REQUEST FOR A SPECIAL PROJECT 2025–2027

MEMBER STATE:	Norway
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Project Title:	**A**rctic **W**eather Satellite **A**ll-sky **R**adiance DA **I**mplementation (**AWARI**)

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.)	2025	
Would you accept support for 1 year only, if necessary?	YES X	NO ☐

Computer resources required for project year:		**2025**	**2026**	**2027**
High Performance Computing Facility	[SBU]	30M	35M	30M
Accumulated data storage (total archive volume)[2]	[GB]	70 000	110 000	150 000

EWC resources required for project year:		**2025**	**2026**	**2027**
Number of vCPUs	[#]			
Total memory	[GB]			
Storage	[GB]			
Number of vGPUs[3]	[#]			

Continue overleaf.

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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 10,000,000 SBU should be more detailed (3-5 pages).

Extended abstract

The new Arctic Weather Satellite (AWS) under ESA responsibility is planned for launch in mid 2024 (now likely July). It will carry a new generation, small microwave sounder suitable for future constellations of small satellites. It is designed to complement the existing larger microwave sounding satellites to provide frequent-revisit information on tropospheric temperature, humidity and cloud properties with good coverage of the Arctic region. The instrument design adds measurement channels at higher frequencies than the traditional satellites, with stronger sensitivities to clouds, which bring both new challenges and new possibilities for enhancing weather monitoring and forecasting. The satellite will be deployed and operated as a prototype satellite for a potential EUMETSAT small-satellite constellation called EPS-Sterna (expected to be decided by early 2025).

MET Norway is involved in a Swedish-led, Nordic AWS project funded by ESA ("*Performance Evaluation of Arctic Weather Satellite data*"), which aims at covering the preparation phase (early data processing, and calibration/validation) for the assimilation of AWS radiances. Due to large uncertainties in the model over the Northern latitudes, only clear-sky observations and channels that are not sensitive to the surface are considered in these preliminary experiments. The AWARI project aims at extending the use of this future sounder to better constrain the atmospheric analysis in cloudy and rainy/snowy conditions as well as over mixed surfaces (sea-ice, snow and coast).

In this project, we will monitor and assimilate the AWS radiances, tune the system and investigate new methodologies to optimise the use of AWS in our operational regional NWP system (AROME-Arctic).

1) Investigation: In order to enable the assimilation of AWS in all-sky conditions, a special attention will be given to this innovative and unique set of channels located around 325 GHz. Being very

sensitive to clouds and precipitation, we will explore how to extend and refine the so-called "all-sky" DA approach for the particularities of the AWS instrument. Over land, coast and sea-ice surface, we will test the dynamic emissivity method and some new tools (such as the footprint operator) to assimilate low-peaking channels over complex surfaces.

2) Implementation & experimentation: In a second step, we plan to implement the new findings and test them into our NWP AROME-Arctic forecast system. The most advanced version of the operational forecast model and observing system will be used as a baseline. Code modifications will be implemented to enhance the assimilation of AWS in all-sky and all-surface conditions (if applicable). The model will be run over two periods (winter and summer) in several test configurations.

3) Validation toward operational implementation (if applicable): Finally, we will evaluate in detail the benefits of assimilating AWS data into the AROME-Arctic forecast system. The baseline experiments (without AWS) will serve as a reference. Results will be evaluated following an incremental approach. The reference will be compared to an experiment with AWS 1) in clear-sky, 2) all-sky, 3) all-sky and all-surfaces. The overall forecast scores against independent observations will be computed for each test configuration. Also, comparison with the ECMWF analysis field might be an additional point of comparison (if time permits). We also plan to characterise the impact of AWS DA on the forecast of extreme events. For that matter, we aim at running the forecast simulations over a period that include a strong Polar Low storm or heavy precipitation events.

Depending on the level of improvement that these new developments might provide to the forecast skill, an operational implementation in AROME-Arctic could be foreseen. These developments might also be beneficial to the partners from the ACCORD consortium as we are sharing the same NWP code system (HARMONIE-AROME).

