REQUEST FOR A SPECIAL PROJECT 2026–2028

MEMBER STATE: Norway

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Project Title: **N**eural **N**etwork-based **R**esponsive **I**ce **C**over for **O**perations (**NN-RICO**)

To make changes to an existing project please submit an amended version of the original form.)

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.)	2026	
Would you accept support for 1 year only, if necessary?	YES x	NO ☐

Computer resources required for project year:		**2026**	**2027**	**2028**
High Performance Computing Facility	[SBU]	20M	1M	1M
Accumulated data storage (total archive volume)[2]	[GB]	55000	65000	75000

EWC resources required for project year:		**2026**	**2027**	**2028**
Number of vCPUs	[#]			
Total memory	[GB]			
Storage	[GB]			
Number of vGPUs[3]	[#]			

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.
[3]The number of vGPU is referred to the equivalent number of virtualized vGPUs with 8GB memory.

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Extended abstract

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

Following submission by the relevant Member State the Special Project requests will be published on the ECMWF website and evaluated by ECMWF and its Scientific Advisory Committee. The requests are evaluated based on their scientific and technical quality, and the 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 exceeding 5,000,000 SBU should be more detailed (3-5 pages).

Scientific Mission:
The ongoing increase in global temperatures is contributing to a significant reduction in Arctic sea ice extent. This transformation is opening new socio-economic opportunities in the region, including fishing, exploitation of natural resources, maritime transport, and tourism (Karlsdottir et al., 2011, Emmerson and Lahn 2012). However, all of these endeavors require accurate and timely weather forecasts. With many of these operations now taking place close to, or even within, the Marginal Ice Zone (MIZ), it is imperative to improve the representation of this dynamic environment in regional forecasting models (Müller et al., 2023). This becomes particularly relevant for institutions like the Norwegian Meteorological Institute (MET Norway) who are responsible for issuing forecasts and warning in high-latitude areas, in this case most of the European Arctic in the Barents and Nordic seas (Jeuring et al., 2019).

Currently, the mesoscale numerical weather predication system HARMONIE-AROME, operationally used by MET Norway, contains several shortcomings in its treatment of sea ice (Batrak et al., 2024). Most critically, sea ice is represented as a static medium, with no dynamic processes, such as ice drift, resolved over the course of the model forecast. Coupling HARMONIE-AROME with a physical ocean/sea ice model to address this issue was deemed unfeasible for operational use. The main caveats are substantial computational cost, increased complexity of data flow, and the necessity to maintain and tune an ocean data assimilation system in addition to the atmospheric one. Furthermore, the complex interactions between the atmosphere, ocean, and sea ice in the model are seldom properly assessed due to a persistent lack of process understanding and in-situ observations (Müller et al. 2025).

Our project aims to tackle both of these challenges. We propose to couple HARMONIE-AROME to a neural network (NN)-based machine-learning model trained to predict evolving sea ice conditions. This approach offers a computationally efficient alternative to coupling with a traditional dynamic-thermodynamic sea ice model. A proof of concept for the coupling framework using sea ice forecasts from the ocean-ice forecasting system BarentsROMS (Melsom et al., 2009, Duarte et al., 2022) revealed domain-wide impacts on temperature, moisture, clouds, and precipitation for a 66 h forecast in winter 2023. Sensible and latent heat fluxes changed atmospheric temperature and moisture developments, over the sea ice, MIZ, and the open ocean. Over the sea ice and MIZ a warmer and deeper planetary boundary layer (PBL) formed due to evolving leads in the ice (Fig. 1b). In contrast, downstream of the MIZ, within a fetch of 300 km, the shift in sea ice extent (Fig. 1a) delayed the onset of pronounced heat fluxes, leading to a colder (Fig. 1b) and shallower PBL. These lower temperatures yielded a stronger contrast to the sea surface temperature, triggering more vigorous convection and precipitation compared to the experiment with static sea ice. The short experiment already revealed the complex interactions that need to be considered and studied for enabling a responsive sea ice in our model system. These interactions need to be diagnosed and validated.

