REQUEST FOR A SPECIAL PROJECT 2026–2028

Member STATE: Germany, Israel, Italy

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Project Title: Improving NWP kilometre-scale precipitation by linking microphysics and polarimetric-radar observations using ICON-SBM coupled with EMVORADO

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]	80M	145M	125M
Accumulated data storage (total archive volume)[2]	[GB]	150,000	200,000	200,000

EWC resources required for project year:		**2026**	**2027**	**2028**
Number of vCPUs	[#]			
Total memory	[GB]			
Storage	[GB]			
Number of vGPUs[3]	[#]	0	0	0

Continue overleaf.

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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).

Summary

Traditional precipitation forecast verification suffers from a fundamental limitation: the indirect relationship between surface precipitation observations and the underlying microphysical and dynamical processes that govern precipitation formation in convective systems. In this project, we address this gap by employing the EMVORADO radar forward operator package to translate model microphysical states directly into observable polarimetric radar signatures. The direct evaluation of (polarimetric) radar signatures through systematic variation of ICON's microphysical scheme complexity -- from 1-moment to 2-moment to spectral-bin microphysics -- will establish clear physical pathways and identify corresponding microphysical processes and parameter-space adjustments necessary for improving kilometer-scale precipitation forecasts. Furthermore, establishing the linkage between microphysical processes and dual-polarization radar data is an essential step toward directly using radar data in data assimilation to obtain initial conditions (analysis) for better representation of cloud and precipitation in operational kilometer-scale numerical weather prediction models.

Motivation

The representation of mixed-phase cloud processes leading to precipitation remains a challenge for the numerical weather prediction (NWP) community. Accurately representing moist processes that interact diabatically through heating and cooling cycles, particularly latent heating effects, is crucial for intense weather forecasting like deep convective event (Bauer et al. 2015).

Both non-polarimetric and polarimetric radar observations provide an unprecedented wealth of information to evaluate and improve cloud microphysical parameterizations in NWP models. The information can be leveraged in complementary ways: (1) using the radar microphysical and thermodynamic retrievals, and/or (2) using forward radar operators for converting the model state outputs into the fields of radar (polarimetric) variables (Ryzhkov et al. 2020). Cloud microphysical schemes have to realistically approximate cloud microphysical processes and hydrometeor properties, such as size distributions and partitioning into different classes and types, bulk densities and fall speed. Therefore, **the synergy between radar observations and state-of-the-art microphysical schemes should lead to better understanding of mixed-phase processes, enabling improved representation and calibration of precipitation in NWP** (Tromel et al. 2021; Shrestha et al. 2022).

The Efficient Module VOlume scan RADar Operator (EMVORADO) is a synthetic radar module designed to efficiently integrate into ICON-NWP and link between the modelled microphysical state and radar observations (Zeng et al., 2016; Blahak et al. 2016; Blahak and de Lozar, 2020; Mendrok et al., 2021). It enables a modeler to compare the model state versus radar quantities like horizontal (total) reflectivity, differential reflectivity as well as derived microphysical state variables like total ice mass, ice number and effective particle size. The EMVORADO uses one- or two- layered hydrometeors with different water-ice-air mixing schemes and melting topologies.

The recently implemented spectral-bin microphysical scheme in ICON (ICON-SBM; the warm-phase version was published in Khain et al. 2022) solves explicitly for changes in mixed-phase particle size distributions (PSD) including explicit rimed/liquid fractions. It is therefore well suited for the full complexity of the two-layered T-matrix approach in EMVORADO (Ryzhkov et al. 2011; Shpund et al. 2019). Comparing ICON's single-moment (1M), two-moment (2M) and SBM microphysical schemes using the same ICON-NWP version coupled to EMVORADO enables us to synergistically understand the variability of microphysical phase-space that drives precipitation.