Finally, on a longer term, AWS being a prototype for the eventual EPS-Sterna constellation project (if validated by the EUMETSAT Council), this project might help considerably with the preparation of such a mission. The constellation should involve the deployment of 6 to 9 micro-satellites starting in 2029 with some expected unprecedented positive impacts on the forecast, especially over Polar regions.

Introduction

The new Arctic Weather Satellite (AWS) under ESA responsibility is planned for launch in mid 2024 (now likely July). It will carry a new generation, small microwave sounder suitable for future constellations of small satellites. It is designed to complement the existing larger microwave sounding satellites to provide frequent-revisit information on tropospheric temperature, humidity and cloud properties with good coverage of the Arctic region. The instrument design adds measurement channels at higher frequencies than the traditional satellites, with stronger sensitivities to clouds, which bring both new challenges and new possibilities for enhancing weather monitoring and forecasting. The satellite will be deployed and operated as a prototype satellite for a potential EUMETSAT small-satellite constellation called EPS-Sterna (expected to be decided by early 2025).

MET Norway participated in a EPS-Sterna OSSE exercice under EUMETSAT fundings project and in a Swedish-led, Nordic AWS project funded by ESA ("*Performance Evaluation of Arctic Weather Satellite data*"), which aims at covering the preparation phase (early data processing and calibration/validation) for the assimilation of AWS radiances in clear-sky conditions. In that ESA project, limited trial assimilation experiments in numerical weather prediction (NWP) will be run "on the fly" while receiving the first batch of data. Only a preliminary setup and assessment will be performed, so here we propose a new project to develop our processing and NWP system to exploit the full benefits of this new satellite. This will prepare its operational implementation in the Norwegian AROME-Arctic forecast system, which is the basis for the MET Norway operational forecasts for our Northern areas.

This project is going one step further to the "traditional" clear-sky assimilation of AWS. It aims at extending the potential of this future sounder to better constrain the atmospheric analysis in areas where the model is not performing well enough to allow the assimilation of radiances: cloudy and rainy conditions as well as surface-sensitive channels over mixed surfaces (sea-ice, snow and coast).

In order to enable the assimilation of AWS in all-sky conditions, we plan to use this innovative and unique set of channels located around 325 GHz. Being very sensitive to clouds and precipitation, we will explore how to extend and refine the so-called "all-sky" DA approach (Geer et al., 2014) for the particularities of the AWS instrument. Over land, coast and sea-ice surfaces, we will test the dynamic emissivity method (Karbou et al. 2006, 2014) and some new tools (such as the footprint operator, Mille et al. 2024) to assimilate low-peaking channels over complex surfaces. A set of data assimilation experiments will be run to evaluate, against independent observations, the benefit of using these additional AWS radiances into our operational NWP AROME-Arctic forecast system.

Model 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 ACCORD 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) including operational AROME-Arctic as well (Randriamampianina et al. 2019). Beside operational 3D-Var, the 4D-Var is also available and applicable in the HARMONIE-AROME DA system. 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.

In order to assimilate radiances in our NWP system, the RTTOV radiative transfer model is used in operations. Following initial developments presented in Azad and Randriamampianina, 2022, this project aims at extending the use of clear-sky microwave observations to cloudy and rainy conditions and this will require the use of RTTOV-SCATT. It also aims, to some extent, at improving the assimilation of low-peaking channels over complex/mixed surfaces (sea-ice, snow and coast) with the dynamic emissivity method. Some initial developments have been ported from IFS to our version of the HARMONIE-AROME DA system, but it is only applicable to the MHS instrument and still not fully validated. In these early developments, we have implemented source-code modifications in common cy46 release to extend the radiance assimilation with the necessary all-sky capabilities. In this special project, we are aiming at using newer cycle releases (namely cy48 or cy49) with a similar approach and adapting it to this innovative AWS instrument. New cycle releases open the door for a more flexible and more maintainable source-code implementation. It is planned to run a large set of experiments, including a baseline for reference, in order to evaluate the code changes that are needed to handle all-sky radiance assimilation.