To diagnose the underlying processes and evaluate the effect of a changing sea ice cover under different atmospheric conditions—such as Cold Air Outbreaks (CAO), Warm Air Intrusions (WAI), and transition periods—we will use the HARMONIE-AROME's embedded tool DDH (*diagnostics par domaines horizontaux,* Météo-France, 2019). DDH generates time-step model output, including resolved variables as well as physical tendencies (Kähnert et al. 2023). This will allow us to examine in great detail the process representation within the MIZ.

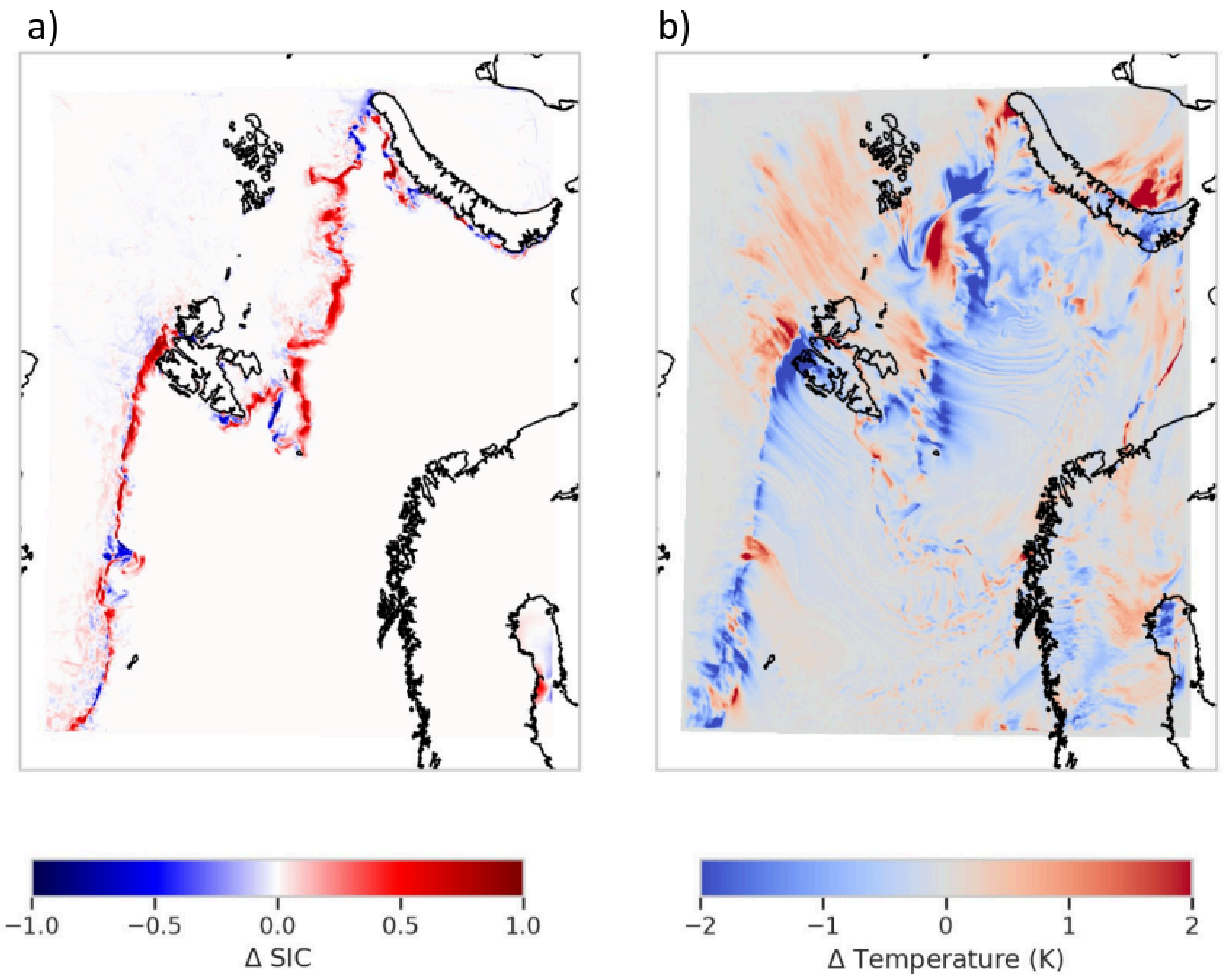

Fig 1: Difference in sea ice concentration (left) and air temperature at the lowest model level (right) after 66 hours of forecast between an HARMONIE-AROME run with and without evolving sea ice.

To validate the model's air-sea-ice interactions we will use recent observational data from two SvalMIZ campaigns, one in 2024 (Müller et al., 2025), and one in 2025. During the campaigns, autonomous platforms in the form of OpenMetBuoys (Rabault et al., 2022) were deployed on sea ice north of Svalbard. Equipped with