REQUEST FOR A SPECIAL PROJECT 2020–2022

MEMBER STATE: Norway

Principal Investigator[1]: Máté Mile (matem@met.no)

Affiliation: Norwegian Meteorological Institute

Address: Henrik Mohns plass 1, P.O. box 43, Blindern, N-0313 Oslo

Other researchers: Kai Håkon Christensen (kaihc@met.no), Roger Randriamampianina (rogerr@met.no), Jens Boldingh Debernard (jensd@met.no), Norwegian Meteorological Institute

Gert-Jan Marseille (gert-jan.marseille@knmi.nl), Royal Netherlands Meteorological Institute

Project Title: Advanced assimilation of satellite observations and the impact of improved atmospheric forcing over a limited-area Arctic region

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.)	2020	
Would you accept support for 1 year only, if necessary?	YES ☒	NO ☐

Computer resources required for 2020-2022: (To make changes to an existing project please submit an amended version of the original form.)		**2020**	**2021**	**2022**
High Performance Computing Facility	(SBU)	20000000	20000000	20000000
Accumulated data storage (total archive volume)[2]	(GB)	40000	40000	40000

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] 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.

Principal Investigator: Máté Mile

Project Title: Advanced assimilation of satellite observations and the impact of improved atmospheric forcing over a limited-area Arctic region

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 and Technical Advisory Committees. 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 will receive a detailed review by members of the Scientific Advisory Committee.

Introduction

The Arctic weather prediction is receiving increasing attention by the growing high-latitude activities and infrastructure, but the NWP models have usually lower forecast skill than at mid-latitudes (Jung et al. 2016). This is partly because unique Arctic weather systems pose challenges different to those at mid-latitudes for which most of these models are developed, and partly due to the scarcity of in-situ observations in ocean and sea ice areas to complement and 'anchor' the denser satellite observation. Forecasting high-impact weather (HIW) events in the Arctic has proven to be especially challenging. Repeated severe forecast misses, aggravated by fast climatic change inducing unusual weather, have dramatic consequences for local communities.

Initial conditions (ICs) for weather forecasts are generated through a process known as data assimilation (DA), where a statistically optimal blend between a previous forecast or model state, and the currently available observations is obtained. In addition to the radiosonde network, satellite observations are a crucial data source in the Arctic. Retrieval methods are, however, challenged by the prevalence of snow and ice-covered surfaces and clouds resulting in sub-optimal observational data usage and rejection of large data volumes.

Remote-sensing measurements have generally brought significant improvement to operational data assimilation and NWP forecast skill. However, the resolution and density of satellite observations are not fully tailored to the NWP model resolution (Liu and Rabier, 2002) and therefore, they are used in a conservative way, particularly in limited-area models (LAM). At most of the NWP centres, the assimilation of satellite observations was implemented in the nineties (see e.g. Andersson et al. 1994), with relatively lower NWP model resolution (also lower than the footprint of some satellite observations) than today. Hence, in operational data assimilation the satellite observations usually undergo a data-thinning procedure (Bormann and Bauer 2010) in order to avoid observation error correlations which are assumed to be negligible in most of DA systems nowadays. Moreover, for observations directly measuring assimilation control variables, the model equivalent of the observation is calculated by simple interpolation in the observation operator (considering only 4 or 12 model grid-points horizontally) which is not fully representative for observation's footprint of most satellite systems. In such a suboptimal system, resolution mismatch causes representativeness error on top of observation instrument error, which alters the pre-defined observation error in the data assimilation system. In order to estimate the observation representativeness error, the effective resolution of both observation and model must be examined and fitted. When observation effective resolution is lower than model effective resolution, which is the case for most of the mesoscale LAMs and satellite observations, the supermodding method is able to reduce the representativeness error (Marseille and Stoffelen 2017). While in those cases when the observation has higher effective resolution than NWP system (e.g. in coarser resolution global models), the superobbing method is effective to reduce representativeness errors (see e.g. Berger and Forsythe, 2004).

