REQUEST FOR A SPECIAL PROJECT 2021–2023

MEMBER STATE: Sweden

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Project Title: An enhanced use of passive microwave radiances in the scandinavian HARMONIE-AROME km-scale limited-area data assimilation systems

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 ☒	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)	15M	15M	15M
Accumulated data storage (total archive volume)[2]	(GB)	27000	54000	89000

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.

1. Background

Utilization of passive microwave satellite observations has been demonstrated to be important both in global and limited-area data assimilation (Geer et al., 2017; Storto and Randriamampianina, 2010). Factors important for obtaining a positive impact from passive microwave radiances include data availability, preparation of data assimilation code (including radiative transfer models etc.) to handle the data. Another important factor is the ability of the data assimilation system itself. For the Nordic countries Denmark, Finland, Norway and Sweden the main modelling tool is the limited-area NWP system, which is a product from common collaboration in the framework of the shared "Aire Limitée Adaptation Dynamique Développement InterNational" (ALADIN) - High-Resolution Limited-Area Model (HIRLAM) NWP system. This system, which share many components with ECMWF IFS system (for example observation operators, observation processing and internal observation data base format), can be run with different configurations and at SMHI the so-called HIRLAM ALADIN Regional Meso-scale Operational NWP In Europe-Application of Research to Operations at Mesoscale (HARMONIE-AROME) is used (Bengtsson et al., 2017). At present Sweden, Norway, Finland and Estonia share a common operational system named MetCoOp. Currently, Denmark have a common operational system with Iceland but is in the final steps of extending the collaboration to include also Ireland and the Netherlands. This four country collaboration, called United Weather Centers West (UWC-west) is planned to start in 2023 and to be based on the system outlined above. UWC-west is planned to merge with MetCoOp in 2028. Shown below in Figure 1, is the the current operational MetCoOp domain (left), the current operational Danish/Icelandic domains (middle) and the planned UWC-west domains (right). Shown is also the AROME-ARCTIC domain, run by the Norweigian meteorological service over an Arctic domain with an microwave radiance observation usage rather similar to MetCoOp.

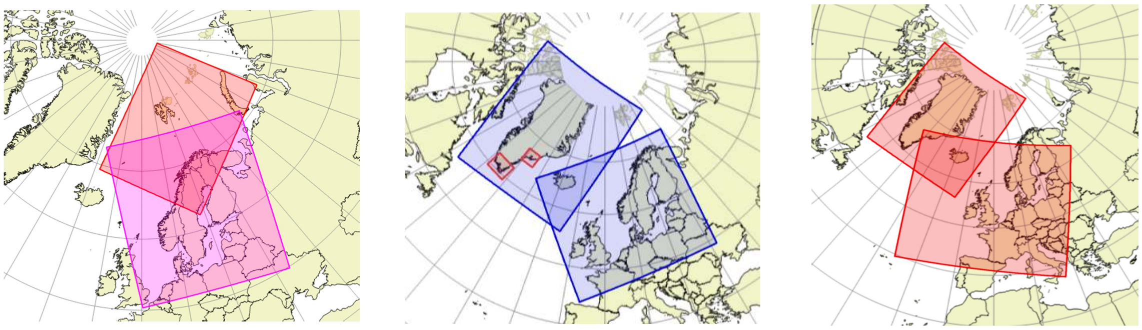

Figure 1. MetCoOp and AROME-Arctic current operational model domains (left), Danish/Icelandic operational model domains (middle) and planned UWC-west domains (right).

At present both MetCoOp and Denmark/Iceland utilize operationally microwave radiances from the Microwave Humidity Sounder (MHS) and the Advanced Microwave Sounding Unit-A (AMSU-A) instruments on-board the NOAA and METOP polar orbiting satellites. In addition Denmark/Iceland have prepared for assimilation of radiances from the Advanced Technology Microwave Sounder (ATMS) on-board the Suomi NPP polar orbiting satellite. MetCoOp on the other hand has gained experience from the Micro-Wave Humidity Sounder-2 (MWHS-2) on-board m FY-3C and FY-3D satellites. Thus there are some respective sharing of developments needed for both of the operational systems and that will also feed back to the HARMONIE-AROME reference system. In addition there is a need to upgrade the Danish/Icelandic Operational System, the MetCoOp operational system as well as the HARMONIE-AROME reference system for use of ATMS radiances from the NOAA-20 satellite as well as from microwave radiances from new sensors on-board the EPS-SG-A and B-platforms (MWS on the A-platform and ICI and MWI on the B-platform), the first (A1 and B1) planned for launch in 2023 & 2024, respectively, and a new small passive microwave demonstrator satellite, the Arctic Weather Satellites (AWS) planned for launch in the same time frame as EPS-SG and possibly to be followed by a constellation of up to 20 small such AWS's. Such developments will be the focus of this project and research will be carried out over a common area similar to the MetCoOp area and the Danish/Icelandic North European domain (lower right blue area in the middle panel of Figure 1) and with roughly 1000 x 1000 horizontal grid points and with 2.5 km grid-distance and 65 vertical levels. As a second step, not covered in this project, there will be room for further fine-tuning of the use of the microwave satellite data, regarding for example handling of surface sensitive channels. Another example of such further refinements is to improve the handling of the well tested MW radiances in areas covered by clouds. This is highly related to the subject of a EUMESAT financed research-fellowship CREATE (characterising and reducing uncertainties in all-sky microwave radiative transfer) hosted by Chalmers Technical University in Sweden with involvement also from SMHI and ECMWF.