a variety of sensors these buoys observed air and surface temperature, sea-ice drift (Fig. 2), and wave energy spectra. Using the campaign data, we focus on one-month periods: April 2024 and mid-April to mid-May 2025. Several dynamic weather events were captured during these periods, including a CAO and WAI, making the dataset particularly relevant for our study.

Ultimately, this work supports a dual objective: improving the physical understanding of modelled atmospheric processes in the MIZ and paving the way for operational implementation of a responsive sea ice concentration within HARMONIE-AROME.

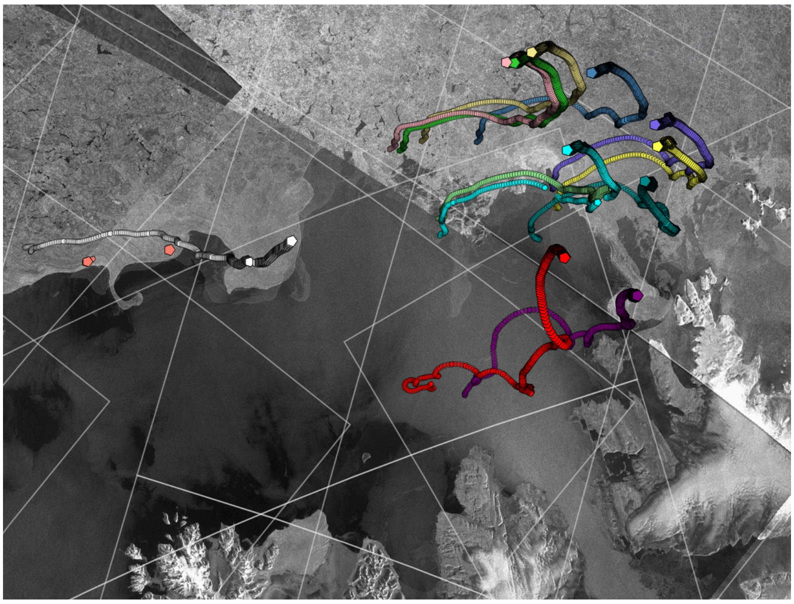

Fig. 2: Example of weekly trajectories (colored dots) from OpenMetBuoys released during the 2024 SvalMIZ campaign north of Svalbard. The shown period is 26-30 April 2024. Image source: ESA Ocean Virtual Laboratory.

Computational requirements:
To achieve the objectives outlined in this project, we request access to computing resources to support model simulations, running neural network inference, and performing various diagnostics.