To constrain the short-term stochastic properties of convection and remediate errors embedded in boundary conditions, data assimilation (DA) is typically used. In particular, DA of polarimetric radar datasets should provide more accurate storm-scale analyses for better initialization of severe convection forecasts (Putnam et al. 2021). Model error describes deficiencies in NWP models' ability to represent the required spatial, temporal, and physical processes of the observed atmospheric state. Therefore, model error quantification is essential in DA for optimal weighting between observations and previous (prior) forecasts, and consequently for computing the analysis (e.g., Feng et al. 2021). We therefore anticipate that synergistic use of the ICON-SBM and ICON-2M schemes through DA could improve km-scale precipitation.

Research Plan

To directly link precipitation, the underlying microphysical processes, (polarimetric) radar signatures, and data assimilation, we will rely on a numerical system based on the ICON model with gradually increasing complexity. The research plan consists of the following work packages (WPs):

WP-1

Building on recent physics developments and parameter-space adjustments, this part of the study aims to evaluate km-scale precipitation forecasts using ICON's 1M and 2M microphysical schemes over the Mediterranean region. As previous studies (Khain et al. 2021) and experience gained within the COSMO and ICON modelling communities demonstrate that interactions between microphysics and convective parameterizations strongly influence precipitation forecasts, we will evaluate optimal parameters configuration for the Mediterranean region, which may differ from those used for Central Europe. This will serve as a baseline version for subsequent development steps.

WP 1.1 Review and implementation of recent physics developments in ICON; preliminary evaluation of key forecast features in the Mediterranean region.
WP 1.2 Evaluating precipitation performance at 2.5- and 1.0- kilometre resolutions across various precipitating convective cloud systems over the Mediterranean during autumn and winter seasons, ranging from mesoscale to locally-forces to shallow convective events.
WP 1.3 Suggest an optimal configuration of microphysical and dynamical parameters for the Mediterranean region.

WP-2

EMVORADO is a forward operator synthetic radar especially designed to efficiently simulate PPI volume scan measurements of entire radar networks from the prognostic model state of an NWP model for direct comparison with radar observations. This task aims at coupling EMVORADO to the recently developed SBM microphysical scheme in ICON, emphasizing the utilization of state-of-the-art scattering properties.

WP 2.1 Coupling the EMVORADO forward operator module to the recently developed SBM microphysical scheme in ICON alongside the 1M and 2M schemes. Debugging and assuring EMVORADO's look-up tables and hydrometeors topology are fully functional and consistent with the SBM microphysical scheme.
WP 2.2 Using idealized simulations of deep convection to assure the coupling works flawlessly, emphasizing on each polarimetric synthetic variable to act within expected range.

WP-3

EMVORADO's synthetic observations will be directly compared with real observations and signatures of microphysical processes including their temporal evolution for the 1M, 2M and SBM microphysical scheme. Thus, the ability to represent realistically precipitation variability will be directly evaluated across different schemes. Missing polarimetric process fingerprints in the synthetic observations may hint at specific deficiencies (e.g. Kumjian, 2012) and inform where adaptation is needed in order to increase the coherence between real and virtual observations. In this task, we aim at using both non-polarimetric and polarimetric radar datasets as well as collocated rain distrometers to evaluate the microphysical phase-space that drives various regimes of Mediterranean precipitation. Furthermore, to ensure the results are more generalized across the Mediterranean region, cases will be chosen at varying intensity, seasons, and topography (mainly across Israel and Italy).

WP 3.1 Identifying and simulating selected Mediterranean precipitation regimes during autumn and winter (Cyprus Lows, Cold Fronts, Cuttoff Lows, Medicanes (e.g., *Daniel*, *Ianos*)). Comprehensively compare with available 3D radar observations and distrometers.
WP 3.2 For each microphysical scheme, map the phase space of relevant microphysical process rates and discuss the differences in terms of deficiencies observed in radar signatures.
WP 3.3 Evaluating the microphysical performance of moderate-to-high intensity precipitation, specifically in light of hail generation, growth and spatial distribution of hydrometeor size spectra.