A first focus of this project is to enhance the pre-operational versions to make use of currently available instruments in the form of AMSU-A, ATMS, MHS and MWHS-2 placed on-board polar orbiting METOP, NOAA and FY-3 satellites. As a next step we will prepare the HARMONIE-AROME system for utilization of radiances from a microwave passive sensor, measuring at 325 GHz, one of the options planned on-board the AWS, a Swedish (OHB-Sweden for the overall programme and Omnisys Instruments for the instrument) led initiative for a prototype satellite under the European Space Agency (ESA) European Earth Watch Programme.These new microsatellites are proposed to be equipped with sensors measuring at frequency bands measuring around 50-58 GHz, 183 GHz and 325 GHz. The first two frequency bands mentioned are heritage bands corresponding to what is already used in AMSU-A and MHS instruments. The band around 325 GHz is less well-established, and have the potential to provide information related to for example ice particles in clouds. For for utilization of heritage frequency bands from the new satellites code developments (for example in radiative transfer model) in the present HARMONIE-AROME modelling framework are needed as well as a pre-launch test data set. A close collaboration with the NWP SAF and data providers are foreseen. We also expect close contact with ECMWF since we share large parts of the observation processing code with ECMWF and required updates of radiative transfer code to handle microwave sensors on-board AWS would be of interest also for ECMWF. Our research is carried out also in collaboration with Chalmers Technical University regarding EPS-SG MWS and AWS. In addition, we plan to design and carry out Observation System Simulation Experiments (OSSEs), aiming at evaluating the impact of various configurations of small AWS satellites for nordic limited-area modelling systems applications. ECMWF nature run (Hoffmann *et al.*, 2019) is among the candidates to be used for simulating the truth. For the longer term utilisation of less traditionally used 325 GHz data we foresee a need for more advanced ensemble based assimilation methods, including flow dependent background error covariances and a control vector extended to contain also cloud micro-physics variables. Such a research will build on findings by Michel *et al.* (2011), Lorenc (2003) and Gustafsson et al. (2014). Over the the three years, our project will involve the following major items, and associated experiments:

1. Prepare HARMONIE-AROME for handling of currently available microwave sensors in the form of AMSU-A, MHS and MWHS-2 and evaluate impact.

2. Update the present code to process data from AWS, design and perform OSSEexperiments to evaluate the impact of AWS heritage frequency bands.

3. Research towards a future enhanced ensemble based variational limited area data assimilation system for handling of radiances from the future planed sensor measuring around 325 GHz.

2. Plan of the implementation and configuration of the experiments.

The implementation plan for the period 2021-2023 follow closely bullets 1-3 outlined in Section 1 above.

2021:

Experiments to evaluate the impact of an enhanced used of currently available microwave sensors in the form of AMSU-A, MHS and MWHS-2. The experiments will be carried out over a Nordic domain to be decided covering Denmark, Sweden, Norway and Finland and with a grid distance of 2.5 km. There will be 65 vertical levels and approximately 1000 x 1000 horizontal grid-points. Parallel data assimilation and forecast experiments will be carried out for summer and winter periods. Each of this experiments include a one-month spin-up period of variational bias correction coefficients, followed by a two month period in which a version with enhanced microwave radiance usage is compared with a control run. A three hour data assimilation cycle will be used in a deterministic framework and with forecasts up to 48 hours launched every sixth hour.

2022:

OSSE experiments to evaluate impact of using microwave sensors on-board AWS heritage frequency bands) constellations. Again experiments will be carried out over a Nordic domain to be decided covering Denmark, Sweden, Norway and Finland and with a grid distance of 2.5 km. There will be 65 vertical levels and approximately 1000 x 1000 horizontal grid-points. Here we aim for a two month period of a parallel experiment, with and without the use of AWS data. However we would like to repeat this experiment with a different choice of observation cut-off and configuration of AWS satellite passes. So at least two different parallel experiments of each two months and each having a control and a modified run.

2**023:**

Research towards a future enhanced ensemble based variational limited area data assimilation system for handling of radiances from the future planed sensor measuring around 325 GHz. Here we are mainly interested in a number (order of five week long) of case studies to be defined and plan to use an HARMONIE-AROME ensemble with 20 members and defined on a somewhat smaller domain (order of 700 x 700 horizontal grid-points, 65 vertical levels and 2.5 km grid distance).

