special-projects/special-project-application/special-project-request-submission.

All Special Project requests should provide an abstract/project description including a scientific plan, a justification of the computer resources requested and the technical characteristics of the code to be used.

Following submission by the relevant Member State the Special Project requests will be published on the ECMWF website and evaluated by ECMWF as well as the Scientific Advisory Committee. The evaluation of the requests is based on the following criteria: Relevance to ECMWF's objectives, scientific and technical quality, disciplinary relevance, and justification of the resources requested. Previous Special Project reports and the use of ECMWF software and data infrastructure will also be considered in the evaluation process.

Requests asking for 1,000,000 SBUs or more should be more detailed (3-5 pages). Large requests asking for 10,000,000 SBUs or more might receive a detailed review by members of the Scientific Advisory Committee.

The Arctic is warming much faster than the global average (IPCC: Meredith et al. 2019, ACIA: McBean et al. 2005). Melting sea-ice, permafrost and snow cover as well as changing precipitation phase are bringing radical changes to the ecosystem (e.g. IPCC: Larsen et al. 2014). At the same time many sectors are seeing increased interest in the Arctic, including shipping, fishing, tourism and oil & gas industries.

With its large relatively homogeneous surfaces and well-defined borders between ice and open water, the Arctic is also an interesting laboratory for regional modelling and process understanding (e.g. Tjernström et al. 2008, Heinemann 2008, as well as the ongoing MOSAiC).

Global climate models are used to obtain a physically consistent representation of the global climate system, including atmosphere, ocean, sea ice and land surface. Due to their complexity and geographical coverage they are typically run in a horizontal grid resolution of ~1 degree. However, many processes are on smaller scales, motivating the use of regional climate models (RCMs) over limited areas (Rummukainen 2016). RCMs are used to dynamically downscale global model data to help provide a better understanding of regional climate change and as input to various impact models.
The Arctic CORDEX community (http://www.climate-cryosphere.org/activities/polar-cordex/arctic) facilitates collaboration and intercomparison of results from the different modelling groups performing dynamical downscaling over the Arctic. This special project will enable the first Arctic CORDEX contribution from the regional climate model HARMONIE Climate (HCLIM, Belusic et al. 2020) model.

We will use HCLIM to downscale both the ERA5 reanalysis and global climate models from the CMIP6 archive. This will serve 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 other reanalysis datasets (e.g. CARRA, ASRv2, see below).

Future global climate simulations for downscaling will be selected from the CMIP6 ensemble, based on an evaluation of current climate as well as future spread of projections (e.g. Parding et al. 2020).

While the default simulation protocol is presently at a courser 0.44 degree resolution, a few groups have also produced simulations at 0.22 and 0.11 degrees downscaled from ERA-Interim. At the time of this writing, future scenario simulations in the Arctic CORDEX archive are all at 0.44 degrees, except one simulation at 0.22 degrees. Due to computational cost, 21st century scenario simulations will be made at 0.22 degrees also in this special project.

Regarding reanalysis datasets over the Arctic, the upcoming Copernicus Arctic Regional Reanalysis (CARRA) will provide convection-permitting simulations at 2.5 km, but is limited to two Arctic subdomains and years 1997-2021. The Arctic System Reanalysis version 2 covers the pan-Arctic at 15 km for years 2000-2016. While our HCLIM simulations are in climate mode, i.e. without data assimilation, they can still provide data that is representative for analysis of climate, and complement the above mentioned reanalysis datasets and provide added value for earlier periods and extended areas.
Reference data for comparison may include the already mentioned CARRA and ASRv2, as well as TOPAZ4 and satellite datasets such as MODIS and CLARA.

Model details
HARMONIE Climate (HCLIM, Belusic et al. 2020) is the regional climate model branch of the ALADIN–HIRLAM NWP system. As such, it shares much of the model system with the HARMONIE-AROME system used in operational NWP in many European countries as well as CARRA. However, because convection-permitting simulations are too expensive for multi-decadal simulations over a large pan-Arctic domain, we will instead use the hydrostatic atmospheric physics packages available in HCLIM: ALARO and ALADIN.

A thermodynamic sea-ice scheme within the Simple Ice model (SICE, Batrak et al. 2018) as well as snow on sea-ice will improve upon some of the shortcomings of current reanalyses (Batrak et al. 2019). HCLIM-ALARO with thermodynamic sea ice thickness and snow on ice has previously been used to downscale 18 members from the CESM Large Ensemble over a Norwegian Arctic sub-domain at 12 km (Landgren et al. 2019). The particular setup envisioned for this project has already been tested in a mini-ensemble of six configurations for shorter simulations of one year, all carried out at the ECMWF HPCs. The domain is shown in Fig. 1. Some initial results are presented in Belusic et al. 2020, and a more thorough evaluation is currently in preparation. ECMWF HPCs are also well-suited for producing these runs because of the international collaboration within the HARMONIE consortium.

Resource requirements and data sharing
The estimated SBU requirements are shown in Table 1. The numbers are based on 1-year simulations conducted at ECMWF CCA. Regarding data storage, we will use ECMWF as intermediate storage, transferring to our own infrastructure as simulations finish.

The Norwegian Meteorological Institute has a long tradition of providing data for free to users. Model results will be provided to users via the Earth System Grid Federation nodes.