We plan to run an operational-like configuration of HARMONIE-AROME over the AROME-Arctic (Müller et al., 2017) domain for two distinct one-month periods—one in 2024 and one in 2025. The setup runs 66h forecasts, eight times per day, using a 3h assimilation cycle. For each period, the model will be run in two different configurations; the baseline configuration (REF) and the coupled neural network (NN) sea ice prediction setup. These runs will allow us to evaluate the impact of evolving sea ice cover on forecast accuracy across different scenarios. The computational cost of one 66h model forecast is about 20,000 SBU, yielding a total estimated cost for these model simulations of **20,000,000 SBU** (20,000 SBU* 8 cycles * 30 days * 2 month * 2 experimental setups). This includes a 10-day model spinup period (with only 3 hours forecasts) which will amount to 20,000 SBU.

One 66h forecast requires about 53 GB of storage for archiving. Upscaling it to our project we require **55,000 GB** of storage in the first year (2 experiments*53 GB* 8 cycles * 30 days * 2 months). The following two years will be dedicated to the sensitivity experiments and DDH studies (see below), where we estimate to archive additional **10,000 GB** of data per year.

To investigate atmospheric process representation and sensitivity to evolving sea ice in greater detail, we will conduct targeted simulations of distinct weather regimes (e.g., CAO, WAI, transitional phases) using the DDH diagnostic tool. DDH produces time-step output allowing for in-depth process studies in the MIZ. Several physical configurations of the model will be run to test the sensitivity of individual processes to changes in the sea ice cover and their interactions along the MIZ. As an example we will test a new option for treating shallow convection in HARMONIE-AROME, which yields a better representation of organised convection in the boundary layer. This new option reduces the strength of parameterised shallow convection based on grid scale vertical velocities and sub grid scale precipitation. The new scheme is expected to strongly modulate the developments downstream from the MIZ during a CAO, which will again be modulated by an evolving sea ice cover. It is these interactions between different processes and their respective impacts on the grid scale temperature, humidity, or wind speeds, that will be disentangled by assessing the DDH-enabled sensitivity experiments. The additional computational costs for these experiments are estimated at **2,000,000 SBU**.

For the machine learning component of the project, we will train a diffusion NN using observational sea ice concentration from satellites and past AROME-Arctic model outputs of 2m-temperature and 10m-wind. This training, which requires considerable GPU resources, will, however, be conducted on a separate HPC. Once trained, the NN will be used for inference during the forecast within the coupled HARMONIE-AROME-NN system. We plan to run an ensemble of 8 members requiring **2 GPUs** (1 GPU per experiment). We estimate our diffusion NN to require 52 SBU for a single 66h experiment (assuming 1 GPU equals 1 node). This amounts to about **25,000 SBU** for our coupling experiment (52 SBU * 2 months * 8 cycles * 30 days). These costs are already included in the aforementioned 20,000,000 SBUs.

Technical information:

AROME-Arctic is the operational NWP model run at MET-Norway for the European Arctic. It is a non-hydrostatic, convection-permitting model with a grid spacing of 2.5 km and 65 vertical levels, whereby 20 model levels are located below 1 km. Lateral boundary conditions are taken from the ECMWF global IFS forecast system. The model is a configuration of the HARMONIE-AROME model and is tested on ATOS to run without issues. The same applies to the coupling framework based on the OASIS coupler.

The NN is implemented in Python using Pytorch and Pytorch Lightning. The NN is a Diffusion model currently implemented as a Denoising Diffusion Probabilistic Model (DDPM). Its backbone is a UNet-inspired architecture, implemented with ConvNeXT blocks constituting the Encoder and Decoder. Transformer blocks are forming the bottleneck.

Potential problems in the coupled setup can arise from combining a system running on CPUs (AROME-Arctic) and one that uses GPUs (diffusional NN). In order to ensure the possibility of running the coupling experiment a separate NN will be trained. This NN will represent the deterministic backbone of the diffusion model and can operate on CPUs. Such a coupling setup was already successfully tested on ATOS. The SBU costs for this backup-alternative are expected to **not** increase our total SBU requirements.

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