WP-4

To explore DA methods of polarimetric data, we first will use an idealized setup comparable to Zeng et al. (2021) that simulates a supercell, includes full radar observation operator EMVORADO-POL and is coupled to Kilometer-scale Ensemble Data Assimilation (KENDA) system (Schraff et al. 2016). DA experiments will be performed in presence of model error by sampling for model microphysical uncertainty using method proposed by Janjic and Zeng (2021). To simulate the error, the new implementation of SBM microphysics scheme in ICON will be used for the generation of the observations, while in the DA system the ICON model will use 1M or 2M schemes. To mitigate the problem with model error, the additive model error following work by Feng et al. 2021 will be implemented.

WP 4.1 Implementing the method of Feng et al. 2021 for the SBM microphysics scheme and test different DA settings for the assimilation of polarimetric data accounting for microphysics model error.
WP 4.2 Preliminary experiments using SBM for DA (without model error) will be performed. In addition, a series of tests will be performed to determine the number of ensemble members needed to obtain good results as well as other DA settings. The evaluation of DA and forecast experiments will compare results between WP4.1 and WP4.2.

Justification of the Computer Resources

In order to estimate the computing resources needed for this project, we evaluate below a basic configuration of our simulation serving as a first guess for the proposed portfolio of simulations. For simplicity we thereafter assume that using the ICON-2M microphysical scheme consumes ~ 30% more resources compared with the 1M scheme. As the ICON-SBM is a new scheme in ICON and we aim to cover several key precipitation regimes, we add an allocation buffer for WP-2 and WP-3 for debugging purposes and validation.

Requirements for WP-1:

We plan to simulate selected precipitation cases, ranging from relatively short locally-forced convection (6-12h) to relatively long mesoscale convective cases (72h) which are typical of the Mediterranean region during autumn and/or winter. To simulate 10 selected cases separately, spanning a ~5 parameter-space with 100 combinations for 72h using the 1M microphysics scheme, we need: 10 cases x 300 SBUs/h × 100 permutations × 72h = 21.6 MSBUs.

Validating the results and ensuring tuning convergence over 10 additional cases will require in total 25 MSBUs with 25 TB of storage. Using the 2M scheme will consume 30% more of the detailed above which concludes in 32.5 MSBUs. Altogether, this work package is expected to consume **57.5 MSBUs** with **50 TB** of storage. The majority of the output data will be moved to ECFS, so that no dedicated storage is required on scratch.

Requirements for WP-2:

This work package is characterized by coupling the ICON-SBM code with EMVORADO and ensuring the code correctly uses the full hydrometeor phase complexity to obtain realistic scattering properties (e.g., polarimetric signatures). We will focus on ICON's 3D idealized cases of mesoscale convective systems (a supercell and/or a squall-line) with extensive testing to debug and validate that the coupling works flawlessly. We request an allocation for 100 idealized simulations of 5000 SBU each of an 8h squall line, thus consuming approximately **5 MSBUs** with **100 TB** of storage (ECFS).

Requirements for WP-3:

This work package builds on previous work packages and is the most comprehensive of all. Here we extensively compare radar signatures and relate them to the underlying microphysical processes that govern precipitation performance. A single ICON-SBM simulation for 72 hours requires

approximately 800,000 SBU, with 20 selected cases to be compared with cases chosen in WP-1 x times 10 permutation each is expected to consume 160 MSBU. Applying and testing changes in both the 1M and 2M microphysical schemes requires an additional 500,000 SBUs.
In addition, expanding the study on hail growth, including 2 Medicanes cases that requires relatively large domain and long simulations, requires an additional 50 MSBU and 100 TB.
Thus, the resources needed for this WP are approximately **210 MSBU** with **200 TB** of (ECFS) storage.

Requirements for WP-4:

For exploring DA methods, we will vary DA settings as well as ensemble member configurations using ICON-SBM, first in idealized cases. For this part, we request comparable SBUs to those requested for WP2: 5 MSBU and 10 TB of storage. Following successful DA performance, we will run 3 configurations of 3-months length assimilation cycle based on real cases with ICON-SBM. For this task we will use 265,000 SBUs/day x 90 days x 3 configurations 72 MSBUs and 100 TB of storage. For this WP we ask a total allocation of **77 MSBUs** and **110 TB** of (ECFS) storage.

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