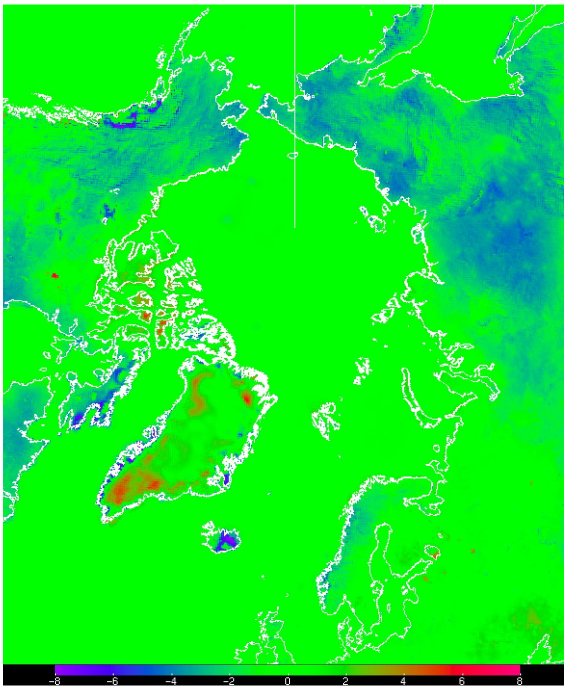

Fig. 1: The pan-Arctic domain, exemplified by data from HCLIM-ALADIN 24 km, downscaled from ERA-Interim. Figure shows T2m bias against Arctic Systems Reanalysis 15 km for June-August 2014. Units are Kelvin. In this case some biases present in ERA-Interim are propagated after downscaling, in particular the cold bias in Siberia. A warm bias in the Canadian Arctic Archipelago is caused by too early snowmelt in ERA-Interim. In the special project we will use ERA5 and global climate models as input data.

Table 1: SBU estimates. GCM selection will be determined in discussions with all Arctic CORDEX institutes. Some details, such as exact time periods, may change once official simulation protocols are agreed upon, likely at the Polar CORDEX meeting in October 2020.

Boundary data	Downscale to resolution [km]	Time period and scenario	Cost [M SBUs]
ERA5	12	1991-2020 (30y)	15
GCM A	24	historical 1980-2014 (35y) SSP5-8.5 2015-2100 (86y) SSP1-2.6 2015-2100 (86y)	4.375 10.75 10.75
GCM B	24	historical 1980-2014 (35y) SSP5-8.5 2015-2100 (86y) SSP1-2.6 2015-2100 (86y)	4.375 10.75 10.75
			Tot: 66.75

References

Batrak, Y., Kourzeneva, E., & Homleid, M. (2018). 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), 3347-3368. https://doi.org/10.5194/gmd-11-3347-2018

Batrak, Y., & Müller, M. (2019). On the warm bias in atmospheric reanalyses induced by the missing snow over Arctic sea-ice. *Nature communications*, *10*(1), 1-8. https://doi.org/10.1038/s41467-019-11975-3

Belušić, D., de Vries, H., Dobler, A., Landgren, O., Lind, P., Lindstedt, D., Pedersen, R. A., Sánchez-Perrino, J. C., Toivonen, E., van Ulft, B., Wang, F., Andrae, U., Batrak, Y., Kjellström, E., Lenderink, G., Nikulin, G., Pietikäinen, J.-P., Rodríguez-Camino, E., Samuelsson, P., van Meijgaard, E., and Wu, M.: HCLIM38: a flexible regional climate model applicable for different climate zones from coarse to convection-permitting scales (2020), *Geosci. Model Dev., 13*, 1311–1333, https://doi.org/10.5194/gmd-13-1311-2020

Heinemann, G. (2008). The polar regions: a natural laboratory for boundary layer meteorology–a review. *Meteorologische Zeitschrift*, *17*(5), 589-601.

Landgren, O. A., Batrak, Y., Haugen, J. E., Støylen, E., & Iversen, T. (2019). Polar low variability and future projections for the Nordic and Barents Seas. *Quarterly Journal of the Royal Meteorological Society*, *145*(724), 3116-3128. https://doi.org/10.1002/qj.3608

Larsen, J.N., O.A. Anisimov, A. Constable, A.B. Hollowed, N. Maynard, P. Prestrud, T.D. Prowse, and J.M.R. Stone, 2014: Polar regions. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1567-1612.

McBean, G., Alekseev, G., Chen, D., Førland, E., Fyfe, J., Groisman, P. Y., King, R., Melling, H., Vose, R. & Whitfield, P. H. (2005). Chapter 2: Arctic Climate: past and present. *Arctic Climate Impact Assessment.*

Meredith, M., M. Sommerkorn, S. Cassotta, C. Derksen, A. Ekaykin, A. Hollowed, G. Kofinas, A. Mackintosh, J. Melbourne-Thomas, M.M.C. Muelbert, G. Ottersen, H. Pritchard, and E.A.G. Schuur, 2019: Polar Regions. In: *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. In press.

HCLIM wiki webpage, https://hirlam.org/trac/wiki/HarmonieClimate

Parding, K. M., Dobler, A., McSweeney, C. F., Landgren, O. A., Benestad, R., Erlandsen, H. B., Mezghani, A., Gregow, H., Räty, O., Viktor, E., El Zohbi, J., Christensen, O. B. & Loukos, H. (2020). GCMeval–An interactive tool for evaluation and selection of climate model ensembles. *Climate Services*, *18*, 100167. https://doi.org/10.1016/j.cliser.2020.100167

Rummukainen, M. (2016). Added value in regional climate modeling. *Wiley Interdisciplinary Reviews: Climate Change*, *7*(1), 145-159. https://doi.org/10.1002/wcc.378

Tjernström, M., Sedlar, J., & Shupe, M. D. (2008). How well do regional climate models reproduce radiation and clouds in the Arctic? An evaluation of ARCMIP simulations. *Journal of Applied Meteorology and Climatology*, *47*(9), 2405-2422. https://doi.org/10.1175/2008JAMC1845.1