Planned research

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

1. Investigation

In the first part of the project, we will investigate and extend the initial and preliminary work done in a Swedish-led, Nordic AWS project funded by ESA ("Performance Evaluation of Arctic Weather Satellite data"). In clear-sky conditions first, we will run some diagnostics to tune the usage of high peaking AWS channels in the DA system (i.e observation errors, thinning distance, bias correction).
Special attention will be given to the new set of channels located around 325 GHz. The variational bias correction (VarBC) will be adjusted to enhance, via the monitoring procedure, an optimal correction of the assumed instrumental bias. In addition, these channels being very sensitive to clouds and precipitation, we will explore new methodologies to extend and refine the so-called "all-sky" DA approach for the particularities of AWS.
In the context of "all-surface" DA, this work will also explore the capability of the dynamic emissivity method to enable the assimilation of AWS low-peaking channels over complex surfaces (coast, sea-ice and snow-covered surfaces). Emissivity is retrieved at a window channel and it is allocated to adjacent sounding channels (Karbou et al, 2006). This method assumes that, at a given location, observations from a window channel and a sounding channel have the exact same geographic coordinates. This will not be the case for AWS due to the instrument design. Using a tool such as the footprint operator or the latest version of RTTOV (version 14) will be very helpful to understand and refine the method for the specificities of AWS.

2. Implementation and experimentation

In a second step, we plan to implement the new findings and test them into our NWP AROME-Arctic forecast system. The most advanced version of the operational forecast model will be used as a baseline, together with the full observing system. Code modifications will be implemented to enhance the assimilation of AWS in all-sky and all-surface conditions (if applicable). The model will be run over two periods of 6 weeks minimum (winter and summer) in several test configurations. A spin-up period of 2 weeks to warm-up the VarBC coefficients and to get stable initial atmospheric state will be run beforehand each run.
We will aim at enabling and extending the operational assimilation of AWS data in the AROME-Arctic forecast system. As a first step, AWS will be added to the preoperational chain in clear-sky conditions, potentially within the “all-sky” route.

3. Validation

Finally, we will evaluate in detail the benefits of assimilating AWS data into the AROME-Arctic forecast system. The baseline experiments (without AWS) will serve as a reference. Results will be evaluated following an incremental approach. The reference will be compared to an experiment with AWS 1) in clear-sky, 2) all-sky, 3) all-sky and all-surfaces.
The overall forecast scores against surface and radiosonde observations will be computed for each test configuration. Also, comparison with the ECMWF analysis field might be an additional point of comparison (if time permits).
We also plan to characterise the impact of AWS DA on the forecast of extreme events. For that matter, we aim at running the forecast simulations over a period that include a strong Polar Low storm or heavy precipitation events.

Resource requirements

Here is the HARMONIE-AROME resources requirement with the AROME-Arctic model setup according to the latest available cycle (cy46). The results are shown for one experiment.

Task	**High Performance Computing Facility (SBU)**	**Data storage capacity (total archive volume in gigabytes)**
Compilation of full source code package	350	2.5
Assimilation and 3 hours forecast	2500	30
Assimilation and 24 hours forecast	9200	60
Assimilation cycle and two 24 hours forecasts per day	33000/day	300
Spin-up of 15 days (3 hours only)	300000	3600
One full experiment of 15 days	500000	4300

In this project, we have estimated that we will need to run between 30 to 40 test experiments in total. For each experiment, the model will be run for 6 weeks over 2 seasons. It will require around 30 to 35M SBU per year.

SBU:(0.3M * 40 exp *2 seasons) + (0.5M * 40 exp * 2 period * 2 seasons) = 104M / 3 years = 34,6M
spin-up data assimilation for a month

In terms of archiving, we will save around one quarter of the total output of each experiment. It will require around 80 000 GB per year.

Storage: (3600GB * 40 exp *2 seasons) + (4300GB * 40 exp * 2 period * 2 seasons) = 976000GB / 3 years = 325333GB / 4 cleanings = 81333 GB

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 during the lifetime of the project.

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