Beyond aiming to reduce the representativeness error of satellite observations in atmospheric data assimilation and weather forecasting, a better model representation of surface, especially sea ice, and ocean processes is also very important. The lower atmospheric boundary layer and sea ice surface are very strongly coupled when it comes to radiation and turbulent fluxes. Therefore a dynamically coupled ocean-sea ice-atmosphere system can help to further our understanding and improve forecasting in general and in particular that of HIW events. Differences in resolution between models, and between models and observations, clearly influence and deteriorate the solution both in the atmosphere and sea ice models if not treated carefully. Ideally a fully coupled assimilation between sea ice and lower atmosphere taking into account of the true nature of the observations should improve the analysis phase in both models and thereby introduce consistency in the ICs across the ocean-atmosphere boundary.

Models and software packages

The chosen NWP model is a part of ARPEGE/IFS model family and used operationally at MET Norway, dedicated to the Arctic (Müller et al. 2017)(Randriamampianina et al. 2019). It is called AROME-Arctic which is a configuration of the non-hydrostatic HARMONIE-AROME (Bengtsson et al. 2017) model with 2.5 km horizontal grid spacing. The AROME model is developed jointly by 27 European national meteorological services and the ECMWF global IFS forecasts are usually used as lateral boundary conditions in ALADIN-HIRLAM consortium. The data assimilation system is based on a 3 hourly cycled 3D-Var method which is employed at many centres (Gustafsson et al. 2017; Mile et al. 2015) including operational AROME-Arctic as well (Randriamampianina et al. 2019). Beside operational 3D-Var, the 4D-Var is also available and applicable in HARMONIE-AROME DA system. Apparently, the ARPEGE/IFS common cycles and HARMONIE-AROME model configurations are installed on ECMWF's HPC facilities and based on various software packages developed by ECMWF. HARMONIE-AROME system uses e.g. EcFlow, GRIB-API, and EcCodes just to mention the most relevant packages.

The important processes of sea ice and interactions across the air–ice–ocean interface are represented by a one-dimensional sea ice model (SICE) (Batrak et al., 2018). The Regional Ocean Modelling System (ROMS, Shchepetkin and McWilliams, 2005; Haidvogel et al, 2008) is now being implemented at MET Norway for Arctic limited-area ocean modelling, using atmospheric forcing from AROME-Arctic. The ROMS model, including its 4D-Var system (e.g. Sperrevik et al., 2017), is mainly developed by Rutgers University and University of California with contributions from many other institutes and users. MET Norway researchers collaborate with the ROMS developers on ocean data assimilation, and particularly to enable 4D-Var for the ocean in coupled modelling systems. ROMS is also coupled to the CICE (CICE Consortium, 2018), hereafter ROMS-CICE, extending its capabilities to describe more accurately the sea ice and ocean surface conditions. The SICE, CICE, and ROMS are currently installed on MET Norway's platforms, but it is planned to use and run experimentally on ECMWF's HPC as well.

Planned research

During the proposed special project, the following topics are planned.

1) Reduction of satellite radiance representativeness error in AROME-Arctic data assimilation

Considering the current AROME Arctic data assimilation system, the use of satellite observations and applied error statistics are going to be examined first. For most of the operationally employed satellite observations in AROME-Arctic, the supermodding approach is assumed to be adequate for the reduction of representativeness error due the effective resolution of those remote-sensing observations is coarser than the effective resolution of AROME model (2.5km horizontally). The representativeness error of scatterometer observations was already studied in 2019 when the method was successfully implemented in the variational assimilation scheme. These first supermodding experiments provide basis for satellite radiance assimilation studies following similar implementation strategies and error correction methodologies. The related planned activities on ECMWF's HPC can be summarized as the following:

- Implementation of supermodding observation operator for satellite radiances involving mostly source code compilation and execution of simplified experiments with various assimilation configurations.
- Validation of the implemented supermodding method with sanity checks of full assimilation and forecasting model
- Diagnosing observation and background error statistics in order to estimate optimal settings for supermodding application.
- Execution of assimilation and forecasting model to verify the impact of supermodding (observing system experiments and case studies)