4. Justification of the computer resources and storage needed.

2021

A one-month deterministic HARMONIE-AROME experiment with 1000 x 1000 horizontal grid-points, 65 vertical levels, a 3 hour data assimilation cycle and with 48 h forecasts launched every sixth hour requires approximately 1.7 MSBU and 3000 GB of storage. Considering that two such months will be run for two parallel experiments and for two seasons implies that in total 8 times 1.7 MSBU (=13.2 MSBU) will be used and 24 000 GB storage needed. In addition one spin-up month per run and season is needed, but with forecasts launched only up to a range of 3 hours to enable the 3 h data assimilation cycle and spin-up of soil properties and variational bias correction predictor coefficients. Each such a month requires approximately 0.4 MSBU, which makes a total of 1.6 MSBU for spin-up runs and 15 MSBU in total for 2020. The data from the spin-up periods require additional 3000 GB of storage, which makes a total of 27 000 GB. Some additional 5 MSBU will be needed for derivation of background error statistics the selected domain (unless we do not chose to interpolate the statistics from an existing domain), but these will be taken from national member-state SBU quotas. This assumptions is based on running four ensemble da cycles for a summer month and a winter month to get representative statistics. The derivation of background error statistics require neglible additional computational storage.

2022

As described in 2021 section above, a one-month deterministic HARMONIE-AROME experiment with 1000 x 1000 horizontal grid-points, 65 vertical levels, a 3 hour data assimilation cycle and with 48 h forecasts launched every sixth hour requires approximately 1.7 MSBU and 3000 GB of storage. In 2022 we plan to run in total 8 months with simulated observations. That makes a total of 13.6 MSBU. We estimate that preparation of simulated observations from a selected nature run would at require additional 1.4 MSBU and therefore ask for 15 MSBU also for 2022. In addition to the 8 times 3000 GB of storage of data from the experiments we estimate that roughly 3000 GB are needed for storage of simulated observations, which make total of 27 000 GB. Additional sensitive studies and complementary runs to be done will be based on member-state national quota.

2023

An ensemble over a small domain (roughly 650 x 650 horizontal grid points, 65 vertical levels and with 2.5 km grid-distance) and forecasts up to 12 hours four times a day with 21 members (20 members + control run) will cost approximately 0.4 MSBU per day and 2.8 MSBU per week. The corresponding storage requirements are approximately 1000 GB per day and 7000 GB for a week. Considering that 5 one week cases will be run we estimate the ensemble costs to be 14 MSBU and storage requirements 35000 GB. In addition we estimate research experiments evaluating developments of a refined data assimilation methodology, utilizing the ensemble information to require at least additional 1 MSBU. Therefore we ask also during 2023 for 15 MSBU.

5. References

Auligné, T., Lorenc, A., Michel, Y., Montmerle, T., Jones, A., Hu, M. and Dudhia, J., 2011. Toward a New Cloud Analysis and Prediction System. *Bull. Amer. Meteor. Soc.*, **92**, 207–210, https://doi.org/10.1175/2010BAMS2978.1

Bengtsson, L. *et al.*, 2017. The HARMONIE-AROME model configuration in the ALADIN-HIRLAM NWP system, *Mon.. Wea. Rev.*, **145**, 1919–1935, https://doi.org/10.1175/MWR-D-16-0417.1.

ESA, EUROPEAN SPACE AGENCYEARTH OBSERVATION PROGRAMME BOARDDraft Revision of the Declaration for the European Earth Watch Programme: Arctic Weather Satellite Element. ESA/PB-EO(2019)54 Att: ESA/PB-EO/LXXXVII/Dec. 1, rev. 24 (Draft) Paris, 10 September 2019

Geer, A, and CoAuthors, 2018. All-sky satellite data assimilation at operational weather forecasting centres. https://doi.org/10.1002/qj.3202.

Gustafsson, N., J. Bojarova and O.Vignes, 2014: A hybrid variational ensemble data assimilation scheme for the HIgh Resolution Limited Area Model (HIRLAM). *Non-linear Precesses in Geophysics*, 21, DOI:10.5194/npg-21-303-2014.

Hoffman, R.N., Malardel, S. and Peevey, T., 2019. New 14-month forecast available for research. ECMWF Newsletter 158. https://www.ecmwf.int/en/newsletter/158/news/new-14-month-forecast-available-research

Lorenc, A., 2003: The potential of the ensemble Kalman Filter for NWP – a comparison with 4D-Var. *Quart. J. Roy. Meteorol. Soc.*, 129, 3183-3203, DOI: 10.1256/qj.02.132

Michel, Y., Auligné, T. and Montmerle, T., 2011. Heterogeneous convective-scale background error covariances with the inclusion of hydrometeor variables. *Mon. Wea. Rev.* **139.9**,pp. 2994–3015.doi:10.1175/2011mwr3632.1.

Storto, A., and R. Randriamampianina, 2010: The relative impact of meteorological observations283in the norwegian regional model as determined using an energy norm-based approach. *Atmos. Sci. Let.*, **11**, 51–58.