2) The use of satellite radiances over sea ice in AROME-Arctic data assimilation

The low peaking and window channels from polar-orbiting satellites over sea ice and open ocean are currently blacklisted in AROME Arctic. With improved representation of sea ice emissivity, it is planned to employ and, if necessary, further develop two methods for radiance assimilation, Thyness et al. (2005) and Karbou et al. (2014). Therefore, the default 'static' sea ice emissivity and surface characteristics settings in AROME-Arctic are going to be replaced with dynamic emissivity and/or emissivity atlas in the observation operator. Furthermore, other developments from ALERTNESS (Advanced models and weather prediction in the Arctic: Enhanced capacity from observations and polar process representations) project like implementation of sea ice-surface temperature assimilation in SICE using near real-time satellite observations are going to be taken into account in this second phase of the special project. The planned activities on ECMWF's HPC are the following:

- Running AROME-Arctic assimilation experiments (for mostly short runs or case studies) with dynamic emissivity and/or emissivity atlas for ATOVS and/or IASI low-peaking and window channels
- Study of specific issues arising from the use of radiance observations over ocean and sea ice
- Performing observing system experiments with the newly activated satellite channels in AROME-Arctic

3) Evaluation of improved atmospheric forcing in a coupled ocean-sea ice model

The third phase of this special project would be to compute and provide atmospheric forcing from the AROME Arctic system including the advanced assimilation of satellite observations into the ROMS-CICE coupled ocean - sea ice model. We plan for at least two different experiments. The first set of experiments, which will be performed within the project "Vær- og havvarsling for arktisk miljøberedskap" Arktis 2030, will examine the direct effect of the new forcing on the sea ice and ocean forecasts. The second set of experiments will let the sea ice and ocean models surface fields impact the surface analysis of the atmosphere model. It is envisaged that the coupled ice - ocean model response to the new forcing can give valuable information back to the atmosphere and surface temperature analysis and ICs done with SICE. This could also be extended to using the sea ice and SST forecasts as lower boundary conditions in the AROME Arctic forecasts. The related activities on ECMWF's HPC are planned as the following:

- Generating AROME-Arctic forcing for coupled sea ice and ocean model experiments (first set of experiments)
- Running coupled ROMS-CICE model with improved atmospheric forcing on ECMWF's HPC
- Sensitivity experiments of AROME-Arctic assimilation and forecasting model with improved ocean-sea ice surface properties and fluxes (second set of experiments)
- Running observing system experiments to evaluate the best possible benefit of the coupled and more advanced assimilation systems

Resource requirements

Here is the HARMONIE-AROME resources requirement with the AROME-Arctic model steup according to the latest available cycle (cy40h1.1).

Task	High Performance Computing Facility (SBU)	Data storage capacity (total archive volume in gigabytes)
Compilation of full source code package	300	0
Assimilation and 3 hours forecast	2400	15
Assimilation and 24 hours forecast	9000	40
Assimilation cycle and two 24 hours forecasts per day	32400 / day	155
One full experiment of 14 days	469000	2170

The main purpose of this special project is to offer a platform for scientific experimentation. Real-time applications such as daily production of AROME-Arctic execution are not within the scope. The list of scientists involved may be extended with other scientists from MET Norway or KNMI during the lifetime of the project.

References

Andersson, E., J. Pailleux, J.N. Thépaut, J.R. Eyre, A.P. McNally, G.A. Kelly and P. Courtier, 1994: Use of cloud-cleared radiances in 3D and 4D variational data assimilation. Quart. J.R. Meteor. Soc., 120, 627-653.

Batrak, Y., Kourzeneva, E., and Homleid, M.: Implementation of a simple thermodynamic sea ice scheme, SICE version 1.0-38h1, within the ALADIN-HIRLAM numerical weather prediction system version 38h1, Geosci. Model Dev. Discuss., https://doi.org/10.5194/gmd-2018-22, in review, 2018.

Bengtsson, L. Andræ, U., Aspelien, T., Batrak, Y., Calvo, J., de Rooy, W., Gleesone, E., Hansen-Sass, B., Homleid, M., Hortal, M., Ivarsson, K.-I., Lenderink, G., Niemelä, S., Pagh Nielsen, K., Onvlee, J., Rontu, L., Samuelsson, P., Santos Muñoz, D., Subias, A., Tijm, S., Toll, V., Yang, X., and Ødegaard Køltzow, M, 2017: The HARMONIE-AROME model configuration in the ALADIN-HIRLAM NWP system, Mon. Wea. Rev., 145. 1919-1935.

Berger H, and Forsythe M. 2004. ‘Satellite wind superobbing’, Technical report 451. Met Office Forecasting Research. http://www.metoffice.gov.uk/

Bormann, N., and Bauer, P., 2010: Estimates of spatial and interchannel observation-error characteristics for current sounder radiances for numerical weather prediction. I: Methods and application to ATOVS data. Q. J. R. Meteorol. Soc. 136. 1036-1050.

CICE Consortium, 2018: https://github.com/CICE-Consortium, DOI:10.5281/zenodo.1205674

Gustafsson, N., Janjic T, Schraff C, Leuenberger D, Weissman M, Reich H, Brousseau P, Montmerle T, Wattrelot E, Bucanek A, Mile M, Hamdi R, Lindskog M, Barkmeijer J, Dahlbom M, Macpherson B, Ballard S, Inverarity G, Carley J, Alexander C, Dowell D, Liu S, Ikuta Y, Fujita T., 2017: Survey of data assimilation methods for convective-scale numerical weather prediction at operational centres. Q. J. R. Meteorol. Soc. doi:10.1002/qj.3179

Haidvogel, D. B., et al. (2008), Ocean forecasting in terrain-following coordinates: Formulation and skill assessment of the Regional Ocean Modeling System, J. Comput. Phys., 227(7), doi:10.1016/j.jcp.2007.06.016.

Jung, T., Gordon, N.D., Bauer, P., Bromwich, D.H., Chevallier, M., Day, J.J., Dawson, J., Doblas-Reyes, F., Fairall, C., Goessling, H.F. and Holland, M., 2016. Advancing polar prediction capabilities on daily to seasonal time scales. *Bulletin of the American Meteorological Society*, *97*(9), pp.1631-1648.

Karbou, F., F. Rabier and C. Prigent, 2014: The Assimilation of Observations from the Advanced Microwave Sounding Unit over Sea Ice in the French Global Numerical Weather Prediction System, Mon. Wea. Rev., 142, 125–142.

Liu, Z., Q., and Rabier, F., 2002: The interaction between model resolution, observation resolution and observation density in data assimilation: A one-dimensional study. Q. J. R. Meteorol. Soc. 128. 1367-1386.

Marseille, G-J., and Stoffelen, A., 2017: Towards scatterometer winds assimilation in the mesoscale HARMONIE model, IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing. 10: 2383-2393.

Mile, M., Bölöni, G., Randriamampianina, R., Steib, R., and Kucukkaraca, E., 2015: Overview of mesoscale data assimilation developments at the Hungarian Meteorological Service. Időjárás Vol 119. No.2 pp. 215-239

Müller, M. Batrak, Y, Kristiansen, J, Køltzow, MAØ, Noer, G, Korosov, A, 2017: Characteristics of a convective-scale weather forecasting system in the Arctic. Mon. Wea. Rev. 32, 609–627, https://doi.org/10.1175/WAF-D-16-0099.1, 2017.

Randriamampianina R., Schyberg, H., Mile, M., 2019: Observing system experiments and observing system simulation experiments using mesoscale model in Arctic. Remote Sens. 11(8), 981: https://doi.org/10.3390/rs11080981

Shchepetkin, A. F., and J. C. McWilliams (2005), The regional oceanic modeling system (ROMS): A split-explicit, free-surface, topography-following-coordinate oceanic model, Ocean Modell., 9(4), 347–404, doi:10.1016/j.ocemod.2004.08.002.

Sperrevik, Ann Kristin, Johannes Röhrs, and Kai Håkon Christensen. "Impact of data assimilation on Eulerian versus Lagrangian estimates of upper ocean transport." *Journal of Geophysical Research: Oceans* (2017). https://doi.org/10.1002/2016JC012640

Thyness, V., Pedersen, L., T., Schyberg, H., Tveter, F., T., 2005: Assimilating AMSUA over sea ice in HIRLAM 3D-Var, ITSC XIV. Proceedings, Beijing.